ГЕОЛОГІЯ РОДОВИЩ КОРИСНИХ КОПАЛИН

УДК 551.24:3
DOI: http://doi.org/10.17721/1728-2713.107.08

Liubov OSMACHKO, DSc (Geol.), Senior Researcher
ORCID ID: 0000-0003-1248-261X
e-mail: osml@ukr.net
State Institution "Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine", Kyiv, Ukraine

Valentin VERKHOVTSEV, DSc (Geol.)
ORCID ID: 0000-0002-1015-6725
e-mail: verkhovtsev@ukr.ne
State Institution "Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine", Kyiv, Ukraine

STRUCTURIZATION OF TECHNOLOGICALLY CHANGED VOLUMES OF THE "PIVDENNYI" QUARRY OF C. KRYVYI RIH

(Представлено членом редакційної колегії д-ром геол. наук, доц. С.Є. Шнюковим)

Background. *The research took place within the "Pivdennyi" iron ore quarry in Kryvyi Rih c. with the aim of comprehensive and effective further use of the technogenically transformed areas of the subsoil and the earth's surface of Kryvbas. A brief overview of the achievements of previous researchers is given.*

Methods. *Generally accepted research methods are applied. The fixation of bedding elements in relatively undisturbed, small-sized blocks (hereinafter – "blocks" or "surviving block") of quartzites and shales of the Saksagan suite and in blocks of demarcation of surviving block – technogenic accumulations was carried out. In relatively undisturbed blocks of quartzite, such elements for banding, schistosity, linearity of mineral aggregates, axes of folded forms, striation, furrows, etc. were measured. The actual material regarding the placement of structural elements was processed using the StereoNett 2.46 program, and the displacement calculations of the blocks of the studied formations were also made.*

Results. *Among technogenic accumulations (scree slope, embankments and filled artificial cavities), according to the degree of structuring, unstructured and structured to varying degrees were observed. Layering, mechanical schistosity and linearity are fixed within them.*

It was found that the formation of the system of blocks of the "Pivdennyi" quarry took place during their rotation along both the vertical and horizontal axes.

Conclusions. *The emergence of newly formed planes of technogenic accumulations took place with the inheritance of the structural anisotropy existing in the surviving block with the creation of its own stratification. Therefore, the investigated system "surviving block – technogenic accumulations" developed and formed as a complete object, mutually coordinated, years – decades in surface conditions.*

The transformation of technogenic accumulations, their "completion"/structuring, as a result of which the integrity of disturbed and missing areas of the geological volume is restored, are constructive phenomena. They are practically a natural laboratory of processes of formation of structural and textural elements in loose accumulations. Their tracking in time would make it possible to actually observe the processes of self-creation/reproduction of modern technogenic-natural objects.

The ranking of structural neo formations in technogenic accumulations can be used as one of the criteria for assessment the assimilation potential of these accumulations and their suitability for economic reclaim.

Keywords: *ferruginous horizons, "Pivdennyi" quarry, undisturbed blocks, technogenic accumulations, bedding elements, structuring.*

Background

The research was carried out on the territory of the Saksagan district of Kryvyi Rih, where iron horizons of the Saksagan suite of the Kryvyi Rih series were discovered within the "Pivdennyi" iron ore quarry. The studies were carried out in connection with the ***problem*** of the lack of systematic monitoring information about the trends in the development of geodynamic processes and changes that occur within the technologically transformed areas of the subsoil and the earth's surface of Kryvbas. Therefore, the research of such areas is relevant and carried out with the ***aim*** of their comprehensive and effective use and prevention of the development of negative natural and technogenic processes (Geological investigation..., 2023).

According to archaeological research, the use of iron by mankind in the Dnieper region has been known since the middle of the 2nd millennium BC. (Nikitenko, 2023).

From the end of the 18th century, active economic development of the south of Right Bank Ukraine began. Under the leadership of V.F. Zuyev, iron ores in Kryvbas were discovered during one of his expeditions. Thanks to the work and perseverance of O.M. Pol', in 1876 the industrial development of Kryvyi Rih iron ores began. This became the starting point in the anthropogenic transformation of Kryvbas (Denisik, & Zadorozhnya, 2013).

At the end of the 19th century and at the beginning of the 20th century, ore deposits were mined to a depth of 25–50 m using an open method. As the depth of mining operations increased, ore deposits were mined in shallow (50–100 m) mines. The cavities formed as a result remained or were filled with loose overburden, mainly clays and loams (Geological investigation..., 2023).

The "Pivdennyi" quarry was put into operation in 1972, in 2001 it was transferred to the mine management for underground ore mining of KDGMK "Kryvorizhstal". The iron ore deposit was discovered to a depth of 1,100 m (Extraction..., 2018). Currently, the "Pivdennyi" quarry is being developed by "RUDOMAIN" LLC. Achieved dimensions of the quarry: length – 1050 m, width – 630 m, depth – 140 m; the quarry is extended submeridionally (Fig. 1).

The fourth, fifth and sixth iron and shale horizons of the Saksagan suite of the eastern limb of the Saksagan syncline are spread directly within the territory of the development of the "Pivdennyi" quarry. On the western side of the quarry, in its upper part, the upper tectonic scale, or part of the Saksagan anticline, is partially exposed, which is represented

ISSN 1728-3817

within the quarry by rocks from the talc horizon to the fourth shale horizon (Geological investigation..., 2023).

The Saksagan syncline is characterized by a strike azimuth of 0–30°, a dip of the axial surface to the west at an angle of 45–70°, and a plunge of the hinge to the north at an angle of 0 to 20° (Extraction..., 2018; Geological investigation..., 2023).

According to the results of the geological-surveying of "RUDOMAIN" LLC, it was established that the section of the "Southern" quarry in its current form was formed due to technogenic factors caused by the underground method of working out rich iron ores, which led to the collapse of overlying rocks and their mixing with iron martites ores and ferruginous quartzites, to the processes of subsidence and slumping of the host rocks. As a conclusion, it was ascertained that the "Pivdennyi" quarry site belongs to the technogenic genetic type of deposits (Geological and..., 2018; Protocol..., 2018).

Fig. 1. General view of the "Pivdennyi" quarry in the direction from south to north

In 2021, a ground-penetrating radar survey was carried out on the site of the "Pivdennyi" quarry, its western flank and the surrounding area with the help of the low-frequency ground-penetrating radar complex "Loza-2N". A total of 23 profiles were made, the total length of which is 15,404 m. According to the results of the work, 140 anomalies were identified, which were summarized into four groups: anomalies, which are vertical collapse zones that were filled with clay or soil; local anomalies such as voids; anomalies that form large conical structures and are filled with a mass of collapsed rocks or filled with rock from dumps, or clay or soil; structural anomalies reflecting the geological structure or individual structural elements, for example, folds, faults, etc.

Most of the detected anomalies, which can be interpreted as collapsed and landslide rocks, are located on the western side of the quarry. Also, the bottom of the pit has signs of numerous collapse processes and backfilling. The eastern side of the quarry is less involved in these processes (Geological investigation..., 2023).

It is extremely difficult to estimate the volumes of technogenic subsidence and collapses as a result of underground mining within the "Pivdennyi" quarry, but it can be argued that they significantly exceed the volumes of the rock mass mined underground (Geological investigation..., 2023).

As a result, the quarry can be represented as a technogenic-geological formation, where relatively undisturbed blocks of crystalline rocks (surviving block) and blocks of technogenic accumulations alternate. The apparent thickness of both types of blocks ranges from a few meters to the first tens of meters.

The totality of the action of human industrial activity and natural processes generate processes that are layered on the created mining complex. This is a special group of processes and phenomena that G.I. Denisik and G.M. Zadorozhnya are proposed to be called derivatives (Denisik, & Zadorozhnya, 2013). These researchers typify derivative processes and phenomena observed within the mining landscapes of Kryvyi Rih according to a number of signs: by genesis, speed, area, sequence of activation, age, relation to the earth's surface, nature of manifestation and degree of regulation (Denisik, & Zadorozhnya, 2013).

Research conducted in Kryvbas by V.P. Voloshchenko, G.M. Malakhov, I.D. Rivkin and a whole galaxy of their followers were allowed to have a fairly clear idea of the geomechanical processes occurring in the upper part of the earth's crust as a result of the underground development of iron ore deposits. Very briefly, the essence of the phenomenon can be reduced to the following (Extraction..., 2018; Geological investigation..., 2023): a) the collapse of the ceiling of the void causes the advance of overlying rocks starting from the surface along the lying side. As a result, sedimentary rocks from the surface fall into the depth; b) the void is also filled with the rocks of the hanging side; c) on the surface there is a trough of deflection, with zones of collapse and landslide. The landslide zone develops at an angle from 80° to 42° (Extraction..., 2018; Geological and..., 2018; Geological investigation..., 2023).

As it was shown above, the shape of bodies of technogenic accumulations, methods and conditions of their

formation were mainly studied. The internal structure of technogenic formations remained outside the attention of researchers. The above is ***part of a general problem*** that has not been solved before, which this work is devoted to.

Methods

The authors within the framework of the "Pivdennyi" quarry used generally accepted methods of research – expeditionary, natural sites, cartographic, aerospace, observation, analysis. In this article, we present the results of the work, which consisted in measuring with a compass the bedding elements of the horizons of quartzites and slates of the Saksagan suite, both relatively undisturbed and to varying degrees technogenically altered. In particular, the azimuths and angles of dip of planar structural elements – banding, schistosity, and the azimuths and pitch angles of linear elements – were measured within the boundaries of individual relatively undisturbed blocks of quartzites and slates (surviving block). Banding is usually represented by alternating bands of quartzite, differing in color, mineral composition and sizes of mineral grains. Schistosity is expressed by uniformly oriented and scaly minerals and their aggregates close together. Linear structural elements are represented by hinges of folded forms, elongated mineral aggregates, striation, furrows (Fig. 2).

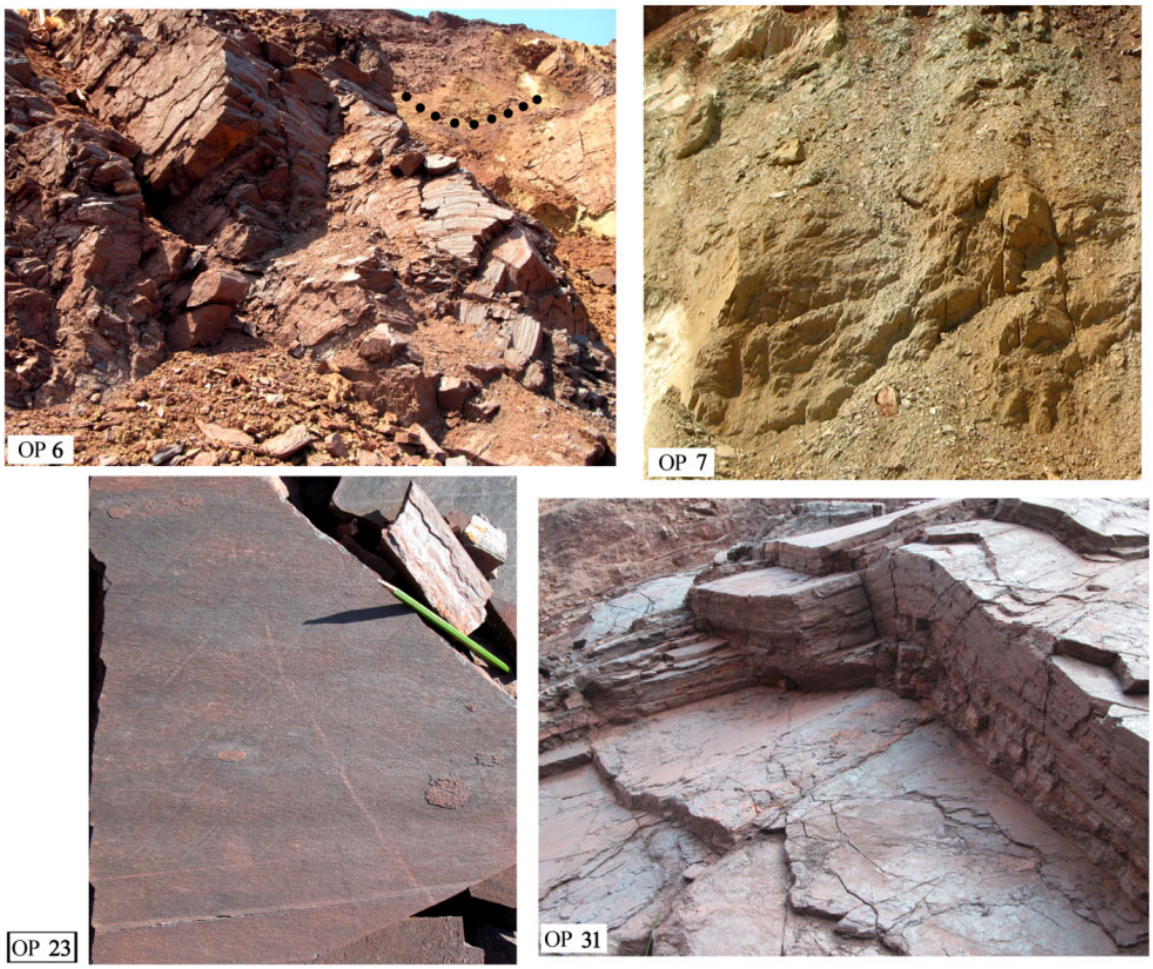

Fig. 2. Photo of structural elements – planes of banding, schistosity and folded forms of separates surviving block of quartzite and shale of the "Pivdennyi" quarry.

OP – observation point. OP 6, 7 – the western side, OP 23, 31 – eastern side of the quarry. Within OP 6, the exit of the structuring planes in the scree slope is emphasized by the dot-dashed line. OP 23 – several linearities in the banding plane of ferruginous quartzites by furrows, elongated mineral aggregates and striation. OP 31 – folded form in ferruginous quartzites

Among technogenic formations (scree slope, embankments and filled artificial cavities), according to the degree of structuring, we observed at least two varieties – unstructured and structured to varying degrees. Within the limits of the first of the mentioned types of technogenic formations, no signs of structural and textural regularity were found. Within the structured technogenic formations, signs of structural and textural arrangement are recorded. They are expressed by layering, schistosity and linearity, the bedding elements of which were recorded. The layering of technogenic accumulations is represented by the alternation of layers, which differ among themselves in terms of color and size of rock fragments. Such planes are emphasized by schistosity, which is expressed by uniformly oriented, flat mineral aggregates and fragments of crystalline rocks in layering planes (Fig. 3). Only one linear structural element within technogenic formations has been recorded in the form of a hinge of the heap fold. The azimuths and dip angles of the planes of separation between the surviving blocks and slumps, scree slopes, filled cavities and other technogenic accumulations were also measured.

Accordingly (Korzhnev et al., 2005; Denisik, & Zadorozhnya, 2013), the functioning of processes and phenomena in mining landscapes (and hence the degree and speed of structuring of technogenic accumulations) depend on the intensity of mining operations in quarries,

ISSN 1728-3817

which create peculiar conditions/microclimate. These are the following conditions: initiation of additional technogenic vibration, migration and redistribution of matter, increase in fracturing and water permeability, change in thermal regime and conditions (Eh–pH).

The technogenic layering was most likely formed as a result of successive pouring of crushed rock during the creation of man-made and non-man-made accumulations of fragments of crystalline rocks and, subsequently, gravitational compaction, granulation differentiation of such accumulations and the action of the man-made factors listed above. Schistosity is created due to the rotation and reorientation of individual flakes and packages of mineral flakes as well as fragments of crystalline rocks under shear conditions. The mechanisms of formation of layering and schistosity in natural conditions are substantiated in the works of O.I. Lukienko with co-authors (Lukienko, Vakarchuk, & Kravchenko, 2014; Lukienko, Yanchenko, & Kravchenko, 2018). In particular, in the conditions of the diagenetic subzone of the primary epizone, the optimal architecture of the accumulation environment is formed, which is in balance with the tectonic and P-T conditions at the time of the formation of layering and mechanical schistosity formation. The paper (Lukienko, Vakarchuk, & Kravchenko, 2014; Lukienko, Yanchenko, & Kravchenko,, 2018) also provides data on the creation of artificial electromagnetic fields, which initiate, in addition to the creation of banding and schistosity in rocks in the solid state, and the migration of matter with the formation of new minerals (hematite, magnetite, etc.). Formations similar to the above-mentioned heap fold, under natural conditions, are completed because of the bordering of relief irregularities and the subsequent compaction of the heap mass.

All the above-mentioned measurements are presented in the tables (Tab. 1-4). In addition to the actual measurements, Tab. 1 and 2 show the calculations of the displacements of each of the following blocks relative to each of the previous ones and relative to the average statistical azimuths and dip angles for the sides of the quarry along the vertical and horizontal axes. At the end of the tables, the averaged values of the azimuths and dip angles and displacements for the examined surviving block, in general, of the corresponding sides of the pit are shown. Therefore, the averaged values calculated reflect the general situation for the parts of the sides of the quarry which formed surviving blocks. Similar calculations were made for technogenic accumulations (table 3).

All the given data on the bedding elements of the investigated structures of the western and eastern sides and the relative displacements of their components of the "Pivdennyi" quarry are given in the summary Tab. 4, also in Fig. 4.

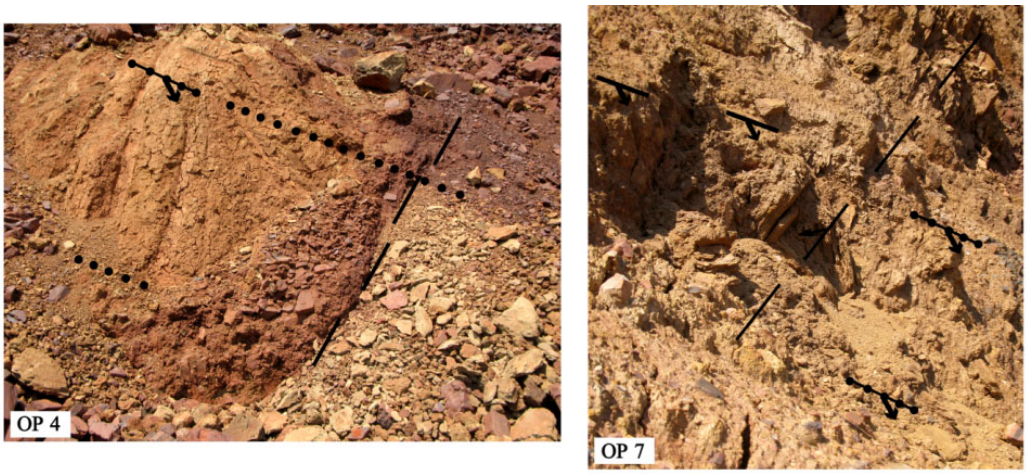

Fig. 3. Photo of structural elements of individual scree slopes and technogenic embankments on the western side of the "Pivdennyi" quarry.

OP 4 – demarcation of scree of different degrees of structuring in the form of a layering/sliding zone, with a dotted line underlined. To the left of the border is a higher degree, a dot-dashed line with an arrow is the exit and direction of dip of the layering planes.
OP 7 – delineation of the surviving block (on the left) and scree in the form of a friction zone, highlighted by a dotted line. Line with an arrow – bedding elements. For other designations, see above

Results

The dip azimuths of banding of quartzites on the eastern side of the "Pivdenniy" quarry vary from 270 to 320°. Dip angles within 10–47°. The average dip azimuth (on 16 measurements) of the banding of quartzites on the eastern side of the quarry is 293.3°, the average dip angle (on 16 measurements) of the banding of quartzites on the side is 31.9°. The average displacement of the blocks (surviving block) within the board, both along the vertical axis and horizontally, is insignificant – a few degrees. But we can talk about the absolute displacement of the surviving blocks of quarry only if we know the bedding elements of rock before the start of iron ore development.

The dip azimuths of banding of quartzites on the western side of the "Pivdennyi" quarry vary quite widely – from 240° to 20°. Also, the dip angles are from 25 to 87°. The average dip azimuth (on 49 measurements) of quartzite banding on the western side of the quarry is 333°, the average dip angle (on 49 measurements) of quartzite banding is 48.8°. The average displacement of the blocks, both along the vertical axis and horizontally, is an order of magnitude higher compared to those on the eastern side (Tab. 4, Fig. 4).

Newly formed textures were found in 70 % of technogenic geological bodies (scree, embankments, etc.) of the "Pivdennyi" quarry, where iron horizons of the Saksagan suite are being re-developed. These are layering and schistosity, which are formed due to successive filling/deposition, and most likely gravitational compaction and granulation differentiation of crushed rock mass during mining, as well as rotation and reorientation of flat mineral aggregates and rock fragments. The bedding elements of such newly formed textures of technogenic bodies in 40 % of the cases imitate the bedding elements of bedrock rocks in surviving blocks. Namely, the dip azimuths of technogenic newly formed textures of the "Pivdennyi" quarry vary between 230 and 88°. Dip angles from 22 to 90°.

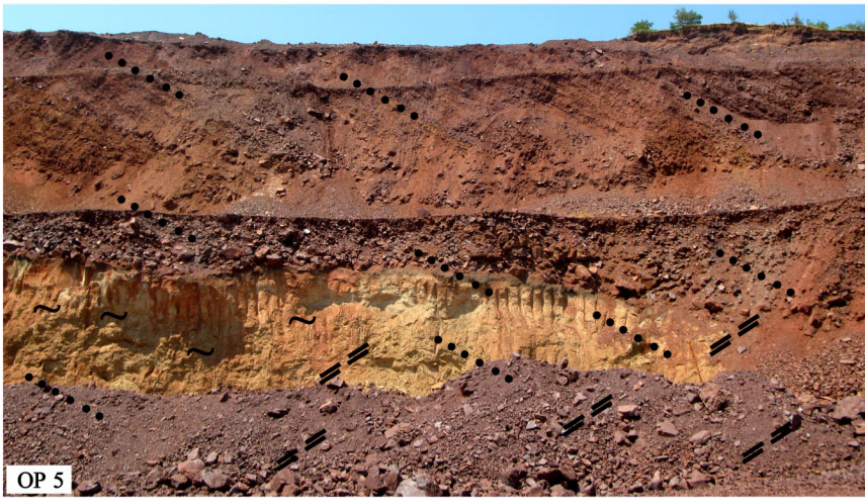

Fig. 4. continuations.

OP 5a – heap fold cloak, the exits of the sides planes are highlighted with a dot-dashed line; the dot-dashed line with arrows (dep direction) is the output of the layering planes of technogenic accumulations; below the photo – cone-shaped unstructured landslide bodies.
OP 5 – heap layering (above), the exits of its planes are highlighted with a dot-dashed dotted line. These planes are through the entire stratum in the photo, they are traced in the lenticular body of clays and weakly in the scree of the foot; squiggly dash – exits of layering planes of clay; double dash – outcrop of layering planes in the scree of the foot. They are also traced into technogenic bodies above.
Bottom picture (OP 29) in the axial part of the "Pivdennyi" quarry, where interspersed relatively undisturbed blocks of ferruginous quartzite (light outcrops), rich martite ore ("bruises", dark outcrops) and technogenic accumulations can be seen interspersed.
All of them are structurally and texturally ordered in the form of banding, which have the same bedding elements for all the listed geological formations. For other designations, see above

ISSN 1728-3817

Table 1

Bedding elements and relative displacements of individual surviving block of the western side of the "Pivdennyi" quarry

№ i/s	OP	Dip of planar structures				Changing the spatial position of the block relative to the previous one (angle of relative rotation, °), by:		Angle of rotation, block relative to the statistical average, (°) by:	
		azimuth,°	average value	angle,°	average value	vertical axis	horizontal axis	vertical axis	horizontal axis
1	1	270	267,75	86	79,75	–	–	– 65,3	+ 30,9
2		273		68					
3		273		78					
4		255		87					
5	2	270	285	75	53,75	+ 17,25	– 26	– 48	+ 4,9
6		290		55					
7		270		35					
8		310		50					
9	6	255	264	45	52,8	– 21	– 0,95	– 69	+ 4
10		250		55					
11		280		44					
12		250		60					
13		285		60					
14	7	330	286,6	35	40,3	+ 22,6	– 12,5	– 46,4	– 8,5
15		290		30					
16		240		56					
17	8	285	306,6	53	51	+ 20	+ 11,3	– 26,6	+ 2,2
18		315		50					
19		320		50					
20	12	290	277	30	41,6	– 29,6	– 9,4	– 56	– 7,2
21		265		45					
22		290		33					
23		270		35					
24		270		65					
25	14	245	277,5	35	52	+ 0,5	+ 10,4	– 55,6	+ 3,2
26		280		55					
27		280		40					
28		270		58					
29		300		62					
30		290		62					
31	16	340	311,6	52	56	+ 34,1	+ 4	– 21,4	+ 7,2
32		300		61					
33		295		55					
34	17	325	335	25	25	+ 23,4	– 31	+ 2	– 23,8
35		345		25					
36	18	312	293,7	57	53	– 41,3	+ 28	– 39,3	+ 4,2
37		293		42					
38		320		45					
39		250		68					
40	19	290	300	30	29,7	+ 6,3	– 23,3	– 33	– 19,1
41		300		27					
42		310		32					
43	20	320	310	40	39	+ 10	+ 19,7	– 23	– 9,8
44		300		38					
45	25	20	16,7	35	35,3	+ 66,7	– 3,7	+ 43,7	– 13,5
46		10		35					
47		20		36					
48	26	320	317,5	45	49	– 59,2	+ 13,7	– 15,5	+ 0,2
49		315		53					
The average value for all studied surviving block on the west side			333	–	48,8	3,82	– 1,5	– 32, 4	– 1,8

Table 2

Bedding elements and relative displacements of individual surviving block of the eastern side of the "Pivdennyi" quarry

№ i/s	OP	Dip of planar structures				Changing the spatial position of the block relative to the previous one (angle of relative rotation, °), by:		Angle of rotation, block relative to the statistical average, (°) by:	
		azimuth,°	average value	angle,°	average value	vertical axis	horizontal axis	vertical axis	horizontal axis
1	9	265	286,7	30	28	–	–	– 6,6	– 3,9
2		300		27					
3		295		27					
4	10	285	298	33	38,2	+ 11,3	+ 10,2	+ 4,7	+ 6,3
5		320		40					
6		305		40					
7		305		38					
8		275		40					
9	11	275	275	40	40	– 23	+ 1,8	– 18,3	+ 8,1
10	21	290	295	47	42	+ 20	+ 2	+ 1,7	+ 10,1
11		300		37					
12	23	285	295	10	10	0	– 32	+ 1,7	– 21,9
13		305		10					
14	31	270	284,3	39	33	– 10,7	+ 23	– 8,7	+ 1,1
15		290		26					
16		293		34					
The average value for all studied surviving block on the side			293,3	–	31,9	– 0,5	+ 1	– 4,3	– 0,03

Table 3

Bedding elements and relative displacements of heap, scree and structuring planes and boundaries between technogenic accumulations and surviving blocks of the "Pivdenniy" quarry

№ i/s	OP	Dip of planar structures				Changing the spatial position of the block planes relative to the previous one (angle of relative rotation, °), by:		Angle of rotation, block planes relative to the statistical average, (°) by:	
		azimuth,°	average value	angle,°	average value	vertical axis	horizontal axis	vertical axis	horizontal axis
1	3	295	327,5	30	42,5	–	–	– 22,5	– 17,1
2		0		55					
3	4	230	230	88	88	– 97,5	+ 45,5	– 120	+ 28,4
4	5	320	320	22	22	+ 90	– 66	– 30	– 37,6
5	7	70	70	75	75	+ 110	+ 53	+ 80	+ 15,4
6		70		75					
7	13	345	36,5	90	80	– 33,5	+ 5	+ 46,5	+20,4
8		88		70					
9	29	270	270	50	50	– 126,5	– 30	– 80	– 9,6
The average value for studied technogenic accumulations on th side			350	-	59,6	– 11,5	+ 1,5	– 21	– 0,02

Table 4

Summary structures data of the "Pivdennyi" quarry

Object	Average dip of planar structures		Blocks rotation, (°) Sum / statistical average	
	azimuth, °	angle, °	by the vertical axis	by the horizontal axis
surviving blocks of the western side	333	48,8	– 201,8 / – 14,3	– 22,4 / – 1,7
surviving blocks of the eastern side	293,3	31,9	– 14 / – 1,9	2,4 / 0,5
technogenic formation	350	61,7	– 91,8 / – 16,3	3,7 / 0,7

ISSN 1728-3817

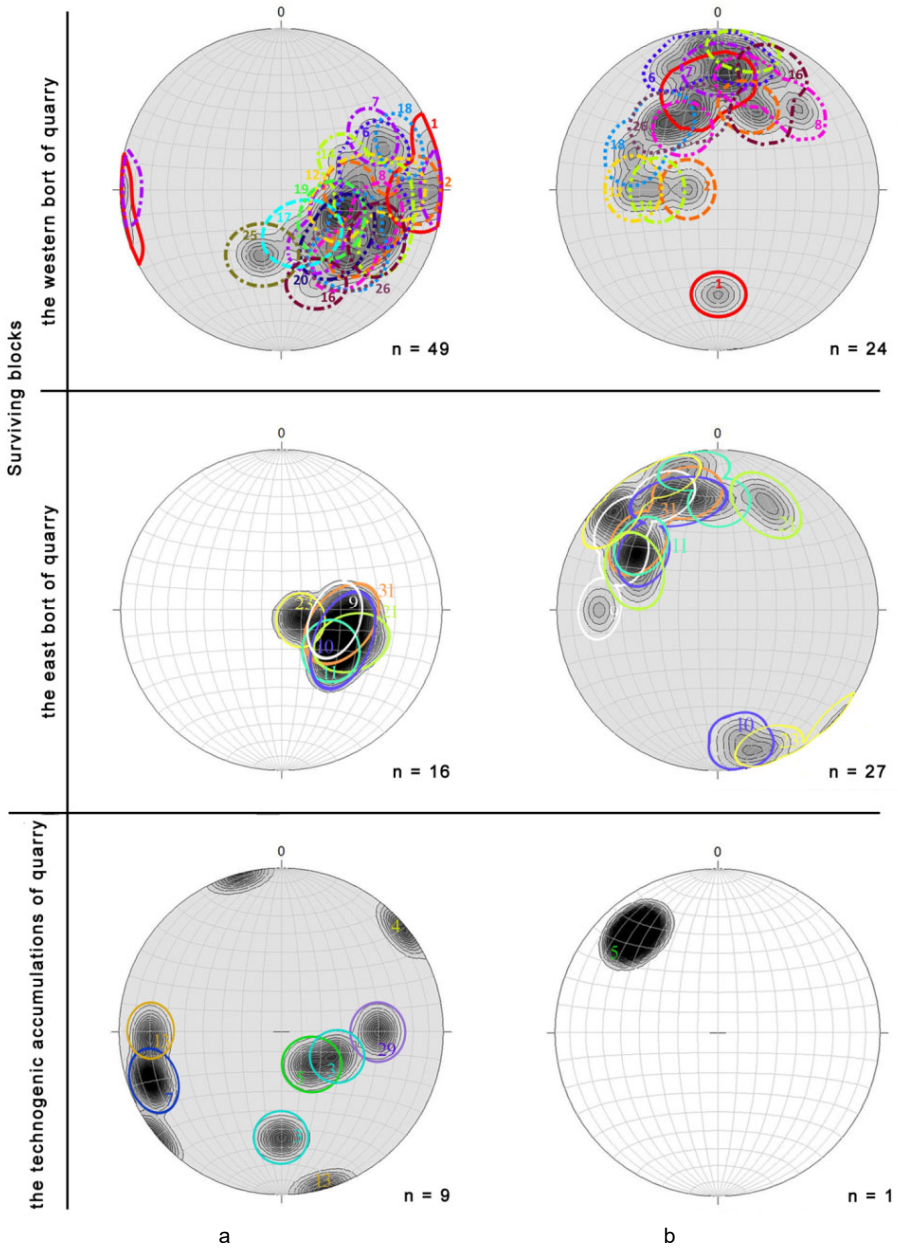

Fig. 5. Stereograms of the studied structures of the "Pivdennyi" quarry, where the projections of each of the studied blocks are drawn with different contours and numbers.

a – planar structures, b – linear structural. Numbers correspond to observation points. Projection to the lower hemisphere. Gradation of isolines: 1-2-3-4-5-6-7-8-9-10-11-12-13-14-15. n – number of measurements. StereoNett 2.46 program

The average dip azimuth (on 9 measurements) of technogenic layers of the quarry is 350°, the average dip angle (on 9 measurements) is 61.7°. The angles of displacement of the blocks (structured embankments and scree between the surviving blocks) are comparable in similar indicators of the western side of the quarry, but on the horizontal axis with the opposite sign.

Discussion and conclusions

1. The formation of the system of blocks of the "Pivdennyi" quarry took place during the rotation around the vertical axis counterclockwise. While the greatest value of such rotation was for the surviving blocks of the western side, the smallest – for the eastern side. The difference between the borts, according to the average value of the measurements, is 39.7°. The calculated average rotation of the block on the western bort is 14.3°. Eastern – 1.9°.

Also, with this formation, there was scrolling around the horizontal axis, the largest such scrolling was for the surviving blocks of the western bort with a negative sign, the smallest for the surviving blocks of the eastern bort with a positive sign. The difference between the borts, according to the average value of the measurements, is 16.9°. The calculated average rotation of the block of the western bort around the horizontal axis is 1.7°. Eastern – 0.5°.

That is, the degree of technogenic disturbance of the western bort is an order of magnitude higher compared to the eastern bort of the "Pivdennyi" quarry.

Blocks of technogenic layering occupy an intermediate position according to the indicated indicators between the western and eastern borts of the quarry.

2. The spatial formation of the newly formed planes of technogenic accumulations took place with the inheritance

of the structural anisotropy existing in the surviving blocks with the creation of its own stratification. That is, surviving blocks and technogenic accumulations developed in a coordinated manner as a complete object. Therefore, the studied technogenic geological formation is a system: "surviving blocks-technogenic accumulations", which was formed over years – decades in surface conditions.

3. For the most part, the processes developing in the landscapes of technogenesis zones are considered undesirable and destructive. In this case, constructive phenomena were recorded – the transformation of technogenic accumulations, their "completion"/structuring, as a result of which the integrity of disturbed, even completely disappeared sections of the geological volume is restored. So, in technogenic accumulations, physico-chemical processes similar to natural ones occur, they are activated due to human economic activity and are aimed at preserving the natural balance of the environment. According to G.I. Denisik and G.M. Zadorozhnya the detected neoplasms can be classified as primary derivatives, micro-mesolevel, superficial, unconsciously regulated.

4. The phenomena described above are practically a natural laboratory of processes of formation of structural and textural elements in loose accumulations. Their tracking in time would actually make it possible to observe the processes of self-creation/reproduction of modern technogenic-natural objects.

5. Identification and ranking according to certain features of the structural elements of technogenic bodies can be used as one of the criteria for assessing the assimilation potential (according to (Dovgii et al., 2016)) of the technogenic changed geological environment.

6. The study of structural new formations in technogenic accumulations can be used in the future to assess the suitability of these accumulations for economic development. After all, the conditions of occurrence and the degree of maturity of such neoplasms will determine the level of stability of the man-made environment.

Authors' contribution: Liubov Osmachko – conceptualization, formal analysis, methodology, writing (original draft); Valentin Verkhovtsev – conceptualization, writing (review and editing).

Acknowledgments, sources of funding: The authors of the article express their sincere gratitude to the management and geologists of "RUDOMAIN" LLC for technical assistance in the research, as well as for providing comprehensive explanations and consultations.

References

Denisik, G. I., & Zadorozhnya, G. M. (2013). *Derivatives of processes and phenomena in landscapes zones technogenesis*. "Edelveis & K" [in Ukrainian]. [Денисик, Г. І,. & Задорожня, Г. М. (2013). *Похідні процеси та явища в ландшафтах зон техногенезу*. ПП "Едельвейс і К"].

Dovgii, S. O., Ivanchenko, V. V., Korzhnev, M. M., Kurylo, M. M., Trofymchuk, O. M., Chumachenko, S. M., Yakovlev, E. O., & Belitska, M. V. (2016). *Assimilation potential of the geological environment of Ukraine and its evaluation*. National Academy of Sciences of Ukraine, Institute of Telecommunications and Global. information space. Nika-Center [in Ukrainian]. [Довгий, С. О., Іванченко, В. В., Коржнев, М. М. (ред.), Курило, М. М., Трофимчук, О. М., Чумаченко, С. М., Яковлєв, Є. О., & Беліцька, М. В. (2016). *Асиміляційний потенціал геологічного середовища України та його оцінка*. НАН України, Інститут телекомунікацій і глобал. інформ. простору. Ніка-Центр].

Extraction of iron ores of site No. 2 of the "Pivdennyi" quarry (iron ores of re-development of the fifth iron horizon). (2018). Report on the environmental impact assessment. Registration number of the case on the environmental impact assessment of the planned activity – 20189171722. Dnipro [in Ukrainian]. [Видобування залізних руд ділянки № 2 кар'єру "Південний" (залізні руди повторної розробки п'ятого залізистого горизонту). (2018). Звіт з оцінки впливу на довкілля. Реєстраційний номер справи про оцінку впливу на довкілля планованої діяльності – 20189171722. Дніпро].

Geological and economic evaluation of the feasibility of attracting poor ores with an on-board Fe content of 36 % within the boundaries of site No. 2 of the "Pivdennyi" quarry in the city of Kryvyi Rih, Dnipropetrovsk region. [Text, maps] (2018). Report on the exploration of a solid mineral deposit. Geoprof; resp. exclamation Kotenko, O. K. [in Ukrainian]. [Геолого-економічна оцінка доцільності залучення бідних руд при бортовому вмісті Fe – 36 % у межах ділянки № 2 кар'єру "Південний" у м. Кривий Ріг Дніпропетровської області. [Текст, карти]. (2018). Звіт про розвідку родовища твердих корисних копалин. Геопроф; відп. вик. Котенко, О. К.].

Geological investigation of the deposit of oxidized iron ores of the 5th and 6th iron horizons of the saksagan suite of the Kryvyi Rih series of plots No. 2 and No. 3 of the " Pivdennyi " quarry (c. Kryvyi Rih)" with the study of technogenic disturbance of the primary geological environment as a result of long-term exploitation of the deposit by open and underground mining methods. (2023). Report (final) on the SRW under the contract No. 02/2023-IGNS dated June 13, 2023 with RUDOMAIN LLC. Science. manager Verkhovtsev, V. G., resp. performed by Pokaliuk, V. V.; Kyiv, State University "Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine" [in Ukrainian]. [Геологічне дослідження родовища окислених залізних руд 5-го та 6-го залізистих горизонтів саксаганської світи криворізької серії ділянок № 2 і № 3 кар'єру "Південний" (м. Кривій Ріг)" з вивченням техногенної порушеності первинного геологічного середовища внаслідок багаторічної експлуатації родовища відкритим і підземним способами видобутку. (2023). Звіт (заключний) про НДР за договором № 02/2023-ІГНС від "13" червня 2023 р. з ТОВ "РУДОМАЙН". Наук. керівник Верховцев, В. Г., відп. виконавець Покалюк, В. В.; Київ, ДУ "Інститут геохімії навколишнього середовища НАН України"].

Korzhnev, M. M., Vyzhva, S. A., Koshlyakov, O. E., Gozhik, A. P., Korneyenko, S. V., Baisarovych, I. M., Aksyom, O. S., & Sukhina, O. M. (2005). *Ecological geology*. PPC "Kyiv University" [in Ukrainian]. [Коржнев, М. М. (ред.), Вижва, С. А., Кошляков, О. Є., Гожик, А. П., Корнєєнко, С. В., Байсарович, І. М., Аксьом, О. С., & Сухіна, О. М. (2005). *Екологічна геологія*. ВПЦ "Київський університет"].

Lukienko, O. I., Vakarchuk, S. G., & Kravchenko, D. V. (2014). *Structural and paragenetic analysis (on a tectonofacies basis). Book 1: Epizone*. VOC "Kyiv University" [in Ukrainian]. [Лукієнко, О. І., Вакарчук, С. Г., & Кравченко, Д. В. (2014). *Структурно-парагенетичний аналіз (на тектонофаціальній основі). Книга 1: Епізона*. ВПЦ "Київський університет"].

Lukienko, O. I., Yanchenko, V. P., & Kravchenko, D. V. (2018). *Structural and paragenetic analysis (on a tectonofacies basis). Book 2: Mesozone and Catazone*. VOC "Kyiv University" [in Ukrainian]. [Лукієнко, О.І., Янченко, В.П., Кравченко, Д.В. (2018). *Структурно-парагенетичний аналіз (на тектонофаціальній основі). Книга 2: Мезозона та катазона*. ВПЦ "Київський університет"].

Nikitenko, I. S. (2023). *Petrology of stone materials of the Middle Dnipro Region archaeological objects*. Extended abstract of Doctor's dis. (Geol.). M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of the National Academy of Sciences of Ukraine [in Ukrainian]. [Нікітенко, І. С. (2023). *Петрологія кам'яної сировини археологічних об'єктів Середнього Подніпров'я*. Автореф. дис. д-ра геол. наук. Інститут геохімії, мінералогії та рудоутворення ім. М.П. Семененка НАН України].

Protocol No. 4472 of the meeting of the collegium of the State commission of Ukraine on mineral reserves at the State geology and subsoil service of Ukraine from august 15, 2018, on the consideration of generalized materials on the geological study of iron ore reserves of site No. 2 of the "Pivdennyi" quarry, submitted by LLC " RUDOMAIN" with the aim of obtaining consultation and methodical assistance regarding whether the assessed subsoil area belongs to technogenic deposits (2018) [in Ukrainian]. [Протокол № 4472 засідання колегії Державної комісії України по запасах корисних копалин при Держ. Службі геології та надр України від 15 серпня 2018 року, з розгляду узагальнених матеріалів з геологічного вивчення запасів залізних руд ділянки № 2 кар'єру "Південний", поданих ТОВ "РУДОМАЙН" з метою отримання консультації і методичної допомого щодо належності оціненої ділянки надр до родовищ техногенного типу. (2018)].

Отримано редакцією журналу / Received: 19.04.24
Прорецензовано / Revised: 31.07.24
Схвалено до друку / Accepted: 20.12.24

Любов ОСЬМАЧКО, д-р геол. наук, ст. наук. співроб.
ORCID ID: 0000-0003-1248-261X
e-mail: osml@ukr.net.
Державна установа "Інститут геохімії навколишнього середовища Національної академії наук України", Київ, Україна

Валентин ВЕРХОВЦЕВ, д-р геол. наук
ORCID ID: 0000-0002-1015-6725
e-mail: verkhovtsev@ukr.ne
Державна установа "Інститут геохімії навколишнього середовища Національної академії наук України", Київ, Україна

ПРО СТРУКТУРИЗАЦІЮ ТЕХНОГЕННО ЗМІНЕНИХ ОБ'ЄМІВ КАР'ЄРУ "ПІВДЕННИЙ" М. КРИВИЙ РІГ

В с т у п . ***Дослідження проводилися в межах залізорудного кар'єру "Південний" м. Кривий Ріг з метою комплексного і ефективного в подальшому використання техногенно перетворених ділянок надр і земної поверхні Кривбасу. Наведено короткий огляд досягнень попередніх дослідників.***

М е т о д и . ***Застосовано загальноприйняті методи досліджень. Виконано фіксацію елементів залягання у відносно непорушених невеликих за розмірами блоках (далі – блоках або "блочках") кварцитів і сланців саксаганської світи (цiликах) та в блочках розмежування цiликів – техногенних нагромадженнях. У відносно непорушених блочках кварцитів замірялися такі елементи для смугастості, сланцюватості, лінійності за мінеральними агрегатами, осями складчастих форм, штрихами, борознами тощо. Фактичний матеріал щодо розміщення структурних елементів опрацьовано за допомогою програми StereoNett 2.46, також зроблено розрахунки зміщень блочків досліджуваних утворень.***

Р е з у л ь т а т и . ***Серед техногенних нагромаджень (осипів, насипів й заповнених штучних порожнин), за ступенем структуризації, спостережено неструктуровані та різною мірою структуровані. У межах останніх фіксовано шаруватість, механічну сланцюватість та лінійність. З'ясовано, що становлення системи блочків кар'єру "Південний" чинилося за їх обертання як по вертикальній, так і по горизонтальній осях.***

В и с н о в к и . ***Виникнення новоутворених площин техногенних нагромаджень відбулося з успадкуванням існуючої в цiликах структурної анізотропії зі створенням власної стратифікації. Отже, досліджувана система "блочки цiликів – техногенні нагромадження" розвивалася й формувалися як цілісний об'єкт, взаємоузгоджено, роки – десятиліття в поверхневих умовах.***

Перетворення техногенних нагромаджень, їх "добудова"/структуризація, внаслідок яких відновлюється цілісність порушених і зникліх ділянок геологічного об'єму є конструктивними явищами. Вони практично є природною лабораторією процесів формування структурно-текстурних елементів у сипких нагромадженнях. Їх відстеження в часі дало б змогу фактично спостерігати процеси самостворення/відтворення сучасних техногенно-природних об'єктів. Ранжування структурних новоутворень в техногенних нагромадженнях може бути застосовано як один з критеріїв оцінки асиміляційного потенціалу цих нагромаджень та сприятливості для господарського освоєння.

К л ю ч о в і с л о в а : ***залізисті горизонти, кар'єр "Південний", непорушені блочки, техногенні нагромадження, елементи залягання, структуризація.***

Автори заявляють про відсутність конфлікту інтересів. Спонсори не брали участі в розробленні дослідження; у зборі, аналізі чи інтерпретації даних; у написанні рукопису; в рішенні про публікацію результатів.

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; in the decision to publish the results.