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Rational use of selected mining by-products in the ceramic industry in Poland

Introduction

The development of the contemporary mining industry is accompanied by enormous pressure on limiting its influence on the environment both in terms of raw materials consumption and the volume of wastes generated. The waste from mining and associated activity account for the largest group of industrial waste generated and stored in Poland. This group includes wastes from coal mining and energy production, the extraction and processing of metal ores, as well as of rock raw materials. According to EUROSTAT (<https://ec.europa.eu/eurostat/statistics-explained>; Woźniak and Pactwa 2018) in 2016 the mining and quarrying constituted around 40% of the total wastes generated in Poland. However, the precise determination of their quantity by category is difficult owing to the lack of comprehensive domestic evidence of wastes and imperfect system of central storage of relevant information. The data published by various sources, including official statistics of Statistics Poland (GUS), are inconsistent and often contradictory. An attempt to balance the amount of wastes generated in the course of exploration, mining and processing of ores and

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other mineral raw materials on a national scale was performed in the beginning of the 2000s by the Polish Geological Institute. According to the data collected in the MIDAS database (www.pgi.gov.pl) the total annual volume of these wastes decreased from ca. 70 million Mg between 2002 and 2007 to 53.7 million Mg in 2010 (latest data available), including almost 3 million Mg of wastes generated in the course of rock minerals extraction and processing alone. The latter figure, like the volume of the rock mining wastes reported by the official sources, seems to be substantially underestimated. According to GUS, between 2000–2017 the amount of wastes from the mining of rock minerals varied between 2.0 and 5.6 million Mg per year (only 1.3 million Mg in 2012), while the percentage of these wastes utilized for various purposes (including recycling) has most recently been reported to be around 70% (Table 1). However, it is assumed that the actual volume of these wastes can be more than 10 million Mg per year, while the rate of their economic utilization does not exceed 40% (Galos 2019). The most important types are those from extraction and processing of compact rocks (limestone, dolomite, sandstone, magmatic rocks), as well as from the mining of clays, sand, and gravel. Some of them has been successfully utilized in civil engineering and in the production of crushed aggregates, in the ceramics (lower quality kaolin or feldspar-quartz raw materials), as well as fertilizers manufacturing (Galos et al. 2009). As a result, the quantity of rock mining and processing wastes being landfilled has been substantially reduced (Table 1).

Table 1. Industrial wastes and wastes from rock mining and processing in Poland according to Statistics Poland (GUS)

Tabela 1. Odpady przemysłowe oraz odpady z górnictwa i przeróbki kopalin skalnych w Polsce według danych Głównego Urzędu Statystycznego (GUS)

	2000	2005	2010	2015	2016	2017	2018
Industrial wastes							
♦ generated – total (million Mg)	125.5	124.6	113.5	131.0	128.3	113.8	115.3
♦ utilized in the given year (%)	76.9	79.2	74.3	21.9	49.5	49.0	58.4
♦ accumulated by the end of the given year (million Mg)	2,011.0	1,752.6	1,724.5	1,681.4	1,710.6	1,736.5	1,760.1
Including							
Wastes from rock mining and processing							
♦ generated – total (million tons)	4.1	2.0	2.0	5.6	4.2	3.9	n.a.
♦ utilized in the given year (%)	80.1	93.5	91.5	69.3	71.6	n.a.	n.a.
♦ accumulated by the end of the given year (million Mg)	99.7	24.3	15.0	31.5	32.5	n.a.	n.a.

n.a. – not available.

The dynamic growth of the ceramic industry in the last decades in Poland resulted in huge demand for natural raw materials utilized in the production of ceramic goods (especially ceramic tiles), followed by their increased importation as well as research for alternative domestic sources. Over the past several years numerous waste materials have been investigated both in Poland and abroad, confirming that the ceramic industry has a potential to absorb great amounts of various industrial rejects that can substitute naturally occurring minerals (Lewicka 2016). In such attempts, fly ash was utilized as an alternative source of alumina-silicate raw material replacing a part of kaolinitic clays or quartz in ceramic tile composition (Dana et al. 2005). The research has also showed some beneficial effects of blast furnace slag in the tile batch by replacing a part of feldspar, as well as the quartz substitution by Si-rich waste as rice husk ash and silica fume in whiteware compositions. Moreover, the use of different alternative fluxing agents partially replacing the feldspars in a ceramic tile batch were investigated with good results concerning the reduction of the sintering temperature and improvement in the mechanical characteristics (Andreola et al. 2016). The waste materials studied included: glass cullet (soda-lime float and container glass) and cathode ray tube panel glass (Andreola et al. 2008), as well as industrial sludge derived from cutting and polishing natural stones (granite, marble and quartzite) (Torres et al. 2004, 2007). The mentioned sludge can be incorporated in high levels (60–70%) in the formulation of the red-clay-based stoneware tiles. Thanks to very thin particles (<0.1 mm) this inexpensive residues can be directly used in industrial compositions, avoiding energy costs related with the milling process. It was also demonstrated that specifically granite sludge, characterized by high content of total fluxing oxides (both alkali oxides, such as Na_2O and K_2O , and Fe_2O_3) that favor a lowering sintering temperature, is a good substitute for feldspar in stoneware tile production. The mentioned examples confirm that the recycling of wastes has an unambiguously beneficial environmental and economic impact, contributing to the reduction of production costs in the ceramic industry.

In Poland, since the mid-1990s in parallel with the growing production of ceramic goods and a huge demand of that industry for raw materials, the partial replacement of primary raw materials by alternative secondary sources has gained increasing acceptance in the industry. The prime examples of such materials are the alkali-rich finest fractions generated in the Lower Silesian (SW Poland) granite mines in the course of the manufacturing of crushed aggregates as well as kaolinite-rich clayey substance remaining after the washing of quartz sand from deposits in the Tomaszów trough (Central Poland) and Bolesławiec trough (SW Poland). Until the mid-1990s large amounts of these by-products were accumulated in settling ponds as useless wastes. Currently both kaolin and feldspar-quartz recovered from the rock mining and processing wastes are classified as commercial products with parameters meeting the market requirements and, as such, they proved to be a good substitute for costly raw materials in the ceramic bodies' composition. Their utilization has contributed to the reduction of the volume of wastes landfilled and environmental and social impacts of the mining industry as well as to preserve the domestic mineral resources, which is in accordance with the principles of a circular economy and rational mineral resources management.

The concept of a circular economy includes the optimal utilization of natural raw materials (no waste) according to the 3R rule: reduce-recycle-reuse applied in the process of production, distribution and consumption (Każmierczak et al. 2019; Woźniak and Pactwa 2018).

1. The evolution of the demand for kaolin and feldspathic raw materials in the ceramic industry in Poland

Due to the economic transformation in Poland accompanied by recovery in the housing construction industry, significant growth of demand for ceramic finishing materials, including ceramic tiles and sanitaryware, has been recorded since the turn of the 1980s and 1990s. That has been coupled with the modernization and expansion of the production capacities of the domestic ceramic industry, involving technological changes, i.e. the implementation of the fast-firing technology (Lewicka 2001; Lewicka and Wyszomirski 2010). This technology makes thermal treatment cycle time-optimized (in the case of ceramic tiles shortened from ca. 70 hours even to 40–50 minutes) with energy-savings and increasing production capacity (Sánchez et al. 2010). The commissioning of this technology contributed to popularization of a new type of ceramic product called gres tile (*It. gres porcellanato*) or porcelain stoneware, a batch of which contains 45–65% of fluxes (preferentially sodic varieties of feldspathic raw materials), while typical flux percentage in the batch of wall and floor tiles usually does not exceed 50% (Dondi 2018). The increased content of flux is crucial to obtain highly vitrified bodies of excellent properties, especially in terms of mechanical strength, hardness and water absorption, at a relatively low temperature (1180–1220°C) (Dondi et al. 1999; Lewicka 2010).

Between 1995 and 2008 the domestic supply of ceramic tiles (Fig. 1) showed more than a nine-fold increase approaching 1.9 million Mg (Lewicka 2012; Minerals Yearbook of Poland 2014). In the following years, despite some annual fluctuations due to global economic crisis, it remained high ranging 1.7–2.0 million Mg per annum. As a result, Poland has become the third tile producer in the EU – after Italy and Spain. At the same time, i.e. from the mid-1990s to 2008, the production of the ceramic sanitaryware increased more than four-fold, exceeding 110,000 Mg, while in the consecutive years it stabilized at 80,000–90,000 Mg per year.

The outstanding growth in the ceramic tiles and sanitaryware production that had been driven by technological innovation has resulted in soaring demand for ceramic raw materials. This, in turn, has caused their intense importation and has encouraged the search for their alternative domestic sources (Galos 2004; Panna et al. 2015). The search focused on various rock mining waste materials, especially on kaolinite-rich clayey residues (<0.1 or <0.2 mm) after quartz sand washing in glass sand mines as well as alkalis-rich finest grain fractions (<0.5 or <0.2 mm) generated in the course of crushed aggregates production in granite mines (Lewicka 2012). Despite a relatively high content of coloring oxides (especially Fe₂O₃, Table 2), due to the very low cost these materials started to be successfully applied

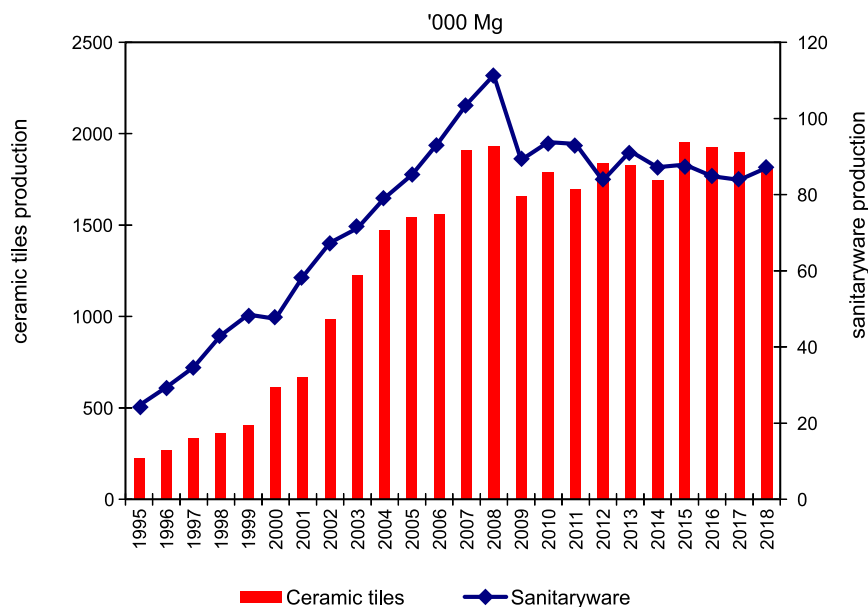


Fig. 1. The production of ceramic tiles and sanitaryware in Poland between 1995 and 2018 (based on GUS data)

Rys. 1. Produkcja płytek ceramicznych i wyrobów sanitarnych w Polsce w latach 1995–2018

Table 2. The chemical composition of kaolinite and feldspathic by-products of the rock mining industry utilized in the ceramic industry in Poland (producers' data; [Ciechański and Sokołowski 1995](#))

Tabela 2. Skład chemiczny kaolinowych i skaleniowych produktów ubocznych górnictwa skalnego wykorzystywanych w przemyśle ceramicznym w Polsce

Component (wt. %)	Kaolinite by-products			Feldspathic by-products		
	Osiecznica/Surmin-Kaolin		Grudzeń Las	Graniczna/Eurovia Kruszywa	Rogoźnica II	Gniewków
	KSP	KOS	Kaolin	Feldspar-quartz raw materials		
SiO ₂	76.5	56.8	63.4	74.15	73.67	71.74
Al ₂ O ₃	16.8	30.9	24.8	13.15	13.61	13.82
Fe ₂ O ₃	0.21	0.36	1.41	2.00	2.18	2.52
TiO ₂	0.22	0.32	0.62	0.26	0.02	0.02
CaO	0.05	0.09	0.09	1.57	1.27	1.61
MgO	0.05	0.11	0.14	0.68	0.39	0.35
K ₂ O	0.19	0.41	0.56	4.30	5.16	6.15
Na ₂ O	0.02	0.02	0.04	3.40	3.09	3.40
LoI	6.00	11.0	8.74	0.49	0.64	0.83

in the production of ceramic goods, the high whiteness of which after firing is not required. Another feature of these by-products is the content of alkalis (Na_2O and K_2O), which is favorably low in the case of kaolinite-rich clayey raw materials and high enough in feldspathic fine-grained fractions (that is crucial to control forming a liquid phase during firing). Due to these properties and ready supply the materials in question have gained wide acceptance in the ceramic industry.

As a result of the phenomena discussed above, since the mid-1990s the domestic consumption of kaolin rose more than twice, approaching 280,000 Mg in 2008 (Fig. 2), while the total demand for feldspathic raw materials (including nepheline syenite) increased over nine-fold, to around 960,000 Mg (Fig. 4). In the following years – after fluctuations corresponding to the economic slowdown – the annual consumption of kaolin raw materials ranged widely from 210,000 Mg in 2009 (25% drop compared to 2008) to 290,000 Mg in 2013, while in the last couple of years it stabilized at 230,000–240,000 Mg/y. Simultaneously, in 2009 the demand for feldspathic raw materials fell by 23% to 740,000 Mg. In the years 2010–2017 it recovered varying between 800,000 and 990,000 Mg/y, while in 2018 the consumption of these raw materials achieved its record volume, exceeding 1 million Mg.

2. The sources of kaolin raw materials in Poland

The Polish domestic supplies of kaolin peaked at 80,000 Mg at the end of the 1990s (*Mineral Yearbook of Poland 2014*). It wasn't long before they doubled to around 160,000 Mg

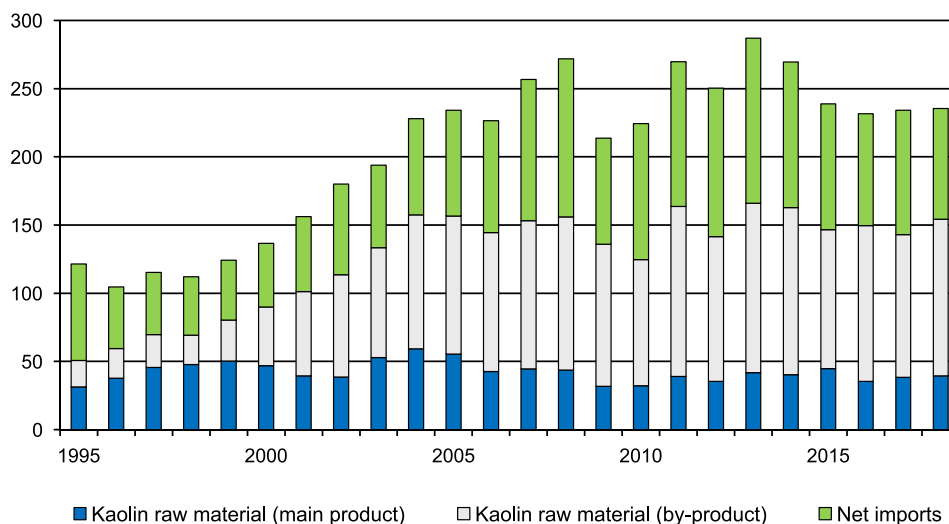


Fig. 2. The consumption of kaolinite raw materials by sources of supply in Poland (thousand Mg) (producers' data, GUS, Author's calculations)

Rys. 2. Zużycie surowców kaolinowych według źródeł pochodzenia w Polsce (tys. Mg)

per year in the beginning of the 2000s, while in the years 2006–2018 they usually ranged between ca. 140,000 and 150,000 Mg per year, sometimes exceeding 160,000 Mg (in 2011 and 2013–2014) (Fig. 2). This resulted largely from progressive increase in the recovery of kaolinite-rich clayey substance generated in the course of quartz sand washing in glass sand mines. In the second half of 1990s the share of that by-product in the total domestic kaolin output represented less than 40%, while in recent years it almost doubled, ranging from 74 to 76% (Fig. 3, Lewicka 2012). In terms of tonnage, the recovered kaolin supplies increased from 20,000–30,000 Mg to 100,000–120,000 Mg per year, respectively. This growth was directly related to developing the production of sand for the glass-making industry driven by expansion of the construction industry and by the simultaneous high demand for kaolin from the ceramics.

The main domestic sources of kaolin have been Maria III and Maria III-1 deposits of kaolinite-rich sandstones, extracted by Surmin-Kaolin SA of Nowogrodzic, SW Poland. Other important sources include deposits of glass sand, i.e.: Osiecznica II operated by KiZPPS Osiecznica Ltd. in the Bolesławiec trough (SW Poland) and deposits located in the Tomaszów Mazowiecki trough (Central Poland). The latter ones are operated by the TKSM Biała Góra Ltd. (Biała Góra – 3 deposits and Unewel-W-Nowy) and by the Grudzeń Las Ltd. (Grudzeń Las, Piaskownica-Zajęczków E and Unewel W-Las deposits).

Surmin-Kaolin (Quarzwerke Capital Group) is the largest domestic supplier of highly processed kaolin for various purposes (ceramics, paper, cement, plastics and gum, etc.).

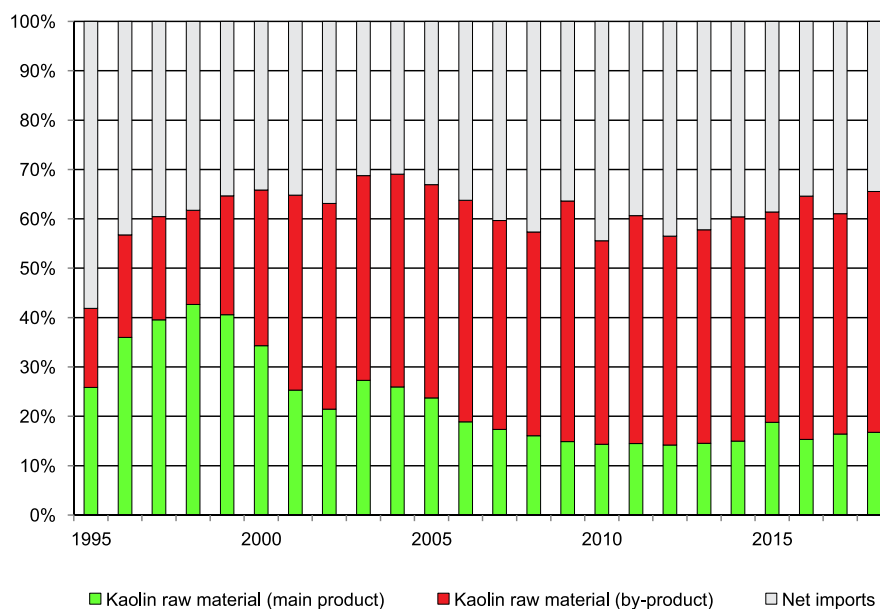


Fig. 3. Sources of kaolin supply in Poland (%)
(Author's calculations based on producers' data and GUS)

Rys. 3. Źródła podaży kaolinu w Polsce (%)

The company has obtained beneficiated kaolin from the above-mentioned deposits of kaolinite sandstones as well as from fine-grained raw material (<0.1 mm) being by-product of quartz sand washing at the KiZPPS Osiecznica plant. In the last couple of years this ancillary production at the Surmin-Kaolin amounted to ca. 40,000 Mg per year (kaolin exclusively for ceramic purposes), while the total supplies of all kaolin grades ranged 70,000–80,000 Mg per year (producer's data).

The remaining domestic kaolin manufacturers, i.e. Grudzeń Las and TKSM Biała Góra, sourced kaolinite-rich raw material from quartz sand processing at the stage of washing of <0.5 mm fraction and occasionally also in course of selective extraction of old settling ponds. In recent years the annual production of kaolin at the Grudzeń Las has approached 60,000–70,000 Mg, while at the TKSM Biała Góra – 10,000–13,000 Mg (reduced from 30,000–60,000 Mg/y in the mid-2000s). Virtually all kaolinite-containing slime generated in course of ongoing quartz sand washing has been processed into crude kaolin. The principal customer of that by-product has been the ceramic tile industry. The recovery of kaolin from waste material allowed the entrepreneurs to benefit from several advantages, including both environmental (no disposal of slime after quartz sand washing, waste-free operation status, reduced space landfilled, lower dust emission, closed water circuit) and economic ones (no landfill charges, periodical reduction in mining fee, a new commercial product sales). It can, therefore, be concluded that the recycling of mentioned kaolin by-product has been in compliance with the rules of circular economy.

In spite of development of kaolin production from various domestic sources, importation has still played an important role in the kaolin market in Poland. However, its share in the total supplies was reduced from almost 60% in the mid-1990s to 31–37% in 1999–2006, 36–44% in the years 2007–2017 and around 34% in 2018 (Fig. 3), despite simultaneous increase of foreign kaolin deliveries to Poland (in tonnage terms).

The volume of imports grew from less than 50,000 Mg per year in the second half of the 1990s to 70,000–120,000 Mg per year in the first decade of the 2000s and 120,000–150,000 Mg per annum in 2011–2017. In 2018 it diminished to around 95,000 Mg. The vast majority, i.e. more than 80%, of the total imports were high-purity beneficiated grades from Germany – 50% (Quarzwerke) and the Czech Republic – 30% (LB Minerals and Sedlecky Kaolin).

3. The sources of feldspar-quartz raw materials in Poland

Since the mid-1990s domestic supplies of feldspar-quartz raw materials have been rising continually, reaching a record of ca. 640,000 Mg in 2008 (Fig. 4). Although in 2009–2010, owing to the downturn in the construction industry, they decreased by 25%, but the following years brought their gradual improvement to 560,000–600,000 Mg/y most recently.

The major Polish producer of feldspar-quartz raw materials (80–90% of the domestic supplies) is the Strzeblowskie KSM, extracting deposits of granitoids in the Strzegom–

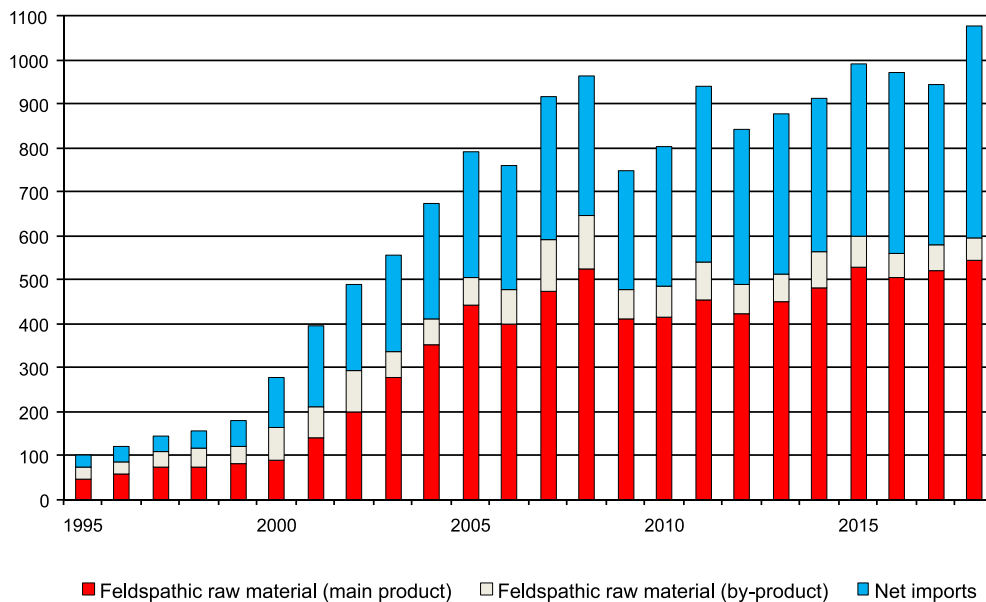


Fig. 4. The consumption of feldspathic raw materials by sources of supply in Poland (thousand Mg) (producers' data, GUS, Author's calculations)

Rys. 4. Zużycie surowców skaleniowych według źródeł podaży w Polsce (tys. Mg)

–Sobótka massif, SW Poland (Pagórki W and E, Strzeblów I and Stary Łom). The company's annual production capacity stands at around 550,000 Mg/y, mainly of feldspar-quartz grits. The vast majority of its offer is intended for the ceramic tile industry (80–90%), while the rest – for the sanitaryware, glass-making, etc. (Lewicka and Wyszomirski 2010; Lewicka 2012).

It should be mentioned that the reserve base of feldspar raw materials in Poland is relatively small and the possibilities to enlarge the domestic resources are limited. Despite thorough research confirming the potential suitability of many rock varieties occurring in Lower Silesia (SW Poland) for the use as fluxes in the production of ceramic goods, making investments in the extraction of their deposits is doubtful due to their location in the areas of environmental protection and social resistance against any mining activity (Lewicka and Wyszomirski 2005). Therefore, along with primary deposits, ceramic fluxes have been increasingly collected from alternative sources, such as the finest grain fractions generated in the course of the production of crushed aggregates in the Lower Silesian granite mines. Their growing consumption was correlated with the development of the ceramic tile production, particularly porcelain stoneware tile. These materials have been introduced as low-cost substitutes for feldspar in the fast-fired ceramic tile bodies in an unprocessed state. Their growing usage was also fed by high market prices of feldspar commodities resulting from the depletion of their deposits of adequate quality worldwide. From the mid-1990s to

2013 the largest quantities of such raw materials were obtained at the Graniczna granite quarry (Lower Silesia) operated by Eurovia Kruszywa SA. That was maximum 60,000–80,000 Mg/y in 2000–2008 and several thousand Mg per year since 2015 (acc. to producer). There were sold both by-products of the current production (0–2 and 0–1 mm) as well as alkalis-rich fine-grained material accumulated in settling ponds. Relatively smaller quantities of feldspar-quartz raw materials have been also offered by the Jeleniogórskie KSM (5,000–9,000 Mg/y), as well as other Lower Silesian manufacturers of granite crushed aggregates, e.g.: Rogoźnica II and Gniewków quarries.

The estimated total annual supplies of the marketable feldspar-quartz raw materials from above-mentioned granite quarries to the ceramic tile factories rose from 27,000–45,000 Mg in the mid-1990s to a record 120,000–140,000 Mg in 2007–2008 (Fig. 4, [Minerals Yearbook of Poland 2014](#)). After ca. 40% reduction in 2009, they probably ranged from 60,000 to 80,000 Mg per annum until 2017 and around 50,000 Mg last year. Simultaneously, their contribution to the total supplies of feldspar-quartz from domestic sources melted from 30–40% to 10%, which was coupled with huge importation of feldspathic raw materials (Fig. 5). However, despite the fact that waste materials incorporation has been carried out in smaller percentages, high ceramic tile production rates have translated it into still quite large usage.

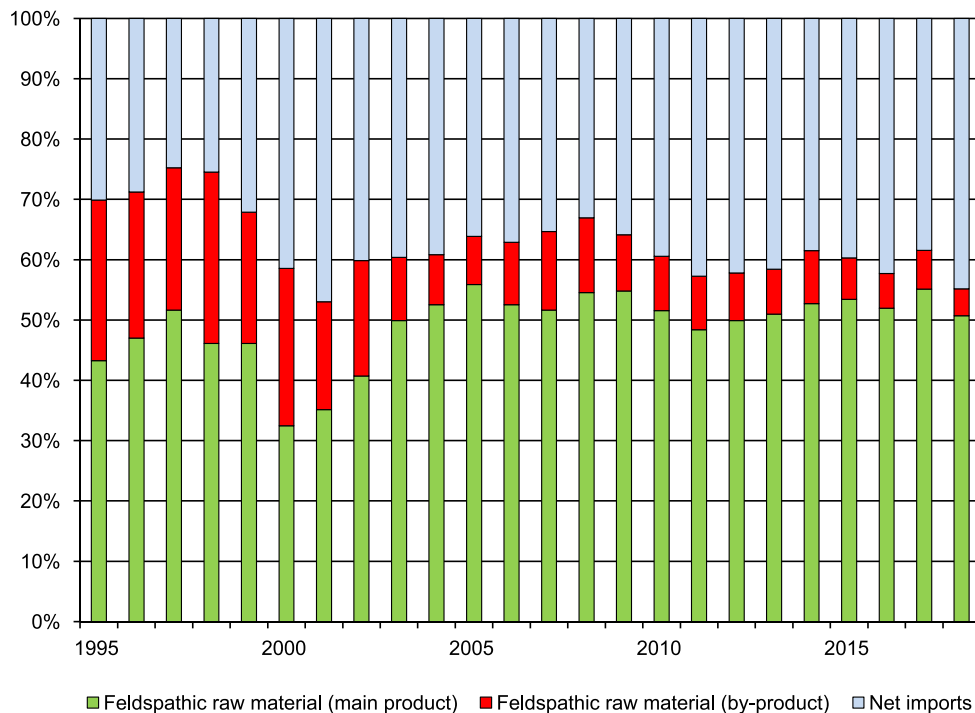


Fig. 5. Sources of feldspathic raw materials supply in Poland (%)
(Author's calculations based on producers' data and GUS)

Rys. 5. Źródła podaży surowców skaleniowych w Polsce (%)

The domestic demand for feldspar-quartz must have been substantially complemented from foreign sources. Various feldspathic varieties have come almost entirely (98% in recent years) from three countries: Turkey (basically sodium feldspar varieties, manufactured by e.g. Kaltun, Kalemaden and Esan), the Czech Republic (potassium feldspar from LB Minerals and sodium feldspar from KMK Granit), and Norway (nepheline syenite from Sibelco Nordic) (Lewicka 2017; Panna et al. 2015; Wyszomirski et al. 2012). These deliveries have been incomparably greater than the imports of kaolin, which resulted from deficiency of deposits of potassium feldspar or of high purity sodium varieties of feldspar in Poland, as well as – which is more important – shortages of domestic supply of feldspathic raw materials in view of huge demand of the ceramic tile industry. Between 1995–2008 the total imports increased more than ten-fold, approaching 320,000 Mg, while recently these deliveries were as high as 350,000–490,000 Mg per annum, including ca. 70,000–80,000 Mg of Norwegian nepheline syenite (GUS). Taking only importation of feldspar raw materials (excluding nepheline syenite, utilized basically in sanitaryware manufacturing, and hardly substituted) into account, the volume of importation ranged 300,000–420,000 Mg per year, 95–97% of which came from the Czech Republic and Turkey (in almost equal shares).

4. The advantages of the use of by-product kaolin and feldspar-quartz in the ceramics

On the country's scale, the development of supply of by-product kaolin has helped not only to maintain the level of the total production to meet the domestic demand but also to preserve the kaolin resources, contributing to their longer sufficiency. Taking the reserves of currently operated Maria III-1 deposit (45,601,500 Mg corrected by the utilization rate of 0.75, Malon 2019a), as well as the average mining output of kaolinite-rich sandstone and the resulting production of primary kaolin in the last 10 years (around 276,000 Mg/y and 38,000 Mg/y, respectively) into account, the sufficiency of domestic kaolin reserves can be estimated at around 900 years. However, in order to maintain kaolin domestic supplies at the level of ca. 150,000 Mg/y (assuming that they will come exclusively from the Maria III-1 deposit), the output of kaolinite-rich sandstone should reach ca. 1,080,000 Mg, which would result in the reduction of domestic reserve base sufficiency to ca. 30 years. Therefore, the recovery of kaolin from alternative sources is an excellent example of rational mineral deposit management in accordance with principles of circular economy (no waste).

As mentioned above, to meet the demand for kaolin of ca. 240,000–250,000 Mg/y in Poland (average of the last 10 years) the domestic supplies have been supplemented by around 120,000 Mg/y of kaolin from foreign sources, the significant part of which has been consumed by the ceramic tile industry. This sector is also the most important recipient of by-product kaolin. Therefore, it should be emphasized that if this source was excluded in the total supplies, probably around 110,000 Mg/y of additional kaolin would have to be imported, resulting in total foreign deliveries of at least 230,000 Mg/y. To assess the cost

of such deliveries the most recent average unit values of kaolin supplies from major countries (PLN 410–470 per Mg) have been applied (Table 3). The resulting total cost of these additional deliveries would be at least PLN 45.1–51.7 million/y, while the value of domestic by-product kaolin sales has been estimated at around PLN 8.8 million/y. That confirms that the utilization of by-product kaolin has represented huge economic benefit for the ceramic industry in Poland in comparison to imported kaolin, limiting its foreign deliveries in terms of quantity and value, lowering costs of the consumed raw materials and thus reducing the production costs.

Table 3. Unit values of domestic kaolin sales versus unit values of kaolin importation to Poland (Author's calculations based on GUS and producer's data)

Tabela 3. Wartości jednostkowe sprzedaży kaolinów krajowych a jednostkowe koszty importu kaolinu do Polski

Unit value (PLN/Mg)	2000	2005	2010	2015	2016	2017	2018
Domestic sales, including	188	135	162	142	140	140 ^e	145
♦ by-product kaolin	52–75	68	98	90 ^e	80	80	83
Importation	628	444	468	504	591	576	610
including:							
♦ Germany	517	359	265	339	441	420	473
♦ Czech Republic	512	374	655	393	388	410	412

^e – estimated.

The reserve base of feldspar raw materials in Poland is relatively small (5,254,400 Mg, including 2,664,000 Mg in two deposits currently operated, [Malon 2019b](#)). The calculation of these reserves sufficiency is difficult and can be flawed because feldspar-quartz raw materials are obtained not only from deposits regarded as feldspar ones, but also from some deposits of granite belonging to the group of road and construction raw materials ([Galos et al. 2012](#)). Therefore, the clear benefits arising from the utilization of recycled feldspar-quartz materials from the point of view reserves sufficiency have not been calculated by the Author.

The precise assessment of the profits from the use of these by-product feldspar-quartz than imported feldspar is also more difficult than in the case of kaolin due to lack of data on the value of domestic production both in the case of primary raw materials and recovered alkali-rich feldspar-quartz. However, some estimations can be made basing on available unit values of imports and feldspar-quartz domestic price ranges. In the last couple of years the unit values of importation of feldspathic raw materials from the main suppliers, i.e. the Czech Republic and Turkey, were in the range of PLN 170–195 per Mg and PLN 190–200 per Mg, respectively, while the average unit values of the total foreign deliveries amounted to

PLN 188–195 per Mg. The price range of domestic feldspar-quartz grits sold by the major producer Strzeblowskie KSM was PLN 40–110 per Mg (Table 4).

Table 4. Unit values of domestic feldspar-quartz sales versus unit values of feldspar raw materials importation to Poland (Author 'calculations based on GUS and producer's data)

Tabela 4. Wartości jednostkowe krajowej sprzedaży surowców skaleniowo-kwarcowych a jednostkowe koszty importu skaleni do Polski

Unit value (PLN/Mg)	2000	2005	2010	2015	2016	2017	2018
Domestic sales (grits)	n.a.	75–110	70–106	40–110	40–110	40–105	40–100
Importation	260	180	168	195	196	188	188
from:							
Czech Republic	162	130	134	195	194	171	169
Turkey	–	180	164	188	190	197	202

n.a. – not available.

Taking into account the recent supplies of 50,000–70,000 Mg/y of by-product feldspar-quartz raw material consumed by the ceramic industry, and assuming that its selling price cannot be higher than PLN 40/Mg (minimum price for the domestic commercial grade of feldspar-quartz), the calculated total value of the recycled raw material should not exceed PLN 2.0 million/y. If this source was excluded in the total supplies, the same quantity of feldspathic raw materials would have to be imported. The cost of such deliveries using the most recent average unit value of the total supplies from abroad (ca. PLN 188/Mg) would be PLN 9.4–13.16 million/y, which considerably exceeds the estimated cost of sales of domestic by-product feldspar-quartz. Therefore it can be certainly stated that these recycled materials contributed to the reduction of foreign deliveries, especially in the period of increased demand of the ceramics in the first decade of the 2000s, supplementing limited domestic supplies of feldspar-quartz raw materials. Their recovery also presented environmental and social advantages such as lower dust emission lower dust emission from settling ponds, as well as economic ones, i.e. reduced charges for waste disposal.

Conclusions

Kaolinite and feldspathic raw materials being by-products of the rock mining and processing in Poland constitute the essential complement to the domestic supplies of mineral raw materials for the ceramics. Their utilization, initiated in the mid-1990s, developed in line with modernization and the capacity expansion of the domestic ceramic tile and

sanitaryware industries. The usage of such raw materials played an important role in view of these sectors materials needs (especially the ceramic tiles industry owing to huge scale of the output), as well as safeguarding of mineral deposits (resource preservation). Therefore, the main profit of their utilization is both enhancing the sufficiency of mineral resources (especially in the case of kaolin) and cost savings due to lower energy consumption during subsequent processing (reduced costs), as well as limiting the amount of wastes generated and disposed by the mining industry.

In the case of quartz sand washing by-product, i.e. a kaolinite-rich clayey substance, the development of its utilization has contributed significantly to countering the increase of foreign deliveries of kaolin to Poland in the 2000s. Consequently, in 1997–2017 the share of imports in the total kaolin supplies remained at just 31–44% per annum, while in the first half of the 1990s it approached 60–70%. At the same time, the consumption of kaolinite raw materials almost doubled and since 2004 it has regularly exceeded 200,000 tons per annum (with a record of 290,000 tons in 2013). It has been calculated that to maintain kaolin domestic supplies at the level of ca. 150,000 Mg/y, assuming that they will come only from the Maria III-1 deposit, the sufficiency of the domestic reserves would be shortened to ca. 30 years. Otherwise, to meet domestic demand (excluding the recycled kaolin supplies), probably around 110,000 Mg/y of additional kaolin would have to be imported of estimated value at least PLN 45–52 million/y, while the value of domestic by-product kaolin sales has been estimated at around PLN 9 million/y. This represents a huge benefit of the use of recovered kaolin in the ceramic industry in Poland in comparison to the raw material of foreign origin from both the economic point of view and the country's resources efficiency.

Little possibility to increase domestic production (due to a relatively small reserve base) coupled with the growing demand for the raw materials from the ceramics, especially in the second half of the 1990s, made interesting also alkalis-rich fine-grained feldspathic by-products of granite crushing. Being constituted mainly by very thin particles, these residues have been directly incorporated in the ceramic batches, reducing the costs of crushing and milling. Their utilization as alternative raw materials partly substituting primary feldspathic fluxes in the ceramic composition contributed to increase of the domestic supplies on the market and reduced scale of imports.

The percentage of imported feldspathic raw materials in the total supplies of these commodities in Poland, despite significant increase in their foreign deliveries after 2000 – up to 350,000–400,000 Mg per annum – generally has not exceeded 40%. Since the mid-1990s by-product feldspar-quartz raw materials, utilized basically by the ceramic tiles industry, have constituted the important complement of domestic production from primary sources (initially – 40% per annum, recently 10–15%). In the period of 1995–2017 the total supplies of feldspathic raw materials in Poland (from all sources, including net imports) increased almost ten-fold, peaking at 990,000 Mg in 2015, while in 2018 it reached a new record of almost 1.1 million Mg. A significant share in such growth had, however, developed mining production from feldspar-quartz deposits.

The assessment of benefits from the use of by-product feldspar-quartz than imported feldspathic raw materials has been much less precise than in the case of kaolin due to lack of data. However, basing on the latest unit value of the total foreign deliveries (ca. PLN 188 per Mg), the cost of importation of raw material being equivalent to the supplies of domestic recycled feldspar-quartz (50,000–70,000 Mg/y) can be estimated at PLN 9–13 million/y. This is obviously much more expensive than the use of the by-product raw material, the cost of which should not exceed PLN 2 million/y.

The overall conclusion is that the by-products of rock mining in question have been the important auxiliary raw materials for one of the fastest growing industries in Poland, i.e. the ceramic tiles sector. The development of their utilization has been an example of rational and comprehensive management of all minerals in operated deposits as well as implementation of circular economy principles in the rock minerals mining in Poland. The recycling of these mining and processing wastes minimizes pressures on the primary resources extraction, provides additional supplies of raw materials on the market, as well as reduces the environmental footprint of the mining industry.

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RATIONAL USE OF SELECTED MINING BY-PRODUCTS IN THE CERAMIC INDUSTRY IN POLAND**Keywords**

kaolin, feldspathic raw materials, by-products of the rock mining,
ceramic tiles, sanitaryware

Abstract

The paper discusses the issue of the utilization of selected raw materials obtained as by-products of rock mining and processing in the ceramic industry in Poland. The raw materials in question are: kaolinite-rich clayey substance remaining after quartz sand washing and alkalis-rich finest fractions generated in the course of the production of granite crushed aggregates. Despite usually high content of coloring oxides, they have been utilized for the production of ceramic goods, the high whiteness of which is not required after firing. High interest in these materials was connected with the implementation of the fast firing method as well as modernization and large scale expansion of the domestic ceramic industry, especially ceramic tiles and sanitaryware sectors. Between the mid-1990s and 2018, the annual consumption of kaolinite raw materials being by-products of quartz sand washing increased from ca. 20,000 to 100,000–120,000 Mg. At the same time the sales of secondary granite fractions utilized as a flux in the ceramic industry rose from 30,000 to 120,000 Mg per year in 2007–2008, and 50,000–70,000 Mg per year most recently. The development of the utilization of these raw materials has been an example of the rational and comprehensive management of all the minerals that occur in deposits in operation. This is particularly important in the context of the depletion of these raw materials reserves and the limited availability of their new deposits. Furthermore, this also makes a contribution towards reducing the scale of imports of raw materials for the ceramic tile industry, which is inevitable due to insufficient supplies from domestic sources.

**RACJONALNE WYKORZYSTANIE WYBRANYCH UBOCZNYCH PRODUKTÓW
GÓRNICHTWA W PRZEMYSŁE CERAMICZNYM W POLSCE****Słowa kluczowe**

kaolin, surowce skaleniowe, produkty uboczne górnictwa skalnego,
płytki ceramiczne, wyroby sanitarne

Streszczenie

W artykule omówiono znaczenie wykorzystania ubocznych surowców mineralnych z górnictwa i przeróbki kopalni skalnych w przemyśle ceramicznym w Polsce. Wśród tych surowców istotną rolę odgrywają: wzbogacona w kaolinit substancja ilasta stanowiąca produkt uboczny płukania piasków kwarcowych oraz bogate w alkalia odpadowe najdrobniejsze frakcje ziarnowe powstające przy produkcji granitowych kruszyw łamanych. Surowce te, mimo zwykle dużej zawartości tlenków

barwiających, znajdują zastosowanie w produkcji wyrobów ceramicznych, które nie muszą mieć wysokiej białości po wypaleniu. Rozwój ich wykorzystania ma ścisły związek z wdrożeniem w przemyśle ceramicznym technologii szybkiego wypalania oraz rozbudową sektora płytek ceramicznych i wyrobów sanitarnych w Polsce. Dynamiczny rozwój zapotrzebowania na surowce do ich produkcji zapoczątkowany został w połowie lat dziewięćdziesiątych XX wieku. Do 2018 r. zużycie surowca kaolinowego pozyskiwanego ubocznie zwiększyło się z około 20 tys. Mg/r. do 100–120 tys. Mg/r. Sprzedaż frakcji granitowych wykorzystywanych w przemyśle ceramicznym w roli topnika wzrosła w tym okresie z poziomu około 30 tys. Mg/r. do maksymalnie 120 tys. Mg/r. w latach 2007–2008, oraz 50–70 tys. Mg/r. w ostatnim okresie. Omawiane surowce nadal będą stanowić istotne uzupełnienie krajowej podaży surowców ceramicznych. Rozwój ich wykorzystania jest przykładem racjonalnej i kompleksowej gospodarki kopalinami w złożach eksploatowanych. Jest to szczególnie istotne wobec wyczerpywania się zasobów złóż eksploatowanych oraz ograniczonych możliwości udostępnienia nowych złóż. W istotny sposób przyczynia się także do zmniejszenia skali importu surowców mineralnych dla przemysłu płytek ceramicznych, w związku z niewystarczającą w stosunku do potrzeb podażą ze źródeł krajowych.