

Kaolins and Sericitites of the Plast Kaolin-Bearing Region, Chelyabinsk District

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Abstract—Necessity to increase economic reserves of kaolin in the Russian Federation stimulated us to examine perspectives of the Plast kaolin-bearing region in the southern Urals located 80 km south of Chelyabinsk. This region includes occurrences and differently explored eluvial kaolin deposits, including the largest currently mined Zhuravlinskiy Log deposit. The sericite-bearing kaolin and sericitite are considered a potential source of fine-flaky light mica. It is expected that specialized geological exploration will expand mineral resources of kaolin in the Chelyabinsk district and the Ural federal region as a whole.

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INTRODUCTION

Currently, only primary (eluvial) kaolin is mined and subsequently concentrated in the Russian Federation. Reserves of the eluvial kaolin available now do not satisfy the economic requirements of our country. These reserves are two orders of magnitude smaller than in leading industrial countries and mostly are of low quality or cannot be developed for some reasons. At present, real (active) reserves of the eluvial kaolin are largely contained in three currently mined deposits located in the Chelyabinsk district: Kyshtym (3.7 Mt), Eleninsk (3.5 Mt), and Zhuravlinskiy Log (6.7 Mt). Thus, the total reserve amounts to only ~14 Mt in total.

Therefore, rapid expansion and improvement of the kaolin resource base is an urgent issue. Otherwise our country will be in the strategic dependence on the import of kaolinic products (200–250 kt/yr) for a long time.

Prospecting and evaluation works carried out by the beginning of the 21st century provided a certain progress in this respect. Main efforts were focused on kaolin resources of the Chelyabinsk and Orsk Transural regions, where the older denudation surface (Transural peneplain) was retained to the greatest extent. The successful prospecting in the Ushkoty kaolin-bearing region (Orenburg district) resulted in the discovery of several promising kaolin occurrences. The crude kaolin reserves at the most prospective South Ushkoty deposit were preliminarily estimated at 38.5 Mt including ~50% of the high-quality kaolin. In 2003–2006, the prospecting and evaluation were conducted over a vast territory in the extreme east of the Orenburg district.

In the Chelyabinsk district, the Plast kaolin-bearing region located 80 km south of Chelyabinsk in the South Ural kaolin-bearing subprovince is one of the most promising objects. To date, five areas with the light kaolin eluvium are known in the region. One area also includes sericitite occurrences that are insufficiently explored to date. The most significant Zhuravlinskiy Log eluvial kaolin deposit is currently mined by the Plast-Rifei Closed Joint-Stock Company within a contour of exploration carried out in 1951–1952 under the supervision of V.G. Lyulicheva. In line with recommendations given by the Central Research Institute of Geology of Nonmetalliferous Mineral Resources, the geological exploration of this deposit were performed in 1994–1997 under the supervision of V.I. Kakorin, and the reserve at flanks of the deposit was estimated at approximately 60 Mt. In general, the resource potential of the Plast region can be still larger and merits further exploration. We believe that results of the exploration will be helpful for the development of program of further promotion of the economic status of the Chelyabinsk district and the Ural federal region as a whole.

GEOLOGICAL POSITION AND STRUCTURE OF THE PLAST KAOLIN-BEARING REGION

According to the concept based on results of the additional geological survey (E.P. Shulkin, V.P. Murkin) and specialized exploration (V.P. Kostarev, V.G. Lyulicheva, T.N. Kochurova, P.M. Sotnikov, V.I. Kakorin, and others), the main area of the Plast kaolin-bearing region is located in the Kochkar anticlinorium, a second-order structural unit of the East Ural Uplift. In the west, the Kochkar anticlinorium borders

along a regional deep fault with the Tagil–Magnitogorsk Synclinorium. In the east, the anticlinorium is faulted against the Plast tonalite–plagiogranite pluton localized in the Alapaevsk–Irgiz structural–mineralogenic zone (*Metallogenicheskaya karta...*, 1987). The eastern contact of the Plast pluton may be regarded as a boundary of the Plast kaolin-bearing region. The geological position of the region is shown in Fig. 1.

The Kochkar anticlinorium comprises several brachyanticlines. Their cores composed by migmatized gneisses and granites occupy approximately half of the kaolin-bearing region. Limbs of the brachyanticlines consist of intricate stratified Neoproterozoic and Paleozoic metamorphic rocks (biotite, muscovite–biotite, garnet–biotite, and chlorite schists; plagiogneisses; mica–graphite quartzites; marbles; metabreccias; metagavelstones; metasandstones; and metapelitic rocks).

We can recognize several plutonic complexes:

(1) Late Riphean–Devonian Andreev Complex of large Andreev and Plast plutons mainly composed of mesocratic plagiomigmatites, tholeiites, and plagiogranites, which occur as remnants in all other large plutons;

(2) Late Riphean–Middle Carboniferous Borisovka Complex of biotite and two-mica granites (Varlamovo, Borisovka, Yefremkino, and Sanarka domes). At their contacts, the country rocks are intensely migmatized and gradually transformed into granite gneisses, gneissic granites, and granites;

(3) Vendian–Silurian Bashtau Complex of gabbro and dolerite sills foliated near their contacts;

(4) Early Silurian Kumlyak Complex of antigorite serpentinites, carbonate–talc rocks, and conglomerate-type serpentinites exposed as small lenses and sheets;

(5) Early Carboniferous Kukushka Complex of granitoids of elevated alkalinity (Klyuchevka and Kukushka plutons) localized in the extreme north and west of the region. Gabbrodiorites and less abundant granodiorites and syenites are associated with granites. The plutonic rocks underwent cataclasis, recrystallization, and replacement by epidote and chlorite in the course of tectonic reworking;

(6) Late Carboniferous–Early Permian Sanarka Complex of granites (the central sector of the Sanarka pluton, separate bodies within the Borisovka and Varlamovo plutons, and dikes of medium-grained biotite granite and fine-grained leucogranite);

(7) Late Permian–Early Triassic Povarneno Complex of numerous dikes and stocks composed of fine- and medium-grained often pegmatoid biotite granites and leucogranites, as well as aplite veins.

In many cases, the granites and country rocks are disintegrated and crosscut by linear faults. One can see intense fracturing of the substrate at their intersections and the development of block displacements.

Therefore, unilaterally uplifted and subsided blocks, as well as graben-shaped escarpments expressed in present-day topography in some places, are typical of the Transural region (Shilkin, 1964). Tectonic zone of the graben-syncline type, which separates the large Varlamovo and Borisovka plutons, is especially characteristic in this respect.

The Mesozoic weathering crust on pre-Paleozoic and Paleozoic rocks is retained to various extents depending on effects of recent and ancient erosional processes. The final product of the weathering of granites is often represented by light-colored kaolin deposits, which are top-priority targets of geological exploration. The Mesozoic erosional–structural depressions commonly inherited from the Hercynian structural grain (Sigov, 1969) control the retention of kaolin-rich weathered rocks and products of their proximal redeposition.

The summary section of the sedimentary cover on the weathering crust consists of the Lower Cretaceous Alapaevsk and the Upper Cretaceous Mysovka formations composed of kaolinite, mica–kaolinite interlayers, coaly clay, clayey sand, and silt that are retained in the depressions of older drainage network commonly related to the karst formation.

Paleogene clays and sands of the Talitsky, Kurtamys, and Naurzum formations fill the axial sectors of ancient valleys. Local bodies of the redeposited kaolin, kaolinite and hydromica–kaolinite clays are largely related to the Naurzum Formation.

Neogene sediments, which are most widespread, comprise the varicolored clays of the Svetloe Formation and the brown and gray sandy clays of the Kustanai Formation. Quaternary brown sandy clays with carbonate segregations crown the section.

The total thickness of Neogene and Quaternary sedimentary cover on the weathering crust varies from 1 to 50 m (10–15 m, on average).

WEATHERING CRUST

The weathering crust occupies approximately 70% of the Plast region. The weathering crust is divided into the linear–areal and contact–karst morphological types. The formation of weathering crust is related to the stage of relative tectonic stability of the Ural Foldbelt that embraced the interval of geologic time from the Middle Jurassic to the early Oligocene. Since the region is situated within a near-latitudinal uplifted tectonic megablock, the Cenozoic erosion was rather deep (Sigov and Romashova, 1984). Therefore, the upper zone of the weathering profile is eroded or its thickness is minimal. The weathering crust is worst retained at the top of watersheds and channels of present-day river valleys.

Taking the high degree of weathering crust erosion into account, its linear fragments should be considered the most promising areas for the discovery of kaolin

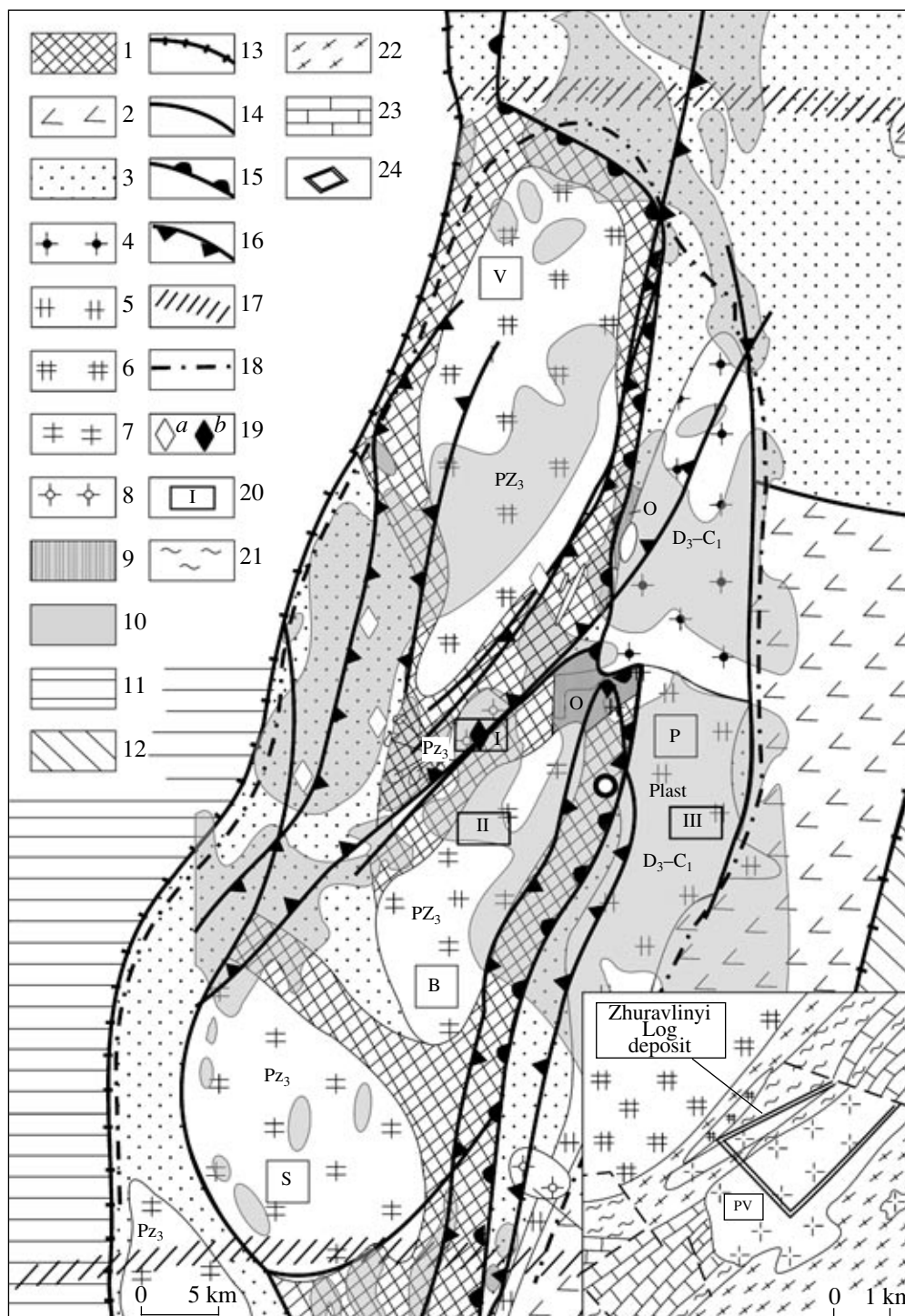


Fig. 1. Geological map of the Plast region (without the sedimentary cover on the weathering crust). (1–9) Lithostructural complexes (*Metallogenicheskaya*..., 1987): (1–3) stratified complexes: (1) Paleoproterozoic metamorphic rocks (pyroxene, amphibole, biotite, two-mica, and graphite gneisses, crystalline schists, and marble); (2) Lower–Middle Paleozoic mafic volcanic rocks (from basalt to andesite and rhyolite) and tuffaceous sandy shales; (3) Upper Paleozoic mafic and felsic rocks (from basalt to andesite and rhyolite), pebbly–sandy–calcareous rocks, and tuffaceous–pebbly–sandy shales; (4–9) intrusions: (4) tonalite–plagiogranite; (5) plagiogranite; (6) granite; (7) plagiogranite and granite; (8) granite and leucogranite; (9) dunite and pyroxenite; (10) Late Mesozoic weathering crust; (11–17) structural elements: (11) Tagil–Magnitogorsk metallogenic megazone; (12) Alapaevsk–Irgiz metallogenic megazone; (13) axes of the major deep faults; (14) faults (normal, reverse, and strike-slip); (15) thrust fault; (16) erosional–structural depressions; (17) hidden transverse fault zones; (18–20) mineragenic elements: (18) boundaries of the Plast kaolin-bearing region; (19) kaolin-bearing objects: (a) occurrences and small deposits, (b) Zhuravlinyi Log deposit; (20) prospective areas: (I) Zhuravlinyi Log, (II) Stafeevo, (III) Plast. Legend for the inset. (21) gneiss; (22) crystalline schist; (23) marble; (24) appraisal area. Granitoid plutons: (V) Varlamovo, (B) Borisovka, (S) Sanarka, (P) Plast, (PV) Povarneno.

deposits. This concerns not only the fault-line kaolinization of rocks, but also the influence of the subsequent block displacements on the local retention of the complete weathering profile largely recorded at walls of the Mesozoic erosional-structural depressions.

The thickness and mineralogical-geochemical characteristics of zones along the weathering profile depend on attitude, structure, and especially lithology of protolith. The predominance of leucocratic protolith is one of the most important prerequisites of the formation of white and light-colored kaolin in the weathering crust. Granites of the Povarneno Complex are the most leucocratic rocks, although leucocratic varieties are also inherent to the Varlamovo, Borisovka, Sanarka, and Plast complexes. In normal leucogranites, potassium feldspar prevails over plagioclase. In plagiogranites, the proportions are reversed or approximately equal. It is noteworthy that plagiogranites are depleted in accessory minerals (in comparison with normal granites) but more intensely altered with the formation of sericite, clinozoisite, chlorite, secondary quartz, and albite.

These specific features of granitic rocks were responsible for differences in properties and quality of kaolin formed as a product of their weathering (see below). The granite weathering profile in the Plast kaolin-bearing region includes three zones. The lower (disintegration) zone consists of clayey (often limonitized) granitic grus and rubble. The middle zone is marked by initial or incomplete kaolinization. The upper zone is characterized by complete kaolinization (complete or nearly complete replacement of feldspar with kaolinite).

The thickness of the lower zone ranges from 0 to 10 m depending on the composition and physical state of protolith (fracturing, cavernosity, cataclasis, gneissosity, and so on). In the weathering profile of plagiogranites, the grus zone is poorly discernible and apparently combined with the overlying zone of initial kaolinization. This zone is expressed more distinctly in the weathering profile of mesocratic plagiogranites owing to their enrichment in dark-colored minerals. In this case, eluvium of this zone is greenish gray or greenish yellow due to the presence of biotite and hornblende, which are partially replaced by kaolinite, and the newly formed smectite or mixed-layer mica-smectite. In the weathered normal granites, the upper subzone of the zone of initial kaolinization is composed of eluvial sediments characterized by the development of both microcline and kaolinite group minerals (occasionally in approximately equal amounts). The thickness of the initial kaolinization zone in the weathering crust of plagiogranites is 3–10 m. The thickness increases up to 15 m in normal granites owing to the development of the alkali kaolin subzone.

The complete kaolinization zone consists of eluvium of the bimineral composition represented by the major kaolinite (halloysite) + quartz assemblage with the subordinate admixture of relict potassium feldspar

and/or muscovite (sericite). The influence of denudation is absent or insignificant. The thickness is 10–30 m in the areal weathering profile and 40–50 m or more in the linear variety.

If the granitic protolith is enriched in muscovite (sericite), kaolin is also generally enriched in this component, indicating significant stability of potassium mica in the course of weathering. Therefore, like relict quartz, sericite is retained in the weathering profile of sericite-rich plagiogranites of the Plast pluton even when potassium feldspar (microcline) is completely replaced with kaolinite. Hence, the weathering profile of mica-rich rocks is crowned by a zone of alkali (micaceous) kaolin consisting of the kaolinite (+ halloysite) + quartz + muscovite (sericite) assemblage.

CHARACTERISTICS OF KAOLIN AND SERICITITE

The main specific features of the formation of the eluvial kaolin in the Urals and its localization are considered in (Belov, 1969; Gorbachev, 1983; Gorbachev and Vasyanov, 1970; Gorbachev et al., 1973; and Petrov, 1968). The Plast region reveals some special characteristics in this respect largely owing to the distinct influence of older erosional-structural depressions that control the retention of the complete weathering profile of kaolin. Therefore, kaolin deposits, occurrences, and manifestations discovered in the study region are located at walls of depressions.

The examination of borehole cores from the weathering crust of the kaolin zone showed that the mineral has gray, yellow, pink, cream, light gray, or white color. The white or almost white kaolin occurs as bodies of diverse shape and size within the colored varieties of kaolin. The largest bodies or clusters of smaller bodies are targets of geological exploration aimed at the quantitative and qualitative evaluation of their resources (reserves).

In terms of the structure of weathering profiles, three economic mineral types of white kaolin are recognized in the Plast region: (1) quartz-kaolinite (kaolin proper); (2) quartz-microcline-kaolinite (alkali kaolinite with potassium feldspar); and (3) quartz-muscovite (sericite)-kaolinite (alkali kaolin with potassium mica).

The *Zhuravlinyi Log deposit* is composed of kaolin of both the first and second economic mineral types. The deposit is situated 12 km northwest of the town of Plast in the Chuksa erosional-structural depression inherited from the Paleozoic graben located between the Varlamovo and Borisovka granitic plutons. The two-mica leucogranite of the small (2.5–3.0 × 0.2–1.7 km) Povarneno pluton serves as a protolith. The leucogranite crosscuts the weathered gneissic suite. Small pegmatite veins are hosted in the leucogranite that ranges from the fine-grained to pegmatoid varieties. In general, the leucogranite has a rather uniform composition. Variations observed in some places are

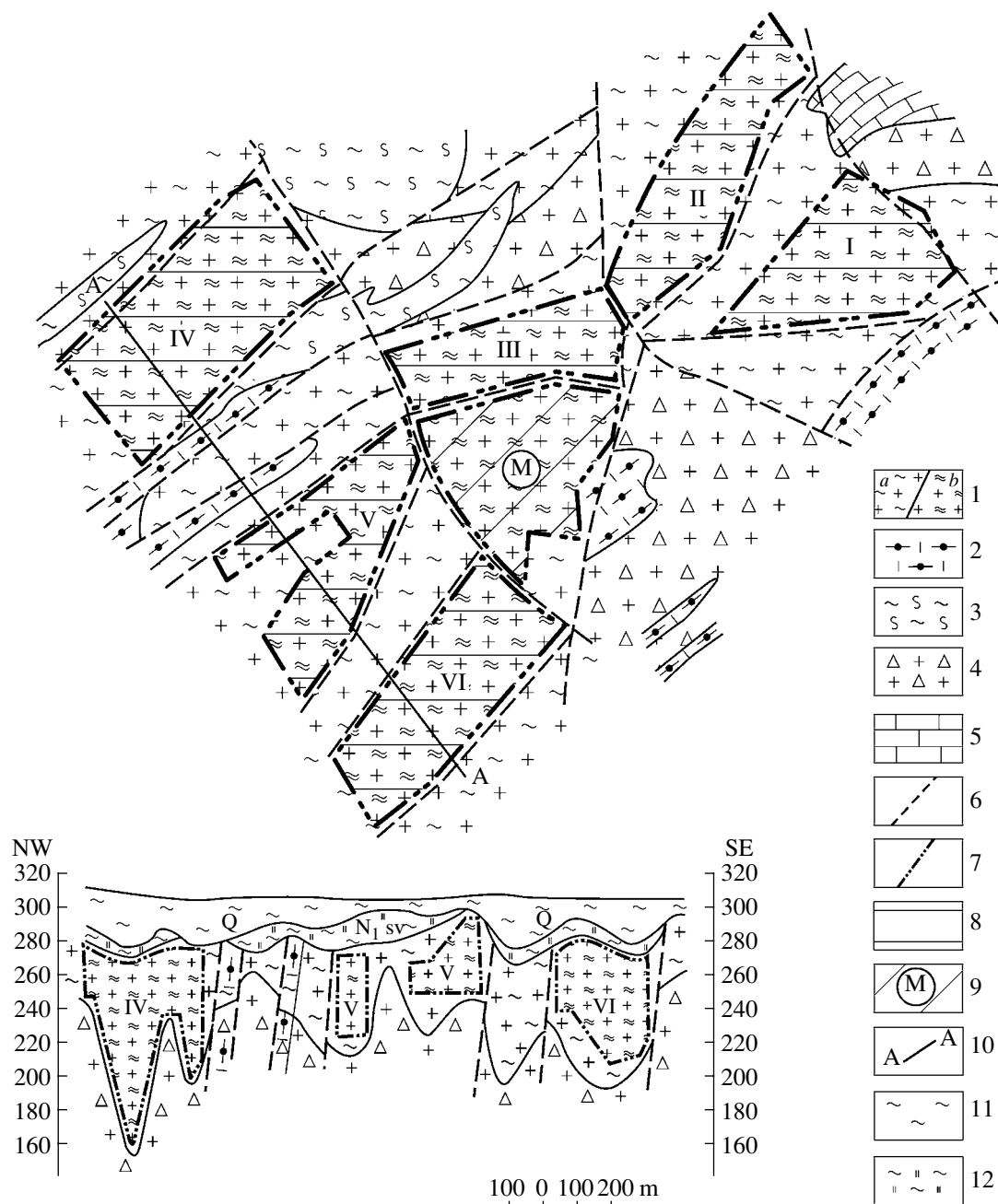


Fig. 2. Geological sketch map of the Zhuravlinyi Log eluvial kaolin deposit based on results of appraisal works (without the sedimentary cover). (1–3) Kaolin weathering crust on: (1) leucogranites with a thickness of (a) up to 10 m and (b) >10 m; (2) gneiss; (3) mica schist; (4) clayey-rubby products of weathering; (5) marble; (6) boundaries of tectonic blocks; (7) areas of light-colored and white kaolin (thickness >10 m); (8) blocks with reserves of category C₂; (9) block with reserves of category B + C₁; (10) geological section. Additional legend for the profile: (11) Quaternary clay and loam; (12) Lower Neogene Svetloe Formation (sand and clay).

caused by different degrees of the replacement of biotite with muscovite and chlorite. Plagioclase is sericitized only slightly.

The relatively good preservation of the upper zone of weathering profile and the leucocratic character of granitic protolith indicate high kaolin potential of the Zhuravlinyi Log area. This is confirmed by the discov-

ery of the Zhuravlinyi Log kaolin deposit in the 1950s. The geological exploration is in progress at the flanks of this deposit.

Figure 2 shows the sketch geological map of this area, contours of the currently mined eluvial kaolin deposit, and blocks of the reserves of category C₂ accepted in Russia (approximately corresponds to the

Table 1. Average contents of the major chemical components in kaolins and concentration products, wt %

Product	Kaolin proper					Alkali kaolin with potassium feldspar				
	Al ₂ O ₃	TiO ₂	Fe ₂ O ₃	K ₂ O	H ₂ O	Al ₂ O ₃	TiO ₂	Fe ₂ O ₃	K ₂ O	L.O.I.
Crude kaolin	20.1	0.22	0.58	0.74	7.70	16.07	0.16	0.56	3.64	5.90
Kaolin concentrate	35.50	0.33	0.99	0.59	13.50	32.80	0.29	1.10	2.87	11.00
Sifted sand	2.94	0.10	0.22	0.92	1.30	8.26	0.18	0.21	5.03	1.13

Table 2. Chemical composition of the crude kaolin in various grain-size fractions

Fraction, mm	Yield, %	Content, wt %					
		SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	R ₂ O	L.O.I.
>10	0.3	98.0	0.028	1.22	0.57	0.126	0.1
10–5	0.8	97.1	0.048	1.62	0.64	0.176	0.3
5–2.5	0.8	93.2	0.047	1.92	0.78	0.196	1.56
2.5–1.0	5.1	96.4	0.038	1.51	0.52	0.176	0.76
1.0–0.5	16.8	97.4	0.049	1.46	0.06	0.197	0.44
0.5–0.2	14.6	96.9	0.076	1.88	0.10	0.368	0.62
0.2–0.09	5.4	83.7	0.32	9.10	0.40	3.880	2.02
0.09–0.063	1.0	70.3	0.39	16.8	0.57	3.270	3.60
<0.063	56.2	48.4	0.35	34.7	0.99	1.457	12.30
Total	100	69.2	0.24	20.44	0.64	1.128	7.06

category of inferred reserves in the Western classification of reserves) at the flanks of this deposit. The occurrence of light-colored kaolin and its sufficient thickness (no less than 10 m) served as criteria for contouring these blocks. Kaolin is absent, insufficiently thick, or developed after Fe-rich gneisses and schists between the blocks. The number and configuration of blocks may change in the course of further detailed exploration.

The deposit has a rather complex structure. As can be seen in the open pit, the boundary of weathered rocks with the overlapping sediments is uneven with swells and depressions. The weathering crust locally crops out at the day surface, but mostly occurs at a depth of 34 m beneath the Neogene and Quaternary sediments. Both kaolin and overlapping rocks are deformed. The base of weathered rocks is also uneven. Such attitude of the weathering crust is most likely controlled by both tectonic displacements of the protolith before the weathering and block movements after the alteration. The thickness of the light-colored kaolin within the contour of reserve estimation varies from 5.6 to 41.9 m, whereas the weathering crust has a total thickness of 2.8–59.3 m. The thickness of the light-colored kaolin has a positive correlation with the thickness of the weathering crust. However, no correlation is observed between the thickness of overburden and weathering crust.

The crude kaolin is a rather loose or poorly consistent psammitic-pelitic material that consists of angular fragments of relict minerals of the sandy-silty dimension (quartz, potassium feldspar, accessory minerals) and small mica flakes incorporated in a clayey matrix largely composed of cryptocrystalline kaolinite with a halloysite admixture and subordinate amounts of sericite and smectite. The distribution of relict minerals is appreciably nonuniform in kaolin formed as a product of pegmatoid granite weathering. The uniformity of light color is also disturbed by diffuse limonitized spots, lenses, and bands with the irregular appearance of cream, yellow, and pink ochreous varieties.

The Al₂O₃ content systematically decreases, while the K₂O content increases with depth. In the lower part of the productive sequence, the crude kaolin commonly contains more than 10% potassium feldspar. The distribution of iron hydroxides in the vertical section is highly variable. Therefore, it is difficult to assess the content of kaolin of the economic and subeconomic categories in terms of the content of admixtures. Table 1 presents chemical compositions of the crude kaolin (<63 µm fraction) and sift sand.

The detailed, fraction-to-fraction examination of a kaolin sample carried out by Solodkii (1995) demonstrates its compositional variations depending on grain size of the fractions (Tables 2, 3).

As follows from Table 2, the majority of grains of relict minerals in the crude kaolin have a size of

Table 3. Chemical and mineral compositions of the kaolin concentrate in <63 μm fractions

Fraction, μm	Yield, %	Content, wt %								
		SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	R ₂ O	L.O.I.	Kaolinite	Micro- cline	Quartz
63–20	9.9	63.9	0.46	22.7	0.61	6.31	5.74	40	37	21
20–10	14.1	51.1	0.33	33.6	0.79	2.75	11.0	78	17	3
10–5	11.5	48.7	0.36	36.2	0.77	0.80	12.5	89	5	4
<5	64.5	46.4	0.34	36.93	1.27	0.54	14.2	93	2	2
Total	100.0	48.8	0.35	34.97	1.08	1.57	12.7	84	9	4

0.2–1.0 mm, and larger grains account for only 7%. The R₂O content increases with diminishing grain size and reaches the maximum in $-0.2 + 0.063$ mm fractions. Figures 3a and 3b demonstrate the distribution of minerals in different grain-size fractions of the kaolin proper and alkali kaolin with potassium feldspar.

Kaolin is easily concentrated by washing on a 0063 sieve. In this process, not only kaolinite (halloysite), but also the finest particles of relict minerals (quartz, microcline, sericite, and leucosene) are transferred to the concentrate. In general, the concentrate yield is 45–60% for the kaolin proper and 35–50% for the alkali kaolin with potassium feldspar. In the process of the crude kaolin concentration, the silica content not always reaches the permissible minimal content of 35% owing to the presence of diluting material (fine particles of relict nonclayey minerals). At the same time, the content of kaolinite group minerals in the concentrate of the kaolin proper and alkali kaolin is 85–97 and 70–85%, respectively. To obtain the kaolin concentrate that fits the above requirement, its particle size should be not larger than 30 μm (Shamrikov, 2001).

The maximum R₂O content (~6.3 wt %) noted in concentrate of $-63 + 20$ μm fraction corresponds to ~35–40% microcline and sericite (Table 3). The calculations showed that when the grain size of the kaolin concentrate is reduced to <20 μm , the yield of concentration decreases by ~10% at the depletion in K₂O to 0.6% and enrichment in Al₂O₃ to 36.5%.

It has been established that the major portion of Ti–Fe oxides (80–90%) is related to the clayey component of kaolin. Therefore, their contents are increased in the concentrate. In general, the kaolin concentrate from the Zhuravlinyi Log deposit is characterized by the low content of Ti (0.1–0.5 wt % TiO₂) and the moderate content of Fe (0.50–1.50 wt % Fe₂O_{3tot}). TiO₂ occurs mainly as fine particles of anatase-derived leucosene. Results of the differential thermomagnetic analysis (DTMA) indicate that Fe₂O₃ occurs as a submicroscopic (close to one-domain) pigmented admixture of ferromagnetic minerals (goethite, hematite). The iron oxide is incorporated in paramagnetic minerals (kaolinite, sericite). This is confirmed by electron paramagnetic resonance spectra. Their interpretation revealed

the replacement of Al ions with Fe ions in the octahedral lattice of the kaolinite structure.

The observed coloration of white kaolin into ochreous yellowish and pinkish hues is caused by the percolation of groundwater from the reddish brown clay blanket with the formation of concentric rhythmic structures resembling Liesegang rings. The kaolin concentrate also contains an insignificant admixture of fine-flaky sericite (0.5%, occasionally up to 10–15%).

Examination of the kaolin concentrate with X-ray and electron diffraction methods and electron microscopy revealed that the concentrate always includes a variable amount of halloysite, and the Hinkley index of crystallinity has an integral value that corresponds to kaolinite with a medium degree of crystalline structure ordering. Therefore, the term *kaolinite* implies kaolinite with a variable content of the halloysite admixture. The presence of halloysite provokes the shift of the first basal reflection from 0.715–0.716 nm (typical of kaolinite) to 0.720–0.725 nm. The quantitative X-ray phase analysis was carried out according to the Peter–Kalman method. Table 4 presents all characteristics of the kaolin concentrate and kaolinite. This table demonstrates a high degree of agreement between the contents of kaolinite determined by the thermal and X-ray methods.

Electron microscopic images show that kaolinite occurs as individual pseudo-hexagonal microcrystals (0.1–1.0 μm in size) and their intergrowths. According to the electron diffraction data, kaolinite pertains to polytype 1 Tk ($b = 0.892$ nm) and occurs as mineral with both perfect (strict order along c axis) and imperfect (disturbed alternation of layers) structures. The distribution of halloysite in kaolin is irregular and varies from sporadic crystals to waxlike microspots almost completely consisting of halloysite (Fig. 4a). Halloysite crystals have various shapes (elongate-tubular, long-prismatic, and occasional tubular plates 1–5 μ long). Increase in the L.O.I. value to 14–15 wt % (despite the absence of carbonates) serves as indirect evidence of halloysite admixture. In fact, kaolin from the Zhuravlinyi Log deposit should be classified as the halloysite–kaolinite subtype of the eluvial kaolin. Taking the metastability of halloysite into consideration, its occurrence may be explained by the impact of Paleogene weathering on the Mesozoic kaolin.

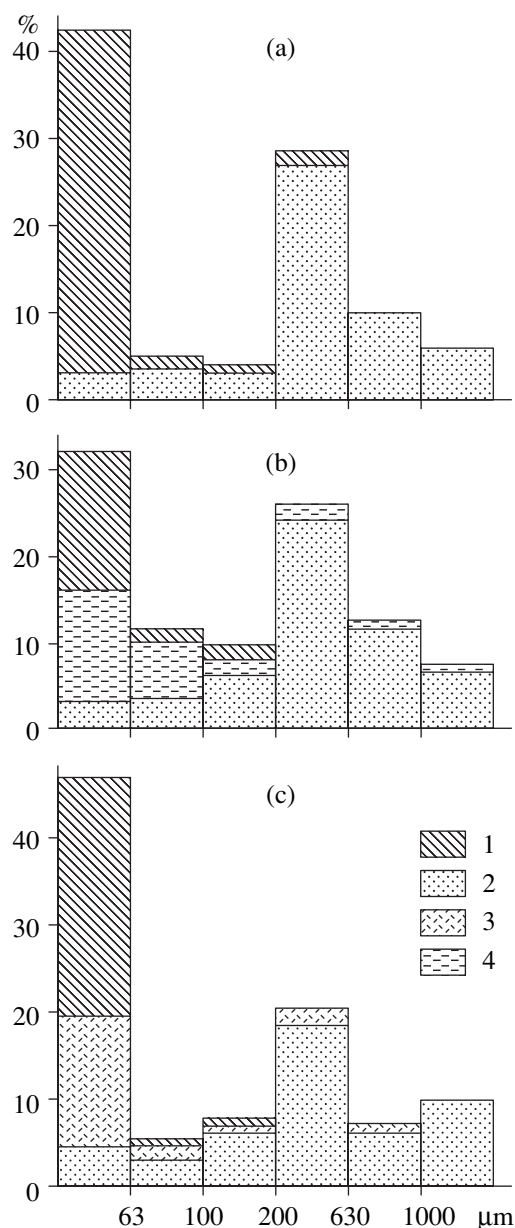


Fig. 3. The grain-size distribution of minerals. (a) Kaolin proper (Zhuravliniy Log deposit); (b) alkali kaolin at the same deposit; (c) sericite-bearing kaolin (Plast area). Minerals: (1) kaolinite, (2) quartz, (3) muscovite (sericite), (4) potassium feldspar.

The white kaolin concentrate has an average coefficient of whiteness close to 83% (up to 87–89% after calcination at 1350°C). The concentrate has satisfactory rheological properties and is suitable for both traditional and new fields of industrial utilization (Maslennikova et al., 2002). The white alkali crude kaolin may be used as a composite material consisting of kaolinite, quartz, and feldspar. As of the beginning of 2006, the crude kaolin reserves were estimated at 6.4 Mt of categories B + C₁ (demonstrated reserves) and about 60 Mt of category C₂ (inferred reserves). Approximately 25%

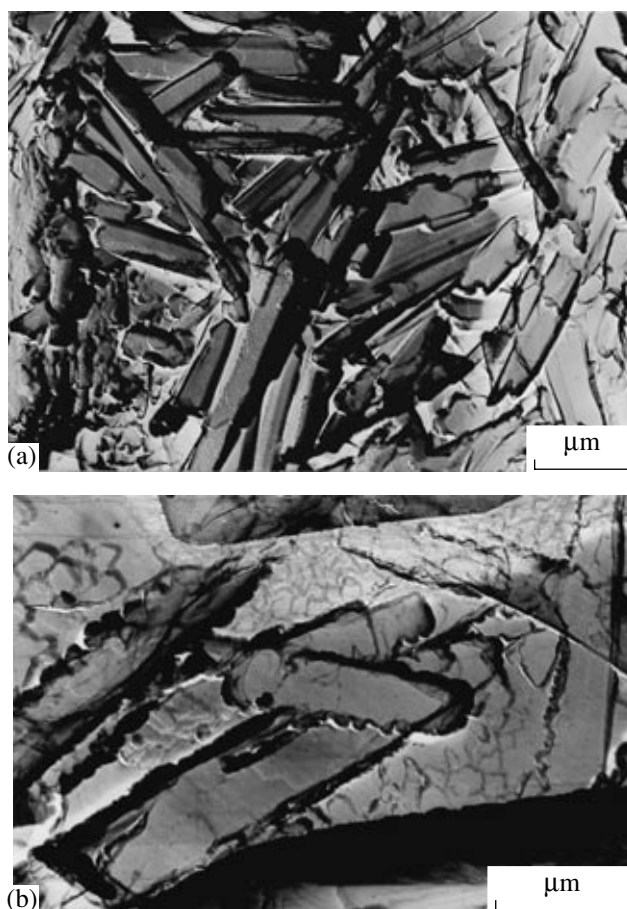


Fig. 4. Electron microscopic images (coal replicas). (a) Halloysite in kaolin developed after leucogranite; (b) elongate-flaky sericite in kaolinized sericitolite.

of these reserves may be used for the production of fine ceramics and electroceramics; 20%, for the production of paper; and 75%, as a filler of synthetic materials, rubber, and paints.

Blocks II and IV (Fig. 2) are the most promising one with respect to the quality and reserves of kaolin. It is evident that the best kaolin accumulations situated under the most favorable mining conditions are confined to the upper part of the kaolin deposit (above the altitude of 292 m asl). The deeper kaolin deposits are composed of alkali varieties, and their economic value will be specified in the course of the current geological exploration.

Alkali kaolin of the third economic mineral type with fine-flaky light mica (sericite) as the major potassium carrier is typical of weathering products of granites and gneisses of the Plast, Reft, and Balataldy plagiogranite plutonic complexes of the Urals. These complexes formed at the early island-arc stage of the Uralian paleocean evolution (Ivanov et al., 1986). It is important to note that these plutonic rocks are affected by regional propylitization, which is largely expressed in the Plast pluton in the form of large-scale and often

Table 4. Mineralogical and chemical characteristics of kaolin concentrate samples

Sample	XRD data					DTA	Results of chemical analysis					Coefficient of whiteness, %
	$C_{\text{kaol}}, \%$	d_{001}, nm	HI	$C_{\text{mica}}, \%$	$C_{\text{quartz}}, \%$	$C_{\text{kaol}}, \%$	$\text{SiO}_2, \%$	$\text{Al}_2\text{O}_3, \%$	$\text{Fe}_2\text{O}_3, \%$	$\text{K}_2\text{O}, \%$	L.O.I., %	
1	90	0.725	0.68	8	2	90	46.85	37.43	0.81	1.03	13.27	86.6
2	89	0.722	0.73	8	3	93	47.06	37.31	0.71	0.89	13.54	81.6
3	92	0.723	0.90	6	2	91	46.97	37.37	0.42	0.73	13.64	86.9
4	93	0.725	0.73	5	2	93	47.14	37.27	0.69	0.56	13.68	79.7
5	95	0.719	0.94	4	1	96	46.20	38.20	0.49	0.54	13.90	84.2
6	91	0.724	0.79	7	2	93	47.14	37.33	0.56	0.67	13.66	83.6
7	90	0.724	0.85	7	3	90	47.58	36.83	0.84	1.00	13.21	82.1
8	90	0.724	0.73	7	3	93	47.53	36.99	0.63	0.62	13.54	80.1
9	90	0.721	0.93	6	4	92	47.75	36.99	0.54	0.78	13.32	82.6
10	88	0.722	0.98	8	4	91	47.84	36.95	0.54	0.86	13.20	82.8
11	95	0.723	0.93	4	1	94	46.56	37.79	0.53	0.43	13.79	82.8
12	96	0.717	0.96	3	1	95	46.44	37.70	0.48	0.56	13.92	84.7
13	85	0.723	0.95	9	6	87	49.66	35.48	0.52	1.00	12.43	82.3

Note: (HI) Hinkley index; (C) mineral content.

complete replacement of plagioclase with fine-grained and cryptocrystalline sericite. The wall-rock sericite-rich metasomatites formed at a later stage. Such metasomatites (local name *tabashka*) make up selvages of gold-ore veins that are mined until now. The regional sericitization probably corresponds to the initial stage of the continental crust (young platform) formation accompanied by the mobilization and input of silica and potassium oxide.

Plagiogranite of the Plast pluton is a meso- and leucocratic, massive or gneissic rock, largely medium- and fine-grained rock with slightly expressed porphyritic appearance in some places. The modal mineral composition of plagiogranite is rather stable. The local enrichment of this rock in biotite is most likely related to the contamination. Leucocratic varieties are depleted in accessory magnetite and ilmenite (Ketris and L'vov, 1968). The secondary muscovite and chlorite replace biotite, while sericite develops after plagioclase. The unaltered chess albite is regarded as a characteristic indicator of propylitization. In mesocratic plagiogranites, sericitization is accompanied by segregations of fine-crystalline clinozoisite and less abundant carbonate.

We outlined a field of weathered leucocratic plagiogranites near the eastern contact of the pluton 9 km east of the town of Plast during prospecting for the eluvial kaolin. The weathering crust is 25–30 m thick and extends to a depth of 60 m in fracture zones (linear morphologic type).

The weathering profile of sericitized plagiogranites is characterized by an almost permanent presence of considerable amounts of relict sericite in all zones.

Depending on the sericite content in the kaolin concentrate (<63 μm fraction), it is expedient to distinguish the sericite-bearing kaolin (<20% sericite, no less than 3 wt % K_2O), sericite kaolin (20–40% sericite, up to 6 wt % K_2O), and sericitites (>40% sericite, >6 wt % K_2O).

Sericitites occur in kaolins of the weathering crust as vein-shaped bodies (Fig. 5), whose orientation, morphology, and dimensions should be specified. They make up a SW- to NE-oriented band about 300 m long and 150 m wide. The sericitites were recovered by boreholes at various depths (maximum 80 m). They alternate with sericite-bearing kaolins. Therefore, we get the impression of a series of veinlike bodies. The morphology of sericitite bodies and their composition were probably inherited from sericitolites formed as products of the hydrothermal metasomatic alteration of leucocratic plagiogranite in fracture zones. Sericitites (initially, sericitolites) are localized in the field of leucocratic sericitized plagiogranite as a specific form of the same alteration. During the weathering, sericite is replaced with kaolinite along cleavage planes, resulting in the disintegration of the initial sericitolites. The intensity of this process decreases with depth.

Kaolin developed after plagiogranite is a loose sandy-clayey light gray and white (with yellowish hue) material that retains the protolith structure. The thickness of light kaolin varies from 4 to 21 m (13 m, on the average). Quartz, kaolinite, and sericite (muscovite) are the major rock-forming minerals. The altered biotite, carbonate, and clinozoisite are relict accessory minerals. Potassium feldspar is absent or subordinate (up to 5%). Figure 3c shows the mineral composition of kaolin in various grain-size fractions.

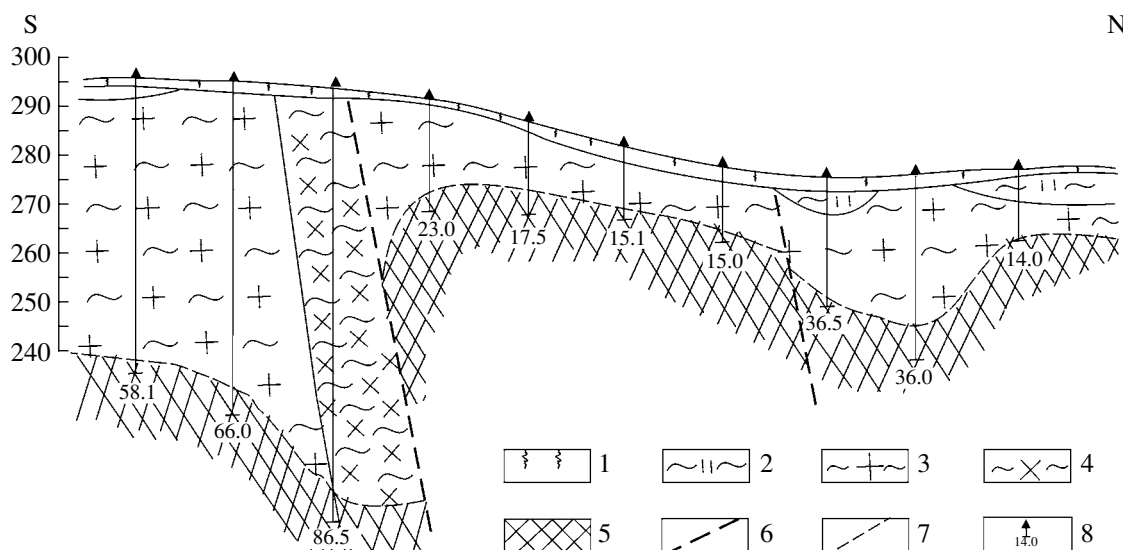


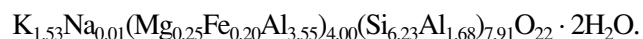
Fig. 5. Weathering profile of sericitized leucocratic plagiogranites of the Plast pluton. (1) Soil-vegetation cover; (2) Lower Neogene Svetloe Formation; (3) sericite-bearing kaolin; (4) sericite; (5) slightly weathered and disintegrated plagiogranite; (6) fault; (7) lower boundary of the weathering crust; (8) borehole and its number.

Kaolinite replaces feldspar and mica. Usually, its content in the crude kaolin is 20–40% and increases to 60–70% in the kaolinic concentrate. Kaolin occurs as pseudomorphs after biotite (0.2–0.6 mm in size) and isometric (rarely, pseudohexagonal) microcrystals (0.5–1.0 μm) and their aggregates. The electron diffraction patterns indicate that kaolinite has a triclinic unit cell and may be referred to as polytype 1 Tk ($b = 0.892$ nm). The mineral has a rather perfect structure with a strict order along axis c . In some cases, the structure becomes disordered due to the shift of layers in the basal plane. Parameters of electron cells of kaolinite and sericite are very similar, suggesting a fragmentary growing of the kaolinite structure into the mica matrix. Characteristic halloysite crystals are detected with an electron microscope in some places.

Together with kaolinite and quartz, sericite is the major mineral of kaolin. According to the XRD results, sericite pertains to polytype $2M_1$. Saturation of a specimen with ethylene glycol does not provoke any shift of the basal reflection of mica. As can be seen from electron microscopic images, sericite occurs as elongated (from 1–2 to 50–100 μm) tabular particles with notches on one face (Fig. 4b). Electron diffraction data indicate a highly perfect crystalline structure of sericite with the following unit cell parameters: $a = 0.518$ nm, $b = 0.8417$ nm, $c = 0.205$ nm, and $\beta = 95.91^\circ$. Electron diffraction patterns of sericite demonstrate the presence of minor kaolinite with a low degree of crystalline structure perfection.

The SEM investigation yielded energy-dispersive spectra of 10 sericite microcrystals up to 5 μm in size. Judging from the analytical data recalculated for the presence of 4.5 wt % H_2O , the sericite has the following

averaged chemical composition (wt %): SiO_2 47.2, Al_2O_3 34.2, FeO 1.0, MgO 1.3, K_2O 9.8, and Na_2O 0.06. The crystallochemical formula of sericite may be written as



The slight enrichment in Si and depletion in Al and K are probably related to weathering.

In the course of kaolin dressing, the yield of <63 μm fraction is 45–60% with 20–40% sericite and 5–10% quartz. Table 5 presents chemical compositions of the crude kaolin, kaolin concentrate, and sericite. The micaceous kaolin concentrate is a low-grade raw material because of its enrichment in iron oxides (1.2–2.5%), which are mostly incorporated in sericite, and, consequently, a low index of whiteness (50–70%). Therefore, such concentrate cannot be used in the production of fine ceramics and paper. However, like kaolin from the Nev'yansk deposit (Sverdlovsk), the Zhuravlinyi Log kaolin is quite suitable for the production of structural ceramics district.

The resources of category P_2 (possible resources) of white and light-colored sericite-bearing kaolin are estimated at 15 Mt.

The sericite-bearing kaolin and, first of all, sericite are of interest for the recovery of sericite, which is a natural analogue of mica product obtained by grinding muscovite derived from pegmatite bodies. In the United States, France, and some other countries, the mica concentrate obtained during the mining of mica-bearing kaolin deposits is used as efficient filler in the production of mechanical rubber goods, plastics, paints, varnishes, cement, insulating and protective coatings, and so on. It is important to note that extraction of the natu-

Table 5. Chemical and mineral compositions of light-colored sericite-bearing kaolins and sericitites from the Plast area, wt %

Component	Kaolin		Sericitite	
	crude (average)	concentrate (average)	crude	concentrate
SiO ₂	75.10	52.50	78.60	69.88
TiO ₂	0.08	0.15	0.07	0.10
Al ₂ O ₃	16.15	33.20	14.21	19.35
Fe ₂ O ₃	0.87	1.15	0.62	0.69
MgO	0.61	1.20	0.29	1.20
CaO	0.01	0.01	0.01	0.02
K ₂ O	3.50	4.10	3.54	5.58
Na ₂ O	0.15	0.24	0.30	0.41
L.O.I.	3.10	8.00	2.23	2.45
Kaolinite	34	52	tr.	tr.
Sericite	22	37	55–60	65–70
Quartz	42	10	40–45	30–35
K-feldspar	2	<1	tr.	tr.
Muscovite	1	<1	–	–

Note: (–) Not detected; (tr.) traces.

rally dispersed mica is tens of times less expensive than the production of the ground muscovite.

Kaolin and sericitite of the Plast deposit merits the detailed examination because of favorable parameters, such as the high content of sericite (up to 50%), moderate contents of Fe₂O₃ (0.5–1.6 wt %) and TiO₂ (0.1–0.3 wt %), and sufficiently high index of whiteness (50–70%). Two samples of flotation concentrate of sericite obtained from kaolin and sericitite turned out to be suitable as filler for paints.

CONCLUSIONS

The kaolin potential of the Plast region is determined by the abundance of leucocratic and other varieties of granites, their intense weathering, and favorable geomorphological factors, e.g., localization in the Transural penepplain zone, which is relatively stable during and after the formation of weathering crust.

This statement is confirmed by the currently mined Zhuravlinyi Log deposit. Eluvial kaolin of this deposit is characterized by the lowest contents of Fe–Ti oxides relative to other deposits in the Chelyabinsk district. Based on the appraisal of kaolin potential of the study region, five prospective areas (Zhuravlinyi Log, Stafeevo, Plast, Kotlik, and Chuksa) have been contoured. The first three areas have the highest potential. The total resources of category P₂ (possible resources) in these areas amount to approximately 60 Mt. We believe that the sericite-bearing kaolin and sericitite can be used for the production of fine-flaky muscovite (sericite).

Unfortunately, the study of sericite-rich kaolin was not continued in the Plast region. However, taking into account the demand for fine-flaky mica, its high consumer price, favorable mode of occurrence, location in a territory with well-developed infrastructure and mining industry, both geological and technological investigations of the kaolin-bearing region should be resumed.

The Stafeevo area is situated 4–5 km south of the Zhuravlinyi Log deposit and confined to the central (leucogranitic) part of the weathering profile of the Borisovka pluton. Kaolin is predominantly light (white, pinkish, and light gray). The average thickness of the weathering crust is 15 m, and the thickness of overburden is insignificant. The hypothetical resources are estimated at 15 Mt.

In addition, kaolin of similar composition and quality may occur at walls of the Chuksa depression southwest of the Zhuravlinyi Log deposit. Small leucogranitic bodies similar to rocks of the Povarneno Complex are expected here beneath the Paleogene and Neogene sedimentary cover. Although the kaolin deposit in this area is located at a relatively great depth, it can be mined successfully and feasibly by the method of hydraulic borehole mining.

There are all grounds to believe that the prospecting and evaluation of the areas listed above will increase resources of the high-quality kaolin and fine-flaky mica. This will strengthen the resource potential and socioeconomic status of the Chelyabinsk district and the Ural federal region as a whole.

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