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POSSIBILITY OF USE THE KAONA QUARTZITE (EAST SERBIA)**

Abstract

The locality of "Kornjica" is located in the area of the village Kaona, about 5 km from the main road Majdanpek-Kučevo-Požarevac-Belgrade, or about 10 km west of Kučevo. Quartzites and quartz metaconglomerates on the surface of about 2 km² were studied at the site "Kornjica". Quartzites and quartz metaconglomerates build a package of layers of thickness about 150 m, which are white, solid, compact and cores. The thickness of pure quartzites is 30 to 40 m, which is multiple interlayered with the other quartzites and quartz metaconglomerates. The rocks are of different compactness and composition. Sometimes, the relict pseptic structures are observed in them as well as the quartz-serie binders. From the existing three horizons of quartzite and quartz metaconglomerates (Kalenić, Hadži-Vuković, 1974), the oldest package occurs at Kaona, which is considered to signify the passage of vendor in the Cambrian. The field geological explorations, petrological tests, chemical tests, physical-mechanical tests and directed technological research (in the laboratory conditions) were carried out. The obtained results of research, along with the already existing data, have enabled the definition of quartzite deposits near Kaona, as well as determining the possibility of using these rocks as the mineral raw materials (whose quality would meet the prescribed standards for use in metallurgy, refractory and chemical industries).

Keywords: *quartzite and quartz metaconglomerates, petrographic characteristics, physical-mechanical characteristics, chemical characteristics, quartzite quality, East Serbia*

1 INTRODUCTION

The location of "Kornjica" is located, by air line, about 10 km in the west of Kučevo, in the attic of Kaona village (East Serbia, Figure 1). This orographic region belongs to the South Carpathians; it is a hydrographic part of the central river basin of the river Pek, and it administratively belongs to the Branicevo District (Municipality of Kučevo). For the immediate vicinity of the explored area, besides the river Pek that

flows in the immediate vicinity, the Kaonski stream is of great importance. The metamorphic complex in the Kaona region (Kalenić, Hadži - Vuković, 1974) was insufficiently studied from the aspect of quartzite exploration as the quartz mineral resource. In order to solve the set problems, in addition to the field observations, a detailed geological exploration the metamorphic complex was carried out on an area of about

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** This paper is the result of the Project No. TR 33021 "Research and Monitoring the Changes of the Stress Strain State in the Rock Mass "In-Situ" around the Underground Rooms with Development of Models with Special Reference to the Tunnel of the Krivelj River and Pit Bor", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia

0.60 km². Interpretation of the obtained results of exploration, along with already existing data, has enabled defining the quartzite deposit near Kaona, development

the necessary graphic and other documentation, as well as determining the possibility of applying these rocks as mineral raw materials.

Figure 1 Geographical position of the Kaona quartzites

2 BASIC GEOLOGICAL DATA AND OVERVIEW OF PREVIOUS EXPLORATIONS

The Kaona area belongs to the Kucevo OGC leaf, scale 1: 100,000 with the mark L-34-128. The leaf Kucevo is located between 44°20'4" and 44°40' of the north latitude, and 21°30' and 22°0' of the east longitude GMT. Includes Braničevo, upper river Mlava, Stig, a part of Homolje and North Kučaj. The boundaries of the explored area are located in a part of the Kladurovo leaf (L-34-128-Ca, scale 1: 25,000). A wider surrounding of the explored area (Figure 2) is built of the Palaeozoic, Mesozoic and Kenoosic rocks (Kalenić, Hadži-Vuković 1974).

In recent years, the paleozoic metamorphic complex in the Kaona area has been relatively little investigated by our and foreign researchers who have been dealing with the individual research in terms of sedimentology (Kalenić, Milosavljević, 1987, 1988), paleontology (Djajić 1992), magmatism or metamorphism (Ivanović. 2000). Djajić states that the original sediments were

deposited in the marine environment, probably by the end of Siluria and the beginning of Devon, and the spores of the first primitive land-based plants were together with the other material transported from the surrounding land or island into the deposition basin. Milosavljević (1992) dealt with the quartzites of Turian and Sena in detail. She determines the quartzites of the Moravian Zone as a part of the Serbian-Macedonian mass that stretches from the Danube to Vlasina Lake, in a narrow zone of about 250 km in length. She describes quartzites as the rocks that appear as one, two or more successive discontinuous horizons (a few tens of meters thick) by the palinopalinological analyses of the proven lower Devon age.

Petrologic - sedimentological studies of quartzites have proved that they are metamorphic sediments (quartzites of the Moravian Zone according to the preserved relict structures and textures are determined as the

primary conglomerates and sand-stones formed by the shallow water sedimentation). Metamorphism caused the recrystallization and loss of contours of the primary grains and fragments. A large amount of silicon binder is present primarily because of isochemical and exochemical dissolution and redissolution of silicon during and after diagenesis. By analyzing the quartz pebbles, detritic minerals (primarily zircon), it has

been proved that the clastic quartzite material originated of the rocks from the metamorphic region. The occurrence of chloritoids and pyrophyllites in the matrix of metaclastite of the Moravian zone were studied by Milovanović et al. (1994). These authors believe that chloritoid, pyrophyllite and chlorite were formed at temperatures around $350^{\circ}\text{S} \pm 50^{\circ}\text{S}$ and pressures of 2-3 kbar.

Figure 2 Geological map of a wider area of explored Kaona territory (Kučevo a part of the leaf Kučevo 1:100 000 (Kalenic, Hadzi Vukovic, 1974) with a view of geological columns (Kalenic et al. 1987)

Legend: 1. alluvium; 2. deluvium; 3. proluviums; 4. river terrace; 5. gravel, sand, clay and limestone; 6. sands and gravels; 7. conglomerates, sandstones, clays, tuffs and coal; 8. conglomerates, shales with coal and marl; 9. massive and banked limestones; 10. marl, marly limestone and limestone with a pink bump; 11. banked and layered limestone, marl limestone and marl; 12. banked and plate limestones with pink bumps; 13. dolomitic limestone and limestone; 14. red sandstones and conglomerates; 15. metapsamites and metadiabasites; 16. acidic metavolcanites, metapelites and metapsamites; 17. metabasites and filitoids; 18. quartzites and quartz conglomerates; 19. sericite schists; 20. exploration area of the Kaona quartzites; 21. location of the geological column Kaona-Turija; 22. location of the geological column Sena-Turija; 23. location of the geological column Sena-Misljenovac

The metamorphic complex in the area Kaona has been insufficiently studied from the aspect of quartzite research as a quartz mineral resource. In the period 1988 - 1990 (Bugarin), a quartzite prospectus was carried out in the area of Kaona, a narrow locality of the "Kornjica" (a detailed geological map 1:2.500, the surface area of 2 km² and 200 ha, was made, covering the area where the quartzite outcrops were observed.) In the same proportions, a structural map of the locality of Kornjica was made. Systematic research of the regional character included: recognition and geological mapping of the terrain for development a geological map of 1:10.000. In geological mapping, the samples were taken for mineralogical-petrological tests as well as for laboratory tests of chemical composition of quartzite. It is determined by the geological researches that it is

a quartzite series of thickness up to 150 m, in the form of packages (layers), whose quality differs macroscopically by compactness, thickness, grain size distribution, etc. The scope and type, as well as the density of applied exploration works was not satisfactory to talk about the reserves of higher categories on which the future exploitation is based.

2.1 Geological Characteristics of the Quartzite Deposit Kaona

The area of field of the quartz raw material, Kaona, was built mainly of crystalline shales, within which quartzites, quartz metaconglomerates and quartz metasands are located (Figure 3). The southeastern and southwestern parts of this terrain are formed by the sedimentary structures of the Miocene age.

Figure 3 Geological map of the explored area Kaona 1:10 000 (a part of the leaf Kladurovo 2-L-34-128-Ca 1:25 000)

Legend: 1. Alluvium; 2. conglomerates, sandstones, sandy clays and coal; 3. conglomerates, sandstones, marls, exfoliated schist, clay and coal; 4. quartzites with metaconglomerates and quartz conglomerates; 5. metamorphosed gabbro; 6. metamorphosed diabase and gabrodiabase; 7. quartz-sericite-chlorite schists and graphitic schists; 8. anticline; 9. fault; 10. exploration area

The deposit Kaona is located at the forehead of putting on the proterozoic and old paleozoic complexes of the Moravian zone, over the Mesozoic structures of the Golubac-Gornjak structural unit. If the Mesozoic sediments east of Kaona are excluded, and in our case they represent only the ground on which the Vend-Cambrian formation is drawn, then the geological situation is quite simple.

By studying quartzite, quartz metaconglomerates and quartz metasandstones of Kaona, it was observed that, in the vertical column, three identical zones can be separated, thickness of about 80 m. From the existing three horizons of quartzite, disintegrated quartzite, and quartz metaconglomerates and quartz metasandstones, the oldest one occurs near Kaona that denotes the passage of proterozoic (venda) into the cambium (Kalenic, Hadzi-Vukovic, 1974).

Quartzites are the metamorphic structures that originate from quartz sands, quartz sandstones and quartz conglomerates, which underwent changes in both methane and cement binder due to the regional metamorphism, both the base mass and cement binder. In spite of the fact that the proportion of cement masses in the higher horizons is not large, however, quartzites of Kaona are a better quality mineral raw material as cleaner.

3 MATERIAL AND METHODS OF QUARTZITE TESTING AS THE MINERAL RAW MATERIAL

Within testing the quality of quartz mineral raw material, the earlier results of systematic testing of regional character (period from 1988 to the end of 1989) were used, by reconnaissance and geological

mapping of the terrain surface, as well as development of shallow trenches. Sampling of trenches was carried out by outbreking a rough furrow (in total 23 samples were taken, which were analyzed on: SiO_2 , Al_2O_3 , Fe_2O_3 , Fe_2O_3 and CaO).

The basic method of detailed geological exploration the deposit of quartz raw material Kaona was the exploration depth drilling with coring. The Kaona deposit at Kucevo was explored by vertical cross-sections (Figure 4), exploration drilling from the terrain surface (9 vertical exploration drillholes). Total of 419.0 meters was drilled.

Geological works followed the exploration drilling; they were performed simultaneously and continued after them.

The applied test methods are reduced to sampling the exploration drillholes. Tests were taken for laboratory (chemical), petrological, and physico-mechanical tests. Testing of the exploration drillholes cores was carried out in parallel with the geological mapping the core of drillhole. For laboratory test (chemical) tests, individual samples were taken along the entire length of the drillholes (except the humus cover interval). The lengths of sampling the cores from drillholes were 2 m (exceptionally, 1.8 m or 2.5 m when, due to the lack of core, the two-meter interval could not be accurately determined). Total of 198 individual samples were taken. Total of 19 samples was taken for petrological testing of samples from exploratory drillholes (Table 6) of which 11 preparations were made. For laboratory tests of physical-mechanical properties, total of 104 samples was taken. The taken samples were analyzed in the MMI Bor laboratories (chemical tests, mineralogical-petrological, geomechanical tests and targeted technological tests).

Figure 4 Map of sampling site Kornjice, 1:10 000 (a part of the leaf Kladurovo 2 L-34-128-Ca)

Legend: ● ABCDEFG - Breakpoints of the exploration area of quartz mineral resources; ● 404 – petrological prospecting point; ● - chemical test outcrops in 1988; ● K-9/07 - petrological tests of exploration drillholes; 5-5' – Exploratory cross section

4 RESULTS OF TESTING THE QUALITY OF MINERAL RAW MATERIAL

4. 1 Chemical Characteristics of the Kaona Quartzite

The basic criterion for contouring the productive interval, i.e. determining the internal contour of the deposit, was a minimum content of SiO_2 of 85% and a maximum content of harmful substances: Al_2O_3 to 5.0%, Fe_2O_3 to 5.0% and CaO to 5.0%.

Based on the demands of certain branches of the quartz raw material industry, the existence of parts of deposits with different SiO_2 medium contents, which had to be taken into account in designing the model, were identified, so that three quality classes (Table 1) were separated within the base.

Table 1 *Quality classes of the deposit Kaona*

Quality class	Content of useful and harmful components (%)			
	Useful components	Harmful components		
	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO
QI	> 93.00	mah 5.00	mah 5.00	mah 5.00
QII	90.00 – 93.00	mah 5.00	mah 5.00	mah 5.00
QIII	85.00 – 90.00	mah 5.00	mah 5.00	mah 5.00

Witin testing the quality of quartz mineral raw material, the previous results of systematic testing of a regional character were also used. Sampling of a trench was done by outbreking a rough furrow. The so-formed individual test sample was analyzed on: SiO₂, Al₂O₃, FeO, Fe₂O₃ and CaO (total of 23 samples were taken). The SiO₂ content ranges from a minimum of 93.82% to a maximum of 98.22%, and a mean content of 96.32 %. The Al₂O₃ content varies from a minimum of 0.10 % to a maximum of 1.63%, and a mean content of 0.68%. The Fe₂O₃ content varies from a minimum of 0.34% to a maximum of 2.12%, and a mean content of 0.96%. The FeO content varies from a minimum of 0.37% to a maximum of 1.01%, and a mean content of 0.64%. The content of CaO from the taken samples is in traces. Three composite samples were formed from the same samples. Composite samples were analyzed on: TiO₂, Cr₂O₃, MgO, K₂O, Na₂O, and loss by ignition. The results of chemical analyses of composite samples are shown in Table 2.

In the laboratory conditions, the chemical analyses of individual samples from drillholes were carried out on useful and harmful components: SiO₂, Al₂O₃, Fe₂O₃, CaO. From the individual samples, the composite samples (total of 41) were formed, which were tested for SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, S-total, SO₃, TiO₂, K₂O, Na₂O, Cr₂O₃ and loss by ignition.

A composite sample was obtained combining the material with five consecutive, individual samples p (ten-meter interval). The mean content of useful and harmful components in the drillholes, calculated on the basis of chemical analyses of individual samples, were obtained as weighted values by the length of testing interval, while the mean content was calculated for the whole deposit as the weighted value of the entire sampling interval (Table 3). The mean content of useful and harmful components, calculated by the MINEX 5.2.1 program package, from the composite samples by the selected quality classes, depending on the requirements of application the mineral raw material, are shown in Table 4 for the whole deposit.

Table 2 *Results of outcrops sampling (composite test)*

Sample designation	Medium content (%)					
	TiO ₂	Cr ₂ O ₃	MgO	K ₂ O	Na ₂ O	G.Ž.
1-13 AB	0.033	0.000	0.027	0.172	0.033	0.390
10-20/ CD	0.033	0.027	0.015	0.183	0.031	0.140
17-A; 17-B; 17-C	0.080	0.000	0.029	0.251	0.037	0.280

Table 3 Medium content of useful and harmful components (by drillholes, from individual tests)

Drillhole designation	Medium content (%)			
	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO
K-1/07	96.222	1.766	1.433	0.230
K-2/07	93.405	1.601	3.051	0.118
K-6/07	92.900	1.268	3.126	0.229
K-5/07	94.848	1.686	1.852	0.451
K-17/07	95.293	1.433	1.663	0.113
K-11/07	92.831	1.926	2.485	0.107
K-20/07	95.582	1.272	1.293	0.220
K-7/07	94.213	1.691	1.845	0.271
K-9/07	94.929	1.618	1.361	0.147
Whole deposit	94.442	1.569	2.013	0.215

Table 4 Medium contents from composite tests by the quality classes, calculated by the software package MINEX 5.2.1.

Quality class	Medium content (%)										
	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	S	TiO ₂	SO ₃	Cr ₂ O ₃
QI (> 93% SiO ₂)	95.19	1.45	1.63	0.23	0.12	0.09	0.33	0.16	0.13	0.42	0.08
QII (90-93% SiO ₂)	91.30	2.06	2.88	0.33	0.16	0.16	0.62	0.26	0.17	0.65	0.03
QIII (85-90% SiO ₂)	88.72	2.42	5.26	0.07	0.20	0.16	0.88	0.14	0.18	0.35	0.04
Whole deposit	94.84	1.76	1.76	0.23	0.13	0.10	0.35	0.17	0.13	0.43	0.08

4.2 Petrographic Quartzite Characteristics

By a detailed observation and measuring on the outcrops of rocks, the way of quartzite occurrence was determined, i.e. the texture properties of the same. Each outcrop is described, determined by coordinates and documented by the photographs on appearance and way of occurrence of these rocks (Figure 4). The samples of quartzite and quartz metaconglomerates were taken from the same outcrops for petrochemical testing (determining the mineral composition and rock structure and chemical testing.). Total of 14 samples were taken by the petrological prospecting the site Kornjica along the routes, parallel profiles, at a distance of 50 meters. Mineralogical - petrographic testing

was carried out on selected samples from the drillholes (total of 11 samples) Total of 25 petrographic preparations were made. The examination of preparations was carried out on the Carl Zeiss/Jena polarization microscope, magnification up to 1200 x.

Based on the mineral composition, structure and texture, the Kaona quartzites are divided into: quartz metaconglomerates, massive quartzites, quartzite with sericity, cataclastic quartzite and quartzite with chloritide. Quartz metaconglomerates are dominant rocks in the researched area. They are of shrunken texture, build the banks of thickness up to a dozen meters (Figure 5). Macroscopic, on the ground, they

are recognized by quartz pebbles, size of 2 to 5 cm, which are deposited in a fine-grained quartz mass. The rock is monomineral, built of quartz, granoblastic structure with elements of blastosamitic and porphyroblastic. Quartz occurs in grains

of size from the tenth part up to several millimeters. Bigger quartz grains make for the most part the pebbles, size up to several millimeters, when the wall gets blastosamitic and porphyroblastic structure.

Figure 5 Banks of quartz metaconglomerates on the north-eastern part of Kornjica, above left a detail of the rock

4.3 Physical - Mechanical Characteristics of Quarcite

Physical-mechanical testing of samples from the exploratory drillholes (104 pcs.) was carried out on prepared test samples according to the valid standards for each type of test or according to the recommendations of the International Society for Rock Mechanics (ISRM). The following physical properties were determined on quartzite and quartz sand samples: humidity $v = 11.40\%$, specific gravity or bulk density of solid particles $\gamma_s = 18.84 \text{ kN/m}^3$, volume weight $\gamma = 16.83 \text{ kN/m}^3$, porosity $n = 3.58\%$, velocity of longitudinal wave propagation

$VL = 4.123.43 \text{ m/s}$. From the mechanical parameters, the following were tested: uniform pressure strength $\sigma_p = 93.89 \text{ MPa}$, and shear resistance parameters (cohesion $C = 25.57 \text{ MPa}$, and angle of internal friction $\varphi = 27.88^\circ$).

4.4 Granulometric Characteristics of Quarcite

Testing the granulometric composition of the quartz mineral raw material from the Kaona deposit at Kučevo was carried out by

two methods. The first method is to test the grain size distribution of the composite samples. Composite samples were formed according to the quality classes for each individual drillhole (Figure 6). The second method of testing consisted in testing the grain size distribution of each individual

sample from all drillholes. The grain size distribution the samples of the quartz mineral raw material of the Kaona deposit is characterized Kaon deposit that fine classes ($-0.212 + 0$ mm) and coarse classes ($+4$ mm) participate with about 10-30%. Classes $-4 + 0,212$ mm prevail, with a share of 70-90%.

Figure 6 Three-component diagram of particle size distribution of composite samples

4.5 Results of direct technological quarcite testing

The direct technological tests (in order to determine the adequate technology to enable the cheapest production of commercial products through laboratory testing of disintegration, screening and atry sand washing), have resulted in a technological scheme for processing the quartz mineral raw materials in the Kaona deposit. A technological sample was formed of materials of all quality classes (run-of-mine raw material = minimal content of SiO_2 85% and maximum content of harmful substances:

Al_2O_3 to 5.0%, Fe_2O_3 to 5.0% and CaO to 5.0%) and the results of these direct technological tests are shown in Tables 5 and 6. The proposed technological scheme for processing the quartz mineral raw materials for the Kaona deposit (Milanović et al., 2009, 2010) contains the primary disintegration into a washing drum, and the secondary disintegration in the atry washing equipment is omitted (based on the achieved laboratory results by simulation the process of atry washing).

Table 5 Content of useful and harmful components in the useful fractions of deposit

Particle size distribution	SiO ₂	Al ₂ O ₃	Fe _{uk}	K ₂ O	Na ₂ O	TiO ₂	Cr ₂ O ₃	G.Ž
(mm)	%							
-30+2.362	96.33	1.62	0.93	0.49	0.052	0.19	0.10	0.053
-2.362+0.63	97.60	0.95	0.67	0.18	0.034	0.068	0.050	0.35
-0.63+0.106	96.13	1.39	0.90	0.26	0.057	0.15	0.11	0.98
-0.106+0.000	88.45	5.46	1.60	0.66	0.17	1.23	0.39	1.95

Table 6 Physical-chemical characteristics of the run-of mine raw material, Kaona

PHYSICAL - CHEMICAL CHARACTERISTICS		
Bond's index - balls	Wi (kWh/t)	12.71
Bulk density of dry sample	γ_s (kg/m ³)	1,102.6
Bulk density of wet sample	γ_v (kg/m ³)	1,363.83
Rough moisture content	v_g (%)	9.53
Density of sample	ρ (kg/m ³)	2,720
ELEMENT	CONTENT (%)	ANALYTICAL METHOD
SiO ₂	95.22	G
Al ₂ O ₃	1.53	AAS
Fe ₂ O ₃	0.35	AAS
K ₂ O	0.069	AAS
Na ₂ O	0.37	AAS
TiO ₂	0.13	ICP-AAS
Cr ₂ O ₃	0.035	ICP-AAS
Fe	1.01	AAS
G.Ž.	0.88	G
pH	8.25	

5 DISCUSSION OF DIRECT TECHNOLOGICAL QUARTZITE TESTING

Quartz raw materials are used in: refractory industry, glass and ceramics industry, plastics industry, chemical industry (to obtain acid resistant materials, enamel for dishes), metallurgy (as fluxes, granulate production for metallurgical processing of ferro alloys), in casting industry (for molds and cores), construction, for production of silicate fillers, as well as the production of

ferrosilicon (Table 7). The use of quartz raw materials depends on the quality (chemical composition) and physical-mechanical properties of the same.

The plan of mining exploitation of mineral resources (open pit mining) foresees the annual mining capacity of 150,000 t/year, commercial fractions or commercial products with application shown in Table 7, and

the expected annual production balance mass of the annual production is shown in Table 8. The proposed technology and technological solutions have achieved the

primary goal: to obtain several commercial products for use in various industrial branches by a relatively small investment (simpler technology).

Table 7 *Fields of application the commercial size classes of quartz mineral resources*

Size class (mm)	Fields of application
-30.00+2.362	Construction, filter fillings, oil industry, air sand blasting
-2.326+0.630	Construction, filter fillings, oil industry, air sand blasting
-0.630+0.106	Casting industry (very good), glass industry (VIII class), ceramic industry (II class)
-0.106+0.053	Construction industry (gas, concrete), chemical industry, extractive metallurgy, casting industry, construction
-0.053+0.000	Building ceramics

Table 8 *Commercial products - expected balance of weight at the annual level, deposit Kaona*

Product	Size class (mm)	Production (t/h)	Mass (%)	Annual production (t/year)
P1	-30+15	3.24	9.08	13,617.60
P2	-15+2.362	5.23	14.65	21,976.66
P3	-2.36+0.63	16.29	45.61	68,418.75
P4	-0.63+0.106	9.54	26.70	40,041.56
Waste	-0.106+0.000	1.41	3.96	5,945.43
Capacity (Qyear)	150,000 t/year (35,712 t/h)			

CONCLUSION

Based on the results of detailed geological explorations (chemical, mineralogical - petrological and geomechanical tests) and direct technological testing (in the laboratory conditions), the deposit of quartzite Kaona is included in the first group of the "Quartzite and quartz sand deposits of uniform thicknesses and chemical - mineral composition with the reserves amounts to over 1,000,000 tons of mineral raw materials". The exploration works include a small part of the deposit, an area of about 0.57 km², which indicates that the geological explorations of the deposit itself should be continued.

Due to the uneven quality of mineral raw materials of the Kaona deposit (chemical composition and physical - mechanical properties), the same can have limited application in the refractory industry, glass and ceramics industry, plastics industry, chemical industry (to obtain acid resistant materials, enamel dishes), metallurgy (as fluxes, production of granules for metallurgical processing of ferro alloys), casting industry (for molds and cores), construction, for the production of silicate fillers, as well as the production of ferrosilicon.

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