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EWA LEWICKA*

Conditions of the feldspathic raw materials supply from domestic and foreign sources in Poland

Introduction

Feldspars are the most abundant group of rock-forming minerals in the nature. They are components of many rock types, including: pegmatite, granite, syenite (especially nepheline syenite), feldspathic sand and sandstone (arkose). The major commercial value of feldspars rests on their chemical composition, especially on the content of alkalis, i.e. K_2O (min. 10%) – preferred in the production of whiteware, or Na_2O (min. 7%) – in glass and ceramic tile manufacture. In the majority of applications the lowest possible content of colouring oxides, in particular of Fe_2O_3 and TiO_2, is required. For example, in the production of ceramic wares of high whiteness (porcelain), the content of Fe_2O_3 and TiO_2 cannot exceed 0.15% and 0.05% respectively, while in the case of high quality glass – max. 0.08% Fe_2O_3 is acceptable. The term 'feldspar raw material' or 'feldspar' refers to both K and Na feldspar-rich grades as well as to feldspar-quartz ones. In Poland there are only the latter obtained, whereas feldspathic and faldspathoid-rich (nepheline syenite) raw materials are imported.

1. Feldspathic raw materials and nepheline syenite applications

The principal end users of feldspar and nepheline syenite are the ceramic and glass--making industries. It is estimated that around 55% of the world feldspar supply is consumed

* Ph.D. Eng., Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Kraków, Poland; e-mail: lewicka@min-pan.krakow.pl

in the ceramic industry and 35% – in the glass manufacturing, while in the case of nepheline syenite the proportions are reversed: 15–20% are ceramic applications and 70% – glass ones. Some grades of feldspar are also utilized as filler in plastics, paint, sealants, adhesives etc., though to a lesser extent.

In the whiteware and technical ceramics feldspar acts as a flux. The flux controls the degree of vitrification of the ceramic body during firing, providing proper densification of the fired material. Since various ceramic bodies require different degrees of vitrification, fluxes of appropriate total content and proportion of alkalis ($K_2O + Na_2O$ and the ratio of K_2O to Na_2O, called alkali modulus) are applied. The traditional whiteware ceramic technologies prefer K_2O-rich feldspar with $K_2O/Na_2O > 1$ (K-spar) over Na_2O-rich one (Na-spar). The modern fast firing technology utilizes sodium-rich feldspar (K_2O/Na_2O around 1 or below) or nepheline syenite (Na_2O/K_2O ratio usually around 2) because of their strong fluxing action. They are characterized by lower melting temperature than K-spar, which contributes to reduction of the firing temperature and shortening the time of the process. It is a consequence of the fact that stoichiometric Na-spar ($Na[AlSi_3O_8]$) melts congruently at 1,118°C, while K-spar ($K[AlSi_3O_8]$) melts incongruently at 1,150°C, transforming into leucite $K[AlSi_2O_6]$ and the melt enriched in silica (Ehlers 1972; Levin et al. 1974). The latter one forms a melt of high viscosity that decreases only slightly with increased temperatures, resulting in good stability against distortion of the ceramic body during the long-lasting process of thin-walled porcelain manufacturing. The glassy phase volume increases gradually and in much slower pace than that of ceramic mixes containing Na-spar. K-spar is also preferred over Na-spar in high-voltage electroporcelain owing to the specific requirements for electrical resistivity. On the other hand, the use of sodium feldspar in the fast firing process results in rapid growth of glassy phase (the firing cycle lasts usually 40–50 minutes) as the arising melt has lower viscosity and higher reactivity against quartz as compared to potassium feldspar. These features are also appreciated in the glass manufacturing. Nepheline syenite – depending on local availability and the price – can compete with feldspar in many applications, especially in the production of high-volume ceramics such as sanitaryware, earthenware, and stoneware. Owing to lower melting temperature (1,140–1,170°C) it has a technical advantage over sodium feldspar, which melts at 1,170–1,200°C, since it shortens the firing time and thus reduces energy consumption (Harben, Kužvart 1996). Furthermore, it is deficient in free silica (quartz) that moderates the melting process, and contains lower levels of iron compounds than many types of feldspar. The proportion of feldspar or similar mineral used in ceramic batch can be as follows: 10–55% in ceramic floor and wall tile, 15–30% – whiteware, 23–35% – sanitaryware, 30–50% – electrical porcelain (Kendall 1993). In glazes and porcelain enamels the feldspar may make up from 30 to 50% by weight.

In the glass-making industry, feldspathic raw materials are principally the sources of alumina Al_2O_3. This is the indispensable component of the glass batch, acting as a stabilizer which increases viscosity during glass formation, improves durability by increasing resistance to impact, bending and thermal shock, and inhibits devitrification (Harben, Kužvart

1996). In general, around 1.5–2% Al_2O_3 is required for container and flat glass, while for certain glass fibers – up to 15%. The raw materials used in the glass-making industry should be characterized by the least possible melting temperature. Such a requirement is met by sodium feldspar and nepheline syenite, which are utilised more frequently than chemically pure aluminium oxide, melting at temperature of 2,050°C. Nepheline syenite is sometimes used as an alternative source of alumina and alkalis, especially in the production of glass containers. Its main advantages as compared to feldspar are as follows: lower content of SiO_2 (60%; >67% in Na-spar), high alumina content (>23%; Na-spar – 18.5%) and moderate content of alkalis (>14% K_2O + Na_2O, i.e. about 9.5% Na_2O and 5% K_2O), as well as higher value of (K_2O + Na_2O)/Al_2O_3 ratio. The use of nepheline syenite results in reduced flux and energy consumption (Esposito et al. 2005). On the other hand, nepheline syenite's high alumina content makes it slower to melt than feldspar, resulting in lengthening of the time required to heat the batch. This adversely affects the flat glass manufacture, which tends to use large batches (Harben, Kužvart 1996). The Na_2O-rich raw materials in the glass batch also lower the melting temperature and consequently reduce the quantity of high cost soda ash that has to be added, which results in faster firing and cost reduction. Molten glass made with the use of nepheline syenite has lower viscosity than feldspar-containing melt, which helps in its working. The proportion of nepheline syenite used in the individual glass batch could be as follows: flat glass – up to 0.5%, container glass – up to 8%, certain speciality glasses – up to 11%, insulation fibre glass – up to 18% (In the melting... 2006).

2. Demand for feldspathic raw materials in Poland

The demand for feldspathic raw materials in Poland – like in other countries – follows the needs of the ceramic and glass-making industries, and indirectly depends on the construction industry condition. Its distinct revival was observed from the second half of the 1990s to 2008. This phenomenon was one of the consequences of the economic recovery, which was triggered by the introduction of market rules, and overcoming the stagnation in the construction industry in the late 1990s. The consumption of feldspar and feldspar-quartz raw materials within these years increased over ten-folds, approaching 900,000 Mg/y in 2007–2008 (Minerals Yearbook... 2010). In 2009, following the world financial crisis, slowdown of the economy and collapse on the real estate market, the first decrease in consumption (by 23%) of feldspathic raw materials in Poland since the mid 1990s was recorded (Table 1). This reflected the weakening of demand in the construction industry for finishing materials, such as ceramic tiles, sanitaryware etc.

The fastest growth of demand for feldspathic raw materials in the last two decades was recorded in the ceramic tile industry. This corresponded to spectacular rise of the tile production capacities that has approached 140 m. m^2 per year. The domestic tile production, which in the beginning of the 1990s amounted to around 10 m. m^2 per year (120,000 Mg/y),

developed to a record level of 90 m. m^2 in 2008 r. (almost 1.9 m. Mg; Lewicka 2003; Lewicka, Wyszomirski 2005 and 2010). One of the reasons of the increase was the implementation of fast-firing technology and the boom in the production of a new generation tile called *gres porcellanato* (porcelain stoneware). This tile is characterized by water absorption close to zero and high physical and mechanical parameters, which are obtained in course of intense sintering of the ceramic body. One of its components is sodium feldspar, which high portion (40–50% or more) is crucial for vitrification of the tiles in the short firing cycle. Since the late 1990s the ceramic tile industry has dominated the consumption of feldspathic raw materials in Poland. In recent years it has accounted for over 80%, while in 1999 – below 70%, and in 1994 – merely 30% (Lewicka 2010). The domestic sanitaryware industry's share in the market were much smaller (4%), despite it also experienced dynamic growth in the past decade, from 48,500 Mg in 1999 to 111,400 Mg in 2008 (Minerals Yearbook... 2010). Like in the tile sector, the technological advancement and modernization of the sanitaryware plants (e.g.: Cersanit, Sanitec Koło, Roca), resulted in increased consumption of feldspar and nepheline syenite. Within 1999 and 2008 the production of other ceramic goods either remained stable or dropped, i.e. porcelained tableware – decreased from around 41,000 Mg to 27,200 Mg, semi-vitreous china-ware – from 11,000 Mg to 2,900 Mg, while electrical porcelain – averaged to 5,000–6,500 Mg/y.

Feldspar and nepheline syenite are also important raw materials of the glass-making industry, despite the main component of the glass batch is quartz sand (>70%). High purity feldspar as well as nepheline syenite (scarce in Poland) are imported almost exclusively from Norway. Raw materials of domestic origin are also utilized, though to a lesser extent. The largest end-users of feldspathic raw materials in this branch, accounting for around 10% of the consumption are flat glass and glass containers manufacturers, dominating the domestic supply of all glassware (around 50% and over 40% of the total supply respectively, being estimated at 2.6–2.9 m. Mg/y in 2006–2008). The dynamic growth of these goods production in Poland has been initiated in the second half of the 1990s and was accompanied by the inflow of foreign capital coupled with commencement of modern plants of the largest world potentates, such as: Saint-Gobain, Pilkington, and Guardian Industries – in the flat glass industry, and Owens-Illinois, Rexam, Ardagh Glass, and Stolzle Oberglass – in the glass container industry (Minerals Yearbook... 2010).

3. Conditions of the domestic production of feldspathic (feldspar-quartz) raw materials

In the last several years the growth of domestic feldspar and feldspar-quartz production and consumption were stimulated by rocketing demand of the ceramic tile industry. Within the mid–1990s and 2008 their supply from domestic sources increased almost ten–fold, approaching 640,000 Mg. In 2009 the production dropped as much as 25% (Table 1) as a consequence of the slowdown in the construction industry.

TABLE 1

Feldspathic raw materials statistics in Poland
(acc. to GUS – the Central Statistical Office, and the author's own sources) ['000 Mg]

TABELA 1

Gospodarka surowcami skaleniowymi w Polsce (GUS, źródła własne) [tys. Mg]

Year	1990	1995	1996	1997	1998	1999	2000	2001
Total production	34.0	71.3	86.1	108.1	116.7	120.1	161.2	208.6
Strzeblowskie KSM	*34.0*	*44.1*	*51.2*	*59.4*	*61.7*	*81.6*	*89.3*	*138.2*
ZP Jopex/Pol-Skal	–	*0.0*	*5.6*	*14.8*	*10.5*	–	–	–
ZBP Skalmin/Bumat(Gniewków)	–	*1.5*	*1.5*	*1.5*	–	*0.5*	–	–
Rogoźnica II et al. (estimated)	–	–	–	*0.2*	*0.7*	–	–	–
Wrocławskie KSM	–	*25.7*	*27.8*	*32.2*	*43.8*	*38.0*	*65.9*	*62.4*
Jeleniogórskie KSM	–	–	–	–	–	–	*6.0*	*8.0*
Imports	14.3	32.6	37.6	42.3	50.1	79.1	114.8	185.4
Exports	–	0.0	0.0	0.2	0.1	0.6	0.8	0.7
Apparent consumption*	48.3	103.9	123.7	150.3	166.7	198.6	275.2	393.3
Year	2002	2003	2004	2005	2006	2007	2008	2009
Total production	293.0	334.4	424.5	505.2	477.6	591.8	643.7	478.0
Strzeblowskie KSM	*199.4*	*276.3*	*367.9*	*422.1*	*354.1*	*382.7*	424.7	343.5
ZP Jopex/Pol-Skal	–	–	*0.6*	*20.0*	*45.0*	*90.0*	100.0	65.0
ZBP Skalmin/Bumat (Gniewków)	–	–	–	–	–	–	–	–
Rogoźnica II et al. (estimated)	–	–	*15.0*	*15.0*	*15.0*	*70.0*	50.0	30.0
Wrocławskie KSM	*83.7*	*53.1*	*35.5*	*43.3*	*58.1*	*43.9*	62.6	34.1
Jeleniogórskie KSM	*9.9*	*5.0*	*5.5*	*4.8*	*5.4*	*5.2*	6.3	5.4
Imports	197.7	221.1	265.3	288.2	287.5	326.2	323.7	276.7
Exports	1.2	1.8	2.2	2.1	5.5	2.7	5.5	9.2
Apparent consumption*	489.5	553.7	687.6	791.3	759.6	915.3	961.9	745.5

* Apparent consumption = production + imports – exports

The largest domestic producer of feldspar-quartz raw materials, supplying 340,000––425,000 Mg per year (65–85% of the total domestic production; Table 1) is the Strzeblowskie Mineral Mines (SKSM) of Sobótka, with the production capacities approaching 500,000 Mg/y. The main offered assortments are feldspar-quartz grits 0–8, 0–5 and 5–8 mm, obtained in course of simple processing (crushing, screening and blending). There are also

supplied, though in much smaller quantities, ceramic flour 0–0,2 and 0–0,071 mm, and glass flour 0–0,1 and 0,1–0,5 mm, obtained by further comminuting (grinding), classification, and (in the case of glass flour) magnetic separation (Lewicka, Wyszomirski 2005). The production of all above-mentioned grades bases on rocks extracted from deposits located in the Strzegom–Sobótka Massif, i.e.: Pagórki Wschodnie (leucogranite), Pagórki Zachodnie (granite deposit, in the periphery of which alkali-rich leucogranite occurs) and – since 2007 – Strzeblów I (granite). As a result of detailed reconnaissance and verification of deposits being at the company's disposal (including Stary Łom deposit) in the first decade of the 2000s, the reserve base of feldspar-quartz in the Sobótka region increased by around 15 m. Mg. This, in the perspective of the consecutive 30–40 years, should enable the SKSM to continue the feldspar-quartz raw materials production at the level of around 450,000––500,000 Mg/y (Kruczek 2006). Following common quality (sodium-potassium character, relatively high content of colouring oxides – usually over 0.2%, max. 0.55%; Table 2), 80–90% of the output is utilised by the ceramic tile industry, and the rest – by producers of sanitaryware, porcelain, glass-making, and other minor consumers.

Another feldspar-quartz raw material producer – the Pol-Skal, which entered the domestic market in 2005, offered potassium-sodium products (Table 2) obtained from weathered porphyry-type granite of the Karpniki deposit. On the 1st July 2010 the company closed the mine due to protest of local community against this activity. The company's annual supply, of the order of 20,000–100,000 Mg, included basically grits 0–8, 1–8 and 0–2 mm, which were obtained in course of simple processing (crushing and classification).

TABLE 2

Quality of feldspathic raw materials offered by domestic producers (acc. to producers' data)

TABELA 2

Jakość surowców skaleniowych oferowanych przez krajowych producentów (wg danych producentów)

Chemical composition [%]	SKSM		WKSM	Pol-Skal	JKSM
	Flour MS. 200 D	*Grit GS. 8 D*	*0–2 mm class*	*Polgrys KR-8*	*Flour, I grade*
SiO_2	min. 74.0	max. 78.0	71.45	71.35	78.0±2.00
Al_2O_3	min. 13.0	min. 13.0	13.57	15.60	13.5±0.50
K_2O	min. 7.50	min. 7.50	4.21	5.10	4.00±0.50
Na_2O			3.49	3.16	3.00±0.50
Fe_2O_3	max. 0.3–0.5	max. 0.50	3.28	2.50	max. 0.20
TiO_2	max. 0.05	max. 0.05	0.30	n.d.	max. 0.10
CaO	max. 0.50	max. 0.50	1.83	0.96	1.30±0.40
MgO	max. 0.50	max. 0.50	0.51	0.35	max. 0.10

n.d. – not determined

Their main customers were ceramic tile manufacturers, while only a small percentage of the output (3–5% per annum) was utilized for the road construction. The suspension of the Karpniki operation will probably result in the reduction of domestic supplies by 60,000––100,000 Mg/y and the increase of supplementary importation. Presumably, this could be moderated by opening out of another Pol-Skal's leucogranite deposits – Kamienica Mała or Proszowa-Kwieciszowice, which are located on the Izerskie Foothills.

Since 2000, relatively small amounts (5,000–10,000 Mg/y) of feldspar-quartz material have been also offered by the Jeleniogórskie Mineral Mines (JKSM) near Szklarska Poręba. There is feldspar-quartz flour produced in three grades of various content of Fe_2O_3 (max. 0.1, 0.2, and 0.35%), appropriated basically for the glass-making industry.

Since the mid-1990s, fine-grained fractions generated in course of crushed aggregates production at Lower Silesian granite quarries are utilized as a source of feldspar-quartz raw materials for the ceramic industry. Despite high content of Fe_2O_3 (Table 2), these cheap alkali-rich products are used in the manufacturing of glazed stoneware and clinker tiles. The largest supplier of these materials (35,000–80,000 Mg/y) is the Wrocławskie Mineral Mines – WKSM (a division of the Tarmac Group). The commercial products are 0–2 and 0–1 mm feldspar-quartz fine-grained fractions generated in course of granite crushing at its own Graniczna quarry.

Fine-grained material (usually 0–5 mm size) is also sold to the ceramic industry by other producers of crushed aggregates and building stones in the Lower Silesia, e.g.: Gniewków Mine, Rogoźnica II Granite Mine, and Czernica Granite Mine. It is estimated that total domestic consumption of these feldspar-quartz by-products in the ceramic industry (which is not taken into account in the official statistics) could have recently ranged from 50,000 to 120,000 Mg per year.

4. Foreign supplies of feldspathic and feldspathoid raw materials in Poland

Substantial and almost uninterruptedly increasing portion of feldspathic raw materials on the domestic market has been delivered by foreign suppliers. In the 1990s, along with expansion of the ceramic and glass-making industries in Poland, the importation of feldspar and nepheline syenite increased almost ten-fold, while between 2001 and 2008 it almost doubled, exceeding 320,000 Mg/y (Table 3). In 2009, however, the total imports dropped by almost 15%, including 21% reduction in feldspar deliveries (basically from Turkey) mitigated by 5% rise in purchases of nepheline syenite from Norway. In recent years 34–40% of the total demand has been satisfied by imports. It is estimated that above 60% of them has got the ceramic tile industry. There were basically sodium-rich tile grades (alkali modulus $K_2O/Na_2O < 1$), characterized by low content of colouring oxides that successfully compete with domestic products. Principal deliveries originated from the Czech Republic, and – since 2002 – also from Turkey.

TABLE 3

Principal foreign suppliers of feldspathic and feldspathoid raw materials to Poland, 1990–2009 [‘000 Mg] (acc. to GUS – the Central Statistical Office)

TABELA 3

Główni dostawcy surowców skaleniowych i skaleniowcowych do Polski [tys. Mg] (GUS)

Year	1990	1995	1996	1997	1998	1999	2000	2001
Total imports	14.3	32.7	37.6	42.3	50.1	79.1	114.8	185.4
Feldspar, from:	14.3	30.8	34.9	35.6	40.0	57.4	82.0	144.2
Czech Republic	*5.4*	*12.3*	*10.2*	*9.3*	*12.3*	*21.2*	*38.4*	*82.0*
Finland	*2.2*	*8.8*	*10.1*	*12.0*	*12.3*	*15.7*	*12.7*	*9.3*
France	*–*	*0.1*	*0.2*	*0.1*	*0.1*	*0.2*	*4.2*	*9.6*
Norway	*6.7*	*8.9*	*11.6*	*13.0*	*14.6*	*12.8*	*14.7*	*32.9*
Turkey	*–*	*–*	*–*	*–*	*–*	*0.0*	*–*	*0.0*
Nepheline syenite, from:	n.d.a.	1.9	2.7	6.7	10.1	21.7	32.8	41.2
Norway	*n.d.a.*	*1.7*	*2.6*	*6.5*	*9.9*	*21.4*	*32.5*	*41.0*
Year	2002	2003	2004	2005	2006	2007	2008	2009
Total imports	197.7	221.1	265.3	288.2	287.6	326.2	323.7	276.7
Feldspar, from:	168.2	155.4	201.3	217.3	222.0	250.1	245.2	194.3
Czech Republic	*85.8*	*94.6*	*109.6*	*118.0*	*103.5*	*141.9*	*106.3*	*93.7*
Finland	*7.4*	*8.5*	*10.3*	*6.6*	*7.7*	*6.1*	*2.9*	*0.4*
France	*7.5*	*12.9*	*0.4*	*1.0*	*2.3*	*7.6*	*9.3*	*9.5*
Norway	*52.8*	*14.4*	*13.4*	*18.9*	*24.7*	*15.5*	*11.4*	*10.6*
Turkey	*11.9*	*19.8*	*59.9*	*67.9*	*81.1*	*74.1*	*110.7*	*71.1*
Nepheline syenite, from:	29.5	65.7	64.0	70.9	65.6	76.2	78.5	82.4
Norway	*29.5*	*65.7*	*63.9*	*70.9*	*65.6*	*76.1*	*78.5*	*82.3*

n.d.a. – no data available

Other consumers of imported feldspar raw materials, i.e. manufacturers of porcelain, sanitaryware, and glass, utilize standardized grades of appropriate purity, i.e. of low content of colouring oxides and high content of alkalis (Table 4). The producers of whiteware, especially of tableware and electroporcelain, use K-spars (alkali modulus >3 or even >5), that are scarce on the domestic market and have to be imported, basically from the Czech Republic, as well as from France and Norway. In the last couple of years the porcelain industry’s demand for raw materials dramatically decreased due to the reductions of output in

many plants and their financial problems arising from unfavourable exchange rates (loss in profitability of exportation) and lift of limitations on imports of Asian (mainly Chinese) cheap ceramic goods to the European Union. As a consequence, some of the plants (Książ, Porcelana Śląska) have bankrupted.

5. Characteristics of feldspathic and feldspathoid-rich raw materials imported to Poland from selected countries

Since the late 1990s the main Polish foreign supplier of feldspathic raw materials has been the Czech Republic (30–40% of total imports in recent years). The largest quantities have been delivered by: LB Minerals/Lasselsberger – mainly K-spar originating from Halámky deposit, and KMK Granit – sodium-potassium feldspar from Krásno deposit (Table 4). Above-mentioned deposits represent two different genetic types (Starý, Kavina 2005).

The Halámky deposit is of secondary origin. It consists of fluvial Quaternary feldspathic sand and gravel, accumulated in the upper course of the Lužnice River, in southern Bohemia (SE of České Budějovice). The deposit was formed by deposition of weathered and disintegrated medium grained to porphyry granites, rich in K-spar phenocrysts (up to 55–70%). The raw material is extracted from water by open-pit method and processed by comminuting, dry grinding, multistage screening, and high intensity electromagnetic separation to reduce the content of colouring oxides (basically iron contained in biotite) (Starý, Kavina 2005).

The Krásno deposit, operated by KMK Granit, is located in the Krušné Hory mountains (NW part of the country, SW of Karlovy Vary). It comprises fine or medium grained leucocratic albite-bearing aplitic granite with 55–75% of NaK–feldspar and max. 0.6% Fe_2O_3, and feldspathite with 75–90% of KNa–feldspar. The aplitic granite is mined by open-pit method and simply processed (crushing, grinding to 0–5 mm, and blending); only a small part is purified by electromagnetic separation. The feldspathite (leucocratic alkali feldspar syenite) is situated at a depth of the Krásno deposit (Krásno-Vysoký kámen). This rock is assumed to be mined by underground method in the future, thus will prolong the lifespan of the mine by dozens of years.

In the 2000s Turkey became one of the most important foreign supplier of feldspathic raw materials to Poland. Until 2008 deliveries from this country increased around ten-fold, achieving a record level of 110,000 Mg. In 2009 however, they dropped by 36%, despite Turkey continued to be one of the largest foreign suppliers of feldspathic raw materials to Poland (Table 3). The main Polish contractors, being concurrently the leading Turkish feldspar exporters, are the following companies: ESAN Eczasibasi, Kaltun, and Kalemaden. The vast majority of Turkish abundant feldspar reserves (in a large majority of pure albite, estimated at 260 million Mg) occur in the metamorphic Menderes Massive in SW part of Anatolia (in the provinces of Muğla and Aydin), an area forming a triangle (called 'feldspar triangle'). Its three vertices are at Izmir (north), Çine (east) and Güllük (west). The Menderes

TABLE 4

Specifications of selected feldspathic raw materials imported to Poland (producers' data, Glass &... 2000, Wyszomirski et al. 2002)

TABELA 4

Specyfikacje wybranych surowców skaleniowych importowanych do Polski (dane producentów, Glass &... 2000, Wyszomirski i in. 2002)

Chemical composition [%]	Ž65K20[1] LB Minerals (Czech Republic)	Norflux 45[1] North Cape Minerals (Norway)	Ataflux 45[2] North Cape Minerals (Norway)	Norfloat 600[3] North Cape Minerals (Norway)	ŽK 05[4] KMK Granit (Czech Republic)	F501E10[4] Esan (Turkey)	STD-01[4] Kaltun (Turkey)	632[4] Kalemaden (Turkey)	FFF K6 28 M[3,4] SP Minerals (Finland)
SiO_2	72.3	65.9	56.0	68.4	73.5	69.0	69.6	71.2	68.1
Al_2O_3	14.7	18.6	24.0	19.0	15.7	18.5	18.5	16.4	18.6
Na_2O	1.79	2.90	7.80	7.60	4.10	10.0	9.75	9.11	5.60
K_2O	9.48	11.80	8.80	2.80	4.52	0.40	0.34	0.50	6.20
Fe_2O_3	0.20	0.07	0.10	0.10	0.47	0.14	0.13	0.12	0.09
TiO_2	0.05	0.002	0.10	0.002	0.06	0.30	0.30	0.05	<0.005
CaO	0.34	0.40	1.60	1.80	0.44	0.70	0.75	0.54	0.90
MgO	0.06	–	max. 0.10	–	0.09	0.20	0.13	0.13	<0.033

[1] – mainly for the production of porcelain, [2] – nepheline syenite for glass manufacturing, [3] – feldspar for glass manufacturing, [4] – for the production of ceramic tiles

Massive has an orthogneiss core of probably Precambrian age, in which aplitic and pegmatitic fillings form elongated dykes and lenses or veins.

ESAN, through its 24 mines and 6 processing plants located in Milas and Güllük, has the annual capacities to process 1.5 m. Mg/y. The large portion of the output and exports (1.4 and 1.29 m. Mg respectively in 2006 r.; Wan 2009) are feldspar raw materials of outstanding sodium character appropriated basically for the ceramic tile industry. They are usually sold either directly or after simple processing (crushing, grinding, and blending). Due to the ore bodies' formation, very careful and sometimes selective mining is required in order to remove the rock with high content of undesirable impurities, such as rutile (TiO_2) and iron-bearing micas. The commodities of the highest purity, e.g. glass grades with Fe_2O_3 and TiO_2 contents reduced to respectively 0.01 and 0.02%, are obtained – after beforehand comminuting to below 5 mm and milling down to 500 μm (Bozdoğan, Göknel 2004) – in course of flotation and magnetic separation in beneficiation units of Milas and – since 2008 – Yenikoy (total production capacities of 650,000 Mg/y of flotation concentrate). ESAN also sells dry ground sodium feldspar in 75, 63 and 45 μm grain-sizes (20,000 Mg/y). Moreover, the company mines smaller quantities of potassium feldspar from deposits in the Çine region.

One of the leading Turkish producers and exporters of feldspar is Kaltun (1.7 and 1.22 m. Mg respectively in 2006 r.; Wan 2009). Its reserves, exceeding 150 m. Mg, are the largest in the country. Kaltun operates 28 mines, the majority of which are located between Çine, Milas and Yatagan, including Sarikisik region, which is Turkey's richest feldspar production zone. Another the company's important site of the highest purity sodium feldspar mining is Hisarardi near Yatagan, including quarry (25 m. Mg reserves of feldspar-biotite rock, feldspar raw material output of 200,000 Mg/y), high intensity magnetic separation plant (360,000 Mg/y), and flotation unit (150,000 Mg/y) (Moores 2007). Into three stage magnetic separation, aimed at iron and titanium bearing minerals removal, enters material of 100––500 μm size, obtained in course of crushing of larger (around 50 cm) lump of run of mine ore down to below 5 mm, sieving (removal of <100 μm grains), grinding, and classification. One of the highest purity products obtained there is high–alkali sodium feldspar called *Premier grade* with 10.5% Na_2O and close to zero contents of colouring oxides (0.03% Fe_2O_3 and 0,05% TiO_2), which can be used in both glass and ceramic applications. Kaltun operates also 300,000 Mg/y crushing and grinding installation (grades milled to 45 μm, and micronised to 10 μm for coating and porcelain industries), and – since 2003 – an eight-cell flotation unit in Çine, as well as stockpile (100,000 Mg capacity) with crushing and blending/homogenization facilities at dry bulk port of Güllük. To the flotation, in which additional removal of impurities of iron and titanium bearing minerals takes place, is fed the material of 63–300 μm size, obtained by water-flushed screening. The flotation sodium feldspar concentrates, due to high humidity, are appropriated for the ceramic industry, while dry products of magnetic separation are going to the glass industry.

The Kalemaden operates an abundance of sodium feldspar mines also within 'feldspar triangle', including Kavsit (reserves of 900,000 Mg), Ceyhan (1.1 m. Mg), and Milas (1.2 m. Mg) (Moores 2007). The majority of commercial products are produced in course of

simple processing and homogenization in two plants: Çine and Güllük of annual production capacities of 400,000 Mg each. At the Kalemaden's beneficiation plant (100,000 Mg/y capacity) there are also floated sodium concentrate obtained with reduced to 0.02% contents of colouring oxides. The company also offers small quantities (1,500–2,000 Mg/y) of potassium feldspar grades, which are mined from Demirci deposit (reserves of 40,000 Mg) in the Manisa province, north of Çine.

Substantial supplies of feldspathic raw materials to Poland, both of potassium and sodium characteristics, as well as nepheline syenite, have originated from Norwegian North Cape Minerals. The source of feldspars are Precambrian pegmatite dikes and irregular bodies within gneiss and amphibolites that are extracted at the company's Glamsland Mine near Lillesand, around 30 km east of Kristiansand. The pegmatite consists of around 29% of K-spar (mainly orthoclase), 40% Na-spar (mainly albite), 28% – quartz, and 2–4% – other minerals. The mine has an annual output of approximately 25,000 Mg of potassium feldspar, around 30,0000 Mg of sodium feldspar and ca. 15,000 Mg of quartz. The rock is processed by three-stage flotation: in the first stage – ferruginous impurities are removed, in the second one – quartz is separated, and in the third one – selective sodium and potassium feldspar products are obtained. This is the only example in the world of selective flotation of feldspar on an industrial scale.

Production of nepheline syenite in Norway is derived from a deposit on the southern shore of Stjernøy Island, Alta Fjord, around 400 km north of the Arctic Circle, reserves of which are quoted at 300 million Mg. The production is about 330,000 Mg/y, 70% of which is glass grade and 28% – ceramic one. Nepheline syenite is found locally in dykes and larger intrusive forms (stocks). One of them forms a northwest-oriented lens-shaped outcrop ca. 1,800 m long and 300 m wide. The wall rocks on the NE side are an altered carbonatite and hornblendite, while on the SW – gabbro gneiss occurs. These rocks belong to the Caledonian province of basic, ultrabasic and alkaline rocks. Within the ore body, two types of nepheline syenite have been identified: a biotite and a hornblende-pyroxene, the latter of which is more common and commercially significant. Both of them are made up of 56% perthite feldspar, 34% nepheline, and minor amounts of accessory minerals, such as hornblende, biotite, albite, magnetite, pyroxene, calcite, and sphene. Basing on the results of mine- ralogical research it is assumed (Harben, Kužvart 1996) that the primary rock for the nepheline syenite had been a pure syenite, consisting almost exclusively of feldspar, which became probably altered (nephelinized) in the period of Caledonian tectothermal activity.

Imports of feldspathic raw materials from other than above-mentioned countries to Poland are of less importance. One of the best recognized on the market is Finnish flotation concentrate – FFF (*Finnish Flotation Feldspars*). FFF-feldspar originates from the region of Kimito in the southwest archipelago of Finland. This area is a part of schist zone, in which the oldest rocks are supracrustal quartz-feldspar schist or leptite cut by gabbro and diorite. There are numerous pegmatite veins or group of veins recognized, which penetrate all other rocks. Pegmatite has been known and mined since the mid 18th century. The rock is characterized by high content of feldspar, stable mineral composition and low content of iron oxides

(max. 0.1%). The run of mine is processed in the flotation plant of the SP Minerals that from 1st June 2010 has changed the name to Sibelco Nordic (the production capacity of 100,000 Mg/y). After wet grinding and desliming, in the first stage of flotation mica is removed, and then – in a further process – feldspar and quartz are separated (Larsson, Venäläinen 2000). The obtained products – after drying – are submitted to magnetic separation, aimed at iron minerals removal. After separation the grades can be ground again to desired fineness. By these methods there are 9 different grades obtained, from among FFF K6 28 M is the most frequently used in the production of porcelain stoneware (Table 4). It contains over 50% of sodium feldspar and less than 40% of potassium feldspar, slightly quartz and anorthite.

Conclusions

The supply of feldspar, actually of feldspar-quartz raw materials, in Poland comes from a few domestic producers, among which the leading is the Strzeblowskie Mineral Mines. Relatively large quantities originate also from Lower Silesian granite quarries, mainly Graniczna Mine operated by the Wrocławskie Mineral Mines. There are rich in alkalis, fine-grained classes, generated in course of crushed aggregates production. Feldspar-quartz raw materials coming from domestic sources are characterized by relatively high content of colouring oxides, moderate alkalis percentage, and K_2O/Na_2O ratio around 1. Therefore, the potassium-rich feldspars of high purity (<0.1% of colouring compounds), which are scarce on the domestic market, since many years have been brought from abroad, especially by the whiteware manufacturers. In recent years, owing to rocketing of the ceramic tile production, the domestic supply of feldspar-quartz raw materials have been supplemented to an increasing degree by imports. Within the mid 1990s and 2008 the total deliveries of feldspar and nepheline syenite to Poland grew almost ten-fold, with a 15% reduction in 2009. The largest foreign suppliers were: the Czech Republic, Turkey, and Norway. The raw materials imported from these countries are distinguished by high content of alkalis and high purity, manifested by low content of unwanted impurities. This refers especially to the material of Turkish origin, the quality of which is connected with advantageous features of run off mine (being almost entirely pure albite). As a consequence, even in course of simple processing, i.e. crushing, grinding, and blending, the products of required parameters are obtained. This contributes to competitive price of Turkish raw materials on international market. This remote country is supposed to remain the leading supplier of feldspar to the Polish ceramic industry, especially ceramic tile manufacturers. Further increase of total importation to Poland, also from other countries, seems to be unavoidable, as the Karpniki Mine was closed in 2010 and the domestic supplies of feldspathic raw materials were reduced.

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UWARUNKOWANIA ROZWOJU PODAŻY SUROWCÓW SKALENIOWYCH ZE ŹRÓDEŁ KRAJOWYCH I ZAGRANICZNYCH W POLSCE

Słowa kluczowe

Surowce skaleniowe, syenit nefelinowy, podaż krajowa, import

Streszczenie

W artykule scharakteryzowano krajowy rynek surowców skaleniowych, omawiając najważniejsze zjawiska decydujące o kształtowaniu się rodzimej podaży i popytu oraz kierunki wykorzystania tych surowców. W Polsce, począwszy od połowy lat dziewięćdziesiątych, datuje się wyraźne ożywienie zapotrzebowania na te surowce, którego przyczyną była ekspansja krajowego przemysłu płytek ceramicznych, a zwłaszcza wdrożenie technologii szybkiego wypalania i rozwój produkcji płytek gresowych. Spowodowało to konieczność uzupełniania krajowej podaży surowców skaleniowo-kwarcowych importem. Rosnące ilości surowców skaleniowych zaczęły być sprowadzane nie tylko z tradycyjnych kierunków, jak Czechy czy kraje skandynawskie, ale także – od 2002 r. – z Turcji. Ta ostatnia stała się w ciągu kilku lat jednym z głównych polskich kontrahentów, dostarczając dobrej jakości surowce sodowe, pozyskiwanie nierzadko na drodze prostej przeróbki mechanicznej. Artykuł zawiera charakterystykę najważniejszych zagranicznych dostawców surowców skaleniowych, ze szczególnym uwzględnieniem źródeł pozyskiwania surowców sprowadzanych do Polski. W związku ze wstrzymaniem w 2010 r. produkcji surowców skaleniowych przez jednego z krajowych producentów – firmę Pol-Skal – i w konsekwencji ograniczeniem rodzimej podaży przewiduje się, że w najbliższych latach nastąpi wzrost wielkości importu, zwłaszcza z Turcji, a także innych kierunków. Będzie to jednak uzależnione od przełamania niekorzystnych tendencji w budownictwie, jakie zarysowały się w 2009 r., oraz utrzymania produkcji wyrobów ceramicznych, zwłaszcza płytek, na co najmniej dotychczasowym poziomie.

CONDITIONS OF THE FELDSPATHIC RAW MATERIALS SUPPLY FROM DOMESTIC AND FOREIGN SOURCES IN POLAND

Key words

Feldspathic raw materials, nepheline syenite, domestic supply, importation

Abstract

The paper characterizes the domestic market for feldspathic raw materials, describing the most important features that influenced the supply, demand and end-use pattern. In Poland, since the mid-1990s the increase in demand for these materials have been observed. That has followed the expansion of the domestic tile industry, including the implementation of fast firing technology and development of porcelain stoneware tiles manufacturing. Thus resulted in the necessity of supplementing of the domestic production by increasing imports, coming not only from traditional suppliers, such as the Czech Republic and Scandinavian countries, but also from Turkey – a new one, emerged only in 2002. In a few years the last one turned to one of the largest Polish contractors, delivering good quality sodium feldspar, frequently obtained in course of simple processing. The article presents the most important foreign suppliers of feldspathic raw materials, emphasizing the sources of their obtaining. As one of the Polish producers – the Pol-Skal – stopped the production in 2010, and – as a consequence – domestic supply was reduced, an inevitable increase in imports should be anticipated in the forthcoming years, especially from Turkey, and other countries as well. Such a scenario will be attainable if the disadvantageous tendencies observed in 2009 in the construction industry are overcome, and the production of ceramic goods, especially tiles, is continued at least at the level recorded so far.