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Utilising feldspathic overburden and basement rocks from the Vidnava kaolin deposit as secondary raw materials for the ceramic industry

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Abstract: The study describes the first comprehensive research focused on the overburden and bedrock of the Vidnava kaolin deposit as substitute raw materials for the ceramic industry in the dependence of the context of reducing the European Union on imports of critical feldspars. These materials, previously considered waste, were characterised in terms of their chemical and mineralogical composition and subsequently tested for the first time in model porcelain-type ceramic materials. Recipes containing kaolin KD (the trade name for a commercially available type of kaolin), Vidnava feldspar detritus, and waste feldspar powder from the Halamky I deposit (all sourced in the Czech Republic) were evaluated after firing at temperatures of 1260°C and 1360°C in oxidising and reducing atmospheres. The results showed that the selected materials meet the requirements of the CSN EN 60672-3 standard for basic physical properties even at lower firing temperatures, but their use is limited by their higher iron content and the colouration of the firing ceramic shard, making them suitable for producing technical ceramics. Practical tests of the behaviour of the raw ceramic body during the pressing process confirmed its technological suitability for wet pressing technology. The second part of the study focusses on the modification of feldspar kaolins and weathered granites from the bedrock of the deposit by magnetic separation. The results confirmed the promising melting properties of the products obtained and the potential of the overburden and subsoil of the Vidnava deposit as a source of secondary raw materials for the ceramic industry.

Keywords: feldspar detritus, low-grade feldspar, magnetic separation, ceramic body, kaolin

1. Introduction

In recent years, the issue of reducing dependence on imports of critical raw materials, including feldspar, has become increasingly relevant in the European Union (European Parliament and Council, 2024; Sigeman, 2026). At the same time, mineral extraction in Europe is restricted by legislative requirements to minimise the amount of waste generated during extraction (European Parliament and Council, 2006). During surface mining of mineral resources (kaolin), it is necessary to remove the overburden layers, which are usually deposited in dumps and thus become waste material. These layers contain clay minerals (kaolinite), mica and feldspar, representing a potential source of material that could be used in industrial applications. The specific properties of these materials will not limit their full use. The use of waste materials in technical and applied ceramics has already been extensively researched (Al Hoseny et al., 2018; Brasileiro et al., 2012; El-Hamid et al., 2025; Kumar et al., 2001; Novais et al., 2015; Zhang, 2013). Due to their low feldspar content (10–45%), these materials cannot be used directly as a substitute for feldspar. However, they do represent a significant source of feldspar, the use of which can contribute to the efficient use of open deposits (Pticen, 2024). Similar studies have been conducted in many kaolin deposits(Ali and Meshesha, 2025; Bedassa et al., 2019; Kotenko et al., 2024), but none have yet been carried out at the Vidnava deposit.

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Another reason for using secondary raw materials is the pressure to reduce production costs and the gradual depletion of mineral resources in Europe. Therefore, there is growing interest in the use of waste materials not only from mining, but also from other industries (Al Hoseny et al., 2018; Brasileiro et al., 2012; El-Hamid et al., 2025; Kumar et al., 2001; Novais et al., 2015; Zhang, 2013). In kaolin mining, these wastes are known as feldspar detritus (feldspar detritus is a mixture of low-grade feldspars with quartz, mica, and clay minerals), which can be processed in the field of technical ceramics.

The Vidnava kaolin deposit is a primary kaolin deposit formed by the weathering of a granite massif (Murray, 1988; Pticen et al., 2024). The overburden consists of clay minerals, mica minerals, and feldspar, and the chemical composition of the parent rock influences the presence of contaminating oxides such as iron and titanium oxides (Bauluz et al., 2014; Mesele et al., 2021). These layers can be described as feldspar detritus or low-grade feldspar kaolin with a K_2O and Na_2O content of around 3.0% and a feldspar content of up to 40 % (Ehrenberg, 1991; Pticen, 2024). The low feldspar content prevents their direct use as standard ceramic feldspars, but these materials (feldspar detritus and low-grade feldspars) have potential for use in less demanding industrial applications.

The bedrock of the Vidnava deposit consists of granite rocks and feldspar kaolin that usually remain unused even though the mining area has already been opened. Until now, weathered granite materials have been processed mainly using flotation methods, which produce pure high-percentage feldspar and pure quartz (Huang et al., 2024). However, these technologies rely on reagents that are environmentally problematic (Heyes et al., 2012; Shen et al., 2023).

The purpose of this study is to propose and verify the possibilities of using feldspar detritus and the underlying parts of the Vidnava deposit in ceramic bodies suitable for industrial ceramics, and possibilities of processing bearing substrate parts (substrate granite and feldspar kaolin) into what are called "low-grade feldspars" (i.e., a mixture of quartz and feldspar with a feldspar content of less than 55%) without utilising flotation.

2. Materials and methods

2.1. Materials

Samples of feldspar detritus (overburden) from the Vidnava deposit were used to prepare a model recipe for ceramic material. The basic characteristics of the selected samples were being summarized in

Table 1. Basic characteristics of the feldspar detritus from the Vidnana deposit. Data and labelling taken from Pticen 2024 (Pticen, 2024). (description: CV, total well through the deposit and NL well in the overburden above the deposit), and data for kaolin KD taken from (Hanykýř, V. and Kutzendörfer, J., 2008). Values are given in [%]

Sample	Kaolinite	Mica minerals (including illite)	Quartz	K- feldspar	Na-Ca feldspars	Sum of feldspars	K_2O	Na_2O	Sum K_2O and Na_2O	Fe_2O_3
CV_01_3-11m	9.0	5.0	51.4	23.1	11.3	34.4	4.63	1.02	5.65	1.16
CV_01_23,7-26,5m	8.7	4.7	48.4	22.7	15.3	38.0	4.53	1.52	6.05	0.99
CV_03_36-43m	14.8	4.4	40.1	19.5	20.7	40.2	3.94	1.89	5.83	1.38
CV_04_35-42,3m	10.4	5.2	45.9	21.6	16.7	38.3	3.87	1.67	5.54	1.60
NL_2_2020_9,4-13m	24.8	4.3	37.7	25.1	7.9	33.0	4.57	0.88	5.45	1.71
Feldspar dust off Halamky I	-	7.0	13.0	56.6	23.0	79.6	8.10	2.0	10.2	2.58
Kaolin KD[1)]	87.0	-	8.0	-	-	5.0	-	-	1.0	0.8

Note: [1)]Over the years, the mineralogical composition of kaolin KD has changed significantly (higher alkali content (up to 2%), higher content of iron compounds, etc., but also higher content of mica and feldspar). The amount of kaolinite is supplemented by the addition of kaolin with a high content of aluminium oxide from the Rokle deposit near Kadan.

Table 1. Another material used was feldspar dust off, which was being produced as a waste product during the grinding of raw feldspar at the Halamky I deposit. The main properties of these materials are summarized in Table 1 In terms of feldspar content, this feldspar powder was comparable to feldspars of class Z75.

Unlike commercially available feldspar, however, the waste dust was containing a higher iron content, which may have been leading to characteristic discolouration of the material or melt.

Commercially available kaolin KD from the Krasny Dvur deposit was being used in the model recipe. As Hanykýř was stating, these kaolins were usually also containing an admixture of montmorillonite (Hanykýř and Kutzendörfer, 2008). An overview of the properties of the sample is provided in Table 1.

Other materials assessed were materials from the underlying parts of the Vidnava deposit, specifically the underlying feldspar kaolins. Their key physicochemical properties are summarised in Table 2.

Table 2. Basic characteristics of samples from the underlying parts of the Vidnava deposit. Data taken from the Final Report on the Vidnava Geological Project (Nekl, 2024). All values are given in [%]

Sample	Kaolinite	Mica minerals (including illite)	Quartz	K- feldspar	Na-Ca feldspars	Sum of feldspars	K_2O	Na_2O	Sum K_2O and Na_2O	Fe_2O_3
262_10,9-13,2 m	36.30	6.9	37.4	18.50	-	18.50	4.15	0.17	4.32	1.36
271_40,1-45,9 m	13.10	7.8	32.2	20.7	22.6	43.3	4.75	2.38	7.13	2.61

2.2. Experimental design

Each sample was prepared with an identical rational composition of 30% feldspar, 20% silicon dioxide, and 50% kaolinite. The percentage composition of the individual raw materials was calculated for this rational formula. The recipes were made up of the following raw materials: kaolin KD, Vidnava deposit feldspar detritus (this is basically an unprocessed raw material that was only dried and mechanically broken before use), and Halamky I feldspar dust off. The composition of individual model recipes is shown in Table 3.

Table 3. Model material recipes designed to correspond to a rational composition of 30% feldspar, 20% quartz and 50% kaolinite. All values are given in [%]

Number of sample	D1	D2	D3	D4	D5
Marking of feldspar detritus	CV_01_ 3-11m	CV_01_ 23,7-26,5m	CV_03_ 36-43m	CV_04_35- 42,3m	NL_2_2020_ 9,4-13m
Kaolin KD (%)	56	56	52	55	46
Feldspar dust off Halamky I (%)	14	12	7	11	11
Feldspar detritus (%)	30	32	41	35	43

The samples labelled D1-D5 were prepared according to the recipes listed in Table 3. The raw materials were dried at a temperature of 105°C for two hours. Individual recipes D1–D5 were prepared from the input raw materials. The ingredients weighed and mixed were ground for 1 minute in a vibrating mill to ensure thorough homogenisation. From the prepared recipes D1–D5, 5 g of material was taken from each and moistened with 1 ml of water.

The first set of test samples was fired in an oxidising atmosphere at a temperature of 1260°C for one hour, while the second set of test samples was fired at a temperature of 1360°C for one hour in a reducing atmosphere.

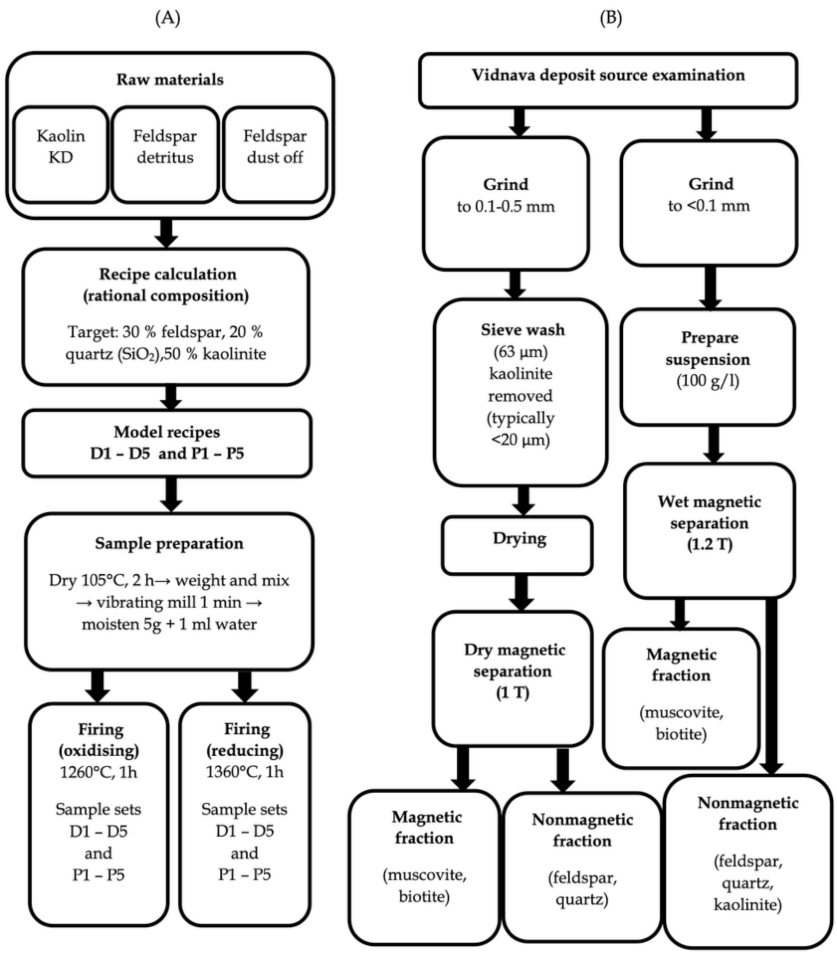

Fig. 1. A) Diagram of the first part of the experiment, where ceramic bodies D1 - D5 and P1 - P5 were prepared based on feldspar detritus, kaolin KD, feldspar dust off Halamky (ceramic bodies D1 – D5) and commercially available feldspar Krasno Z55 NaK60 (ceramic bodies P1 – P5). B) Schematic of the second part of the experiment, where low-grade feldspar was prepared from the subsoil of the Vidnava kaolin deposit

In the second part of this study, the possibilities of the underlying parts of the Vidnava deposit as a source of feldspars were examined. First, samples ground to a fraction of 0.1–0.5 mm were processed. These samples (262, 271) were first washed in a sieve with a mesh size of 63 µm, due to the removal of kaolinite (the particle size of kaolinite is typically less than 20 µm). The oversize residues of these samples were dried and then subjected to dry magnetic separation in a magnetic field of 0.8 to 1.0 T. Micas (muscovite, biotite) transition into the magnetic fraction, This phenomenon is consistent with the generally accepted fact that mica behaves as a paramagnetic substance (this behaviour is explained by the presence of iron impurities in its crystal lattice) (Kendall and Yeo, 1948; Ma et al., 2020). Feldspar and quartz are transferred to the nonmagnetic fraction.

2.3. Methods

The following methods were used in the research. The first method used was the firing test. The firing test was based on firing a small amount of raw material on a ceramic substrate at a temperature of 1360 °C in a reducing atmosphere. Subsequently, the appearance of the raw material (iron melting) was evaluated. In addition, the following are the basic physical characteristics. The basic technological properties of individual samples were evaluated in terms of bulk density, water absorption, and open porosity. These characteristics were determined using the Archimedes method according to CSN EN

60672-2 (Sample was dried at 105°C for 1 hour and weighed after drying. The samples were saturated with the liquid by boiling for one hour. The liquid-saturated samples were left in water for 24 hours. Saturated samples were weighed. Based on the data obtained, the characteristics of the above-mentioned material were calculated) and assessed according to CSN EN 60672-3 (acceptance criteria according to CSN EN 60672-3 for porcelain are: open porosity max. 3 %, bulk density min. 2.2 g/cm^3, max water absorption. 1.5 %). Magnetic separation was used to remove iron. Dry magnetic separation was performed on an LSV magnetic separator (Sollau) with a magnetic field about magnetic induction of 1.0 T. Wet magnetic separation was performed on an MX-L matrix magnetic separator (Sollau). A coarse matrix (Sollau) was used. Magnetic field with magnetic induction 1.2 T. The chemical composition was determined using an XRF DELTA professional handheld X-ray fluorescence spectrometer (Olympus Corporation, Tokyo, Japan). This X-rax fluorescence spectrometer utilised a miniature X-ray tube (4W max. 200 µA current) and a large-area silicon drift detector (SDD). The results were evaluated and quantified using Innov-X Delta Advanced PC software (Innov-X System, version 2.5). The mineralogy composition of the samples was determined using X-ray diffraction analysis (XRD). The mineralogical composition of the samples was determined using a Bruker D8 Advance powder X-ray diffractometer (Bruker AXS, Karlsruhe, Germany) in Brag-Brentag configuration. The diffraction record was taken in an angular range of 4 to 80°C 2Θ with a step of 0.015°. The results were evaluated and quantified using Topaz 5 (Bruker AXS 2014). The strength was determined using the three-point bending method on an Instron 3400 machine.

3. Results and discussion

The results of the firing test on raw feldspar detritus are shown in Fig. 2. According to the results of this test, all feldspar detritus was identified as suitable for application in ceramic materials. The results of basic physical characteristics determinations are summarised in Table 4.

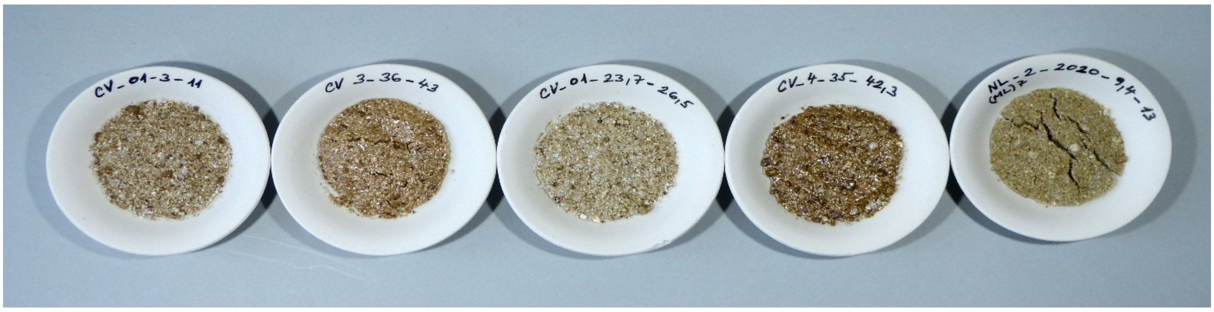

Fig. 2. Firing of raw feldspar detritus from Table 1, carried out at a temperature of 1360°C C (heating rate 3 °C/min, holding time at maximum temperature (1360°C) 1-hour, natural cooling, reducing atmosphere 800–1100 °C, carbon monoxide content in the reducing atmosphere 8%). The picture shows that no melt out occurred and therefore these materials were acceptable for use in this study. On this picture there were negative consequences presence iron in these materials as him coloration

Table 4. Determined values of water absorption, bulk density, and open porosity for samples of formulations D1–D5, fired at a temperature of 1260°C (heating rate of 3°C/min, holding time at peak temperature of 1-hour, natural cooling), fired at a temperature of 1360 °C (heating rate 3 °C/min, holding time at maximum temperature 1-hour, natural cooling, reducing atmosphere 800–1100 °C, carbon monoxide content in the reducing atmosphere 8%)

Sample labelling	Firing temperature	D1	D2	D3	D4	D5
Absorbency [%]	1260°C	0.84	0.67	0.76	1.27	1.66
	1360°C	0.14	0.13	0.16	0.19	0.33
Bulk density [g/cm^3]	1260°C	2.20	2.31	2.33	2.34	2.30
	1360°C	2.29	2.29	2.29	2.28	2.27
Open porosity [%]	1260°C	1.86	1.54	1.76	2.98	3.82
	1360°C	0.33	0.31	0.38	0.43	0.75

Based on the results shown in Table 4, formulations D1 to D3 can be considered suitable in terms of bulk density and water absorption for porcelain-type materials as specified by the CSN EN 60672-3 standard. Comparison of firing temperatures of 1260°C and 1360°C (reducing atmosphere) showed that higher firing temperatures and a reducing atmosphere contribute to better sintering of the ceramic material, as can be seen in Table 4 above, i.e., the values for samples D1 – D5 fired at a hot 1360°C reduction show lower values of water absorption and open porosity.

However, one of the limiting properties of these materials was their colouration, which was caused by the presence of a higher proportion of Fe_2O_3 in the raw materials used for the formulation design, in particular the high proportion of Fe_2O_3 in Halamky I feldspar powder (2.58%), as shown in Table 1, but also by the high iron content in the feldspar detritus itself (0.99% - 1.71%), as shown in Table 1. These higher iron contents largely determined the possibility of using this feldspar detritus in areas where the whiteness of the fired ceramic body was not emphasised. The colour of the ceramic shard could be seen in Fig. 2. The colour of the body could be partially corrected by the firing atmosphere, with a reducing atmosphere producing a body with a slightly lighter colour.

Based on the finding, materials D1 – D3 comply with the absorbency and open porosity of porcelain-type materials. Their appearance is strongly influenced by the high iron content in the ceramic material. A supplementary experiment was conducted with commercially available Ž55 NaK60 feldspar from the Krasno site. Identical recipes were prepared, as shown in Table 3.

Table 5. Determined values of water absorption, bulk density, and open porosity for samples P1–P5 fired at fired at a temperature of 1260°C (heating rate of 3°C/min, holding time at peak temperature of 1-hour, natural cooling), fired at a temperature of 1360 °C (heating rate 3 °C/min, holding time at maximum temperature 1-hour, natural cooling, reducing atmosphere 800–1100 °C, carbon monoxide content in the reducing atmosphere 8%)

Sample labelling	Firing temperature	P1	P2	P3	P4	P5
Absorbency [%]	1260°C	0.84	0.70	0.84	1.22	1.27
	1360°C	0.28	0.09	0.20	0.20	0.15
Bulk density [g/cm^3]	1260°C	2.35	2.32	2.33	2.29	2.32
	1360°C	2.27	2.29	2.27	2.26	2.29
Open porosity [%]	1260°C	1.99	1.63	1.96	2.79	2.96
	1360°C	0.64	0.21	0.46	0.44	0.34

Halamky I feldspar powder was replaced with Krasno Z55 NaK60 feldspar. Samples with a recipe where Z55 Krasno feldspar was used instead of Halamky feldspar dust off were labelled P1-P5. These samples were fired at temperatures of 1260°C and 1360°C (reduction), and then identical characteristics (water absorption, bulk density, open porosity) were determined as for samples D1 – D5. These results is shown in Table 5.

Based on a comparison of the values in Table 4 and Table 5, it was clear that the type of feldspar used did not have a significant effect on the characteristics of the sample (water absorption, bulk density, and open porosity). The effect of the feldspar used was not apparent even in terms of the colouration of individual samples (see Fig. 3).

To verify the technological properties of the proposed ceramic bodies, the D2 ceramic body was selected due to its low iron content in its chemical composition. The D2 ceramic body was prepared as described above and, in order to homogenise a larger quantity, it was ground in a jar mill. The prepared mixture was moistened with an emulsion of mineral oils, natural oils, and water, as recommended by Valenta (Valenta, 1999). A model product (Fig. 4) was pressed from the prepared ceramic body on a mechanical press to verify the pressing properties of the ceramic body. Furthermore, the mechanical strength of the material D2 was determined to be 15.74 MPa and the shrinkage was determined to be 13.61%. Both of these values were determined for samples fired at a peak temperature of 1260°C (oxidising atmosphere).

Another important factor was the nature of the waste raw materials used (feldspar dust from Halamky and feldspar detritus from the Vidnava deposit). In both cases, these were very fine raw

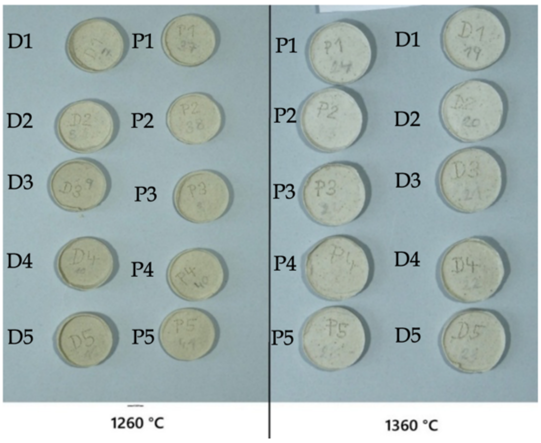

Fig. 3. Fired test samples of materials D1 - D5 and P1 - P5 fired at temperatures of 1260°C (heating rate of 3°C/min, holding time at peak temperature of 1-hour, natural cooling), fired at a temperature of 1360 °C (heating rate 3 °C/min, holding time at maximum temperature 1-hour, natural cooling, reducing atmosphere 800–1100 °C, carbon monoxide content in the reducing atmosphere 8%). The appearance of the samples after firing is not affected by the type of feldspar used, but in the firing atmosphere in a reducing atmosphere the iron is reduced, resulting in a lighter-coloured ceramic shard

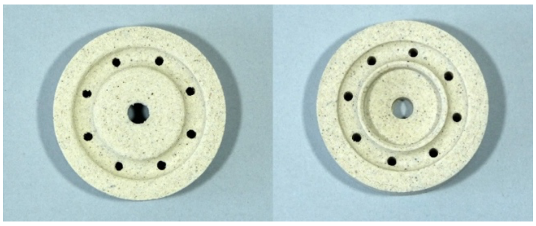

Fig. 4. Model ceramic part from ceramic body recipe D2, fired at 1260°C (heating rate of 3°C/min, holding time at peak temperature of 1-hour, natural cooling), prepared by wet pressing technology for demonstration of technological properties of this ceramic body I real production process

materials that could significantly reduce the grinding time of the ceramic material. Another important technological aspect was that, in addition to saving energy, time and wear and tear on machinery due to shorter grinding times, feldspar detritus could partially replace feldspar (which was now a critical raw material) and, above all, quartz sand, which was used as grog in porcelain-type materials and required a longer grinding time than the proposed materials using feldspar detritus, which already contained finely dispersed quartz in their composition. Further potential savings could be seen in the use of Halamky feldspar dust as a substitute for commercially available feldspars.

The main limitation of the proposed materials was the higher iron content in their chemical composition and thus their characteristic colouration. For this reason, the use of these materials containing feldspar detritus could be seen primarily in the field of technical ceramics for products, where a very low iron content was not required in the ceramic body, and where the requirements for the colour of the body were not as strict in terms of colour shade as in functional ceramics.

The second part of the study aimed to find the optimal use of the overburden (feldspar detritus) and the underlying parts of the Vidnava deposit, which consisted of feldspar kaolins. On the basis of this assumption, these underlying parts were used as raw material to obtain feldspar. As mentioned above, feldspar was classified as a critical raw material (European Parliament and Council, 2024). The sample taken from the overburden deposit was marked 262 (10,9 – 13,2 m), and the sample from the underlying part of the Vidnava deposit was marked 271 (41 – 45,9 m) was crushed into fractions smaller than 0.1 mm and into fractions of 0.1 to 0.5 mm.

The proportion of the non-magnetic product for individual samples was quantified in Table 6. At that stage, the obtained quartz–feldspar mixture could be classified as low-grade feldspar suitable for use in the ceramics industry. To verify the melting effects of these feldspar-quartz mixtures, a firing test was performed on non-magnetic fractions obtained by dry magnetic separation of granite samples from

Table 6. Dry magnetic separation performed on washed samples from the Vidnava deposit (fraction 0.1–0.5 mm). All values are given in [%]

Sample labelling	262	271
Nonmagnetic product	63.81	78.59
Intermediate product	15.09	7.82
Magnetic product	21.11	13.60

the underlying parts of the Vidnava deposit. The results of firing tests at a temperature of 1380°C are shown in Fig. 5. The mineralogical composition of these samples is shown in Table 7.

As can be seen in Fig. 5, in all cases, the materials obtained were well melted. The non-magnetic fractions of samples 262 and 271 after dry magnetic separation were characterised by pure feldspar with a high quartz content (Agus et al., 2000; Gougazeh, 2022). Table 7 showed that these samples did not contain kaolin.

Mineralogical composition was determined (XRD) – see Table 7. Based on published data, the primary source of iron in feldspar materials is biotite (mica) (Hestnes et al., 2013). Since mica was not detected by XRD in the obtained feldspar-quartz mixture and given the light colour of the fired material, it can be assumed that iron is present in the material only in trace amounts. The XRF method determined that the material contained approximately 0.4% iron.

Table 7. Mineralogical composition samples (262, 271) from the Vidnava deposit, ground to a fraction of 0.1-0.5 mm, separated by dry magnetic separation at an induction of 1.0 T. All values are given in [%]

Sample	Quartz	K-Feldspar	Albite	Mica
262 (10,9 – 13,2 m)	76.5	23.5	-	-
271 (41 – 45,9 m)	66.1	33.9	-	-

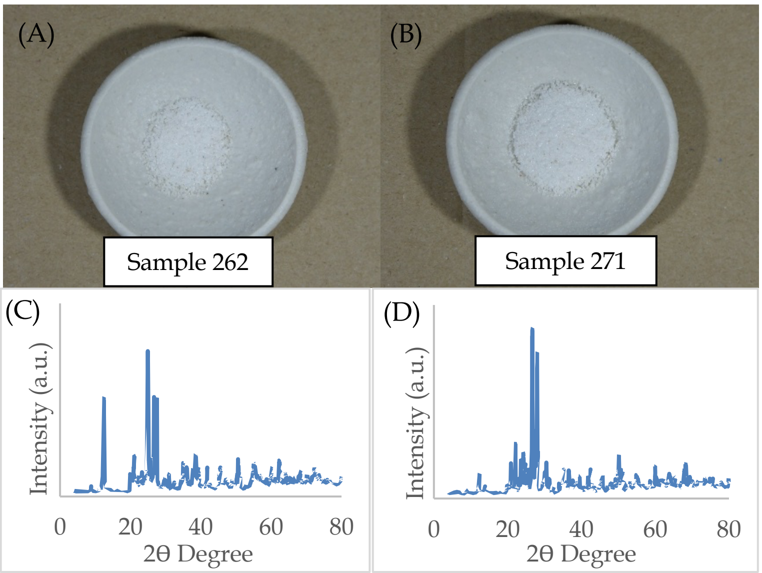

Fig. 5. A) Sample 262 from the Vidnava deposit, ground to a fraction of 0.1-0.5 mm, separated by dry magnetic separation at an induction of 1.0 T, non-magnetic fraction fired at a temperature of 1380 ° C (heating rate of 3°C/min, holding time at peak temperature of 1-hour, natural cooling). The sample is white in colour, this phenomenon corresponds to the low iron content in the sample, which was determined to be 0.25% by the XRF method. B) Sample 271 treated in the same way as sample 269 (Figure 5A). This sample was also white after firing identically to the sample in Fig. 5A, and the iron content was determined to be 0.33% by XRF. C) XRD record of sample 262 after dry magnetic separation, no micas (biotite) were detected in the sample, which are one of the main contaminants of feldspar with iron; this finding is also confirmed by the white colour of the firing, see Fig. 5A. D) XRD record of sample 271 after dry magnetic separation, no micas were detected in the sample, which is also why the light colour of the burnished stone corresponds

In addition to the dry magnetic separation process, an alternative process was tested on a second set of samples (samples 262, 271) from the Vidnava deposit, when the samples were ground to a fraction of less than 0.1 mm. Ground samples were transferred directly to a suspension and then double wet magnetic separation was performed using a coarse matrix. The balance of wet magnetic separation is shown in Table 8. The non-magnetic fractions were again fired at a temperature of 1380°C. The fired samples are shown in Fig. 6.

Table 8. Mass yields into products of wet magnetic separation on unwashed samples of the Vidnava deposit (fractions below 0.1 mm). All values are given in [%]

Sample labelling	262	271
Non-magnetic product	62.41	85.78
Magnetic product	37.59	14.22

Table 9. Mineralogical composition samples from the Vidnava deposit (262, 271), ground to a fraction of <0.1 mm, separated by wet magnetic separation at 1.2 T on a coarse matrix. All values are given in [%]

Sample	Quartz	K-Feldspar	Albite	Kaolinite	Mica
262 (10,9-13,2 m)	6.9	24.5	1.5	60.4	7.1
271 (41 – 45,9 m)	13.5	19.4	44.9	17.0	5.2

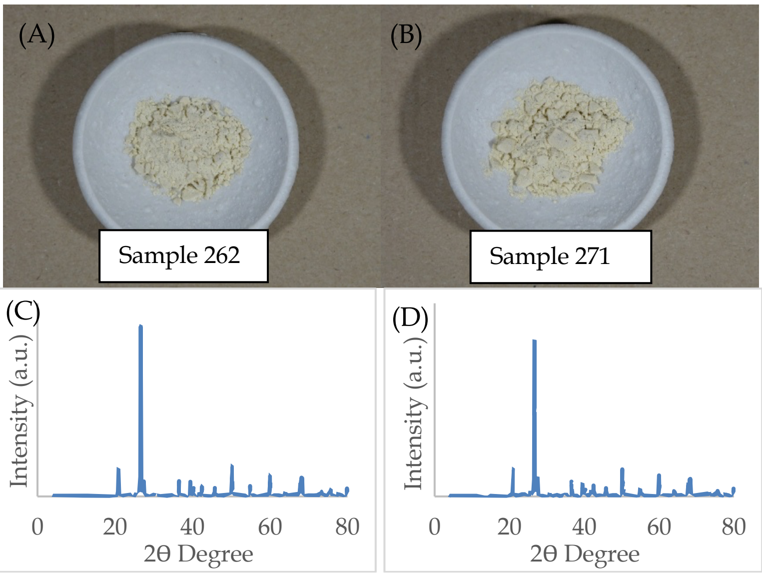

Fig. 6. A) Sample 262 from the Vidnava deposit, ground to a fraction of <0.1 mm, separated by wet magnetic separation at an induction of 1.2 T, non-magnetic fraction fired at a temperature of 1380°C (heating rate of 3°C/min, holding time at maximum temperature of 1-hour, natural cooling). The sample is not white in colour, this phenomenon corresponds to the content of kaolin and the mica in the material and small iron content in the sample, which was determined to be 0.39% by the XRF method. B) Sample 271 treated in the same way as sample 269. This sample was also not white after firing to the sample and the iron content was determined to be 0.42% by XRF. C) XRD record of sample 262 after wet magnetic separation, micas were detected in the sample, which are one of the main contaminants of feldspar with iron; this finding is also confirmed by the darker colour of the firing, see Fig. 6A. D) XRD record of sample 271 after wet magnetic separation confirms the conclusions from picture 6C

As shown in Fig. 6, omitting the technological step in which the kaolinitic fraction was removed using a 63 μm screen resulted in a material with a different structural character. The firing did not result in such perfect melting and vitrification as in the previous case. This phenomenon was caused by the presence of kaolinitic components (see Table 9). In Fig. 5, the kaolinitic fraction was completely removed by washing in 63 µm sieves, whereas in the samples shown in Fig. 6 the kaolinitic fraction remained present.

Based on the results, we concluded that the final product of the processing materials from the overburden of the Vidnava deposit (sample 262) was a low-grade feldspar-quartz mixture with a feldspar content of 23.5% (Table 7). We obtained this mixture by sieving the sample through a sieve with a mesh size of 63 µm. When screened using a mesh of 63 µm mesh, albite, which had particles smaller than 63 µm, was removed (Kilinc-Aksay, 2018), as was kaolinite, which had particles smaller than 20 µm (Yang et al., 2023). Given that the resulting quartz-feldspar mixture contained only 23.5% feldspar (indicating that it was a lean feldspar), the question of whether it would have been more advantageous from a technical standpoint to prepare a mixture containing kaolin, feldspar, and quartz from this raw material (sample 262). A mixture such as the one described above could have been prepared using wet magnetic separation, in which case this mixture would have constituted the virtually non-magnetic fraction remaining after wet magnetic separation. The composition of this mixture was 60.4% kaolinite, 24.5% potassium feldspar, and 6.9% quartz; the amount of albite in this mixture was only 1.5%. This kaolin-feldspar mixture could have been used directly in ceramic bodies, where it would have replaced part of the kaolin and feldspar (since feldspar was currently classified as a critical raw material).

The underlying sections of the deposit, consisting of feldspar-rich kaolins and underlying granites (sample 271), could be processed in a similar way. Using these raw materials, a feldspar-quartz mixture with a feldspar content of 33.9% was prepared by combining screening on a mesh of 63 µm mesh and dry magnetic separation. When this material was processed using wet magnetic separation, a mixture of potassium and albite feldspar with admixtures of kaolinite and quartz admixtures was obtained; see Table 9.

When we compared the materials of Fig. 5A,B and Fig. 6A,B, it was evident that the materials obtained by wet magnetic separation (Fig. 6A,B) were darker after burning. No iron minerals were detected during the determination of the mineralogical composition (Table 9). The most likely explanation for this phenomenon is that the kaolinite particles were coated with an amorphous iron-rich film, as reported by Guillemin et al. (Guillemin et al., 2024).

A comparison of Tables 7 and 9 clearly showed that screening through a 63 µm mesh allowed the separation of kaolinite with particle sizes below 20 µm (Yang et al., 2023) and also allowed the effective separation of potassium feldspar and albite based on differences in particle size (Kilinc-Aksay, 2018).

As part of this research, feldspar-quartz mixtures and feldspar kaolins were obtained, with the feldspar content in the material ranging from 23.5% to 64.3%. The proposed process is compared to currently used feldspar processing technologies, including flotation (Boulos et al., 2015), combined flotation with magnetic separation (Hestnes et al., 2013), and dry magnetic separation alone(Yassin et al., 2023). However, these methods currently primarily rely on raw materials from deposits of high-quality feldspar, which are limited.

Our ready-to-use products offer a cost-effective alternative that can partially replace traditional raw materials (high-percentage feldspar), thereby reducing the cost of manufacturing ceramic goods. Production of these products utilizes secondary raw materials generated during kaolin mining, which helps reduce the amount of waste produced during mining processes and is in line with the environmental sustainability requirements of the European Union.

With a recovery use rate exceeding 60%, the proposed processes are suitable for industrial implementation as a supplementary production process to the main kaolin production. The main advantage of these products is their lower price compared to high-percentage feldspars. The use of proven magnetic separation technologies, which are commonly used in industry and are economically viable It is also important to emphasise that no environmentally harmful flotation agents are used in the manufacture of the proposed products, which contributes to their sustainable use and minimises their environmental impact.

The main limitation of the materials described above was their higher iron content, which was primarily due to their nature as by-products of kaolin mining. As could be seen from the firing tests (Fig. 5), the elevated iron content made these materials particularly suitable for technical ceramic applications, where the emphasis was placed less on the colour of the ceramic body and more on the cost and availability of raw materials.

Regarding the limitations of the present study, the number of samples taken from the underlying parts of the Vidnava deposit was limited, although the possibility of processing these materials into feldspar–quartz mixtures was demonstrated. In light of this, more research in the form of operational tests was recommended.

4. Conclusions

The purpose of this study was to verify the possibilities of using feldspar debris from the overburden of the Vidnava kaolin deposit as an alternative raw material in the design of ceramic materials. At the same time, the potential usability of the underlying parts of the Vidnava deposit as a source of low-grade feldspar was assessed.

The use of waste dust off from feldspar dust off from Halamky vs. commercial feldspar 55 NaK60 from Krasno) has no significant effect on the basic physical characteristics of fired samples. Differences in water absorption, open porosity, and bulk density were minimal, both when fired at 1260°C and when fired at 1360°C in a reducing atmosphere. In terms of technological properties, Halamky feldspar dust off appears to be a fully-fledged substitute for commercially available feldspars.

The main limiting factor for the use of Halamky feldspar debris and feldspar dust off from Halamky is the higher content of Fe_2O_3. This predestines these raw materials for usage in the field of technical ceramics, where the requirements for the whiteness of the fired body are not so high.

A major advantage of using feldspar dust off and detritus lies in their very fine grain size, which allows a reduction in the grinding time required for ceramic materials. This leads to savings in both energy and processing time and reduces wear on technological equipment**.** In addition, feldspar detritus can partially replace quartz sand, which typically requires longer grinding times, as finely dispersed quartz is already a natural component of these raw materials.

The second part of the study confirmed that the overburden and underlying parts of the Vidnava deposit represent a potentially usable source of feldspar raw materials. The combination of washing on a 63 μm screen and dry magnetic separation allows nonmagnetic fractions to be obtained, which correspond in character to low-grade feldspars and exhibit relatively good melting properties when fired at a temperature of 1380°C. Therefore, removal of the kaolinitic fraction leads to a significant improvement in the colour quality of the resulting feldspar raw material. When the kaolinitic fraction is not removed, the material is classified as feldspar kaolin rather than low-grade feldspar; nevertheless, it remains suitable for technological applications.

In conclusion, the findings demonstrate that feldspar detritus and processed materials from the underlying parts of the Vidnava deposit exhibit considerable potential for usage in the ceramics industry. Their utilisation may contribute both to the partial substitution of critical raw materials, such as high-purity feldspar, and to more efficient use of waste materials generated during kaolin mining.

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