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POLOGIVSKIY KAOLIN DEPOSIT: GEOLOGY, MINERAL AND CHEMICAL COMPOSITION, TECHNOLOGICAL PROPERTIES

(Представлено членом редакційної колегії д-ром геол. наук, проф. О. М. Іванік)

The area of the Pologivskiy deposit of kaolins and refractory clays is located on the border of two geological regions: the Azov crystalline massif and the Konksko-Yalynska depression. Precambrian crystalline rocks and sediments of the Cretaceous, Paleogene, Neogene, and Quaternary systems take part in the geological structure of the district. The geological structure of the district is based on the results of field exploration (23–25) and geological surveying works. Deposits of the Quaternary system are widespread in the territory and are similar to mantle on the underlying rocks. The lower border of the Quaternary system is formed at the base of the Berezanskiy climatolite in accordance with the Geological Map of Ukraine legend (the scale 1:200 000) of the 1996 Central Ukrainian series. The underlying rocks are red-brown Pliocene clays in most parts of the territory, in the rest there are rocks of crystalline basement of Cretaceous, Paleogene and Neogene systems.

The thickness of the Quaternary deposits is 10–20 m. Deposits of the Novopetrivska Neogene suite are productive for the extraction of clays and kaolins, in the base of which the undivided deposits of the Upper Eocene (Kyivska suite) and Oligocene (Kharkivska suite) lie. These are coastal-marine deposits – marls, calcareous clays, siltstones, weakly cemented sandstones and glauconite quartz sands. The total thickness of the Kyivska and Kharkivska suites varies from 0,0 to 60–70 m. Clays and kaolins are characterized by almost the same mineral composition. Most of them are composed of fine-grained kaolinite, and quartz predominates among impurities. Accessory and ore minerals are represented by zircon, rutile, ilmenite and hematite. Quartz is present in clays and kaolins in the form of rolled, semi-rolled and unrolled grains. High-quality aluminosilicate products are obtained from the kaolins of the deposit. Pologivskiy kaolin can be used to make chamotte without the clay addition, as well as a binder. The ratio of chamotte and binder is 80–20 %. The refractories obtained in the laboratory meet the requirements of high density for Class A blast furnace bricks and other products of appropriate determination. Pologivskiy clays are recognized as suitable for the production of 100 % refractories, as well as a binder component instead of Chasov-Yarska clays. Products made entirely of semi-acid clay meet the requirements for semi-acid refractory products of class B. Pologivskiy kaolins and clays have long been used in refractory, machine-building, ceramic, cement and other industries.

Keywords: kaolin, Pologivskiy deposit, geology, stratigraphy, mineral, chemical composition of kaolin and clays, technological properties.

Problem setting. Kaolin (primary and secondary), refractory clays are a complex raw material used by many industries. Secondary kaolins, as well as refractory clays, are used for the production of high-alumina, chamotte and semi-acidic products and non-formed materials (mortars, masses, concretes, powders). Regarding this, the discovery of the Pologivskiy deposit of kaolins and clays at the beginning of the 20th century (developed by locals since 1929) had to be the reason for the lower cost of high-alumina, chamotte and semi-acid products and non-formed materials production. However, in the late 1980s and early 1990s, the economic and political situation in the former Soviet Union did not contribute to the development and exploration of deposits of construction raw materials in southern Ukraine (North-Western, Eastern Pryazovie). The south of Ukraine was planned to be used exclusively for recreational and medical purposes, which could lead Ukraine to economic dependence. After Ukraine gained independence (1991), in the 1990s the authorities did not pay enough attention to the development of the raw material base, especially in the south. Geological exploration expeditions (Bilozerska Geological Party (Mykhailivka, Zaporizhzhia region), Pryazovska GEE (Volnovakha, Donetsk region) conducted research of Zaporizhzhia region, Pryazovie on their own and discovered ore bodies of iron ore deposits, related deposits, etc.

The authors of the article (L.M. Datsenko) cooperated with these institutions in the terms of stratigraphic studies of the Meso-Cenozoic cover in connection with the work on the Geomap – 200, the implementation of research projects, financed by the state budget, from the early 2000s to 2014 (*Datsenko, 2014; Datsenko et al., 2020*). We believe that the obtained data on minerals and raw materials base of the south of Ukraine have not only scientific but also economic significance, especially at the present stage of the state development.

Nowadays there are no unified requirements for the quality of secondary kaolins, due to the fact that the compound and the physical and ceramic properties of kaolins from different deposits are not the same and vary widely. Chemical composition and fire resistance are primarily used as classification criteria in assessing the quality of secondary kaolins. Depending on the chemical composition, fire resistance, and in some cases the content of coarse-grained or sandy particles, secondary kaolins are divided into different varieties at each deposit.

Analysis of recent publications. Analysis of scientific publications of foreign scientists shows that almost all studies of kaolin deposits aim to establish their economic potential and suitability for industrial processing. This focus of research is due to high demand for raw materials.

The data processing of the world geological community in relation to kaolin deposits in Russian Federation (*Ivanov at al., 2019; Grishin at al., 2017*), Nigeria (*Adagunodo at al., 2018; Oyebanjo at al., 2018; Akinsunmade at al., 2019*), China (*Fang et al., 2019*), Iran (*Zirjanizadeh et al., 2018; Abedini, Rezaei Azizi, 2019*), Ethiopia (*Bedassa et al., 2019*), Algeria (*Laraba, 2019*), South Africa (*Raphalalani et al.,* *2019*), Malaysia (*Hussin et al., 2018*), Cameroon (*Nzeukou Nzeugang et al., 2018*), Turkey (*Yanlk et al., 2018*), Egypt (*Awad et al., 2018; Saber et al., 2018*).), Japan (*Jige et al., 2018*) showed that the kaolin ores of the Pologivskiy deposit have higher geological and economic indicators, the study of which is a further goal for the authors research. The results of geological research of the Pologivskiy deposit of kaolins and clays have been published in scientific journals for the first time.

Research materials and methods. The authors of the article worked with the drill cores, made stratigraphic conclusions, took part in laboratory work on the basis of the Pryazovska geological exploration expedition in the testing shop. Until 2014, chemical and mineralogical analyzes were performed in the laboratory of the Pryazovska GEE, and since 2015 in the chemical laboratory and research geotechnical laboratory of TSATU (Melitopol). The authors had the opportunity to work with the stock materials of the expedition, geological reports, for which they are sincerely grateful to the staff of the Pryazovska GEE. Scientific materials on tectonics, stratigraphy of the deposit were kindly provided by the staff of the Pryazovska GEE, in particular by the leading geologist I.L. Kniazkova.

Testing occupies an important place in the complex of works on studying the quality of minerals, contouring of ore bodies and calculation of the useful components reserves. Sampling was carried out during the field works and was based on the tasks set by the technical assessment. All exploration and production wells drilled within the deposit were tested.

All intervals that revealed minerals (kaolins, refractory clays) were drill core tested for ordinary, group and laboratory-technological sampling. In addition, opencast rocks and bedrock rocks were tested. Samples were taken for chemical, mineralogical, physico-mechanical, ceramic and technological studies.

Taking into account the tasks and the specifics of the mineral, the test interval ranged: for secondary kaolins from 0,5 to 1,3 m, averaging 1,1 m, for refractory clays from 0,2 to 1,6 m, averaging 1,2 m. Before testing, the drill core was cleaned from drilling mud and clay solution. In the process of deposit exploration ordinary samples were taken from the drill core of the wells by splitting the core along the long axis into 2 parts manually, one of which was used as a sample, the other one as a duplicate. In the process of drilling production wells, all the drill core material was sampled.

In order to clarify the geological structure of the deposit, to study the chemical, mineralogical, grain size distribution and ceramic features of the overburden and underlying rocks, ordinary drill core samples were taken. Based on the peculiarities of the geological structure of the deposit, samples were taken for supra-kaolin sands (sand-clay mixture), loams and clays, the average length of the sample was 1,5–2,0 m. Chemical analyzes were performed to determine the content of the main limiting components in the mineral and host rocks of the Pologivskiy deposit.

Chemical analyzes of ordinary kaolin samples were performed on Al_2O_3, Fe_2O_3, TiO_2. Chemical analysis for SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, K_2O, Na_2O, SO_3 was performed in 20 % of ordinary samples.

Topographic and geodetic support of geological exploration works. Topographic and geodetic works related to the creation of a reference and survey base and topographic surveys were performed on the territory of the Pologivskiy deposit. The reference geodetic network consists of points of the state planning and height basis, geodetic condensation networks and is created according to the requirements of the corresponding Instructions. The density of the geodetic basis ensures the performance of topographic surveys in compliance with the requirements of the regulatory documents. Thus, since 1939 to 1949, the survey was carried out on a scale of 1:25 000, then – 1:10 000 (1953), 1:5 000 (1972). Today the area is covered by topographic surveys at a scale of 1:2 000. The works were performed by the traverse survey service of Mining Company "Mineral" LLC in the 1942 state coordinate system of and the Baltic Altitude System (*Shpylchak et al., 1999*).

To determine the planned coordinates of exploration wells, the method of intersection and resection at the side length from 1,5 to 3 km, the polar method and the laying of theodolite traverses through the wells were used. On all exploration stages planned and high-altitude reference of the wells was performed up to triangulation points of III and IV classes (1939–1972), as well as to polygonometry points.

The coordinates of the wells in the intersection were determined by at least 3 starting points, in the resection – by at least 4 starting points, respectively. The angles at the determined points of the intersection and resection ranged from 30º to 150º.

The coordinates of the wells were calculated twice with different choice combinations of the starting points. The final coordinate was the average of the two values, provided that the distance between them did not exceed ±1m. Horizontal angles in theodolite traverses and intersections were measured by the TH theodolite using limb permutations between modes and half-modes by an angle of about 90°. The lengths of the lines while theodolite traversing were measured with 20-meter steel tape in the forward and back directions. If the angles of inclination of lines was above 2º, the corresponding corrections for an inclination were made into the length of measurements.

The height marks of the well were determined by the method of geometric leveling in the Baltic altitude system.

During the operational works control referencing of the wells are selectively carried out by the services of Mining Company "Mineral" LLC. Errors in coordinates at the same time do not exceed admissible values of the Instruction requirements.

The topographic basis was adjusted by Mining Company "Mineral" LLC as of January 1, 2020 (*Shpylchak et al., 1999*).

Results and discussion. *General information about the deposit*. Administratively, the deposit is located in Pologivskiy district of Zaporizhzhia region, 0,5 km west of Pologivskiy. The area of the field is 667 hectares (Fig. 1).

The considered area is a lowland plain, sloping to the north-northwest. The surface of the plain is cut by rivers and ravines. The direction of watersheds and river valleys is mainly north-western. The main features of the orography of the area are mainly caused by its geological structure. Within the outputs to the day surface of the crystalline rocks of the Pryazovskiy crystalline massif, the surface relief is more dissected, with absolute marks of 180–200 m. In places of development of a thick layer of loose deposits (Konksko-Yalynska depression) on the contrary, the relief is more plain, almost flat with marks of watershed plateaus of 120–140 m. The main water artery of the district is the Konka River, a left tributary of the Dnipro River. The Konka River starts within the Pryazovskiy crystalline massif, in the form of two rivers of Sukha and Mokra Konka. In the highlands they are strongly branched, have narrow valleys (300–500 m) with rather steep, sometimes rocky shores. North of the Kinski Rozdory (village) at the confluence of Sukha and Mokra Konka the Konka River is formed. In the zone of development of loose deposits the river valley becomes wider up to 1,0 km, and takes an asymmetrical structure. The right slope is higher and steeper, cut by numerous deep ravines. There are many outcrops of native rocks both on the slope of the valley and in the ravines. Markings of the bottom of the Konka River valley vary from 120 m in the Kinsky Rozdory village up to 65 m near the village of Novo-Karlivka.

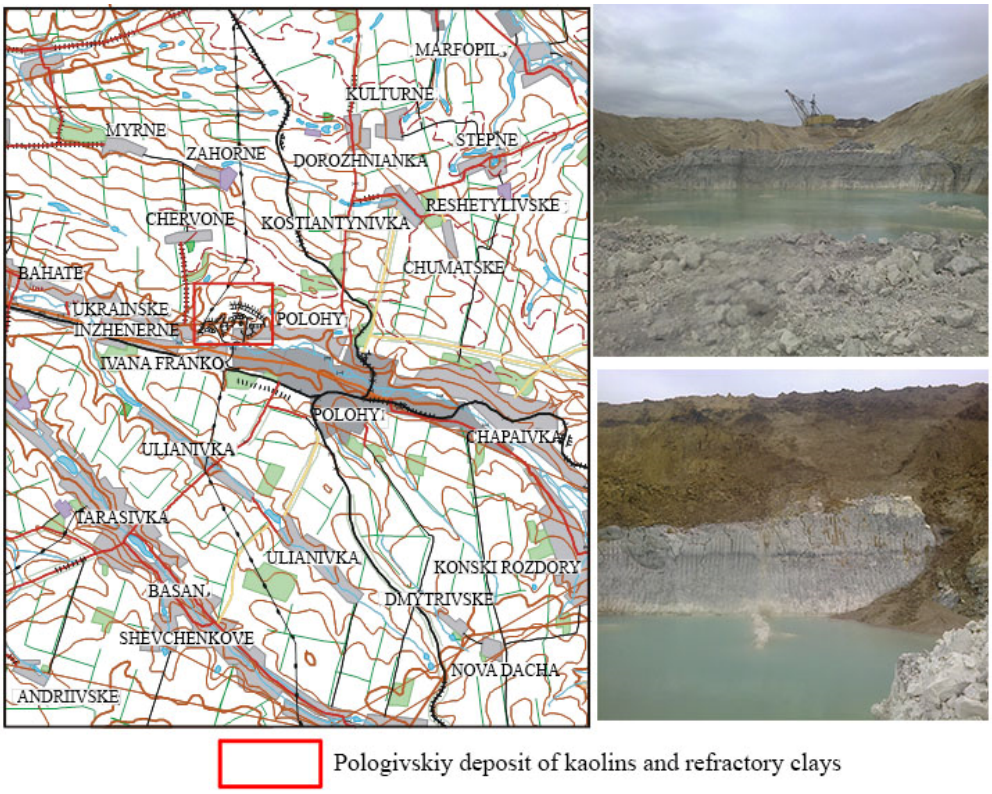

Fig. 1. Overview map of the work area. Scale 1:200 000

In the nature of the ravines and gullies slopes of the district there is the following pattern: the right slopes of the ravines and gullies to the left from the Konka River are more gentle, often made of ravine deluvium, while the left slopes of the ravines to the right from the Konka River, are on contrary, more gentle and made by ravine deluvium. These features in the structure of the ravine and gullies slopes are caused by the general slope of the surface to the northwest.

There are no deluvial deposits on the right bank of the Konka River, and Neogene rocks are exposed almost throughout the bank.

The first floodplain terrace can be traced along the entire Pologivskiy deposit. The width of the terrace is 200–800 m, the height is 4,0–6,0 m. The ledges of the terrace are weakly expressed in the relief. The surface of the terrace rises gently away from the river. Its marks range from 100 to 120 m. There is a slight rise above it towards the watershed, but the higher terraces in relief are not expressed. They were discovered while drilling. The total width of the terraces is 1,0–1,2 km, the height above the river level of the 2nd floodplain terrace is 10–15 m and the 3rd is 20–30 m. The marks are 120–130 m. The bareness of the area is weak, mainly quarries for sand, clay and kaolin.

Geological structure. The area of the Pologivskiy deposit of kaolins and refractory clays is located on the border of two geological regions (Fig. 2): the Pryazovskiy crystalline massif and the Konksko-Yalynska depression. Precambrian crystalline rocks and sedimentary deposits of the Cretaceous, Paleogene, Neogene, and Quaternary systems take part in the geological structure of the district. The geological structure of the district is described according to the results of deposit exploration (23–25) and geological surveying works (*Shpilchak et al., 1999*).

Geologically and structurally, the Pologivskiy area is located on the western wing of the Konksko-Yalynska depression. It is filled with deposits of the Lower and Upper Cretaceous, as well as Paleogene and Neogene. The bottom, composed of Precambrian rocks, has a slope to the south. Judging by the nature of sedimentary rocks, the depression deposition took place in the early Cretaceous. The area of the plots is characterized by a two-storey geological structure.

The lower structural floor is a complex dislocated crystalline foundation of the Ukrainian Shield, in the structure of which there are non-stratified ultrametamorphic, intrusive and metasomatic formations of archaea and Proterozoic.

The upper structural floor is the Phanerozoic deposits of the platform cover of the Mesozoic and Cenozoic. The latter includes the Meso-Cenozoic and Quaternary layers. Meso-Cenozoic deposits are represented by clays, sands, sandstones, argillites, siltstones, limestones, marls, crucibles, kaolins of Cretaceous, Paleogene and Neogene age.

Quaternary deposits are represented by black soils, loams, sands, clays. They are distributed in river valleys, where they form the alluvium of riverbeds and the first floodplain terraces. In addition, they completely cover the older Meso-Cenozoic formations and the crystalline basement.

Stratigraphy. Mesozoic eratema within surveyed area is represented by Cretaceous deposits. The formation of the chalk system in the search area is represented by the lower and upper divisions. In the lower part, a clay-sand bundle (K_1gp) and a Lunacharska suite (K_1ln) are mapped.

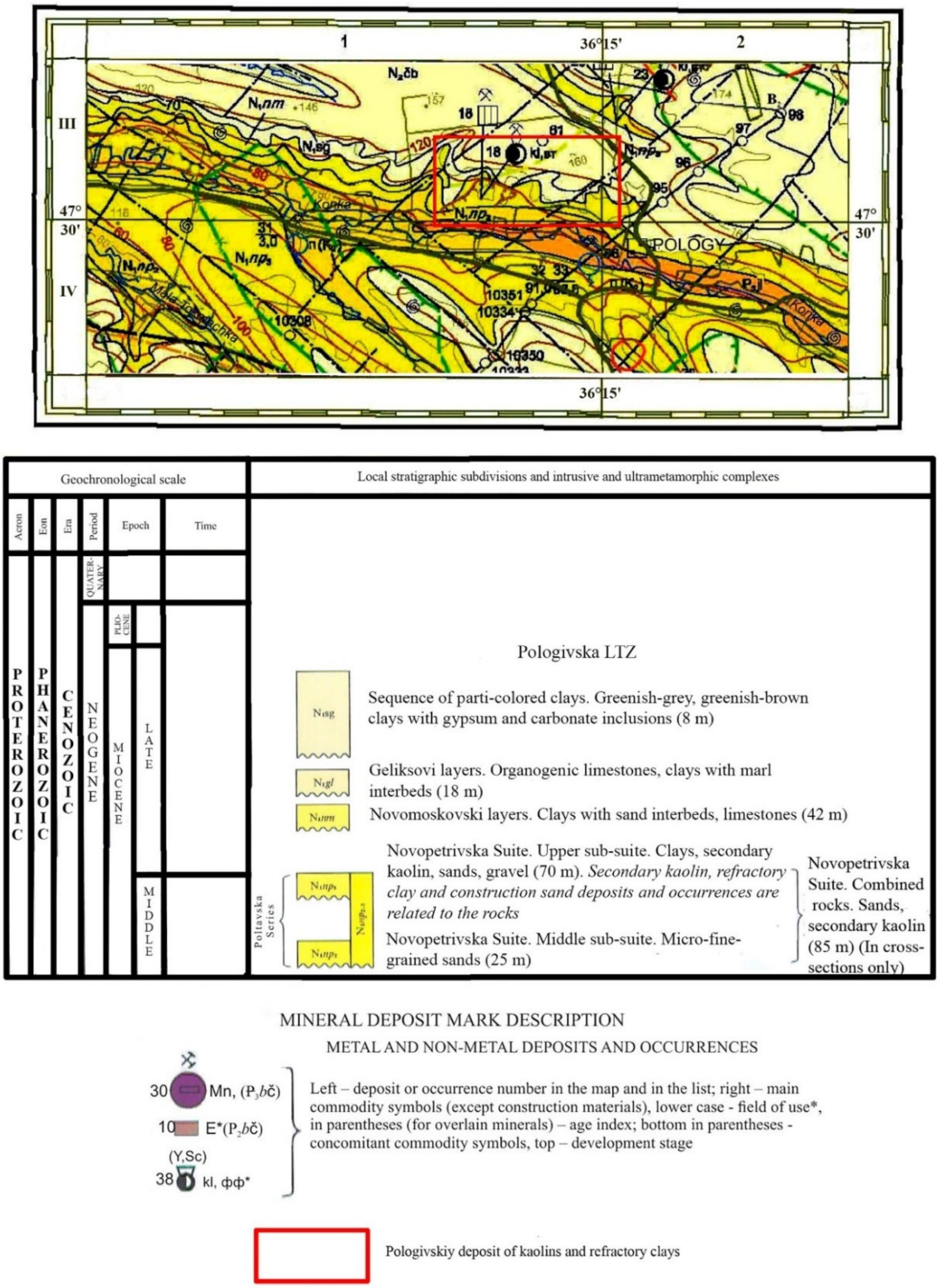

Fig. 2. Schematic geological map of pre-Quaternary formations of the deposit

The area of distribution of clay-sand bundle deposits is controlled by the position of buried erosion-tectonic valleys in the crystalline basement. The bundle is composed of multi-grained sands, siltstones and coal clays, secondary kaolins, brown coal lenses (up to 0,2 m). At the base of the layer there are small pebble and gravel formations. The crystalline rocks are fragmentary represented. The thickness of the bundle does not exceed 20 m. The bundle is covered by the Lunacharska suite. The area of distribution of coastal-marine deposits of the Lunacharska suite is controlled by negative forms of the pre-mezozoic relief. The suite is composed of quartz-glauconite sands and sandstones, cruciform rocks with gravel and pebbles at the base of the thickness, rarely clays. The thickness of the suite is up to 25 m. It is overlapped by the Oleksandrivska suite.

The Genicheska (K_2gn) and Oleksandrivska (K_2ol) suites are mapped in the lower part of the cross-section.

The suite is almost horizontal with a slight slope (less than 5°) towards the Black Sea basin. The Henichesk suite overlaps with the stratigraphic inconsistencies with the Oleksandrivska suite.

The Oleksandrivska suite is spread over the entire area of the deposit. In the lower part of the cross-section it is composed of marls, often chalky, which contain glauconite, less often

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sandstone. Its thickness is up to 15 m. On the marls, sandstones on clay-siliceous cement with belemnite rosters, quartz-glauconite and carbonate sands are found respectively. The age of the suite is the Late Campanian, Maastrichtian.

Within the search area, the Cenozoic eratema is represented by deposits of the Paleogene, Neogene and Quaternary systems. The deposits of the Paleogene system are widespread on the deposit area. They occur with angular and stratigraphic inconsistencies on the eroded surface of the crystalline basement and rocks of the Cretaceous system. They are presented by the Oligocene division (Lower subdivision: Rupelian layer, Mezhivska layer, Kharkivska series).

Yalynska sequence ($_3$jl) is distributed within the south-eastern part of the district, in the form of a wide (up to 7 km) strip (Fig. 3). The surface of the deposits is inclined to the north and north-west. The outputs of the sequence to the day surface were recorded in the area of Pologivskiy.

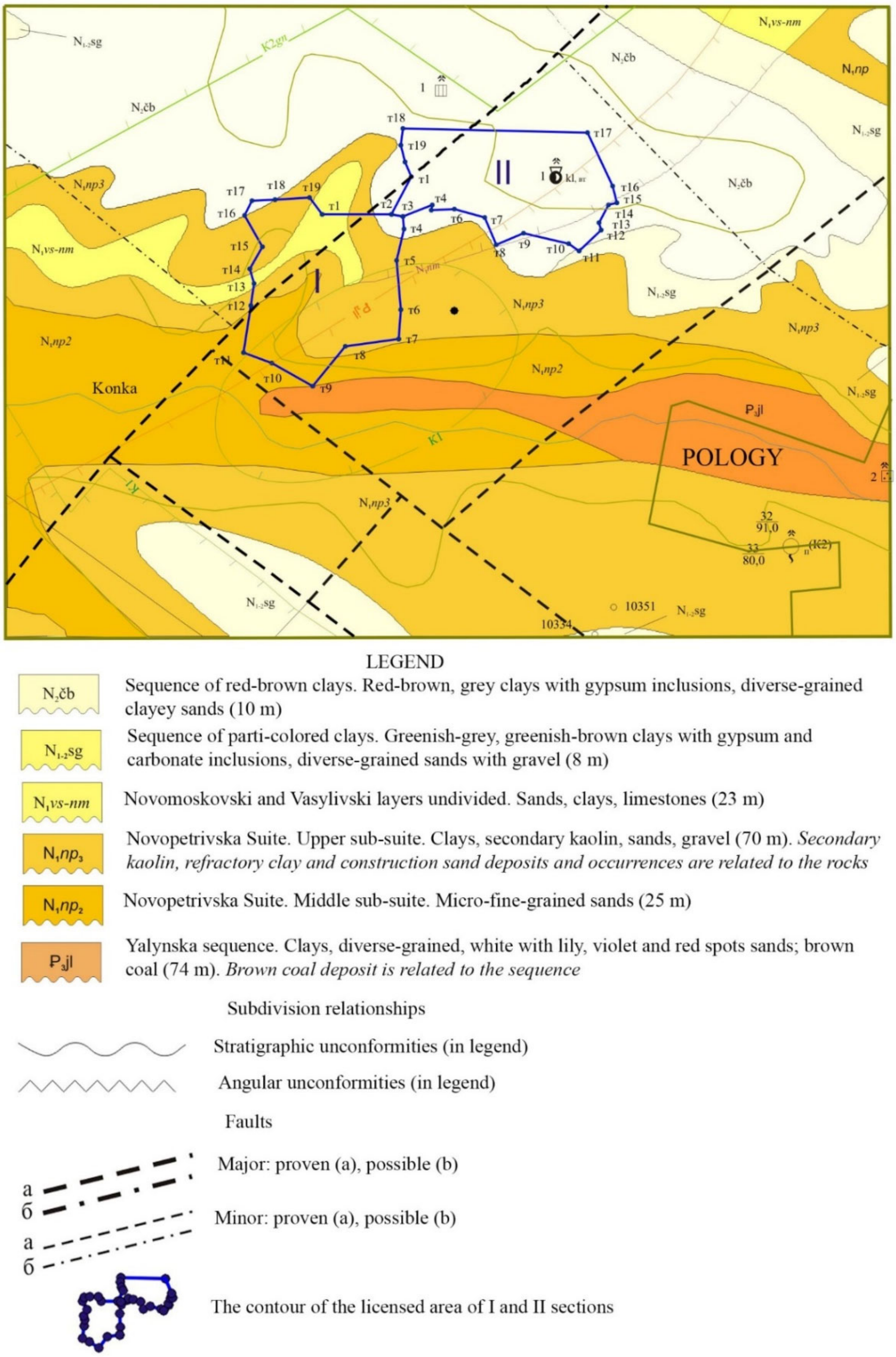

Fig. 3. Schematic geological map of the Pologivskiy deposit area

In the section of the sequence there is a complex layering of sands, sandstones, clays, secondary kaolins with the remains of charred plants. The clays of the upper part are thicker than kaolinite, the lower ones are hydromica with an admixture of beidelite and kaolinite. The transitions between the layers are gradual, sometimes the contacts are sharp, at an angle of 45° to the horizon. The Early Oligocene age of the Yalynska sequence formations is established on the basis of their occurrence on the rocks of the Reshetelivska sequence of the late Eocene and the history of the geological development of the region.

As part of the Neogene system, the formation of the Miocene and Pliocene divisions is distinguished. The Miocene division within the sheets is represented mainly by the middle and upper subdivisions. As part of the middle subdivision on the surveyed territory, the middle and upper sub-suite of the Novopetrivska suite are distinguished (represented by the Poltavska series). The Poltavska series (N_1pl) is represented only by the middle and upper sub-suites of the Novopetrivska suite. The Novopetrivska suite (middle sub-suite – N_1pl) in terms of position in the cross-section of the middle sub-suite of the Novopetrivska suite corresponds to the deposits of the Chokrakskiy layer, which are multifacial the same age formations of a common sea basin.

The rocks of the sub-suite are developed in the central part of the deposit (Fig. 3). The distribution boundary is complex, winding, outlines the deep erosion of sedimentary rocks over time. Their surface is inclined in the south-western direction, decreasing from +80 m to-20 m in absolute height. They are represented by coastal-marine deposits, which occur with stratigraphic inconsistency on the Paleogene and crystalline basement rocks. They are overlapping with deposits of the upper sub-suite of the Novopetrivska suite. Lithologically, they are represented by white homogeneous, well-sorted quartz, with an admixture of feldspar, sands with sponge spicules. The sands are fine-grained. In the sand cover strong, porous, cellular, fine-grained sandstones are often found on siliceous cement. The thickness of sandstones is 0,5–1,5 m, the thickness of the suite is 25 m.

The deposits of the sub-suite are exposed along the valley of the Konka River to the north-west of the town of Pologivskiy (Fig. 2), where organic remains *Dentatium sp., Cardium sp., Loripes sp., Chlamys sp* have been found.

Continental deposits of the upper sub-suite with stratigraphic inconsistency occur on Paleogene and Miocene rocks, and in places of their absence – with angular and stratigraphic inconsistency on the formations of the crystalline basement. They overlap with deposits of the Upper Miocene, and in places of their absence – with rocks of the Pliocene and Quaternary system. They are absent on elevated areas of the crystalline basement and in river valleys. The surface of the deposits is inclined to the north and north-west.

The formations of the upper sub-suite are represented by a complicated complex of different genetic type rocks of the coastal lowland plain – multi-grained kaolin sands with gravel, secondary kaolins, clays, coal clays with layers of brown coal. Deposits lie between faunistically characterized by Middle and Upper Miocene rocks. They are represented by continental deposits formed in the Karahan-konskiy time. The thickness of the upper sub-suite of the Novopetrivska sub-suite reaches 70 m.

On the territory of the deposit, the upper subdivision is mainly represented by marine deposits of the Sarmatian and Pontic layers. Continental rocks of variegated clay layers, which cover the full century interval of the subdivision, are also widespread.

Marine deposits of the Sarmatian layer are slightly spread here. The most complete section of the layers is represented by the middle layer, which corresponds to the Novomoskovskiy and Vasylivkiy undivided layers.

The middle layers (Novomoskovskiy and Vasylivskiy layers are undivided – N_1nm-vs) – deposits occupy the north-western part of the surveyed area (Fig. 2–3). They are found with erosion and stratigraphic inconsistency on the rocks of the Novopetrivska suite. They are overlain by faunistically characterized rocks of the Pontic layer and red-brown Pliocene clays. The lithological composition of shallow marine deposits is represented by sands, montmorillonite clays, organogenic-detrital limestones and pelitomorphic marls. Sandy deposits are widespread, bordering the protrusions of the crystalline massif. Clay rocks occupy the central areas of distribution. Clays are from dark gray to black, at the top gradually change colour to green, thin-leaved due to siltstone layers, fine-grained sand (less than sm) or shell detritus.

Pontic layer (variegated clays layer- N_1sg) – deposits of variegated clays layers are distributed over the most part of the territory. They occur with stratigraphic inconsistency on the rocks of the Poltava series, Sarmatian and Pontic layers. They are covered with a layer of reddish-brown clay. The clays are greenish-gray, with numerous spots of ocher, brown and cherry-red colours, with gypsum druse, marly contractions, iron-manganese lumps, in the lower part of the cross-section they are often ashy-gray, gray with inhomogeneous mechanical composition. The thickness of the motley clays layer is 2–4 m, sometimes up to 8 m. Redeposited radiolarians and spicules of siliceous sponges are found among the organic residues in the layer.

Pliocene deposits include subaerial formations of watershed plateaus and subaquatic deposits of ancient river terraces, which stand out as undivided deposits of red-brown clay (N_2čb). Deposits of red-brown clays with stratigraphic inconsistency occur on Miocene rocks (motley clays layer). In elevated areas they are found on the rocks of the crystalline basement with angular and stratigraphic inconsistencies. They are absent in river valleys and large ravines, where they were eroded in the Quaternary season. They are overlain by the deposits of the Quaternary system, with which they are connected by gradual transitions. The thickness of the layer reaches 11 cm.

The red-brown clays are represented by dense non-stratified varieties, almost without an admixture of clastic material. The content of the <0,05 fraction mm is 96–99 %. The clays which were composed by montmorillonite and beidelite are characterized by sliding mirrors on which black dendritic films of manganese hydroxides are developed. Iron-manganese oolites, 2–3 mm in diameter, are quite common. Calcareous contractions and gypsum are contained in different quantities and found at the lower part of the cross-section. The size of concretions reaches 30 cm in diameter. Gypsum occurs in the form of single crystals and rubble and does not form significant accumulations. The hardness and fragments of crystalline rocks are found in places where clays occur on the rocks of the crystalline basement, in the lower parts of the cross-section.

In the cross-section of the layer there are two horizons, which correspond to the Siverskiy and Beregivskiy climatolites. Lower, Siverskiy is represented by gray, dark gray clay with brownish, often with greenish hues, and is carbonate and gypsum. Clays are characterized by an increased content of sand and silt fractions in comparison with the comprising strata. In the gamma-ray charts, the horizon is characterized by a decrease in the radioactivity of the rocks and stands out quite clearly. Clays belong to the aeolian-deluvial genetic type. The thickness is 4–6 m. The upper one, Beregivskiy, is represented by fossil soil – red-brown, dense red-brown, non-stratified carbonate clays. The drying cracks, 0,5–2 cm wide, filled with dark gray material of Berezanskiy climatolite, are rarely observed. The shape of the cracks is wedge-shaped, their surface is uneven. They penetrate to the depth of 50–70 cm. Horizon thickness is 2–6 m.

Deposits of the Quaternary system are widespread in the territory and are similar to mantle on the underlying rocks. The lower limit of the Quaternary system is formed at the base of the Berezanskiy climatolite in accordance with the Geological Map of Ukraine legend (the scale 1:200 000) of the 1996 Central Ukrainian series. The underlying rocks are red-brown Pliocene clays on the most parts of the territory, on the rest there are rocks of crystalline basement of Cretaceous, Paleogene and Neogene systems.

The thickness of the Quaternary deposits is 10–20 m.

The Quaternary continental cover belongs to the forest formation of the off-glacial zone. There are two groups of facies: subaerial (forests and loess-like loams, which are interbedded with fossil soils) and subaquatic (alluvial strata) deposits. Lithologically subaerial layer is not sustained both in area and in cross-section. In the lower parts of the cross-section, crushed stone and gravel of crystalline rocks are often found.

In the south-western part of the area, hearth deposits of eluvial, aeolian-deluvial and lake genesis take part in the formation of the layer.

Continental subaquatic Quaternary deposits are represented by alluvial pebbles, conglomerates, sands, sandstones, clays and loams of terrace deposits of river valleys, expressed in relief or buried. The straton, that is mapped, is taken as the degree.

Deluvial deposits are confined to the slopes of rivers and ravines.

The Pleistocene and Holocene are distinguished as part of the Quaternary system. Pleistocene consists of lower, middle and upper divisions. The lower one is represented by the Eopleistocene section, the middle and upper ones by the Neopleistocene section.

Non-stratified formations. Archaea (AR), paleoarchaea (Dniester) – intrusive and ultrametamorphic formations of the paleoarchaea are combined into Novopavlivskiy mafic-ultramafic and Novopavlivskiy granitoid complexes. In order to prevent misunderstandings, and taking into account the same name of Novopavlivski complexes, they are assigned the first and second numbers, respectively.

The vast majority of non-stratified formations of the district were formed in Archean times during three eons. Among them there are both ultrametamorphic and intrusive complexes, and ultrametamorphic processes prevailed at the Paleo-mesoarchean stage of the area development. Meso-neo-Archaic neo-Archaic are already characterized by the predominant development of intrusive rocks. The final stage of formation of the Paleoarchean granulite complex was accompanied by the introduction of intrusions of the gabbro-peridotite formation and ultrametamorphism, in the process of which granitoids of the enderbit-diorite-tonalite formation were formed. The first corresponds to the Novopavlivskiy mafic-ultramaficcomplex (AR_1np_1), the second to the granitoid of the same name (AR_1np_2).

Novopavlivskiy mafic-ultramaficcomplex (AR_1np_1) – intrusive formations of the complex are confined mainly to the ancient sublatitudinal Prakonska fault zone. Bodies occur in the form of xenoliths, schlers and lenses among the granitoids of the Novopavlivskiy-2 complex. Rocks are tectonized, degenerated, amphibolized, converted into amphibolites, actinoliths, crystalline shales and gneisses. Intrusive bodies are ranging in size from 0,46 km^2 to 2 km^2 and are deformed and differently oriented. They participate in folding. The complex is represented mainly by rocks of the main composition such as gabbro, gabbro-amphibolites and apogabric amphibolites. Gabroid rocks are closely related, often gradually transitioning from typical pyroxene gabbro with relics of primary magmatic structures (gabbro) to gabbro-amphibolites and to granoblast apogabral amphibolites. Amphibolized gabbro and gabbro-amphibolites are more common. The isochronous age of the complex formations is 3650 million years.

Novopavlivskiy granitoid complex (AR_1np_2) – ultrametamorphic and palingenic granitoids of the Novopavlivskiy complex in the area comprise quite significant fields. They are characterized by a massive and gneiss-like texture. Due to the composition, they correspond to diorites and tonalites. The complex also includes obscure-striped plagiomigmatites of the same composition as derivatives of diorites and enderbites.

The rocks of the complex form a series of irregularly shaped massifs. The massifs sizes vary within 5 × 16 km to 1 × 2 km. Their outlines are often irregular in shape, amoebic. The internal structure of massifs is often complicated by the presence of xenoliths and schlers of gabbroids, pyroxenites, actinoliths of the Novopavlivskiy mafic-ultramafic complex. The marginal parts of the massifs are composed of tonalites and plagiomigmatites of diorite composition. Central parts of the massifs are mainly composed of quartz diorites. Diorites are restricted and observed only near contacts with the gabbroid remains. The isochronous age of enderbits and tonalites is 3370–3470 million years.

The Neoarchean tectonic-magmatic stage at the site was marked by a wide display of basaltoid and rhyodacite volcanism, accompanied by intrusive magmatism and processes of intense anathexis and palingenesis, which led to the formation of numerous small intrusions and large massifs of autochthonous, para-autochthonous and intrusive granites of the Shevchenko ultra metamorphic plagiogranitoid complex.

The Shevchenkivskiy complex ($AR_3šv$) combines late-folded massive plagiogranites of ultrametamorphic origin, that form isolated individual massifs and numerous small dyke-like bodies of pegmatoid plagiogranites and albites in the surveyed area. The plagiogranites veins are reliably mapped only if they are injected with contrasting material complexes. Therefore, the largest number of them was found in the fields of metavolcanites development in the main composition of the Verkgnyotokmatska sequence. The albites vein are mapped quite easily. At the site, they form two bodies of small size, confined to tectonic faults areas. The nature of the contacts is subvertical. Due to their ultrametamorphic genesis, they are likely to be gradual.

Macroscopically plagiogranites are gneiss-like and massive rocks; cataclyssed varieties are shale-lenticular-striped and small-flecked. According to the mineral composition, biotite and, less frequently, amphibole-biotite are distinguished.

Dikes of pegmatoid plagiogranite composition have a coarse-grained, often porphyry structure and in most cases a gneiss-like texture. Porphyry inclusions are represented by quartz, less often by plagioclase.

Albitites are one of the original formations. Macroscopically, these are large-, medium- and fine-grained, sometimes porphyritic rocks of pink, light gray and milky white color with an uneven distribution of dark (biotite, actinolite, chlorite) minerals. Albite and oligoclase-albite make up to 70–95 % of the rock mass. Their radiogenic age is 3050 million years. Analysis of the relationship of albite with host rocks does not allow to unambiguously determine their genesis. Sharp, inconsistent contacts of the most bodies indicate an intrusive origin, and the gradual albite transitions into the rocks that contain them, with the formation of hybrid metasomatites of albite-chlorite-actinolite composition indicate metasomatic genesis. Most likely, they are the product of the plagiogranite magma residual melt, and its introduction was accompanied by sodium metasomatism of surrounding rocks.

The Proterozoic tectonic-magmatic cycle of the crystalline basement development on the territory of the surveyed area appeared in the Paleoproterozoic period. As a result of this activation, the Anadolskiy complex was formed.

The Anadolskiy complex (PR_1an), which is located on the surveyed area, combines most of the feldspar granites, aplite-pegmatoid granites and pegmatites of ultrametamorphogenic genesis, formed between 2600–2000 million years. Such a long interval of complex formation gives grounds to assert that several complexes are united in its composition, but it is impossible to dissect them without detailed isotope studies.

According to the conditions of occurrence and the nature of the relationship with the rocks that contain them, all granites of the complex are conventionally divided into two groups: granites that form isolated massifs or fields and vein granitoids (pegmatites, aplites, and aplite-pegmatoid granites). The first group forms massifs and bodies of various shapes (often amoeba-shaped) and sizes. In structural terms, a clear confinement of the granite development areas to the fault zones and nodes of their intersection are determined. In the gravitational field, granites correspond, in most cases, to negative values of gravity. In a magnetic field, granites correspond to zones and areas of demagnetization, often clearly inconsistent with the structural plan of the field. The gradual contacts of many bodies are represented by gneiss-like and obscure-striped texture, enrichment of endocontact zones with dark minerals and xenoliths, intensive microclination of the rocks containing them that are confirmed by the ultrametamorphic, autochthonous genesis of granites. Some granites are characterized by obvious signs of intrusive genesis: sharp inconsistent contacts, massive textures, porphyry-like structures. The close mineralogical and chemical composition of granites, geochemical specialization, joint occurrence give a reason to assume their kinship and palingeno-anathectic genesis, followed by separation and partial movement of the melt and its introduction in the form of intrusions.

According to the mineral, very unsustainable, composition of melanocratic (granodiorites), mesocratic and leukocratic (Alaskites) granites of the Anadolskiy petrotype are divided into biotite and amphibole-biotite, rarely pyroxene-containing; according to the structural-textural composition – on massive medium- and coarse-grained, often porphyritic, fine-grained (aplite-like), gneiss-like. Their color is mostly pink with different tints.

Vein aplite-like, aplite-pegmatoid granites are widespread. The occurancy is mainly in agreement with the fall of the rocks that contain them, rarely – inconsistent. Most veins have a non-zonal structure. According to the mineral composition, microcline, microcline-oligoclase, rarely albite-oligoclase-microcline are distinguished. Dark-colored minerals are represented by biotite, muscovite, tourmaline and pomegranate. Macroscopically, they are characterized by pink-gray, pink (almost red), rarely gray, light gray and greenish-gray (oligoclase-albite) color, variegated (from fine to giant) and pegmatoid structures and massive texture. The introduction of granites was accompanied by intensive microclinization of the host rocks, up to the formation of feldspar migmatites.

Geological and technological characteristics of minerals. Deposits of the Neo-Petrine Neogene suite are productive for the extraction of clays and kaolins, in the base of which the undivided deposits of the Upper Eocene (Kyivska suite) and Oligocene (Kharkivska suite) lie. These are coastal-marine deposits like marls, calcareous clays, siltstones, weakly cemented sandstones and glauconite quartz sands. The total thickness of the Kyivska and Kharkivska suites varies from 0,0 to 60–70 m.

Novopetrivska suite is composed of quartz sands, among which kaolin and clay layers are located. In the upper part of the suite the sands are light gray to white, in some areas – yellowish-gray, iron, fine-grained, with a slight admixture of clay particles. Among them, thin lenses of fine- and coarse-grained strong sandstones are rarely found. In the lower part of the suite the sands are clayey gray and light gray from fine- to coarse-grained, with fine-grained and silty layers. Among these sands there are deposits of secondary kaolin and refractory clays (minerals) of various capacities. Kaolins and clays form a single deposit. Clays usually lie under kaolins, however, a three-layer deposit: refractory clays – kaolins – refractory clays, is rare. Refractory clays in sections I and II are very widespread, but in the eastern half of section II they are often absent or have a non-operating capacity, and in the north eastern corner of section II are completely wedged.

The thickness of the refractory clays layer in the section I varies from 0 to 8,4 m, in the section II – from 0 to 6,65 m. Among refractory clays, a layer of clayey sand and substandard sandy clays up to 1.7 m thick is rare.

Secondary kaolins lie above the clays, and are almost everywhere distributed in the section II, but sporadically in the section I – in the form of low-power lenses.

The thickness of the kaolin layer in section II varies from 0,2 to 4,65 m, and in section I it varies from 0,1 m to 2,2 m, reaching 3,5 m in the north.

The total thickness of the kaolin-clay deposit in the section II is 0,2–8,9 m, and in the section I – 0,5–8,85 m.

Kaolins and clays are covered with white, light gray and yellowish-gray fine- and fine-grained quartz sands, which also belong to the Novopetrivska suite in all parts. The supra-kaolin sands of the Novopetrivska suite at the Pologivskiy deposit have been explored as raw materials for the preparation of the mass used in the laying of mine workings in the mines of the Zaporizhzhia Iron Ore Plant. These sands are considered as associated minerals.

The mineral composition of Pologivskiy kaolins and clays was studied by the Kharkiv Polytechnic Institute and the Ukrainian Institute of Refractories (*Shpylchak et al., 1999*). Studies have shown that clays and kaolins are characterized by almost the same mineral composition. Most of them are composed of fine-grained kaolinite, and quartz predominates from impurities. Accessory and ore minerals are represented by zircon, rutile, ilmenite and hematite. Refractory clays are characterized by a finer structure of the main mass and very small grain size (0,001 mm). Organics give kaolinite a brown colour under a microscope. In kaolins, kaolinite is seen as a colourless aggregate of thin scales and individual scales. In large fractions of clays and kaolins kaolinite has the form of thin silvery-white plates. Quartz is present in clays and kaolins in the form of rolled, less often semi-rolled and unrolled grains. It usually makes up most of the large fractions of kaolin. In refractory clays, quartz is represented by the finest grains (0,001 mm). Accessory and ore minerals also have a larger grain composition in kaolins and a thin grain composition in clays. The content of minerals and individual fractions are shown in table.

Table

Mineral composition of kaolin and clay

	Name of minerals	Kaolin			Refractory clay		
		Content in % by fractions			Content in % by fractions		
		0,05	0,05-0,01	0,01	0,05	0,05-0,01	0,01
1.	Kaolinite	0-10	8-60	90-95	-	-	90-95
2.	Galluazite	-	0-3	0-6	-	-	-
3.	Hydromica	-	0-5	1-4	-	-	1-5
4.	Muscovite and sericitis	1-30	20-75	1-2	-	5-10	2-5
5.	Quartz	40-90	2-15	1-3	85-98	60-70	4-7
6.	Chalcedony	0-2	-	-	2-5	1-2	-
7.	Feldspar	2-20	1-3	-	1-4	1-4	-
8.	Tourmaline	-	0-2	-	-	-	-
9.	Zircon	-	0-2	-	-	2-5	-
10	Titanitis	-	-	-	-	1-4	-
11	Rutile	-	0-2	-	-	1-3	-
12	Sillimanite	-	-	-	-	1-3	-
13	Ilmenite	1-3	0-2	-	1-2	3-7	-
14	Limonite	0-4	0-3	-	1-3	2-6	-
15	Pyrite	-	-	-	-	-	-
16	Carbonaceous matter	0-3	0-2	-	1-8	1-3	-

Chemical composition. In order to study the chemical composition of refractory clays and kaolins, shortened and complete chemical analyzes were performed.

Pologivskiy clays and kaolins are characterized by a high content of alumina. Its average content ranges from 29,394 to 35,17 in clays and from 28,69 to 37,51 in kaolins.

The lowest content of alumina is observed in sandy intervals.

The average content of one and a half iron oxides in kaolins is 0,96–1,39 %, in clays 1,15–1,62 %.

The SiO_2 content increases as the variety decreases and in low-grade varieties reaches 56,2 % in kaolins and 69,92 % in clays.

Titanium-containing minerals are mainly associated with sand material, so the content of titanium oxide in low-grade clays and kaolins is higher. At the same time, it is lower in kaolins, than in clays.

The content of calcium oxide and magnesium is almost the same. In kaolins, CaO and MgO range from 0,18 % to 0,24 % and from 0,15 % to 0,22 %, respectively. In refractory clays, the content of CaO is 0,23–0,29 %, and MgO is 0,17–0,23 %.

The content of K_2O and Na_2O increases with increasing variety of the mineral. K_2O – from 0,19 % in clay to 0,33 % in kaolin, and the value of Na_2O varies from 0,111 % in clay to 0,16 % in kaolin.

The SO_3 content is insignificant and is one hundredth of a percent.

The losses during calcination are directly dependent on the value of Al_2O_3 and range from 11,61 % to 13,35 % in kaolin and from 9,37 % to 12,86 % in clay.

Technological properties. Studies of the technological properties of refractory raw materials of the Pologivskiy deposit have their own history, and were conducted both in the laboratory and in the factory (*Verkhovodov et al., 1985*).

In 1952, the All-Union Research Institute of Refractories (ARIR) developed a technology for making ladle bricks from Pologivskiy kaolin by the method of semi-dry pressing. At the same time, experimental batches of ladle bricks were produced at the Zaporizhzhia Refractory Plant. Their tests in production conditions gave positive results.

In 1955, the Kharkiv Polytechnic Institute conducted laboratory and technological studies of kaolins and clays of the section II, as a result of which their suitability for obtaining class A refractories was established.

In 1960, the Ukrainian Institute of Refractories (UIR) took 3 samples of kaolin and 5 samples of clay from the existing on the section I quarry in order to establish their suitability for the production of aluminosilicate refractory products. Technological research was conducted in the direction of maximum use of raw materials of the Pologivskiy deposit, elimination of multicomponent charge and replacement of Chasov Yar clays with Pologivskiy deposits. On the basis of the carried-out laboratory-technological researches the conclusion on possibility of obtaining of high-quality aluminosilicate products from kaolins was made. Pologivskiy kaolin can be used to make chamotte without the clay addition, as well as a binder. The ratio of chamotte and binder is 80–20 %. The refractories obtained in the laboratory meet the requirements of high density for Class A blast furnace bricks and other products of appropriate determination. Pologivski clays are recognized as suitable for the production of 100 % refractories, as well as a binder component instead of Chasov-Yar clays. Products made entirely of semi-acid clay meet the requirements for semi-acid refractory products of class B.

In 1962, the Dnipropetrovsk Metallurgical Institute studied the possibility of using unenriched Pologivskiy kaolin to obtain normal electrocorundum and other products of electric smelting. For this purpose, an experimental smelting of PLK-0 kaolin was carried out at the Zaporizhzhia Abrasive Products Plant, as a result of which normal electrocorundum was obtained. In 1956, experiments were carried out at the Chelyabinsk Electrometallurgical Plant to obtain a high-alumina product from the agglomerate of Pologivskiy kaolin. They also confirmed the results obtained earlier.

Based on the carried out works, the State Metallurgical Committee instructed the Kharkiv Institute "Giprostal" to develop technical and economic considerations for the choice of technology and location for the production of intermediate products for synthetic slag using Pologivskiy kaolins. However, the technological scheme of Kaolin processing of the Pologivskiy deposit for these purposes has not been developed.

In 1964, the Kyiv Experimental Research Plant conducted laboratory and semi-plant studies of the raw materials of the Pologivskiy deposit in order to establish its suitability for the production of sewer pipes, interior tiles and sanitary ware. Material of 3 samples of kaolin, 3 samples of clay and 2 samples of sand taken from the existing quarry was used to obtain experimental products. Tests have established the suitability of clays and kaolins in the production of interior tiles and sanitary ware.

In 1966, the Kharkiv Polytechnic Institute continued to study the technological properties of Pologivskiy kaolin as a raw material for the production of facing tiles. The tests gave a positive result – the quality of facing tiles was higher than that of tiles obtained from primary enriched kaolin.

Pologivskiy kaolins and clays have long been used in refractory, machine-building, ceramic, cement and other industries. The main volume of extracted raw materials is consumed by refractory plants that use it for the production of various products: normal and cupola bricks, siphon tubes, shaped products, etc.

Given the extensive experience in the use of Pologivskiy kaolins and clays in a number of industries, in the exploration in 1985 and the revaluation of reserves in 2010–2020, samples for additional study of the technological properties of minerals were not taken.

Conclusions. Kaolin deposits of the Pologivskiy deposit belong to the secondary (redeposited products of weathering crust) genetic type, which are characterized by significant, but in comparison with other kaolins (within Ukraine) low content of sand impurities on sieves №№ 0,02, 0,09, 0,063, mechanical strength of the mineral samples of the deposit in both dry and calcined state is almost three times higher than the enriched primary kaolins spread throughout the rest of the country.

Kaolin ores of the Pologivskiy deposit have high geological and technological indicators in comparison with other deposits of the world. Deposits of the Novopetrivska Neogene suite are productive for the extraction of clays and kaolins. These are mainly coastal-marine deposits like marls, calcareous clays, siltstones, weakly cemented sandstones and glauconite quartz sands. The total thickness of the Kyivska and Kharkivska formations varies from 0,0 to 60–70 m.

During the long period of exploration and operation of the Pologivskiy deposit the mineralogical and chemical composition, physical-mechanical, ceramic and technological properties of kaolins and clays, which have been successfully used for many years by refractory, metallurgical, chemical and other industries, have been studied with sufficient completeness.

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ПОЛОГІВСЬКЕ РОДОВИЩЕ КАОЛІНУ: ГЕОЛОГІЯ, МІНЕРАЛЬНИЙ ТА ХІМІЧНИЙ СКЛАД, ТЕХНОЛОГІЧНІ ВЛАСТИВОСТІ

Район Пологівського родовища каолінів і вогнетривких глин розташований на межі двох геологічних регіонів: Приазовського кристалічного масиву й Конксько-Ялинської западини. У геологічній будові району беруть участь докембрийські кристалічні породи й осадові відклади крейдової, палеогенової, неогенової та четвертинної систем. Геологічна будова району наведена за результатами розвідки родовища та геологознімальних робіт. Відклади четвертинної системи розповсюджені на території повсюдно і плащеподібно залягають на підстилаючих породах. Нижня межа четвертинної системи проводиться в підошві березанського кліматоліту відповідно до Легенди геологічної карти України масштабом 1:200 000 Центральноукраїнської серії 1996 р. Підстилаючими породами на більшій частині території є червоно-бурі глини пліоцену, на решті – породи кристалічного фундаменту, крейдової, палеогенової і неогенової систем.

Потужність четвертинних відкладів становить 10–20 м. Продуктивними для видобутку глин та каолінів є відкладення новопетрівської світи неогену, у підошві яких залягають нерозчленовані відкладення верхнього еоцену (київська світа) і олігоцену (харківська світа). Це прибережно-морські відклади – мергелі, вапняковисті глини, алевроліти, слабозцементовані пісковики та глауконітkварцові піски. Сумарна потужність київської і харківської свит змінюється від 0,0 до 60–70 м. Глини й каоліни характеризуються практично однаковим мінеральним складом. Основна їхня маса представлена тонколускуватим каолінітом, а з домішок переважає кварц. Акцесорні й рудні мінерали представлені цирконом, рутилом, ільменітом і гематитом. Кварц присутній у глинах і каолінах у вигляді обкатаних, рідше напівобкатаних і необкатаних зерен. З каолінів родовища виробляють високоякісні алюмосилікатні вироби. Пологівський каолін можна використовувати для виготовлення шамоту без додавання глини, а також як сполучну домішку. Співвідношення шамоту та зв'язуючої речовини становить 80–20 %. Отримані в лабораторних умовах вогнетриви задовольняють вимоги підвищеної щільності до доменної цегли класу А та інших виробів відповідального призначення. Пологівські глини визнані придатними для виготовлення 100 % вогнетривів, а також як сполучні компоненти замість часов'ярських глин. Вироби, виготовлені цілком із напівкислої глини, відповідають вимогам до напівкислих вогнетривких виробів класу Б. Пологівські каоліни та глини тривалий час використовують у вогнетривкій, машинобудівній, керамічній, цементній та інших галузях промисловості.

Ключові слова: каолін, Пологівське родовище, геологія, стратиграфія, мінеральний та хімічний склад каоліну і глин, технологічні властивості.