MULTICOMPONENT DEPOSITS WITH BY-PRODUCT AS THE MAIN SOURCE OF FELDSPAR RAW MATERIALS FOR MODERN TECHNOLOGIES

Dr. Geol.-Mineral. Sci., Dr. Geogr. Sci., Dr. Eng. Sci., Prof. Georgii Rudko[1]
Assoc. Prof. Ph.D. Mariia Kurylo[2]
Ph.D. Student Maksym Ozerko[3]
[1] State Commission of Ukraine on Mineral Resources, Kyiv, Ukraine
[2, 3] National Taras Shevchenko University of Kyiv, Kyiv, Ukraine

ABSTRACT

Feldspar is raw materials with a growing volume of production every year, as well as a price for it. Feldspar consumption has been gradually increasing in ceramics, glass industry for solar panels, housing, and building construction.

Feldspar raw materials include intrusive, effusive rocks, weathering crust of crystalline rocks, sedimentary altered and altered rocks, as well as partially medium and basic aluminosilicate rocks. It was defined an industrial application for each species of feldspar. Potassium feldspars (orthoclase, microcline, sanidine) are used in electroceramic, electrode, abrasive, and ceramics industries. For these productions, the potash module is fixed in a ratio of 2: 1. For some industries, in particular the manufacture of high-voltage ceramics, the necessary feldspars are as close as possible to pure potassium (with a modulus of at least 4: 1, which corresponds to 80% of the orthoclase component). Potassium-sodium raw materials, from a potassium modulus of at least 0.9, are used for building construction. Sodium minerals with non-standardized potassium modulus are used for the glass industry, the production of enamels, and products such as vitreous porcelain. Calcium feldspars, represented by plagioclase of higher numbers, have limited practical application and their presence in feldspar concentrates is undesirable.

According to mineral associations, all types of feldspar raw materials can be divided into five types: 1) feldspar (syenites, trachitis); 2) quartz-feldspar (pegmatites, granites, sands, etc.); 3) nepheline-feldspar (nepheline syenites, alkaline pegmatites); 4) quartz-sericite-feldspar (shales, secondary quartzites); 5) quartz-kaolinite-feldspar (sands, alkaline kaolins, secondary quartzites).

It is shown on the example of Ukrainian deposits of feldspar minerals that complex deposits with by-products become the main source for production. Especially if these are new mining operation facilities. The authors have identified three main types of such complex multicomponent deposits: 1) deposits of intrusive rocks where weathering crust of crystalline rocks are mined as a byproduct; 2) complex deposits, where feldspar rocks are enclosing or overburden and can also be considered as byproducts; 3) deposits where feldspar concentrate can be produced as a product of ore components processing.

Keywords: *feldspar minerals, by-product, multicomponent deposit, Ukraine*

INTRODUCTION

Feldspar is raw materials with a growing volume of production every year, as well as a price for it. Feldspar consumption has been gradually increasing in ceramics, glass industry for solar panels, housing, and building construction.

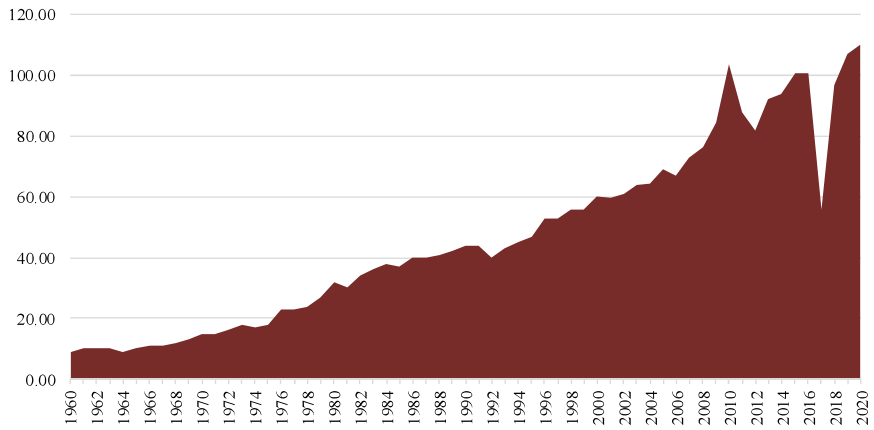

Fig. 1. *Feldspar price dynamics (according to statistical data usgs.gov [3])*

Feldspars deposits are divided into three main groups: potassium feldspars - (orthoclase, microclines) $K_2OAl_2O_3{\times}6SiO_2$, sodium feldspars - (albites) $Na_2OAl_2O_3{\times}6SiO_2$ and calcium feldspars - (anortites) $CaOAl_2O_3{\times}2SiO_2$, which are present to varying degrees in all crystalline rocks. Potassium feldspar is the primary rock-forming mineral of many igneous metamorphic and sedimentary rocks. In addition to the main groups, there are other feldspars, such as barium feldspar – $BaOAl_2O_3{\times}2SiO_2$ (celsian), but they are rarely used in ceramics. The primary parameter that characterizes feldspar concentrates is the potassium modulus (ratio K_2O:Na_2O).

According to modern concepts, feldspar raw materials include intrusive, effusive rocks, weathering crusts of crystalline rocks, sedimentary unaltered and altered rocks, as well as partially medium and basic aluminosilicate rocks.

Each type of feldspar has its field of industrial application:

- potassium feldspars (orthoclase, microcline, sanidine) are used in the electroceramic, electrode, abrasive and porcelain-earthenware industries. The potassium modulus for the porcelain-earthenware industry has been established in the ratio of 2:1. Feldspars as close as possible to pure potassium (with the modulus not less than 4:1 corresponding to 80% of the orthoclase component) are essential in several productions, particularly the production of high-voltage porcelain;
- potassium-sodium raw materials, with a potassium modulus of at least 0.9, are used in ceramic building materials;

- sodium raw materials with non-standardized potassium modulus are used in the glass industry, the production of enamels and products such as vitreous china;
- calcium feldspars represented by plagioclase of higher numbers have limited practical application, and their presence in feldspar concentrates is undesirable.

According to mineral associations, feldspar raw materials can be divided into five types:

- feldspar (syenite, trachyte);
- quartz-feldspar (pegmatites, granites, sands, etc.);
- nepheline-feldspar (nepheline syenites, alkaline pegmatites);
- quartz-sericite-feldspar (shales, secondary quartzites);
- quartz-kaolinite-feldspar (sands, alkaline kaolins, secondary quartzites).

Total balance reserves of feldspar raw materials as of 01.01.2020 amounted to 49109.07 thousand tonnes by categories $A+B+C_1$, cat. C_2 – 192703.8 thousand tonnes, off-balance – 192.91 thousand tonnes. The total production of feldspar raw materials in Ukraine amounted to 634.63 thousand tonnes in 2019 [1], [6], [7]. It is comparable to major global producers.

There are the following types of deposits in Ukraine:

1. Pegmatite deposits: Bilchakivske, Ustia village, Hruzlivetske, Lozuvatske, Volodymyrivske, Balka Velykoho Taboru;
2. Deposits of crystalline rocks: trachytes of the Verbova site, microgranodiorites of the Dubrynetske deposit;
3. Alkaline kaolins: Prosianivske, Pershozvanivske, Biliayivske, Katerynivske;
4. Multicomponent deposits (feldspar raw materials as a by-product): Bakhtyn (fluorite ores), Nosachivske (titanium-ilmenite ores), Perzhanske deposits of rare metals, Mazurivske (tantalum and niobium ores).

Currently, only the pegmatite deposit “Balka Velykoho Taboru” is being developed, and a special permit for the extraction of pegmatites from the “Hirne” deposit is invalid.

Feldspar raw materials were extracted from crystalline rocks - Dubrynytske deposit of microgranodiorite (Transcarpathian region), which occurs in the flysch rocks of the Carpathian Mountains in the form of a dyke-like body. The deposit was developed by OJSC “Steatyt”. Also, work was conducted to study trachytes of the Verbova site in the Telmanovo district of Donetsk region.

According to the analysis of feldspar raw material production, it is noted that the increase in feldspar raw material production is observed primarily in complex multicomponent deposits - the Piatyrichka section of the Dubrivske deposit and the Novakivska site of the Maidan-Vilske deposit, where alkaline kaolins, hard feldspar

and feldspar crystalline rocks (granites, migmatites, plagiogranites, pegmatoid granites) are developed.

The most significant object of additional study of feldspar raw materials is the Piatyrichka site of the Dubrivske deposit, which is being exploited. The Piatyrichka site of the Dubrivske alkaline kaolin deposit is located at a distance of about 400 m north of Hlynianka village (until 2016 - Piatyrichka) in the Baranivka district of Zhytomyr region.

Until 2019, the Piatyrichka site of the Dubrivske deposit was developed as a deposit of primary kaolins approved in 1991 by the protocol of the CCMR SE "Ukrbudmaterialy" in the amount of 614 thousand tonnes as raw materials for the production of refractory bricks. During 2019-2020, it was performed a geological and economic reassessment of primary kaolins as alkaline kaolins at the Piatyrichka site of the Dubrivske deposit with their reevaluation associated with a new direction of use and additional exploration of the lower part of the kaolin deposit – feldspar scree as feldspar raw materials, as well as underlying crystalline rocks (granites, migmatites, plagiogranites, pegmatoid granites) as feldspar raw materials. The quality of alkaline kaolins, feldspar scree and underlying crystalline rocks were determined by the content of SiO_2, Al_2O_3, Fe_2O_3, TiO_2, K_2O and Na_2O. In addition, the quality of crystalline rocks (granites, migmatites, plagiogranites, pegmatoid granites) as feldspar raw materials was previously studied.

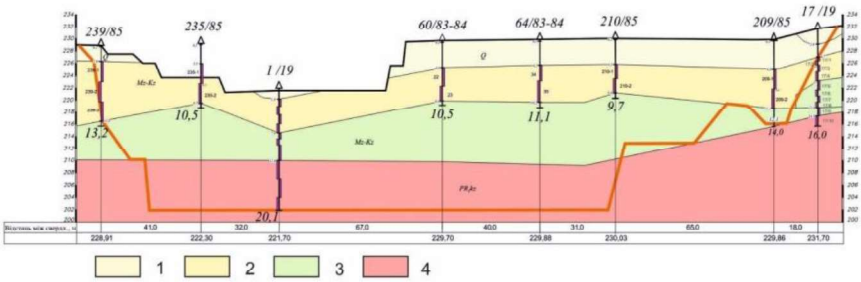

Fig. 2. *Schematic section of the Piatyrichka site of the Dubrivske deposit (according to data of the PC "Geolog")*

1 – sedimentary rocks (Q), 2 – alkaline kaolins (Mz-Kz), 3 – feldspar scree (Mz-Kz), 4 – feldspar crystalline rocks (granites, migmatites, plagiogranites, pegmatoid granites).

Table 1. *The quality of alkaline kaolins, feldspar scree, and underlying crystalline rocks of the Dubrivske deposit*

№	Component (indicator)	Content of the component (value of the indicator)		
		alkaline kaolin	feldspar scree	crystalline rock
Chemical composition (for calcined substance)				
1.	SiO_2 content, %	72,05-75,75	72,87-74,81	71,16-73,96
2.	Al_2O_3 content, %	17,55-18,63	15,33-16,17	15,12-15-64
3.	Fe_2O_3 content, %	0,64-0,68	0,61-1,16	1,10-1,15
4.	TiO_2 content, %	0,13-0,15	0,07-0,09	0,07-0,09
5.	K_2O+Na_2O content, %	6,07-6,86	7,71-7,96	8,40-8,56
Mineralogical composition				
6.	Feldspar, %	30-40	40-60	55-65
7.	Quartz, %	20-30	20-30	20-30
8.	Mica, %	2-5	2-5	2-5
9.	Kaolinite, %	30-40	5-25	0-5

It has been noted that the content of feldspars decreases from the bottom up due to the kaolinization of plagioclase, the content of alumina increases from the bottom up and accumulates in alkaline kaolins. The content of iron oxide is low. The refractory value of alkaline kaolins at the Piatyrichka site of the Dubrivske deposit was 1380-1710 C, feldspar scree – 1320-1580 C, and crystalline rocks – not determined.

Technological tests of laboratory-technological samples to check technological parameters of feldspar masses production in the industrial conditions were carried out at the ISU "Ceramic tile plant" of LLC Epicenter K in ceramic masses with the following content of raw materials.

Table 2. *Technological parameters of feldspar masses production*

№ ceramic mass	Content index			
	clay PJSC "Vesko"	alkaline kaolin site "Piatyrichka"	feldspar scree site "Piatyrichka"	pegmatite
Ceramic mass № 1	40,0	5,0	15,0	40,0
Ceramic mass № 2	40,0	10,0	10,0	40,0

Obtained ceramic masses were ground up and demagnetized from ferrous and weakly magnetic materials using a rod magnet. A mixture of masses was prepared; its technological parameters met the production and state technological requirements B B.2.7-117-2002 "Ceramic tiles for floors. Technical conditions". Currently, the ISU "Ceramic tile plant" of LLC Epicenter K uses both alkaline kaolin and feldspar raw materials for the manufacture of ceramic tiles [7], [9].

One of the complex multicomponent deposits of feldspar raw materials is the Mazurivske deposit of rare metal nepheline-feldspar ores (niobium, tantalum, zirconium) with approved reserves. It is one of the first discovered zircon deposits, where the industrial significance of the discovered ores was established in the course of exploration works in 1934-1948. The Mazurivske deposit was considered as a formation containing 2 ore types: zircon ores of the alkaline complex and

ilmenite ores of basic and ultrabasic rocks. The deposit was operated until 1967 when it was preserved with the advent of cheaper raw materials of the Vilnohirsk Mining and Metallurgical Plant. Due to the absence of an economic technological enrichment scheme, metals were not processed and were sent in the form of sludge (99% of the initial volume of ore) to dumps, where they were stored. About 2 million tonnes of ore were processed. Currently, accumulated "tailings" of the enrichment plant contain nepheline, feldspar, pyrochlore, rare metal, and rare earth minerals, and it is a technogenic deposit – a potential source of feldspar.

44 ore bodies were found at the deposit (Mazurivske ore node), including 10 within the studied area (within the project quarry). Ore bodies are traced at considerable distances, often more than 1000 m for some bodies. Their width is mostly more than 300 m, and the thickness varies from 1 to 45-80 m. Contacts of ore bodies with host rocks are clear, rapid, well-mapped visually in the core holes [4], [5], [8].

The deposit belongs to the geological-industrial type of rare metal albitite associated with nepheline syenites. The main industrial type of ore is disseminated, complex tantalum-niobium-zircon ore. The main carrier of niobium and tantalum is pyrochlore, zirconium – zircon. According to the content of conditional tantalum pentoxide, the generalizing conditional indicator that takes into account the contribution of each basic component to the cost of production, poor (common in various bodies from 16 to 33%), ordinary (28-58%), rich (15-55%) and very rich ores (0-2%) were identified within the deposit. Average contents of useful components (niobium, tantalum pentoxides and zirconium dioxide) in ores of the whole deposit were: 0.118%; 0.0057% and 0.47%, respectively; in the bodies of the detailed block - 0.116%; 0.004% and 0.49%. The distribution of niobium, tantalum and zirconium oxides in industrial bodies was uneven and extremely uneven.

During 2003-2004, state geological enterprise "Donetskgeologiya" carried out exploration works for geological and industrial assessment of technogenic enrichment wastes of the Mazurivske rare metal deposit on the area of 8.5 hectares. In 2005, the SCMR estimated the amount of feldspar raw materials in the dumps of the Eastern part of the deposit in the amount of 1133.5 thousand tonnes. Besides, the presence of associated mineral resources in the processing waste was detected in the amount of niobium pentoxide - 1053 tonnes, with the average content of Nb_2O_5 in the mineral - 0.09%, zirconium dioxide - 1313 tonnes, with the average content of ZrO_2 in the mineral - 0.11%.

During 2014-2016, LLC "Azov-Mineraltekhnika" carried out researches and developed technological regulations for feldspar raw materials. Test results showed the suitability of the material for the colored packaging glass production. Following the test results, LLC "Azov-Mineraltekhnika" developed technical conditions "Alkaline aluminosilicate flux".

Tests of feldspar concentrate with a low content of iron oxides in the ceramic tile and sanitary ware production showed that the material contains impurities, which give a darker color of the ceramic mass when firing ceramics, compared to feldspar materials of other manufacturers (with the same iron oxide content). Thus, feldspar concentrates from the enrichment waste of weathered ores of the

Mazurivske deposit with Fe_2O_3 content up to 0.5% in ceramic production are of limited use - for the production of ceramic products that are covered with opaque glaze. Calculations of technical and economic indicators characterize the economic feasibility of reserve development of the Eastern section of the weathered ore enrichment waste storage of the Mazurivske rare metal deposit [4], [5], [8].

As of 2020, balance reserves of feldspar raw materials of the Eastern section of the weathered ore enrichment waste storage amount to 826 thousand tonnes. Besides, ZrO_2 reserves in the amount of 510.8 tonnes with an average content of 0.172% and Nb_2O_5 - 283.3 tonnes, with an average content of 0.095% were calculated.

Processing stored waste allows us to free up large areas of tailings and eliminate the source of potential environmental hazard given the existing connection of tailings with the river Kalchyk basin. However, a base of feldspar raw materials can be created for the ceramic industry quite quickly and without significant investment [2]. Such production will become a testing ground for the preparation of the complex development of the Mazurivske deposit.

Due to the growing demand for rare metal raw materials, the Perzhanske ore field, within which there is the Perzhanske beryllium deposit, is of particular interest; it is represented so far by the only industrial-genetic and technological type of high-quality phenakite-genthelvin ores in alkaline (feldspar) metasomatites.

Two sites have been explored at the field: Pivnichna (5,5x1,5 km) and Krushynska (4,0x2,0 km). Ore zones occur with the extension of basic structural elements of the Sushchano-Perzhanska zone, their length reaches 5 km with a width of up to 35-100 m. Ore zones have been traced up to 400 m in depth. Each ore zone consists of a series of en echelon ore bodies with a thickness of a few meters up to 20-30 m. Ore bodies are composed of feldspar and mica-quartz-feldspar metasomatites, they form lenticular and vein-like formations of complex shape (characteristic swellings, obtuse wedging) deposits with rich genthelvite (genthelvite – Zn_4 $(BeSi_2)_3S$) mineralization (average BeO content is 0,55 %, maximum content - 8%). Ore bodies are bordered by a strip of 5-30 m of granite with blue newly formed quartz. The upper parts of ore bodies are composed primarily of albite-microcline metasomatites, the lower parts – mica-quartz-feldspar metasomatites. Phenakite mineralization, which is formed at an early stage of mineral formation, is spatially separated from the genthelvite one and localized primarily in the western part of endocontact of the Perzhanskiy granite massif forming a poor (average BeO content - 0.2%) impregnated mineralization. Cassiterite, columbite, and zircon are present as accessory minerals [10], [11].

The Perzhanske ore field is located in the central part of the Sushchano-Perzhanska tectonic-metasomatic zone of the north-eastern extension (north-western part of the Volyn megablock of the Ukrainian Shield), at its junction with the latitudinal North Ukrainian linear zone of tectonic activation [4]. This ore field together with Yastrubetske, Yurivske and Sushchanske ore-bearing fields form the Perzhanskiy ore district within the Sushchano-Perzhanska structural-metallogenic zone [10], [11].

Studies of the chemical composition of rocks in the Perzhanskiy ore node have shown that the amount of K_2O+Na_2O is 6,9-12,8 % in hydrothermal-metasomatic formations (syenites, granites, metasomatites) with a potassium modulus of 0,6-1,9, and they can serve as a material for feldspar concentrates, which will increase economic attractiveness.

One way to increase the investment attractiveness of deposits is the complex development of various ore objects in the ore field by one mining and processing plant, which would allow producing commodities for different purposes (beryllium oxide, zinc sulfide, ilmenite, apatite, disthene, zircon, rare earth, fluorite and feldspar concentrates) to ensure the development of electronic, nuclear, automotive and aviation industries and highly profitable agriculture.

It should be noted that the Mazurivske and Perzhanske deposits of rare metals are classified as priority development objects.

There are other multicomponent deposits with feldspar raw materials as a co-product - Bakhtyn (fluorite ores), Nosachivske (titanium-ilmenite ores).

Bakhtyn fluorite deposit is located in Murovanokurilovetsky district of Vinnytsia region. The deposit is confined to the Olchedaevsky and Yampolsky feldspar-quartz sandstones of the Vendian age. Deposit consists of two ore bodies (upper and lower) of a sheet-like form, consisting of disconnected lenticular bodies on an area of 700 x 1200 m, the depth of occurrence is 21.3–118.5 m. The total thickness of fluorite-containing sandstones varies from 0,4 to 4.7 m, and the fluorite content in them ranges from 5 to 48.9% (average 15%). Fluorite in sandstones is a typical epigenetic mineral replacing cement, partly quartz and feldspars. The Bakhtyn fluorite deposit is planned to be developed with an underground mine with a life of mine more than 20 years. During the operation of the deposit and flotation processing of ores, more than half of the commodity product will be feldspar concentrates.

Nosachivske apatite-ilmenite deposit is located in the Smelyansky district of the Cherkasy region of Ukraine. The deposit consists of two elongated sheet-like deposits. The length of ore bodies along the strike is up to 2000 m, the width across the strike is from 450 to 1000 m. Taking into account the mining and geological conditions of the deposit (the dip angle of deposits is 45º - 75º, the development depth is below 700 m from the earth's surface), the need to preserve the earth's surface with the existing high-grade objects and rational use of the subsoil, the most acceptable and economically feasible is the underground method of development. The output of the feldspar concentrates will be more than 2 million tons with planned productivity of 4 million tons of ore.

CONCLUSION

It is shown on the example of Ukrainian deposits of feldspar minerals that complex deposits with by-products become the main source for production. Especially if these are new mining operation facilities. The authors have identified three main types of such complex multicomponent deposits: 1) deposits of intrusive rocks where weathering crust of crystalline rocks are mined as a byproduct; 2)

complex deposits, where feldspar rocks are enclosing or overburden and can also be considered as byproducts; 3) deposits where feldspar concentrate can be produced as a product of ore components processing.

The production of feldspar concentrates as by-products with ore processing of multicomponent deposits is one of the ways of increasing their profitability. This is due to the large production volume of feldspar products and an increase in raw material prices. The price of feldspar products is not as high as that of the main components - metals, fluorite, apatite, but the huge output of these products affects the final deposit value as well as the prices of the main components.

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