https://doi.org/10.30836/igs.1025-6814.2022.3.253551
UDC [551.311.231 : (553.612.08:549.623.9)](477)

Y.V. KROSHKO *, M.S. KOVALCHUK, H.O. KUZMANENKO, T.V. OKHOLINA
Institute of Geological Sciences of NAS of Ukraine, Kyiv, Ukraine
E-mail: ykrosh.79@ukr.net; kms1964@ukr.net; geology.kuzmanenko@gmail.com; svilya@ukr.net
* Corresponding author

STRUCTURAL AND LITHOLOGICAL MODEL OF THE ZHEZHELIV DEPOSIT OF ELUVIAL KAOLIN

This study characterizes the geological structure of the Zhezheliv eluvial kaolin deposit, zoning and material composition of the weathering crust, and the mineral composition and physicochemical characteristics of eluvial kaolins. The relationship between rock-forming oxides and the distribution of the contents of Fe_2O_3, TiO_2 and Al_2O_3 in the vertical section and through the area were investigated. The content of titanium and iron oxides in the kaolin concentrate and its granulometric composition were characterized, depending on the petrotypes of the weathered parent rocks. Maps of the relationship between isolines of the top surface of eluvial kaolins, isolines of their thickness and isolines of the surface of their base have been compiled. A correlation has been established between the topography of the bottom and top and the thickness of the kaolin deposit. A map of the spatial distribution of kaolin whiteness has been compiled. The vertical distribution of whiteness and Fe_2O_3 and TiO_2 contents was investigated for individual wells in the kaolin deposit. It was found that there is no steady correlation between the content of Fe_2O_3 and TiO_2 in the vertical section. The whiteness index of kaolins in the vertical section depends on the content of the indicated oxides or one of them. Based on the analysis of satellite images at different times, the change in the area of the disturbed geological environment during the deposit development through 2006-2020 was assessed.

Keywords: *Ukraine; Zhezheliv deposit of eluvial kaolin; structural and lithological model; geological structure; material composition; change of the area of disturbed geological environment.*

Introduction

Kaolin is a light, clayey rock, the main component of which is the mineral kaolinite, formed as a result of weathering or hydrothermal transformation of Precambrian crystalline rocks. Due to the high content of aluminum oxide, kaolin is the main component of the mixture for the production of porcelain, earthenware, sanitary and building ceramics, cement, and due to its high whiteness and fine composition it is the main filler in the production of paper, cardboard, rubber products and others (Heleta et al., 2011). Ukraine occupies one of the leading positions in the world in terms of the number of explored and previously estimated re-

Citation: Kroshko Y.V., Kovalchuk M.S., Kuzmanenko H.O., Okholina T.V. 2022. Structural and lithological model of the Zhezheliv deposit of eluvial kaolin. *Geologičnij žurnal.* 3 (380): 67-80. https://doi.org/10.30836/igs.1025-6814.2022.3.253551
Цитування: Крошко Ю.В., Ковальчук М.С., Кузьманенко Г.О., Охоліна Т.В. Структурно-літологічна модель Жежелівського родовища елювіальних каолінів. *Геологічний журнал.* 2022. No. 3 (380). С. 67—80. https://doi.org/10.30836/igs.1025-6814.2022.3.253551

serves of kaolin (Hurskyi et al., 2006; Rudko et al., 2015). About 10% of the world's kaolin reserves are concentrated in Ukraine (Hurskyi et al., 2006; Heleta et al., 2011). In terms of kaolin reserves, Ukraine is second only to the United States, Great Britain, and China.

The quality of kaolin from Ukrainian deposits is one of the best. Kaolins in Ukraine are represented by two genetic types: primary kaolin (of basic and alkaline composition) and secondary kaolin (Rudko et al., 2015). The largest province of eluvial kaolins is the Ukrainian Shield, where thick areal and linear kaolin weathered crusts were formed upon the crystalline basement rocks of different ages and various genesis (Rusko, 1976; Hurskyi et al., 2006).

According to the conditions of formation, depth of occurrence and preservation of deposits within the province of the Ukrainian Shield, five subprovinces are distinguished here, namely the Volyn', Podillya, Central, Dnieper, and Peri-Azov (Rudko et al., 2015).

In the northern part of the Vinnytsia region, the Glukhivtsi-Turbiv kaolin district is located, which hosts a number of fields and ore manifestations (Velyki Hadomtsi, Glukhivtsi, Zhezheliv, Turbiv, Chubyntsi, Huryntsi, Tucha-Mykolaivka) with geologically and economically estimated kaolin reserves. They are economically feasible and technologically acceptable for industrial use by their properties, quality, conditions and quantity in accordance with established state standards and technical requirements of the potential consumer. Those fields represent about half of the explored reserves of eluvial kaolins in Ukraine.

The state balance of mineral reserves in the region includes4 deposits: Glukhivtsi, Turbiv, Zhezheliv and Velyki Hadomtsi. For all these deposits, various enterprises have been grated special permits for subsoil use and mining for their development.

The most typical representative of eluvial kaolin deposits within the Glukhivetsko-Turbivsky kaolin district is the Zhezheliv deposit, which has a complex geological structure of both the crystalline basement and the weathered crust itself (Tkachuk, Sonkin, 1981). It is located within the tectonic contact zone of crystalline complexes of different ages, which differ in origin, mineral composition and textural and structural features (Tkachuk, Sonkin, 1981).

Exploration and evaluation works at the Zhezheliv field and detailed exploration of the Southern section were carried out in 1993 (Report…, 1993). Preliminary and detailed exploration of the field was carried out during 1994-1995 (Report…, 1996). Exploration of the Zhezheliv kaolin deposit was carried out in 2004-2005 (Report…, 2005). Peculiarities of the qualitative composition of kaolins and geological and economic features of the Zhezheliv kaolin deposit have been characterized in several scientific publications (Shevchenko et al., 2000; Shcherbak et al., 2002). Comparative mineralogical and petrographic analysis of eluvial kaolins of Hlukhivetsko-Turbiv district was carried out in (Shevchenko et al., 2000; Shcherbak et al., 2002). General information about kaolins of Hlukhivetsko-Turbiv district of the Ukrainian Shield and prospects of their use were given in the monograph (Tkachuk, Sonkin, 1981).

The structural and lithological parameters of the deposit have been studied indirectly, need updating and digital cartographic visualization, and changes in the area of the geological environment disturbed by the quarry have not been considered.

One of the important factors of sustainable development of Ukraine is the proper provision of the needs of the economy in mineral resources. The development of kaolin deposits in Ukraine is determined by their physicochemical properties and scale of use in almost all areas of production, and is profitable due to shallow depth, significant thickness of deposits, and quality of raw materials.

When developing kaolin deposits, it is advisable to take into account structural and lithological indicators, including relief of top and bottom boundaries of a deposit, its thickness, and qualitative characteristics of kaolin.

The aim of this article is to create a structural-lithological model of Zhezheliv eluvial kaolin deposit, informing on structural conditions of deposit placement, influence of these conditions on structural-lithological features of deposit, namely influence of parent substrate rocks on material composition and zonation of the weathering crust, conditions of occurrence, material composition, and quality of kaolins, and lateral and vertical distribution of oxides that degrade the quality of kaolin. The ecological aspect of the article involves the study of changes in the area of the geological environment disrupted during the extraction of kaolin in 2006-2020.

The work was performed in the scope of the state-funded project of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine "Geological and genetic models of ore-bearing weathering crusts of the Ukrainian Shield and sedimentary formation units formed by their erosion" and "Determining the prospects for the development and use of the mineral resource base of Ukraine with the allocation of priority ore facilities".

Materials and methods

Materials of production reports and scientific publications about the Zhezheliv deposit of eluvial kaolins were reviewed. The field research was conducted; samples of eluvial kaolins were taken and their laboratory investigation (chemical, spectral, X-ray structural, granulometric analyzes) were carried out. The maps were built out on the basis of coordinate data, descriptions and testing of wells in Surfer and Strater of the Golden Software. To determine the changes in the area of the disturbed geological environment within the quarry field, the authors used images from 2006 to 2020 from the US Geological Survey portal . Space images from Landsat 1-5, Landsat 4-5, Landsat 7, Landsat 8, Sentinel 2 systems, which have GEO.tiff format and spatial reference in the WGS-84 coordinate system were used. Processing of space images and measurement of the area of the disturbed geological environment was carried out by QGIS 3.17 software.

Results

The Zhezheliv deposit of eluvial kaolins is located in the Kozyatyn district of the Vinnytsia region, 1 km northeast of the village Zhezheliv, in a wide (300-500 m) valley of the north-western strike (Fig. 1). The field is located in the south of the north-western part of the Ukrainian Shield (Derkach et al., 2001). The main surface watercourses of the field are the Gnilopyat River and its right nameless tributary (length 3.0 km, valley width 20-70 m), which flow in the sublatitudinal direction along the southern flank of the field. The floodplain of the stream is swampy in some areas.

The Archean-Proterozoic rocks, which form the crystalline basement and its residual weathered crusts, comprise the lower structural story. They are diverse in genesis, structural and textural features, and composition and are covered with horizontally lying Neogene and Quaternary sedimentary rocks (Report…, 1993).

Fig. 1. Satellite image of the Zhezheliv quarry

The oldest formations of the lower structural story include gneisses of the Dniester-Bug series, as well as basic and ultrabasic rocks (pyroxenites and serpentinites). Above these, the Paleoproterozoic formations (Berdychiv complex) occur, composed by pink and pink-gray medium-grained and pegmatoid granites, granites of the Berdychiv complex and their migmatites. The formations of the Zhytomyr complex are represented by pink aplitoid and aplito-pegmatoid granites and their migmatites with uniform grains (Report…, 1993).

Crystalline rocks during the pre-Paleozoic and Paleozoic geological epochs were affected by deep physical, chemical and biochemical weathering, which underwent complete or partial erosion and therefore did not survive.

Zonality and substance composition of weathering crust

Favourable climatic (warm and humid climate), paleogeographic (mostly continental), geological (extensive development of rocks of granitoids composition) and tectonic (the presence of intense zones of main and secondary tectonic faults) con-

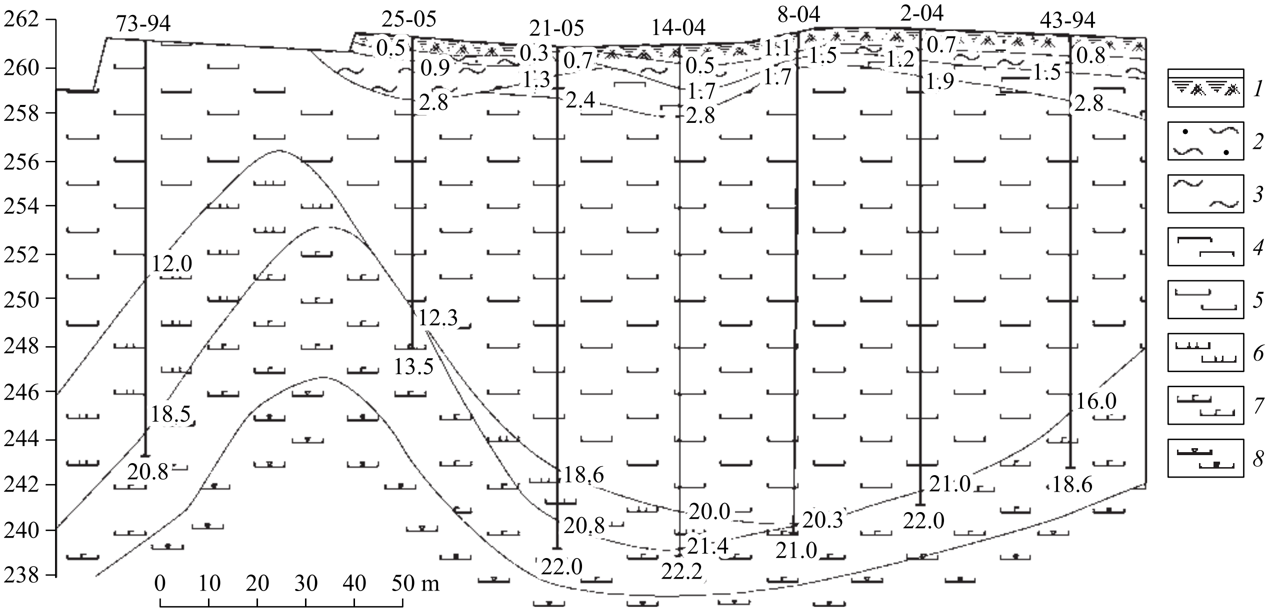

Fig. 2. Typical section of the Zhezheliv eluvial kaolin deposit *1* — soil and vegetation layer; *2* — loam (Q_{IV}); *3* — clay particolored (N_1); *4* — kaolin redeposited (N_1); *5* — zone of final hydrolysis and oxidation of weathering products (primary normal kaolin); *6* — zone of initial hydrolysis (alkaline kaolin); *7* — the lower part of the initial hydrolysis zone (kaolinite-hydromica rock); *8* — zone of disintegration and leaching (kaolinized gruss) (Slyusarenko, 2008)

ditions in the Mesozoic-Cenozoic epoch have favoured to formation of thick residual weathered crust upon the crystalline bedrock which forms the Zhezheliv deposit of eluvial kaolins.

Kaolin weathered crust is widespread almost everywhere in the area. The weathered crust is absent only in the floodplain of rivers, where it is completely or partially eroded, and in the areas of outcrops of slightly altered crystalline rocks of the basement surface, or where the latter occur at shallow depth (Report…, 1993). The thickness of the weathered crust varies widely from the first meters to 100 meters or more. According to its morphological features, the weathered crust belongs to the mixed linear-planar type.

The weathered crust is characterized by a vertical zonation expressed in the gradual vertical change of zones with varying degrees of weathering of parent rocks and the transformation of primary minerals. This zonation reflects the sequence and stages of the process of hypergenesis (Fig. 2).

In the vertical section of the kaolin crust there are three consecutive zones (bottom-up): the first zone is characterized by disintegration and leaching, the second zone represents products of the initial hydrolysis (kaolinite-hydromica), and the third one stands for the final hydrolysis and oxidation of weathering products (kaolinite).

The rocks of the disintegration and leaching zone have subjected to increased microcracking. They are weakened, easily separate into fragments and are partially kaolinized, structured gruss of the parent rocks. The mineral composition of the zone is similar to the composition of parent rocks. Changes in mineral composition are expressed mainly in the hydration of primary and the formation of small amounts of secondary minerals (feldspars are changed; are partially replaced by kaolinite, biotite-hydrobiotite and chlorite on the periphery).

The mineral composition of the initial hydrolysis zone is more diverse and is characterized by the presence of relic minerals (quartz, potassium feldspar, ore and accessory minerals) and a significant amount of newly formed hypergenic minerals like hydromica, chlorite, and montmorillonite (Report…, 1993, 1996). Due to the significant amount of hydromica and chlorite, the rock acquired spotted green-gray (in the case of weathering of granites, especially varygrained varieties), or uniform green-gray or brown-green color (in the case of weathering of gneisses). There are often areas of rusty-brown color due to iron hydroxides within this zone.

The zone of final hydrolysis and oxidation of weathering products is characterized by almost

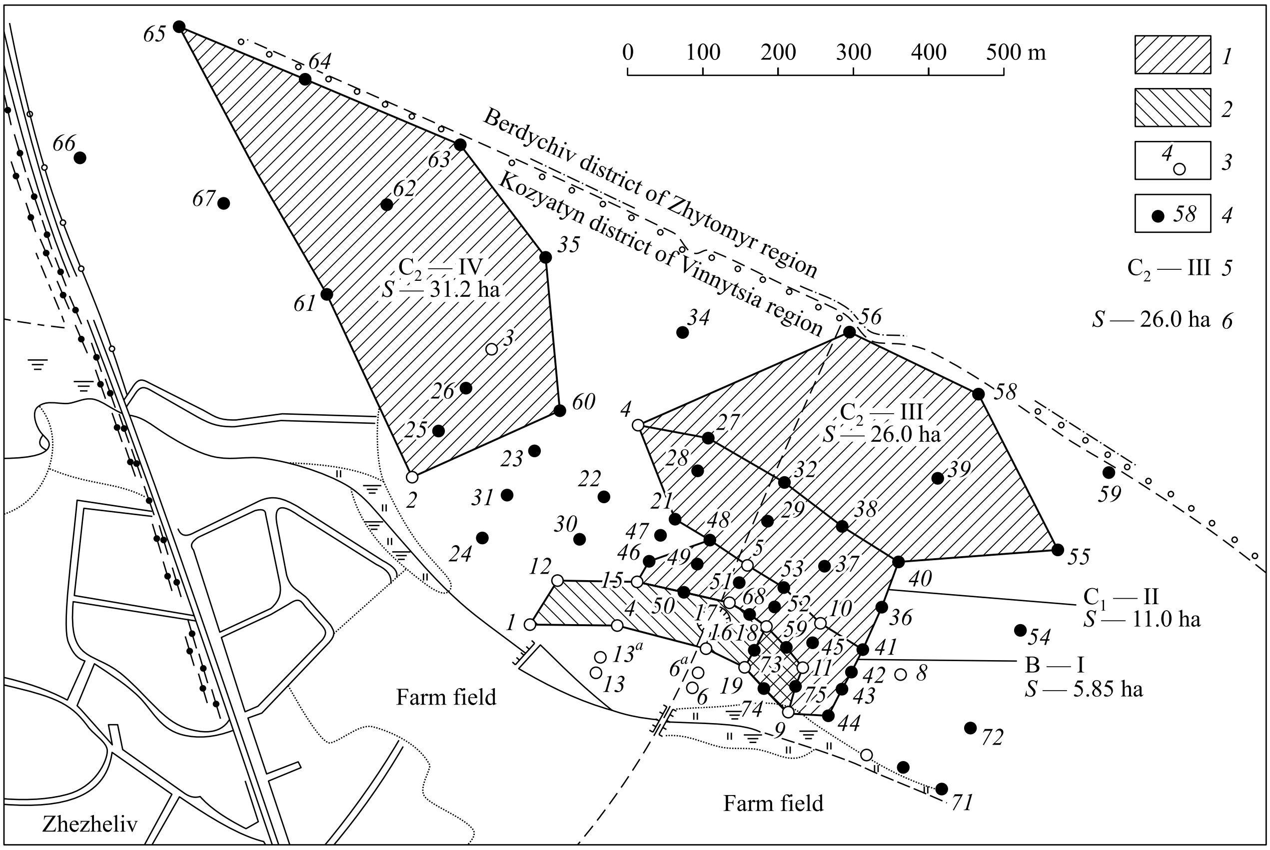

Fig. 3. Schematic plan of the Zhezheliv deposit of eluvial kaolins, according to (Report…, 1993) *1* — the areas of reserves estimation according to the results of preliminary and detailed exploration, 1994-1995; *2* — southern part. Reserves are approved in 1993; *3* — exploration wells, 1992; *4* — wells of preliminary and detailed exploration, 1994-1995; *5* — number of account block; *6* — area of account block

complete replacement of the main rock-forming minerals with final and stable in the upper horizons of the crust products in the sequence of hypergenic mineral formations, namely kaolinite. Along with kaolinite, quartz and accessory minerals are present. Relicts of potassium feldspar grains (mainly in the lower part of the zone) are present in the areas of kaolinite zone development on granitoid rocks with high content of potassium feldspars. There are two subzones in the kaolinite zone: the sub-zone of normal kaolins, which is characterized by complete decomposition of aluminosilicates as well as alkaline kaolin subzone containing 5% of undecomposed potassium feldspar (Report…, 1993, 1996; Slyusarenko, 2008). Visually, alkaline kaolins, in contrast to normal ones, have greater rigidity, are less ductile, and have a granulated sugar appearance at break.

The subzone of normal primary kaolins is characterized by almost complete decomposition and replacement of the original aluminosilicates by kaolinite. There is quartz along with kaolinite in the rock, which content, grain size and distribution nature in kaolin depend entirely on the composition of the parent rocks. The composition of parent rocks also determines the color, the content of coloring oxides and other quality indicators.

Three varieties of eluvial kaolins have been conditionally revealed depending on the composition and structural and textural features of the deposit parent rocks. Several plots have been distinguished by their structural conditions,, technological features of kaolins, and other features within the deposit (Fig. 3) (Report…, 1993, 1996).

Composition and conditions of occurrence of eluvial kaolins

The first variety is kaolin formed by weathering of the Chudniv-Berdychiv garnet-biotite, gray, medium-fine-grained granites and migmatites. Kaolins are characterized by a relict banded texture (striation is associated with the alternation of bands of kaolin on the granite and gneiss substrate of the parent rock) and variegated colour (from light cream to ochre yellow and brown), associated with the presence of the parent granite rocks in some areas. Kaolins are heterogeneous and of variegated quality (Report…, 1993).

The second variety is kaolin, formed by the weathering of pink and pink-gray, medium-grained and pegmatoid granites. Such kaolins are distributed mainly within block B-1 and in the central part of block C_2-IV (see Fig. 3) (Report…, 1993, 1996). Kaolins are characterized by a lighter and more uniform coloration, uneven grain size of quartz inclusions, the presence of areas of kaolin formed by weathering of pegmatoid veins (with angular, different sized grains of quartz, with white spots of pure kaolinite formed due to porphyry grains of feldspars).

The third variety is kaolin, formed by weathering of gneisses, which are small isolated bodies among the kaolins of the first and second varieties. Such kaolins are quartz-free, greasy to the touch, plastic, thin-scaly rock of light gray, white, cream colour and are characterized by the highest (up to 80-90%) yield of enriched kaolin (Report…, 1993, 1996).

The presence of different petrotypes of crystalline rocks, complex relationships and mutual transitions between them make it impossible to draw clear boundaries of the distribution of kaolin varieties both in section and laterally.

The subzone of alkaline kaolins is distributed sporadically and occurs in the lower part of the kaolinite weathered crust and the transition zone from primary kaolins to kaolinite-hydromica rocks (Shevchenko et al., 2000). The thickness of the alkaline kaolin subzone varies from 0.0 to 12.5 m and reaches maximum values in areas of predominant development of kaolins formed due to weathering of granitoids with high content of feldspars (wells No. 10, 27, 39, 40; see Fig. 3) (Report…, 1993; Shevchenko et al., 2000). In the areas of kaolin development formed by weathering of gneisses and banded migmatites with a predominance of gneiss component, the alkaline kaolin subzone is absent or of small thickness. In the subzone of alkaline kaolins there are relics of incompletely decomposed feldspar grains. This causes an increase in the content of potassium and sodium oxides in this subzone ($K_2O + Na_2O \geq 1.0\%$). There is a gradual increase of the hydromica group minerals with depth. In the areas of alkaline kaolin occurrence, a decrease (up to 40% or less) in the yield of enriched kaolin was found.

In the lower kaolinite zone there are local areas where due to the impregnation of kaolin with silica colloids and subsequent cementation, kaolin takes the form of a strong rock, due to different degrees of pelicanization of kaolin (wells 46, 50 and 54, 55; see Fig. 3) (Report…, 1993). Mineralogically, the pelicanites consist of a mixture of kaolinite with opal, as well as quartz, biotite or hydrobiotite, and have the form of aggregates of different sizes.

Among all the zones of the weathered crust, only the upper one, the kaolinite zone is of practical interest as a raw material for the production of enriched kaolin, which is widely used in porcelain, paper, rubber, paint, perfume and other industries. In its enriched form, kaolin can be used for the production of refractory products and in the brick production.

The quality of kaolins and their physical and chemical properties, which determine the area of its potential use, depend primarily on the mineralogical and petrological composition, structural and textural features of the primary rocks, as well as the degree and depth of their weathering and hypergenic mineral formation.

Unenriched kaolin of the Zhezheliv deposit consists of kaolinite (47-71%) and light gray quartz grains (24-48%). Feldspars are present in small amounts — up to 3%, biotite up to 2%, ore minerals are represented by ilmenite and leucoxene, the content of which does not exceed 2%.

Physical and mechanical properties of the raw kaolin are following: bulk density is 1950 kg/m^3, natural humidity is from 18.5 to 20%, plasticity index vary from 9.4 to 12.7. It is moderately plastic raw material, upon the content of coarse-grained inclusions the raw kaolin belongs to raw materials with a high content of coarse-grained inclusions; by the degree of its fire resistance it is a refractory raw material with a melting point of 1610-1630 °C to 1650-1670 °C (Report…, 1993).

Harmful impurities in the eluvial kaolins of the Zhezheliv deposit include iron and titanium. The main sources of these elements are iron and titanium-containing minerals, which are part of the parent rocks and are present in kaolin in the form of residual minerals, as well as hypergenic minerals that are genetically related to kaolinite. The former include titanium-containing minerals, namely rutile and ilmenite, and the latter include garnets and biotite. As a result of weathering of parent rocks, leukoxene, goethite, hydrogoethite, limonite and other minerals are formed, which contain titanium and iron (Report…, 1993, 1996).

During the enrichment of eluvial kaolins, the residual minerals of iron and titanium are completely transported into the sand component and do not affect the quality of raw materials. Enriched kaolin contains some oxides of iron and titanium. Their content in the concentrate affects the quality of raw materials. In this regard, we investigated the relationship between rock-forming oxides and the distribution of Fe_2O_3, TiO_2 and Al_2O_3 in the wells and laterally.

The study of the Fe_2O vs. FeO ratio demonstrates that in most cases the maximum Fe_2O_3 content corresponds to the minimum of FeO content, and vice versa. As the Al_2O_3 content increases, the SiO_2 content naturally decreases. There is a direct correlation between TiO_2 and P_2O_5 contents.

Studies of samples of enriched kaolin formed as a result of weathering of various petrotypes of rocks were conducted in the laboratory of the Faculty of Geology of Taras Shevchenko Kyiv National University (analyst Yu.L. Hasanov). The aim was to establish the forms of iron and titanium oxides in enriched kaolin, determine the nature of the relationship between oxides and the structure of kaolinite, and access the possibility of extracting oxides from kaolin concentrate. Samples of kaolin concentrate were subjected to granulometric analysis, with separation of material fractions 50-10, 10-5, 5-2 and less than 2 μm in an amount sufficient for X-ray diffractometric phase analysis and X-ray fluorescence analysis to study of TiO_2, Fe_2O_3 content and other petrogenic oxides (Tkachuk, Sonkin, 1981; Shcherbak et al., 2002; Slyusarenko, 2008). Analytical studies were performed on devices DRON-UM1 and CPM-25.

Results are presented in Table. It was found that the own mineral forms of titanium and iron are absent in the enriched kaolin. The most probable form of these elements' occurrence is a fine impurity of iron and leukoxene hydroxides in the structure of kaolinite. The Fe_2O_3 content practically does not change both by fractions and by types of rocks. The maximum value of TiO_2 content is characteristic of kaolins formed by weathering of gneisses, and the maximum concentration of TiO_2 in these kaolins, according to the laboratory, is related to the 10-50 μm fraction. When removing this fraction from the total mass of enriched kaolin, a significant reduction in the content of TiO_2 in the fraction less than 10 μm is expected. To obtain enriched kaolin of the best grades, fractional use of concentrate is recommended.

Samples taken from the walls of the quarry were analyzed for chemical composition in the laboratory of M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation, NAS of Ukraine. Abnormal in terms of harmful impurities was a

The content of titanium and iron oxides in the kaolin concentrate and its particle size fractions (depending on the petrotypes, due to which the kaolins were formed) (Tkachuk, Sonkin, 1981; Slyusarenko, 2008)

Component	Content as a percentage				
	Concentrate	By fraction, mm			
		50-10	10-5	5-2	<2
Kaolins formed as a result of weathering of the Chudniv-Berdychiv granites					
TiO_2	0.74	0.99	0.90	1.05	0.41
Fe_2O_3	0.25	0.21	0.26	0.25	0.27
The yield of kaolin concentrate	100	19.8	24.6	15.4	40.2
Kaolins that formed due to weathering of the aplito-pegmatoid granites					
TiO_2	0.55	0.58	0.83	0.90	0.27
Fe_2O_3	0.19	0.20	0.18	0.18	0.16
The yield of kaolin concentrate	100	25.4	6.0	22.5	48.1
Kaolins formed due to weathering of gneisses					
TiO_2	2.99	4.17	3.29	2.19	0.73
Fe_2O_3	0.22	0.22	0.23	0.22	0.24
The yield of kaolin concentrate	100	23.2	47.9	15.7	13.2

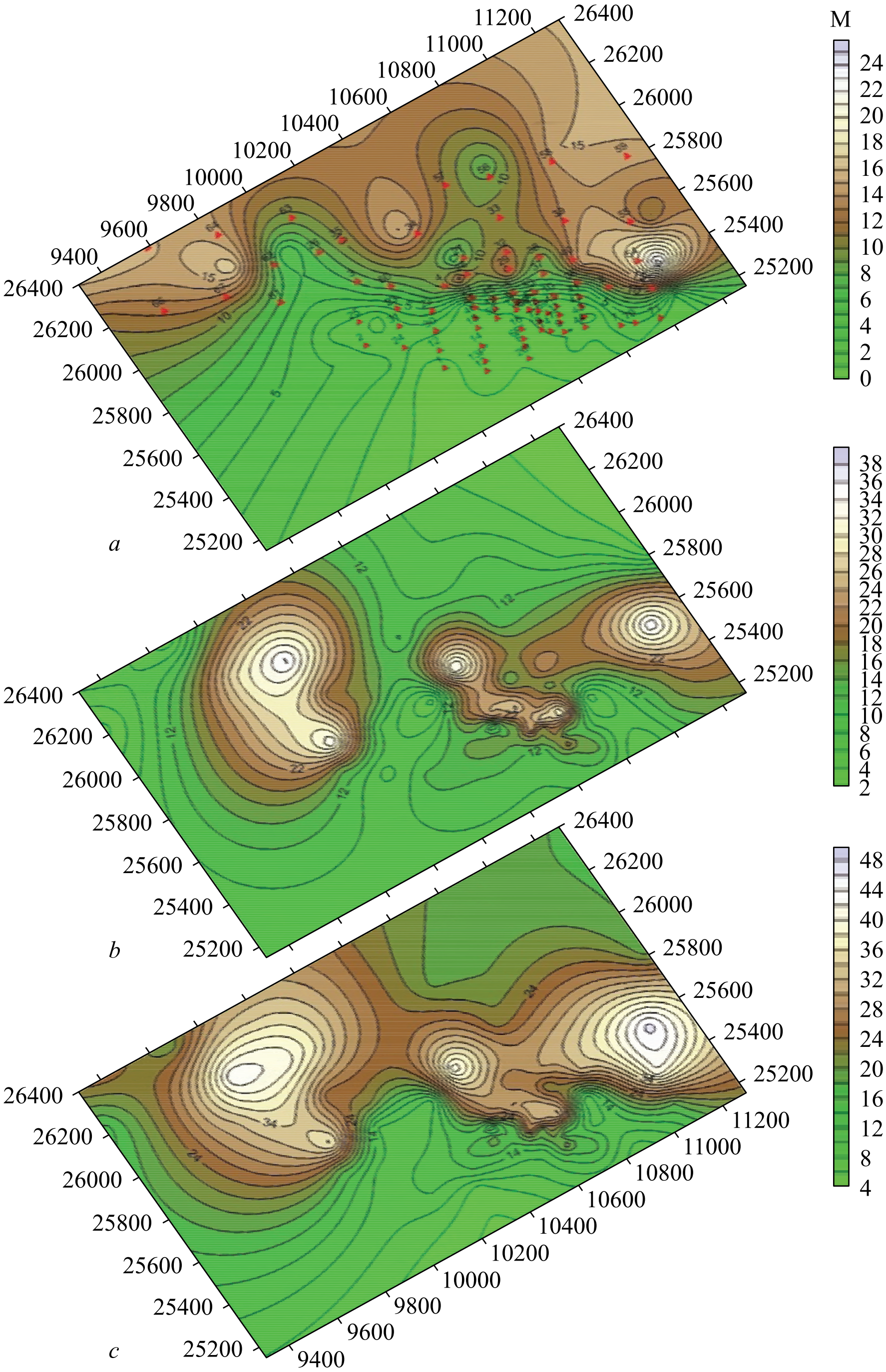

Fig. 4. Maps showing the relationship between the isolines of the top surface of the kaolinite zone of the weathering crust (*a*), the isolines of its thickness (*b*) and the isolines of the bottom surface of the kaolinite zone (*c*)

sample taken from a small lens in the northern wall of the quarry, which had a greyish-yellow colour and fine grain size similar to sand. Spectral analysis for this sample has detected the maximum content of Mn, Ti, V, Zr, Y, P.

The quality of enriched kaolin is slightly affected by the superimposed processes that were associated with the input and removal of some chemical components, and changes in the structural forms of primary kaolin. The first is associated with the reduction of whiteness due to the ferruginization of kaolin, the second one is due to the processes of pelicanization, which cause changes in the particle size distribution, lower yield of enriched concentrate, deterioration of the quality of enriched kaolin.

Due to the fact that the kaolins of the kaolinite zone of the weathered crust have the best quality, we have investigated the features of its top surface, thickness, and bottom surface (Fig. 4).

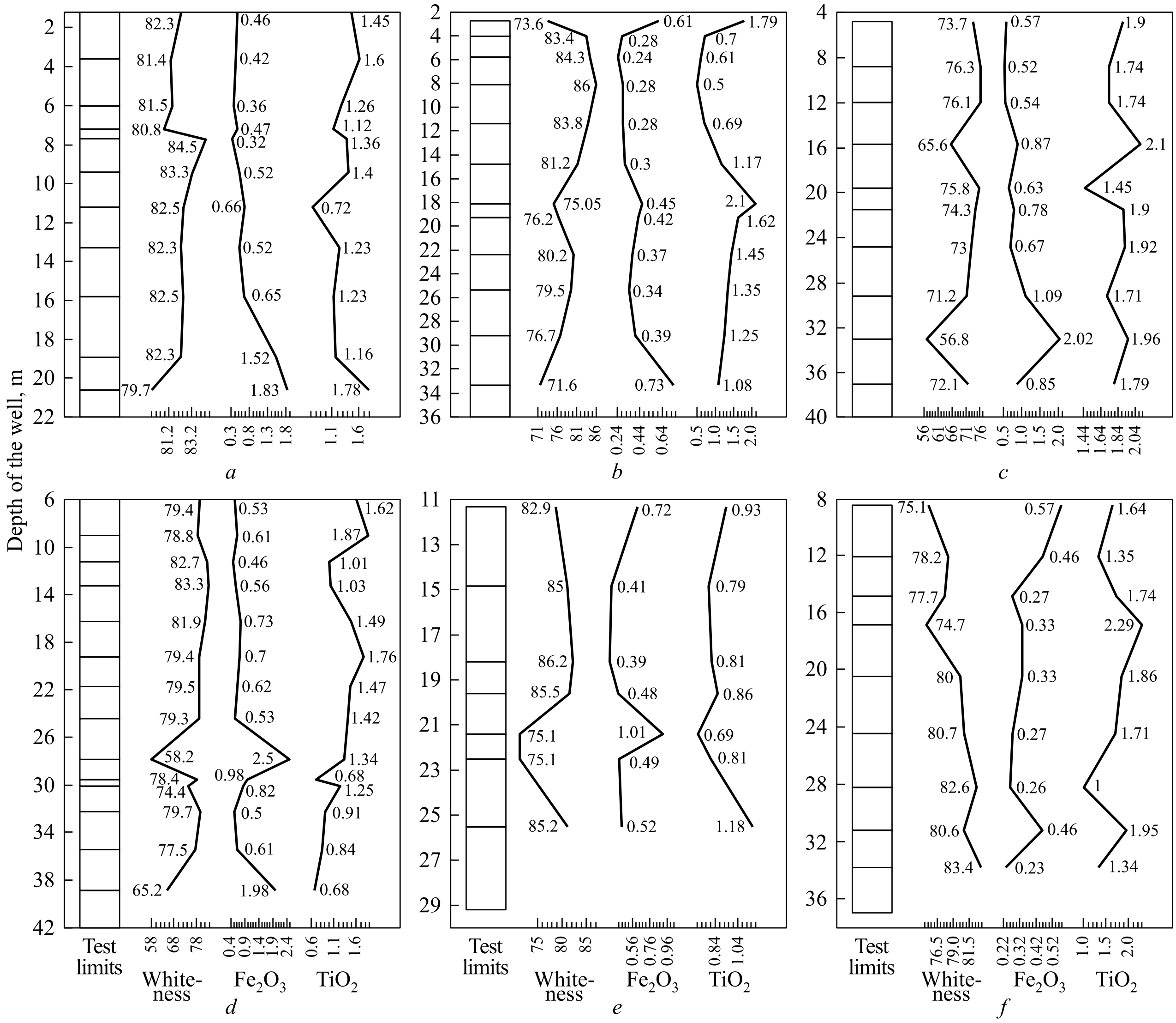

Fig. 5. Vertical variability of whiteness content of eluvial kaolins and their content of Fe_2O_3 and TiO_2: *a* — well 21, *b* — well 25, *c* — well 26, *d* — well 27, *e* — well 32, *f* — well 35

The thickness of the kaolinite zone within the deposit is not constant and varies from zero to 36.8 m. The kaolinite zone has the highest thickness within blocks B and C_1 (wells 5, 53, 10, 52), within the south-eastern and central part of block C_2-IV (wells 25, 26, 62) and in some local areas of the field (wells 27, 55) (Report…, 1996). The thickness of the zone almost everywhere has a direct correlation with the surface of the base of the deposit.

There is a direct correlation between the thickness of eluvial kaolin deposits and their quality. In areas with the highest thickness of kaolin, their quality is higher, meanwhile with decreasing thickness of the kaolin deposit, the quality of kaolin decreases.

The study of vertical (Fig. 5) and lateral (Fig. 7) variability of Fe_2O_3 and TiO_2 contents in the thickness of eluvial kaolins has demonstrated only a partial correlation. Often, in the vertical section and in some areas of eluvial kaolin occurrences, Fe_2O_3 and TiO_2 contents have a direct or inverse correlation.

The study of whiteness in the vertical cross section of eluvial kaolins has showed its significant variability and mainly direct correlation with the contents of iron and titanium oxides, or with one of these indicators (because the contents of Fe_2O_3 and TiO_2 have either direct or inverse correlation). In particular, in well No. 23 the average value of whiteness in the vertical section is 65.8%, with minimum and maximum values of 54.6% and

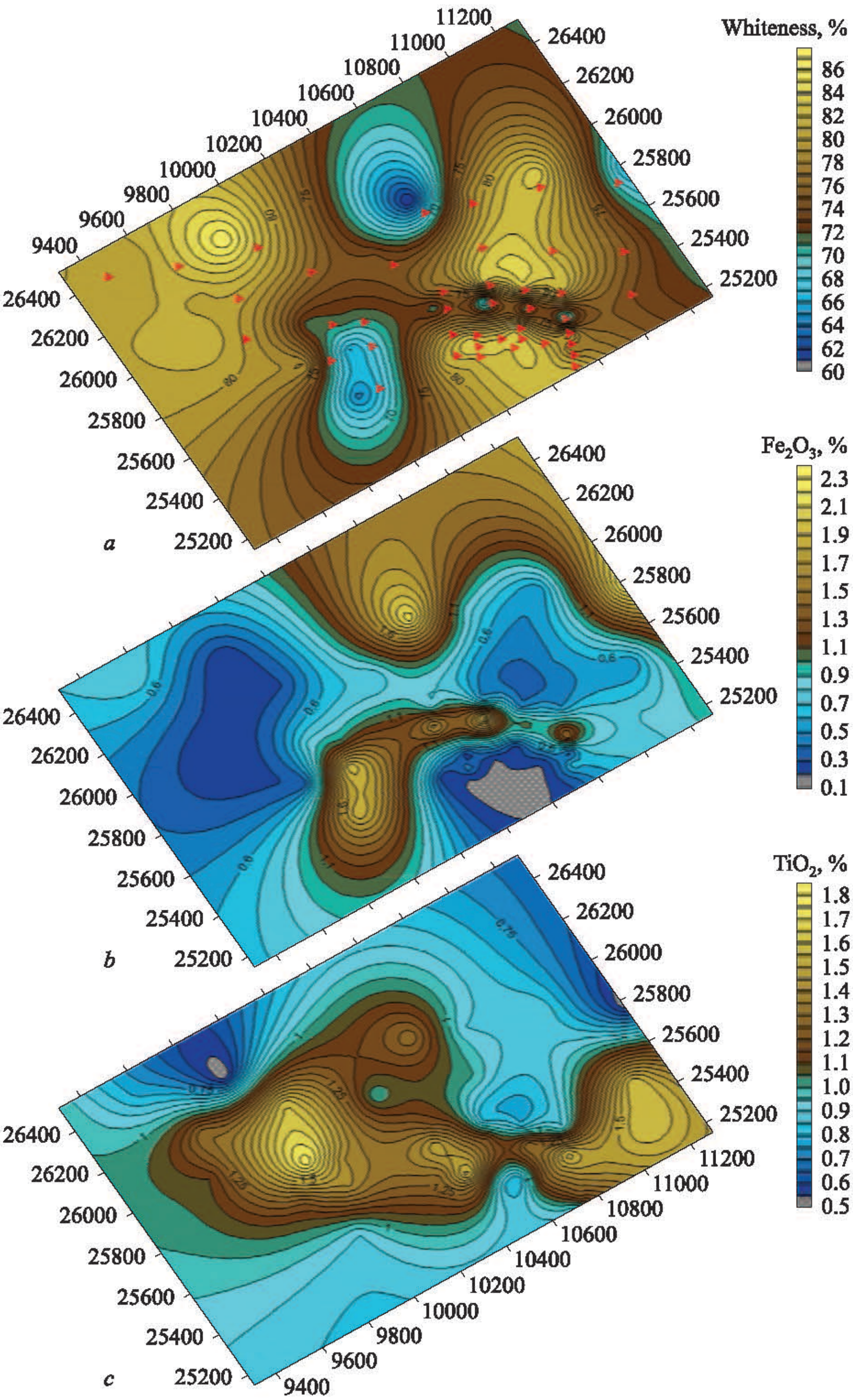

Fig. 6. Spatial distribution of whiteness and contents of Fe_2O_3 and TiO_2 oxides in the eluvial kaolins

78.9%, respectively. There is no regular change with the depth of whiteness of kaolins.

The spatial distribution of the average whiteness of eluvial kaolins has demonstrated generally its high values within most of the deposit area (see Fig. 6).

The lowest average values of whiteness indicators were found within wells No. 57 (60.4%), No. 59 (66.2%), No. 23 (65.8%), No. 24 (64.4%), No. 29 (68, 0%), No. 36 (68.0%). Analysis of the spatial distribution of kaolin whiteness and its content of Fe_2O_3 and TiO_2 oxides has indicated that the whiteness of kaolin mainly depends on the content of Fe_2O_3 in the rock and in some areas — on the total content of Fe_2O_3 and TiO_2.

The spatial distribution of Al_2O_3, Fe_2O_3 and TiO_2 oxides is presented in Fig. 7.

ISSN 1025-6814. Геологічний журнал. 2022. № 3

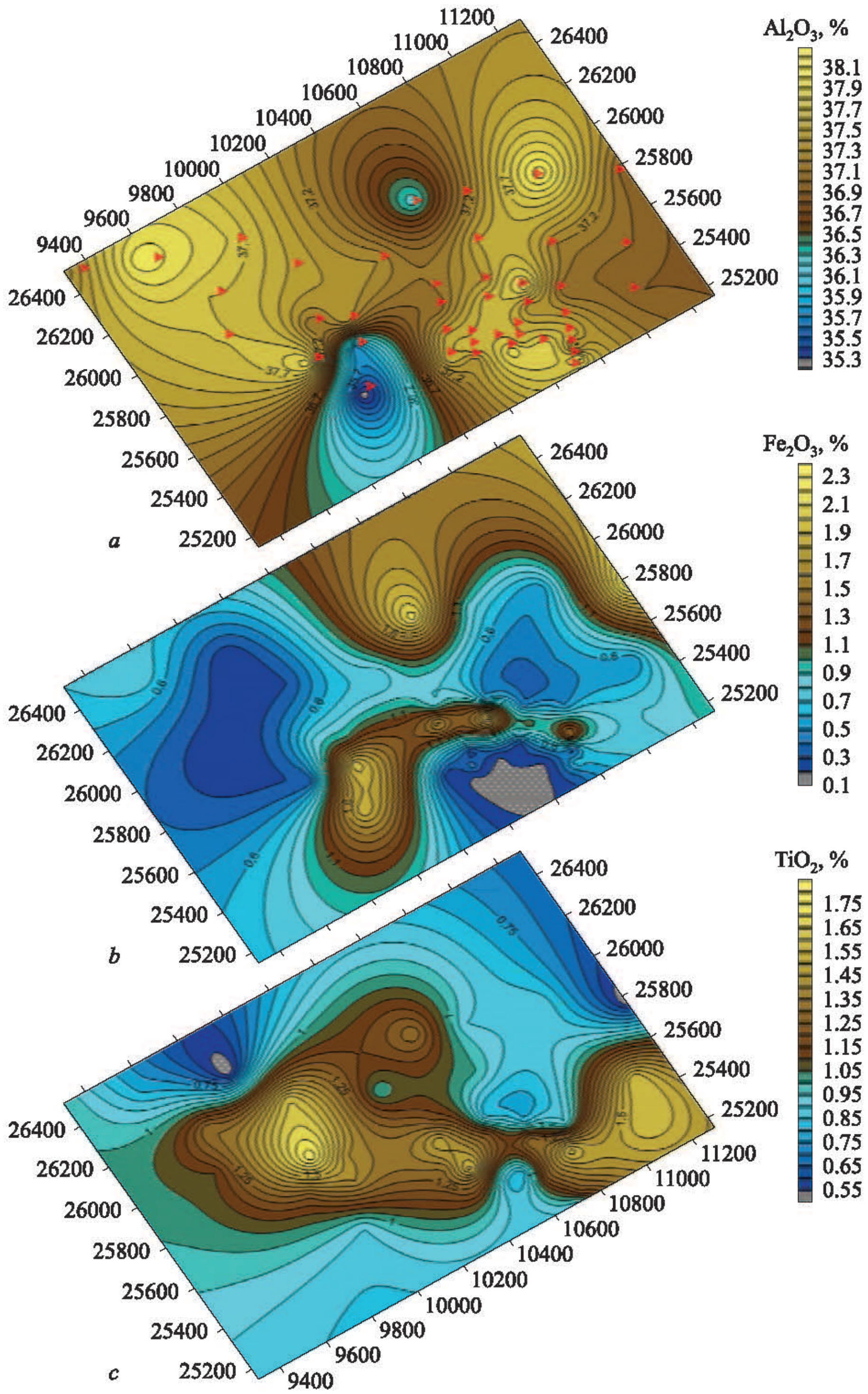

Fig. 7. Spatial distribution of oxides of Al_2O_3, Fe_2O_3 and TiO_2 in the thickness of eluvial kaolins

There was found An inverse correlation of Al_2O_3 content with Fe_2O_3 content is revealed, and only in some areas Al_2O_3 correlates with TiO_2 content.

Changes in the area of disturbed geological environment caused by kaolin mining

One of the most important aspects of ensuring state policy in the field of geological study and rational use of subsoil is the monitoring of subsoil use.

Quarrying of the field has caused changes of the landscape, disturbance of the geological environment and hydrological and hydrogeological regime of waters. It led to air, surface and subsurface water and soil pollution, resulting in irreversible loss of soil and vegetation and their degradation in

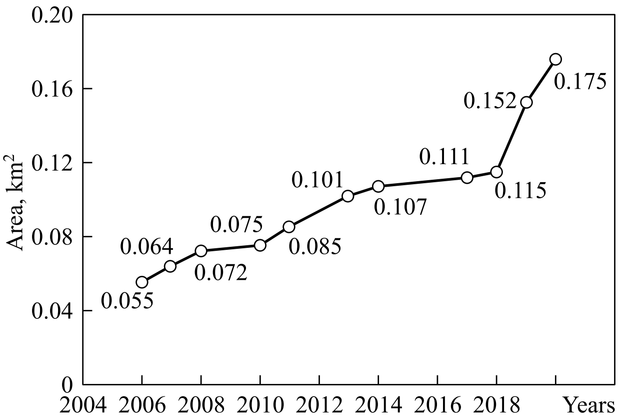

Fig. 8. Dynamics of changes in the area of disturbed geological environment due to the extraction of eluvial kaolin during 2006-2020

the areas adjacent to quarry field. In this regard, monitoring of the geological environment and mining within the quarry field is an integral part of the accompanying works on mining. Time series of space images allows tracking of changes in the geological environment through the time and outline its further changes. Usine these images, we determined the area disturbed by the extraction of eluvial kaolin. This is the area of the quarry itself and the disturbed land plots around the quarry within the land allotment.

To establish the trend of changes in the area of the disturbed geological environment within the quarry field, the authors have processed different time (from 2006 to 2020) space images downloaded from the US Geological Survey portal. Space images from Landsat 1-5 systems (26/07/2015, 25/07/2017, 18/09/2018, 13/09/2019), Landsat 4-5 (24/05/2007, 22/08/2008, 28/04/2009, 15/04/2010, 25/04/2011), Landsat 7 (18/08/2006, 24/07/2012, 30/07/2014), Landsat 8 (01/09/2020, 11/07/2013), Sentinel 2 (30/06/2016) are of GEO.tiff format and georeferenced in WGS-84 coordinate system. Processing of space images was carried out in QGIS 3.17 software. Changes in area of the disturbed geological environment during 2006-2020 are presented in Fig. 8.

The area of the disturbed geological environment within the quarry field increased by 0.12 hectares during 2006-2020. During some years, there has been an increase and decrease in the area of the disturbed geological environment, which is probably due to periods of cessation of mining activities and flooding of the quarry and its restoration.

Conclusions

The structure of the Zhezheliv deposit is determined primarily by its location within the tectonically disturbed contact zone of crystalline basement rocks of different ages and petrotypes. The geological structure of the crystalline basement determined the internal structure of the deposit, in particular the material composition and zonation of the weathering crust, relief of the base of the weathering crust and kaolin in particular, different thickness of the weathering crust, its zones and eluvial kaolins, as well as different material composition and quality of kaolins in the vertical geological section and laterally.

The Zhezheliv deposit of eluvial kaolins was formed in the Mesozoic-Cenozoic epoch due to weathering of the Precambrian crystalline basement rocks of different petrological and mineral composition. These rocks include the Chudniv-Berdychiv garnet-biotite, medium-fine-grained granites and their migmatites, gneisses, medium-coarse-grained and aplite-pegmatoid granites, and in places pegmatites.

The weathered crust within the deposit of planar-linear morphological type has a well-defined vertical zonation (from bottom to top): zone of disintegration and leaching, zone of initial hydrolysis, zone of final hydrolysis and oxidation of weathering products.

The thickness of the weathered crust within the field varies though the area and depends on the subsurface relief of the top of the parent rocks.

In the weathered crust profile, the clay minerals are represented mainly by kaolinite, which is formed in the zone of disintegration and leaching, gradually replacing all mineral formations except quartz and accessory minerals, and converts the source rocks into kaolin in the zone of final hydrolysis and oxidation.

In the zone of final hydrolysis and oxidation, two subzones are distinguished: the subzone of normal kaolins and the subzone of alkaline kaolins.

The quality of kaolins is determined by their petrotype, mineral composition and structural and textural features of the weathered parent rocks, as well as by the degree and depth of their hypergenic transformations. The highest quality kaolins were formed during the weathering of aplite-pegmatoid granites. The main parameters affecting the quality of kaolins are presence of oxides of titanium and iron and the processes of kaolin pelicanization.

The distribution of titanium and iron oxides in the vertical section and laterally is heterogeneous, displaying both a direct and inverse correlation between them. The whiteness of kaolin in the vertical section and laterally is heterogeneous and depends on the total content of titanium and iron oxides.

In general, the quality of raw materials in a larger area of the Zhezheliv deposit, in most respects, is not inferior to other eluvial kaolins in Ukraine and of many other deposits in the world, and in some cases even exceeds.Eluvial kaolins form a mineral deposit with variable thickness and lateral variability. The deposit is characterized by a variable internal structure and variegated quality of the useful component both in the vertical section and laterally. Significant variability of elevations and the thickness of the eluvial kaolin deposit complicates mining operations, especially in the development of upper ledges, which are characterized by a combination of overburden and mining operations. Based on this, the field belongs to the second group in complexity for mining.

In general, the depth of the quarry and the relatively small volume of overburden make it impossible to reclaim the used space for agricultural needs and forestry use. Based on this, the quarry will be reclaimed into a recreational reservoir, and the areas affected by mining will be reclaimed under arable land, pastures and forests.

The structural-lithological model of the Zhezheliv deposit of eluvial kaolins gives an idea of the structural position of the deposit, its internal structure, causal dependence of occurrence conditions, material composition and qualitative parameters of kaolins on petrotypes of crystalline rocks, distribution of qualitative kaolin parameters in vertical and laterally.

A retrospective analysis of different time space images has demonstrated a general increase in the area affected by quarrying during 2006-2020.

REFERENCES

Derkach S.S., Zenko V.G., Lafinchuk S.V., Pavlyuk V.M., Novikova M.M., Fedorov A.V. 2001. State Geological Map of Ukraine in the scale 1 : 200 000, map sheet M-35-XXIII (Berdychiv). Kyiv: Ministry of Ecology and Natural Resources of Ukraine, Northern State Regional Geological Enterprise "Pivnichgeologiya", Pravoberezhna Geological Expedition (in Ukrainian).

Heleta O.L., Kichnyaev A.M., Lyashok V.I. 2011. Characteristics of clays, review of their reserves and industries. *Mineral resources of Ukraine: Clays. Part 2*, No. 4, p. 16-26 (in Ukrainian).

Hurskyi D.S., Yesipchuk K.Yu., Kalinin V.I., Kulish E.A., Chumak D.M., Shumlianskyi V.O. 2006. Metallic and non-metallic minerals. Volume II Non-metallic minerals. Lviv: Center of Europe (in Ukrainian).

Report on "Exploration and evaluation works at the Zhezheliv deposit of primary kaolins and detailed exploration of kaolins of its Southern plot as a corrective additive to brick raw materials". 1993. Kyiv (in Russian).

Report on operational exploration of the Zhezheliv kaolin deposit based on the results of geological exploration works performed in 2004-2005. 2005. Vinnytsia (in Ukrainian).

Report on preliminary and detailed exploration of the Zhezheliv kaolin deposit in the Kazatin district of the Vinnytsia region of Ukraine in 1994-1995. 1996. Kyiv (in Russian).

Rudko G.I., Ozerko V.M., Shepel I.V. 2015. Geology and geological and economic assessment of kaolin deposits in Ukraine. Chernivtsi: Bukrek (in Ukrainian).

Rusko Yu.A. 1976. Kaolinization and kaolins of the Ukrainian Shield. Kyiv: Naukova Dumka (in Russian).

Shcherbak D.M., Prikhodko V.K., Shevchenko V.I. 2002. Peculiarities of qualitative composition of primary kaolins of Zhezheliv deposit. *Visnyk of Kyiv National University. Geology*, No. 22 (in Ukrainian).

Shevchenko V.I., Shcherbak D.M., Zagoruyko Yu.T. 2000. Geological and economic features of the Zhezheliv kaolin deposit. *Visnyk of Kyiv National University. Geology*, No. 18 (in Ukrainian).

Slyusarenko H.O. 2008. Comparative mineralogical and petrographic analysis of primary kaolins of Glukhivtsy-Turbiv district (Podilskyi block of the Ukrainian Shield). *Collection of scientific works of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine*, No. 1, p. 262-268 (in Ukrainian).

Tkachuk L.G., Sonkin L.S. 1981. Kaolins of the Glukhivtsi-Turbiv district of the Ukrainian Shield and prospects of their use. Kyiv: Naukova Dumka (in Russian).

Received 28.02.2022
Received in revised form 25.07.2022
Accepted 28.07.2022

*Ю.В. Крошко *, М.С. Ковальчук, Г.О. Кузьманенко, Т.В. Охоліна*
Інститут геологічних наук НАН України, Київ, Україна
E-mail: ykrosh.79@ukr.net; kms1964@ukr.net; geology.kuzmanenko@gmail.com; svilya@ukr.net
*Автор для кореспонденції

СТРУКТУРНО-ЛІТОЛОГІЧНА МОДЕЛЬ ЖЕЖЕЛІВСЬКОГО РОДОВИЩА ЕЛЮВІАЛЬНИХ КАОЛІНІВ

Подано відомості про геологічну будову Жежелівського родовища елювіальних каолінів, зональність і речовинний склад кори вивітрювання. Наведено дані про мінеральний склад та фізико-хімічні характеристики елювіальних каолінів. Досліджено взаємозв'язок породотворних оксидів та розподіл вмістів Fe_2O_3, TiO_2 та Al_2O_3 у вертикальному розрізі свердловин та за латераллю. Досліджено вміст оксидів титану і заліза в каоліновому концентраті та його гранулометричних фракціях залежно від петротипів, за рахунок вивітрювання яких утворилися елювіальні каоліни. Побудовано карти взаємовідношення ізоліній поверхні покрівлі елювіальних каолінів, ізоліній товщини покладу елювіальних каолінів та ізоліній поверхні підошви елювіальних каолінів та встановлено кореляційний зв'язок між рельєфом підошви і покрівлі та товщиною каолінів. Побудовано карту просторового розподілу білизни каолінів. За окремими свердловинами у покладах каолінів досліджено вертикальний розподіл білизни та вмістів Fe_2O_3, TiO_2. З'ясовано, що постійного кореляційного зв'язку між вмістами Fe_2O_3, TiO_2 у вертикальному розрізі не існує. Встановлено, що показник білизни каоліну у вертикальному розрізі залежить від вмісту вказаних оксидів або одного з них. На підставі аналізу різночасових космічних знімків досліджено зміну площі геологічного середовища, що порушена видобуванням елювіальних каолінів протягом 2006—2020 рр.

Ключові слова: *Україна; Жежелівське родовище елювіальних каолінів; структурно-літологічна модель; геологічна будова; речовинний склад; зміна площі порушеного геологічного середовища.*