Geological Survey of Finland, Current Research 2003–2004,
Edited by Sini Autio.
Geological Survey of Finland, Special Paper 38, 41–47, 2005.

THE VITTAJÄNKÄ KAOLIN DEPOSIT, SALLA, FINNISH LAPLAND

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Key words (GeoRef Thesaurus, AGI): kaolin deposits, mineral exploration, geophysical methods, weathering, mineral composition, chemical composition, beneficiation, Vittajänkä, Salla, Finland

Introduction

In the search for abundant and high quality kaolin resources to satisfy the growing demands of the Finnish paper industry, the Geological Survey of Finland (GTK) has, over the period 1998–2004, investigated more than 20 kaolin deposits in the pre-glacial regolith of northern Finland. Research has focussed on Paleoproterozoic metasedimentary rocks in central Lapland, particularly in areas of relatively low metamorphic grade, using a variety of airborne and ground geophysical techniques, supplemented by drilling. Airborne geophysical data are particularly useful in identifying weathered bedrock, while drilling or excavation during earlier bedrock exploration activities has commonly provided direct confirmation of the presence of kaolin and deeply weathered regolith beneath Quaternary till. In contrast, there is a paucity of prior indications of kaolin from terrain dominated by granitoids and gneisses of higher metamorphic grade.

During the course of investigations, research has gradually focussed on two specific regiona, namely the eastern parts of the Sodankylä municipality and the areas to the east and northeast of the tonwhsip of Salla. The presence of kaolin in the Sodankylä district, at Siurunmaa, has been known since 1976 (Rask & Lintinen 2001, Pekkala & Sarapää 1989), while the Suolakaarko deposit was discovered more recently, in 1998 (Lintinen 2000). The first investigations in the Salla region were undertaken in 1999, as a result of which white kaolin was found at Vittajänkä. By the end of 2004 three separate drilling programs had been carried out at Vittajänkä, with a total length of 2000 m. At the same time, exploratory drilling has been undertaken in surrounding terrain, in the search for analogous occurrences.

Assessment of the quality of kaolin at Vittajänkä has also been carried out concurrently with delineation of reserves, with particular emphasis on its suitability as a paper pigment. Preliminary enrichment tests simulating industrial processing have been conducted at GTK and also at the former VTT mineral processing laboratories (now GTK Mineral Processing Laboratories) and results of studies completed prior to 2004 have been reported by Al-Ani et al. (2004).

Geological setting

The Vittajänkä kaolin deposit is located within the southeastern extension of the Paleoproterozoic Central Lapland greenstone belt (Fig. 1). In this area however, quartz-rich metasediments dominate, bounded to the east by the extensive metavolcanics of the Salla greenstone area, which continues across the national

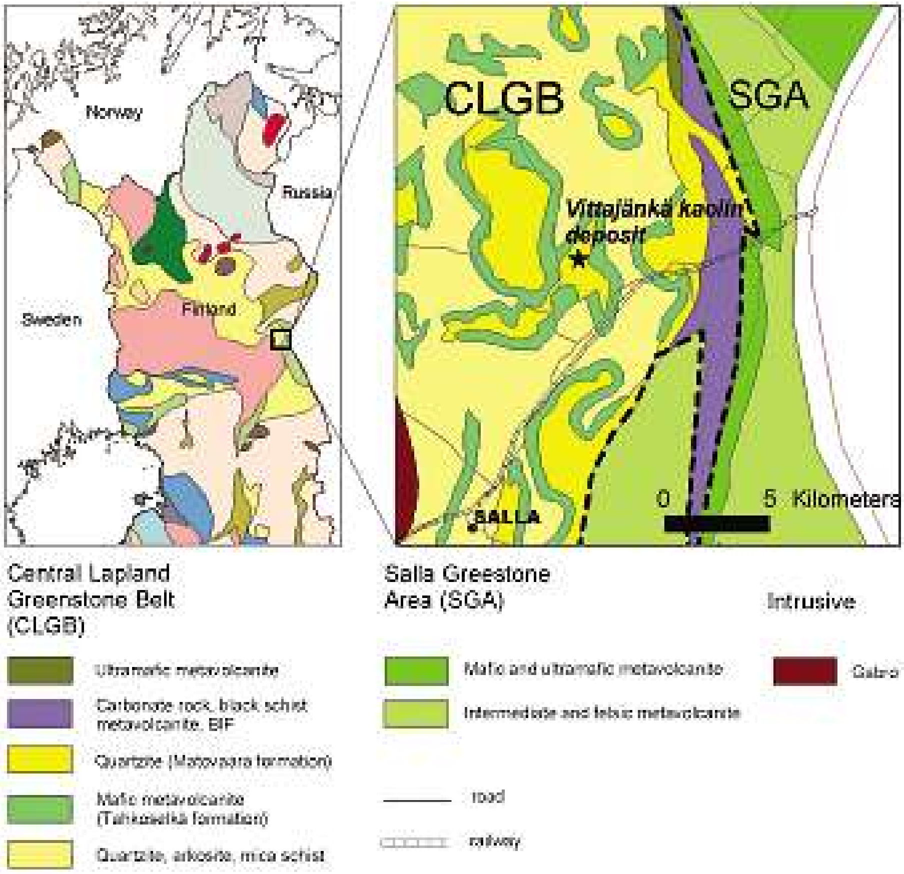

Fig. 1. Geological map showing the location of the Vittajänkä deposit.

border into adjacent Russia. The central Lapland granitic complex occurs to the south and southwest of Vittajänkä, whereas Archean granitic and supracrustal terrain lies to the north.

Regional geological investigations have been carried out during the Lapland Volcanite Project (LVP), by Manninen (1991), on the basis of which the metasedimentary Matovaara Formation is considered to be the protolith from which the Vittajänkä kaolin was derived. Although the area is covered by extensive wetlands, with very few bedrock exposures, the metasediments appear to have been calcareous siltstones, with calc-silicate and laminated orthoquartzite intercalations.

Geophysical investigations

The Vittajänkä kaolin deposit can be distinguished in regional airborne geophysical data as an electromagnetic anomaly with an intense imaginary component and a considerably reduced real component. The Matovaara Formation metasedimentary host rocks are non-magnetic, although they are surrounded by a narrow, conspicuously magnetic zone of tholeiitic volcanics belonging to the Tahkoselkä Formation.

The area delineated by the airborne EM anomaly was surveyed on the ground as well, firstly along widely spaced profiles and then on a systematic grid covering 3.6 km^2 . Both EM VLF-R measurements and gravity surveys were made. In addition, a regional scale gravimetric survey was carried out over 300 km^2 in the Salla district during 2000–2001, with a site density of 8 measurements per km^2. On the basis of these gravity surveys, the Vittajänkä kaolin deposit appears to coincide with a northerly trending elongate 2 mGal gravity minimum, approximately 1.75 km^2 (2.5x0.8 km) in extent (Fig. 2). The shape of the gravity anomaly is controlled by both degree of weathering and the structurally defined bedrock geology, with mafic volcanics surrounding the metasediments.

Sampling strategy

The Vittajänkä deposit was drilled in three stages in 1999, 2001 and 2003, using different equipment and core recovery techniques. Drilling has been both technically challenging and required careful sampling in order to maximize the research value of recovered material.

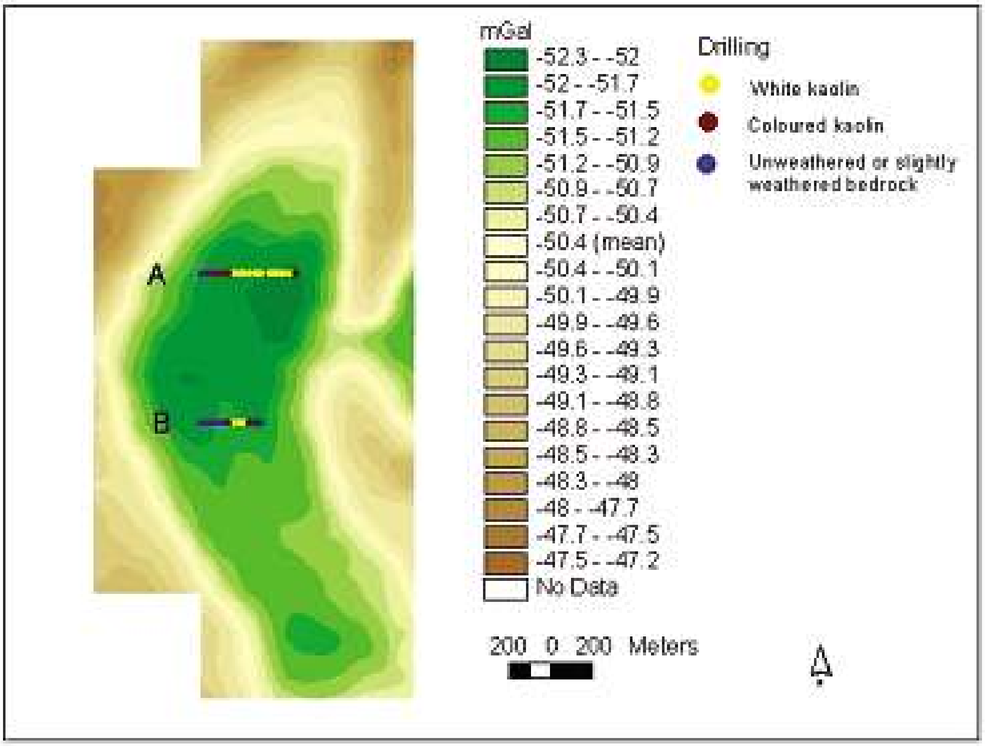

Fig. 2. Bouguer anomlay map of the Vittajänkä kaolin deposit, showing locations of drilling profiles and the distribution of white and coloured kaolin.

The gravity anomaly has been drilled along two E-W profiles 700 m apart (Figs. 2 and 3). The more northerly profile intersected white or yellowish kaolin over a distance of 300 m, while the total width of the weathered zone was about 400 m. In the southern profile the weathered zone was about 150 m across, with 75 m of light-coloured kaolin. White to yellowish kaolin tend to occur in the central parts of the weathered zone, while marginal parts were considerably darker. Overburden thickness varied from 10–25 m, with a mean depth of 15 m. The thickest kaolin intersections were nearly 30 m although the average was around 20 m. Sporadic quartz-rich horizons, or weathered accumulations of quartz sand were sporadically found within the kaolin.

Some diamond drill core was recovered from the quartz-rich intercalations, and from the bedrock beneath the kaolin deposit, despite their being intensely

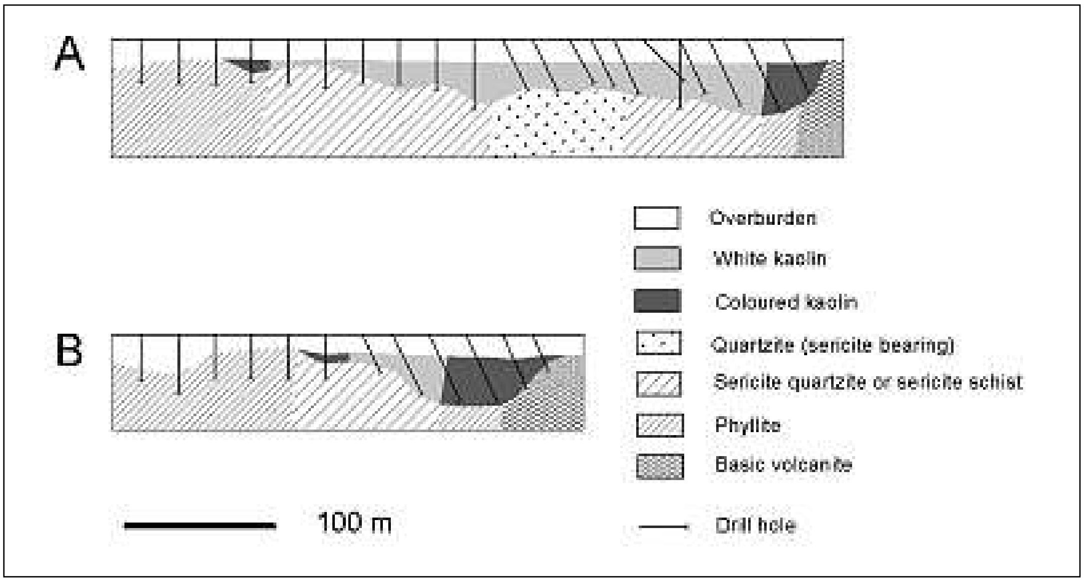

Fig. 3. Simplified cross sections of drilling profiles A and B. For locations, see Figure 2.

weathered. Thus, significantly weathered regolith occurs at depths considerably greater than the main kaolin deposit.

Laboratory analyses and enrichment trials

Methods

A total of 96 samples of kaolin, both white and coloured, were taken for systematic analysis at GTK, with an average sample length of 3.8 m. Samples were classified according to grain size distributions using a combination of sieving and sedigraph analysis. Sample fractions <20 μm were separated and measured for whiteness and yellowness with an L&W Elrepho-spectrophotometer, according to ISO 2496 specifications. In addition, the mineralogy and chemical compositions of the original samples, prior to sieving, as well as the <20 μm fractions were analyzed by XRD and XRF respectively.

The best samples of white kaolin were then evaluated with a trial industrial enrichment process at the VTT (now GTK) Mineral Processing Laboratories at Outokumpu. The process consisted of sieving and centrifuging, followed by magnetic separation and chemical bleaching with sodium dithionite. The centrifuging was intended to recover the size fraction finer than 2 μm. Magnetic separation was performed with a Sala HGMS (High Gradient Magnetic Separation) separator. After bleaching, the samples were filtered, dried and again measured for whiteness and yellowness according to ISOR457-specifications with an Elrepho 2000-colour meter. The final purified samples were then analyzed with both XRD and XRF at the GTK laboratories.

Whiteness and yellowness

Kaolin samples were classified according to the ISO brightness index, for which 'white' refers to a brightness >60 % and coloured to values <60 %. This approach to classification was also used by Sarapää (1996) for the kaolin deposits at Virtasalmi, where the 20 µm size fraction was also used as a cut-off threshold; therefore, results from the two studies are in principle comparable.

Brightness values for kaolin from the <20μm size fraction were, for the samples classified as white, as high as 80–85 %. Such a result can be considered particularly good for kaolin that has not been treated to magnetic or chemical purification. The yellowness of these whitest samples was on average 7–8 %. Pale yel-

Table 1. Mean brightness and yellowness values and respective mineralogical and chemical compositions for different size fractions from the Vittajänkä kaolin deposit. N = number of analyses.

	RAW KAOLIN		<20 microns		<2 microns
	white	coloured	white	coloured	white
	N=59	N=37	N=59	N=37	N=10
Brightness %	-	-	72.2	50.1	79.5
Min	-	-	60	21.7	74.0
Max	-	-	84.6	59.9	84.1
Yellowness	-	-	13.4	29.9	5.9
Kaolinite	30	30	66	56	92
Min	7	0	15	5	85
Max	70	80	90	95	95
Quartz	49	35	9	11	6
Feldspar	6	16	10	15	0
Muscovite	8	4	13	6	4
SiO2	76.23	69.95	51.66	52.19	52.35
Al2O3	13.47	14.72	27.89	25.60	31.40
TiO2	0.32	0.52	0.57	0.64	0.40
Fe2O3	2.00	4.43	2.95	4.15	1.51
MgO	1.18	3.59	1.86	3.72	0.84
CaO	0.03	0.23	0.01	0.10	0.03
Na2O	0.07	1.84	0.18	1.41	-
K2O	3.26	1.78	6.22	3.14	2.62

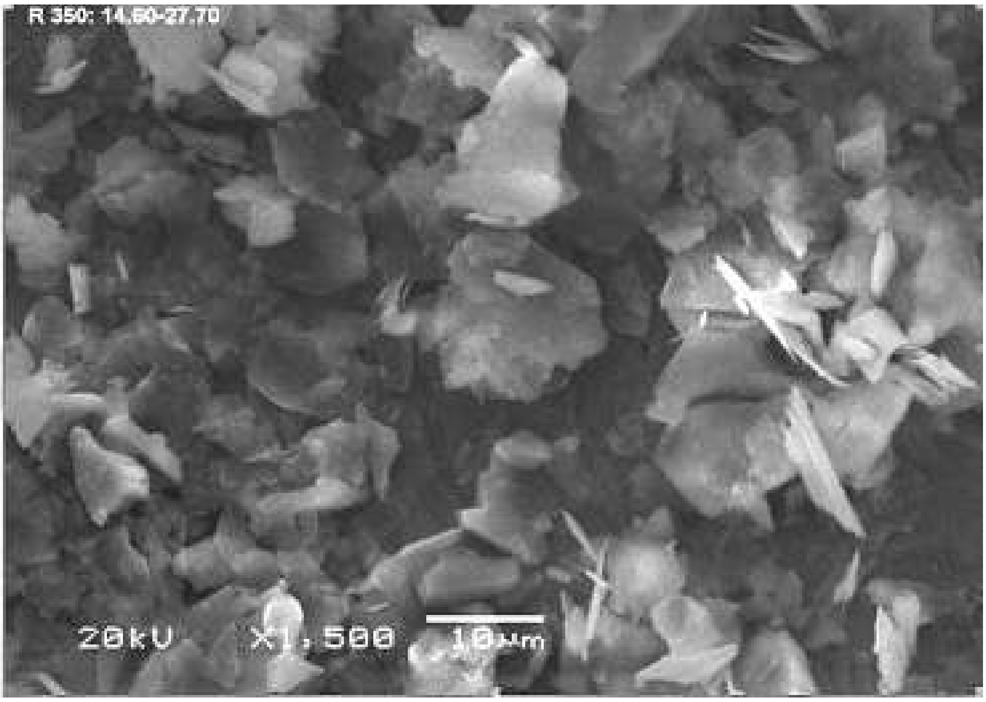

Fig. 4. SEM-image of refined Vittajänkä kaolin. Kaolinite occurs as euhedral flaky particles.

low samples had brightness values between 70–78 % and corresponding yellowness values of 15–10 %.

Magnetically and chemically refined processed kaolin in the <2 μm size range had brightness values only a few percent higher. For example, the brightness index for the <20μm fraction increased from 80 % to around 83 %. On the other hand, yellowness values fell significantly by about half, to values around 3.5–5 %. Because kaolin products suitable for paper pigment require a brightness index of at least 87 % and yellowness below 3 %, these results indicate that the Vittajänkä kaolin would be suitable as a filler only.

Mineralogical composition

Table 1 shows mineralogical and chemical data for selected elements for white and coloured kaolin at various size fractions. Original untreated white kaolin samples contain, on the basis of XRD analyses, an average of 30 % kaolinite, 49 % quartz, 8 % muscovite, 6 % feldspar and trace amounts of hematite and pyroxene. The abundance of kaolin increases to an average of 66 % for the <20μm size fractions, but still contains significant amounts of quartz and muscovite. The refined <2μm kaolin product contains 85–95 % kaolinite, the remainder comprising from 5–10 % quartz and 0–5 % muscovite.

Coloured kaolin contains similar proportions of, or slightly less kaolinite than white kaolin. On the other hand, quartz contents are comparatively lower and feldspar abundances somewhat greater. The eastern parts of the drilling profiles tend to contain more plagioclase, up to 40 % in untreated primary samples and as much as 55 % in the <20μm size fraction. In the central parts of the profiles, inclusions or intercalations of coloured kaolin within the white kaolin contain significant amounts of hematite, in places up to 20 %.

The refined kaolin products were studied under the scanning electron microscope (SEM), as a result of which illite was identified amongst kaolinite and muscovite. XRD analysis of the settled clay fractions of white kaolin samples also showed a characteristic illite peak, while coloured kaolinite samples were also found to contain mixed layer illite-smectite phyllosilicates. XRD data were used to determine Hinckley crystallinity indices (Hinckley 1963, Aparicio & Galan 1999), with values in the range 0.59–0.88 indicating a relatively high degree of crystallinity for the kaolin lattice, in places moderately crystalline. The SEM images (Fig. 4) also revealed that kaolin crystals were nearly euhedral, with a rather uniform grain size distribution and a tendency for small flaky particles to remain in isolation from one another, rather than aggregate into larger phyllosilicate booklets.

Chemical composition

White Vittajänkä kaolin tends to have relatively high SiO_2- and K_2O- abundances and low Al_2O_3 irrespective of grain size. After refining, the <2μm size fraction contained on average 51.6 % SiO_2, 27.9 % Al_2O_3 and 2.9 % K_2O. The abundance of silica and low alumina can be understood in terms of residual quartz, while the retention of muscovite and illite can explain the high potassium and Fe_2O_3, which attains 1.5 % in some samples. By way of comparison, the ideal theoretical kaolinite composition is 46.5 % SiO_2 and 39.5 % Al_2O_3. As a general rule, kaolin products of commercial quality are very close to this ideal composition, although K_2O abundances may commonly exceed 2 %, providing that Fe_2O_3-abundances remain below 1 %.

Coloured kaolin in the eastern parts of the profiles show elevated Na_2O abundances (mean = 1,5–2 %, maximum = 9,7 %), which corresponds to relatively high amounts of albitic plagioclase. In the <20μm size fraction both Na_2O abundances and plagioclase contents determined by XRD are even higher, which indicates further that the albite is particularly fine-grained. It is therefore possible that the protoliths for the regolith in the eastern part of the profile were tholeiitic volcanics of the Tahkoselkä Formation. However, to the west of the volcanic contact, the coloured kaolin has a chemical composition consistent with derivation from metapelitic rocks or even calc-silicates of the Matovaara Formation, given the relatively high abundances of Mg, Fe and K, and locally high Mg+Fe with low K and Na. Locally dark pigmentation within the white kaolin is usually caused by hematite, which is clearly reflected in Fe_2O_3 concentrations.

Conclusions

Protoliths for the kaolin

The white kaolin is evidently derived from weathering of sericitic quartzites and sericitic schists. Local intercalations of quartzite have weathered to kaolinitic quartz sand. Thin section studies show that the host rocks were exceedingly fine-grained, massive to weakly laminated and generally only weakly foliated, with quartz occurring amongst fine-grained phyllosilicates. Accessory minerals include albitic plagioclase, potassium feldspar, tourmaline and porphyroblasts of scapolite.

The most likely protoliths for the coloured kaolin are phyllitic metasediments and mafic metavolcanics. Weathered volcanics in the eastern part of the drilling profiles contain abundant albitic plagioclase and exhibit relatively high Na_2O, Fe_2O_3- and MgO-abundances. In contrast, weathered metapelites have higher K_2O abundances, with very low Na_2O. Thin section studies reveal that the mafic volcanics are fine-grained and massive, with mineralogy dominated by albite and actinolite, the latter locally replaced by talc. Phyllitic rocks resemble sericite schists, except that in addition they contain biotite.

The kaolinization process

The mineralogical and chemical attributes of the Vittajänkä kaolin deposit, together with its overall geometry indicate that the kaolin formed by *in situ* weathering of silicate minerals. The high degree of crystallinity and euhedral habit of the kaolin is also consistent with a primary weathering origin. The presence of muscovite and illite indicate that the process had not proceeded to completion, at least at the present erosion level. It is probably that most of the kaolin formed during decomposition of feldspar and muscovite.

Preservation of kaolin

At least the lower part of the regolith profile at Vittajänkä has survived, despite repeated glaciation and deglaciation events. In general, pre-glacial regolith is more extensively preserved in eastern and northeastern Lapland than elsewhere in the country. At Vittajänkä the following factors contributed to the preservation of kaolin:

1) Primary compositional variations in the protoliths to the kaolin occurrences, in particular more resistant quartz-rich intercalations have protected adjacent weathered material from the effects of erosion
2) The general topographic depression in the area, inherited from bedrock geology, with highly weathered metasediments surrounded by a ring of more resistant, massive and fine-grained tholeiitic metavolcanics (Fig. 1).

Beneficiation and exploitation of kaolin

At present it is only possible to provide a provisional and speculative estimate of the potential kaolin resource at Vittajänkä, using the dimensions of the gravity anomaly and information from the drilling profiles. Given that the gravity minimum is nearly 2 km in length and that the mean width and depth of the weathered zone are 275 m and 20 m respectively, and assuming a regolith density of 2000 kg/m^3, a total mass of around 22 million tonnes is obtained. Samples analyzed to date have on average 60 % white kaolin, of which the average proportion of kaolinite is about 30 %. Accordingly, the deposit would contain about 13 Mt of white kaolin, which could yield about 4 Mt of kaolin concentrate. It should also be noted that although the mean depth of the kaolin regolith is only 20 m, kaolinization is extensive to much greater depths.

After refinement, the Vittajänkä kaolin product still contained considerable amounts of quartz and muscovite, which is reflected in the higher SiO_2- and lower Al_2O_3- abundances than in commercially available kaolin products. Despite all of the refining processes used, the brightness remained below the acceptable levels for kaolin pigment. One of the main reasons for this is the fine grain size of the protoliths, particularly quartz and muscovite, as a result of which mechanical purification is difficult. Further processing using flotation is planned, which will hopefully be effective in removing not only quartz, but also at least some of the mica, resulting in a product with improved brightness values.

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