

Research into phosphate mineral composition and waste phosphorite ore

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Abstract

Purpose. Theoretical and experimental studies of chemical and mineral composition and the structure peculiarities of phosphorites from Ukrainian deposits to define the degree of their suitability for other industries.

Methods. The ore chemical composition was determined by conventional (wet) analysis using standard certified chemical reagents. The mineral composition was studied on the scanning electron microscope equipped with the attachment for the energy-dispersive electron microprobe analysis (EMPA) with the software for calculating the chemical composition of the studied sample microvolume. The petrographic analysis was carried out by the traditional methods of microscopic section preparation with subsequent identification and description of the minerals. The microscopic study of the original ore samples aimed at their mineral composition determination was conducted on the Nu optical microscope (Germany) both in transmitted and reflected light. The thin and polished sections prepared using the standard technology were used as samples. In the laboratory environment, the phosphorites were subjected to magnetic dressing in magnetic fields with different intensity. The experiments in the weak field were modelled with the help of the magnetic analyzer while the experiments in the strong magnetic field were modelled on the rotor separator. The flotation dressing method was studied on the laboratory mechanical flotation machine.

Findings. It was found that phosphate nodules are rounded mineral formations of irregular shape; they consist of sand bound with the yellow-brown phosphate cement. Ore useful substance is a phosphorus-bearing mineral that by the element chemical composition corresponds to fluorocarbon-hydroxyl-apatite with the dominant content of Ca (45.23%), P (15.67%), and B (27.87%). The results of the integrated petrographic study of the phosphorite samples from the ore body of “Peremoha” area are presented.

Originality. The study has revealed that phosphorus-containing substance in the phosphorite samples is the mass that cements barren minerals (mainly quartz, glauconite, calcite and plagioclase).

Practical implications. According to the phosphate content level, the phosphorites from Malokamyshevatske, Iziumske and Sinichino-Yaremovske deposits can be treated as minerals for ferrophosphorus smelting.

Keywords: ferrophosphorus, ore substance, phosphorite, mineral varieties, petrography, apatite

1. Introduction

As is commonly known, phosphorus and sulphur are generally considered to be harmful elements, and their content in steel must be as low as possible. However, phosphorus, along with alloying elements, can be useful. Therefore, phosphorus appears to be among alloying elements, and its positive effect as an alloying element in low carbon steel has been known for a long time. For instance, phosphorus content of 0.025% in 14 Cr-15 Ni steel contributes to a significant increase in the creep strength of the alloy [1].

It has been shown that in ULC-BH steel, with the addition of phosphorus, the segregation of phosphorus along the grain boundaries can be both beneficial and harmful, which depends mainly on the annealing temperature [2]. The studies [3]-[5] proved a positive effect of phosphorus (from 0.01

to 0.20% wt) on the strength-ductility balance in steels cast on continuous casting machines.

Phosphorus is also widely used in the production of cast iron. Phosphorus addition in amounts of 0.5, 1.0, 1.5, 2.0 and 2.5% wt shows that phosphorus content rise in grey cast iron from 0.45 to 2.58% increases the amount of eutectic phosphide from 4.7 to 17.81%, and weakens mechanical properties (the tensile strength decreases from 297.5 to 184.1 MPa, the impact strength decreases from 4.3 to 2.7 J, the hardness increases from 215.43 to 249.38 and the eutectic temperature decreases from 1139.7 to 1102.5°C) [6].

Cast iron FC250 with phosphorus is used as an electrode connector during aluminium electrolysis [7]. Besides, the effect of phosphorus on the mechanical properties of nodular cast iron [8], [9] is also known.

Received: 10 September 2019. Accepted: 16 February 2020. Available online: 5 March 2021

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Published by the Dnipro University of Technology on behalf of Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

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1.1. Problem statement

Agriculture is known to be the main consumer of phosphorus-bearing minerals. The experience of highly developed countries shows that in order to obtain stable crop yields, it is necessary to apply 250-300 kg/ha of mineral fertilizers to the soil on primary nutrient basis [10]. To establish this level of fertilization, it is necessary to solve the problem of providing Ukrainian factories with mineral raw materials. Moreover, it should be noted that phosphorus is one of the most important components of any complex mineral fertilizer. Therefore, providing enterprises producing complex fertilizers with phosphorus raw materials is an important and urgent task. Until recently, there have been three sources of providing phosphate raw materials for the country. These have been the phosphorite and apatite deposits in the CIS countries, the Arabian-African phosphorite deposits and the Ukrainian phosphorite and apatite deposits. The analysis of the first source indicates that the production of fertilizers was based on these particular raw materials. Thus, all 7 plants producing phosphate fertilizers with a total capacity of 1.6 million tons were designed to process Khibiny apatite (Russia). Therefore, due to a sharp decrease in the Khibiny apatite production and a series of political reasons, Ukraine faced the problem of providing its plants producing fertilizers and ferrophosphorus with its own phosphorites and apatites. At present, the demand of Ukrainian steelmaking industry for ferrophosphorus used in metal alloying is satisfied by import.

The average mass content of phosphorus in the earth's crust (Clarke) is $9.3 \cdot 10^{-2}$. The most important of them are apatite and phosphorite [11].

Apatite $3(\text{Ca}_3(\text{PO}_4)_2) \cdot \text{Ca}(\text{F}, \text{Cl})_2$ is a mineral from the group F⁻ and Cl⁻, apatite contains (OH)⁻, O²⁻, CO₃²⁻, therefore it is classified into fluor- and chlorine-hydroxides, carbonate hydroxyapatites, as well as manganapatite, etc. Fluorapatite contains 43.3% P₂O₅, and chlorapatite contains 41.1% P₂O₅. The melting point of fluoroapatite is 1660°C, and that of chloroapatite is 1530°C. Apatites are used in the production of orthophosphoric acid by the sulphuric acid method, but they are not used in the production of phosphorite.

Phosphorite is a Ca₃(PO₄)₂ mineral of the apatite group, which is a part of natural mineral formations called phosphorites. Thus, apatites and phosphorites represent two groups of natural formations. Apatite deposits are referred to endogenous formations of magmatic origin. Phosphorite deposits have exogenous (sedimentary) character.

Ore formation of phosphorites is related to the accumulation of chemical and biochemical sediments in the areas of ancient shelves.

Over the past 30 years, the average volume of the mined ore has increased from 513 million tons at 14.3% P₂O₅ in 1983 to 661 million tons at 17.5% P₂O₅ in 2013 [12]. The ore processing scheme is standard: it starts with exploration, continues with mining and processing [13], [14].

The quality and reserves of phosphorite ore (phosphate rock) deposits explored in Ukraine are evaluated in conformance with the current quality requirements for phosphorite as a raw material for mineral fertilizers [15]. Phosphorite from the Malokamyshevatske group of deposits (Kharkiv oblast) is among the known and additionally explored phosphorite deposits prepared for booking of their reserves, which, according to preliminary estimates, can be suitable for ferrophosphorus smelting [16], [17]. For this reason, the theoretical and exper-

imental studies of the phosphate rock mineral composition and metallurgical properties allow to analyse the potential sources of raw materials for the production of phosphorus-bearing ferroalloys and determine the degree of suitability of phosphorites from Ukrainian deposits for their production.

1.2. The purpose and objectives of the study

The purpose is to study the microstructure of the phosphorite ore representative samples from "Peremoha" area using the X-ray spectroscopy; to identify the chemical composition of the phosphorites cemented with waste ore mineral formations; to determine the element chemical composition of the ore substance and carry out complex studies of the mineral composition of the phosphate substance and waste rock of phosphorite ore from the ore bed of "Peremoha" area in order to develop the dressing flow sheet.

2. Methods

The ore chemical composition was determined by way of conventional (wet) analysis with the use of standard certified chemical reagents.

The mineral composition was studied on the scanning electron microscope equipped with the attachment for the energy-dispersive X-ray spectroscopy with the software for calculating the chemical composition of the studied sample microvolume. The petrographic analysis was carried out by the traditional methods of the microscopic section preparation with subsequent identification and description of the minerals [16].

The microscopic study of the original ore samples aimed at their mineral composition determination was conducted on the Nu optical microscope (Germany) in transmitted and in reflected light. The thin and polished sections prepared according to the standard technology were used as samples.

Granulometry of the discovered and studied mineral formations was carried out using the standard technique by the following calculating formula:

$$h = \frac{(X_{\max} - X_{\min})}{1 + 3.322 \lg N}, \quad (1)$$

where:

X_{\max} , X_{\min} – the maximum and the minimum sizes of mineral fragments (sections) respectively;

N – the total number of determinations;

h – the breakdown interval width of statistical sampling.

Availability of carbonate minerals (calcite) was estimated by the phosphorite ore sample treatment with hydrochloric acid followed by the reaction: $\text{CaCO}_3 + 2\text{HCl} = \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$.

In the laboratory conditions, the phosphorite magnetic dressing method was studied in magnetic fields of different intensity. The experiments in the weak field were modelled on the magnetic analyzer for magnetic dressing, and in the strong magnetic field – on the rotor separator. Material containing 70% of -0.074 mm class with 30% of the solid mass fraction was delivered in the operating area of the separator made of 200 mm high tread plates. The matrix loading was 0.2 g/cm³. In the separator, the scalp rotor with the induction three times lower than in axial rotors was applied. The scalp rotor was removing magnetic product particles from the plates of the main rotors, which allowed to facilitate the iron-bearing particles extraction into the magnetic product. The magnetic field induction changed from 0.6 to 1.2 T.

The flotation dressing method was studied on the laboratory mechanical flotation machine with cell volume of 0.5, 1.0 and 1.5 L and with air capacity of 1.0 L/m³ of suspension. The impeller rotational speed was 26.7-28.3 s⁻¹, and the sample weights constituted 200, 400 and 600 g, while in the closed-cycle experiments they were 150, 350 and 500 g. The reagents and the reagent scheme were selected according to the phosphorite ore flotation data and the previously conducted experiments. The study was carried out with the anion collectors; sodium silicate was used as a depressing agent. The solid mass fraction in suspension through agitation was 26%, the mixing time – 3-10 min. The pH value was measured within the range from 6 to 11 and was regulated with sodium carbonate. Experiments on the reagent scheme selection were modelled with the help of mathematical design of experiments using the Latin square. The factor levels were varied within the following limits: 500-1000 g/t of soda Na₂CO₃; 100-800 g/t of sodium silicate solute Na₄SiO₄·10H₂O; 200-1000 g/t of flotation reagent – raw tall oil soap.

3. Results and discussion

3.1. General mineralogical character of phosphorite ore; varieties of phosphate layers, phosphate nodules and fraction sizes

In Kharkiv oblast (Izium district), three phosphate rock deposits with reserves of more than 5 million tons of ore (in terms of the equivalent amount of P₂O₅) have been explored. The group of Malokamyshevatske, Iziumske and Sinichino-Yaremovske deposits is the most promising one in terms of phosphate mineral resources use as a raw material for electrothermal ferrophosphorus production. In Malokamyshevatske and Sinichino-Yaremovske deposits, there are three types of a phosphorite bed: a phosphorite plate represented by the nodules of dark grey phosphorites of different shapes and sizes bound with the sand-and-marl cement (very strong in some areas) (Fig. 1); phosphorous nodules of predominantly irregular and rounded shape, ranging from some millimetres up to 3-5 cm in size occurring in the light grey and white sandy chalk and marl; phosphate nodules of various sizes (mainly irregular-shaped), and infrequently – rounded ones, found in the marly glauconitic sandstone.



Figure 1. Phosphate formation from the ore body of Malokamyshevatske deposit (“Peremoha” area) (actual size)

According to the fraction size, phosphate rock from Malokamyshevatske and Sinichino-Yaremovske deposits falls into nodular fractions (+2 mm), grain fractions (-2 + 0.04 mm) and slimes (-0.04 mm). Most phosphorus (represented by phos-

phate nodules, concretions and aggregates) has a fraction size of more than +2 mm. Phosphate rock of +2 mm fraction sizes is totally formed by the nodules and phosphate aggregates and contains from 16.30 to 20.47% P₂O₅. In addition to phosphate, it includes medium and weak carbonate sand inclusions. Occasionally there occur inclusions of clayey material and red iron oxides.

Phosphate nodules are rounded hard formations of irregular shape (from light-yellow to dark-brown and brown colour) consisting of sand material bound with yellow-brown phosphate cement. In big fraction sizes there may be phosphate pseudomorphs from organic residues. The sizes of some nodules reach 20×30, 40×40 mm, sometimes – 50×60 mm. Apart from nodular fractions, the granular part of ore with increased concentration of P₂O₅ can be of practical interest. Grain phosphate classes are represented by the micronodules and fragments, shapeless spalls and aggregates. There can occur a small amount of phosphate grains that are peculiar for granular phosphorites – pseudomorphs from organic residues – fecal concretions, teeth and shells.

There are four main areas in terms of the phosphate rock occurrence conditions in Malokamyshevatske deposit. One of them is “Peremoha” area (situated 4.5 km to the south of Kamenka village) with the reserves of P₂O₅ > 170000 t.

3.2. Experimental studies of phosphate and accessory mineral types of waste phosphorite ore by the electron microprobe analysis (EMPA) and petrography

The samples extracted from the open pit of “Peremoha” area were used as the object of the phosphorite ore mineral composition research. The microstructure of the studied phosphorite sample is represented by the conglomerate of the phosphorus-containing substance of sedimentary origin with inclusions of mineral containing insignificant quantities of phosphorus: quartz, feldspar etc.

The results of the chemical composition analysis at the points of the phosphorite ore sample from Malokamyshevatske deposit are shown in Figure 2 and in Table 1.

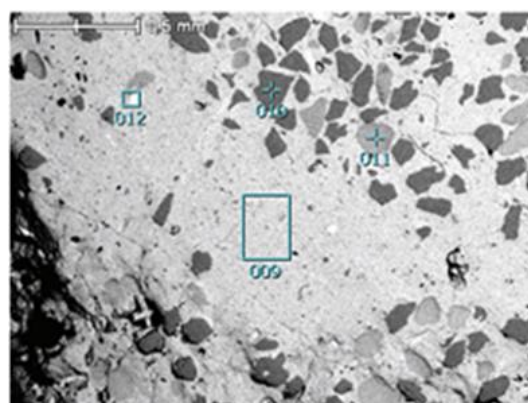


Figure 2. Results of the quantitative analysis of mineral formations chemical composition at the points of the phosphorite ore according to EMPA data

Sections of the phase microprobes in the areas are marked in Figure 2 as frames, while the points of local composition determination – as crosses; the corresponding data on the chemical composition of minerals are also presented. The mineral substance of white colour (frame 009) is a phosphorus-containing mineral – apparently, fluorocarbon-hydroxyl-apatite containing 45.23% Ca; 15.67% P; 27.87% O; 3.77% F, and 4.05% Si.

Table 1. Chemical composition of mineral phases at the studied points (Fig. 2) of phosphorite ore

Sample No.	Chemical composition of mineral phases, % wt											
	O	F	Na	Mg	Al	Si	P	S	K	Ca	Ti	Fe
009	27.87	3.77	0.71	0.47	1.21	4.05	15.67	0.61	0.41	45.23	–	–
010	37.94	–	–	–	0.15	57.54	1.40	–	–	2.96	–	–
011	32.02	0.65	–	2.79	7.12	31.66	1.36	–	8.32	3.33	–	12.77
012	28.01	2.38	0.68	0.23	1.11	4.68	11.71	0.46	0.70	31.00	13.31	5.75

The dark-grey sections of the metallographic specimen (frame 010) are almost pure quartz represented by grain fragments of various shapes. The light-grey sections of the metallographic specimen (frame 011) have complex chemical composition and are considered as aluminosilicates with a small concentration of phosphorus. They also contain oxides, hydroxides and ferric oxyhydroxides, potassium oxides, sodium oxides, magnesium oxides etc. The bright point inclusion (frame 012) is a mineral, apparently containing

ilmenite which, during the ferrophosphorus reduction melting, is mainly concentrated in slag.

3.3. Integrated petrographic studies of phosphorite from Malokamyshevatske deposit

The representative samples from the ore body of Malokamyshevatske deposit in “Peremoha” area were exposed to the integrated study of phosphorite ore mineral composition. The bulk composition (% wt) of the samples is presented in Table 2.

Table 2. Chemical (bulk) composition of the phosphorite ore sample from Malokamyshevatske deposit (% wt)

P ₂ O ₅	Fe ₂ O ₃	FeO	SiO ₂	CaO	MgO	Al ₂ O ₃	MnO	Na ₂ O	K ₂ O	F	LOI
17.00	5.05	0.65	31.30	30.91	2.45	1.72	0.30	0.42	0.69	1.50	6.80

The phosphorus-bearing substance in the phosphorite samples is represented by the mass cementing barren minerals (mainly quartz, glauconite (K, Na, Ca)_{<1}, (Al, Fe³⁺, Fe²⁺, Mg)₂ [(OH)₂] Al_{0.35}Si_{3.65}O₁₀], calcite and plagioclase). This peculiarity of the studied samples structure is shown in Figure 3.

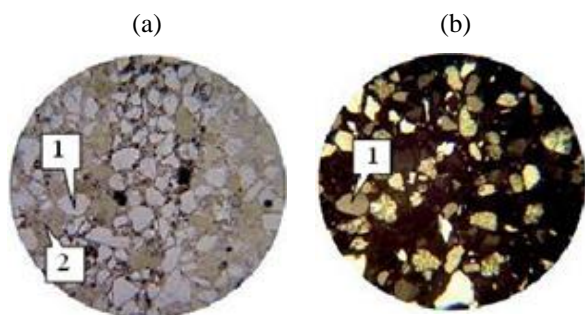
Francolite cement (Fig. 3) is represented in phosphorites by crypto-crystalline mass (aggregate) whose particles are indiscernible under the optical microscope. The formation of free phosphorite aggregate fragments is determined by other minerals' particle release, mainly quartz and glauconite.

Waste ore minerals (Fig. 4). Quartz is represented by the poorly rounded fragments without the intergrowth with other minerals. Quartz is known to exist in two modifications: α -quartz and β -quartz. When heated to 574°C, α -quartz transforms into β -quartz with volume ΔV increase by 80%. Quartz modification in phosphorite requires further investigation. The quartz grains granulometry revealed that section dimensions of quartz fragments in the microscopic section plane are measured from 0.13 to 0.52 mm (Fig. 5). The most frequent quartz particle size ranges from 0.086 to 0.157 mm. When selecting the process flow diagram parameters for phosphorous dressing, one should consider the necessity of the ore disintegration with respect to the fragment sizes of the waste ore minerals, mainly quartzous and glauconitic ones.

Glauconite is a complex hydroxylaluminosilicate (of the mica group) of the following composition: 4[(K, Na)(Al, Fe³⁺, Mg)₂(Al, Si)₄O₁₀(OH)₂]. The peculiarity of the mineral is the possibility for substitution of sodium atoms with calcium, and magnesium atoms with ferrous iron Fe²⁺.

Glauconite is classified as an intermediate member of the isomorphous series: aluminium-rich skollite K(Mg, Fe²⁺, Ca)(Al, Fe³⁺)₃H₄Si₆O₂₀ → aluminium-free celadonite K(Mg, Fe²⁺)(Al, Fe³⁺)Si₄O₁₀·(OH)₁₀ (layered silicates). The mineral crystallizes in monoclinic crystal system. The hardness of the mineral on the Mohs scale is 2.0 and the density is 2.4-3.0 g/cm³ depending on the iron and water content. At that, the following substitutions can occur: Fe³⁺ and Al³⁺ may be substituted with Mg²⁺ and Fe²⁺. Potassium can be substituted with Ca and Na, and Si with aluminium.

Glauconite is often associated with apatite (phosphorite), pyrite, various clayey minerals and calcite. In phosphorous ore, glauconite is represented by the dark-green and brown-green agglomerations of spherulithic type. The size interval of isolated glauconites is 0.026-0.260 mm, and the preferential size is 0.044-0.119 mm, which is less than for quartz (Fig. 5).

**Figure 3. Poorly rounded quartz fragments (1) in phosphorite cement (2); transmitted light, x30: (a) nicols II; (b) nicols X**

Both the energy-dispersive analysis and the X-ray phase analysis of the phosphate rock phase composition from “Peremoha” area were carried out. It was identified that the phosphate cement is represented by francolite from the apatite group [18].

According to the “Dictionary of Mineralogy” by G. Strubel and S.H. Zimmer [19], francolite is a synonym for carbon-apatite, and the latter is synonymous to carbonate-fluor-apatite and carbonate-hydroxyl-apatite. The dictionary also states that these minerals refer to the apatite group and are described by the most general formula Ca₅[(F, OH)(PO₄)₃]. In the “Encyclopedia of Mineralogy” edited by K. Frey, francolite (carbonate-fluor-apatite) is also referred to the apatite group.

There is also such mineral as dahllite Ca₃(PO₄·CO₃)₃(OH) (carbonate-hydroxyl-apatite) that results from phosphorite recrystallization and, similar to apatite, belongs to hexagonal syngony. Since our research focuses on the development of the rational process flow diagram for phosphorite dressing, it is important to note that francolite has a hardness of 5 on the Mohs scale, it is brittle with density of 3.18 g/cm³. In sedimentary rock, francolite occurs in rounded grains.

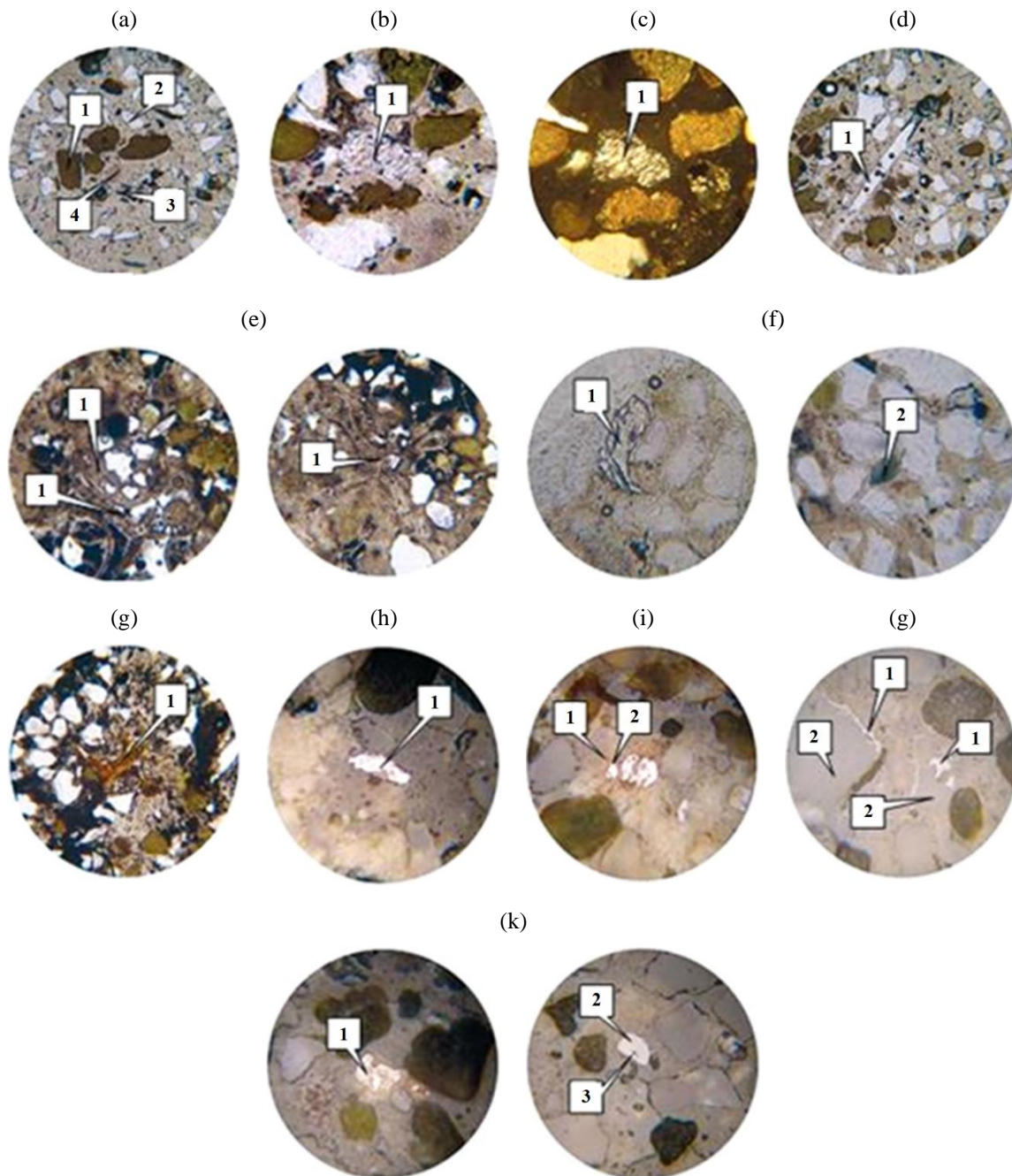


Figure 4. Petrography of accessory minerals and mineral impurities in the studied phosphorites: (a) assemblage of rounded glauconite formations (1) with quartz fragments (2) and ilmenite fragments (3) in phosphorite cement (4), transmitted light, nicols II, x30; (b) plagioclase fragment (1), transmitted light, nicols II, x50; (c) plagioclase fragment (1), transmitted light, nicols X, x60; (d) paleontological remains (1) in phosphorite cement (reddish brown) including quartz fragments (white) and glauconitic spherulites (green), transmitted light, nicols II, x30; (e) paleontological remains (1) in phosphorite cement (reddish brown) including quartz fragments (white) and glauconitic spherulites (green), transmitted light, nicols II, x30; (f) accessory minerals in phosphoritic sandstone, transmitted light: apatite fragment (1), x60; a “flake” of chlorite (2), x60; (g) accessory minerals in phosphoritic sandstone, transmitted light: fine flaky hydrobiotite aggregate (1), x30; (h) ilmenite fragments, reflected light: section of skew tilted fragment (1), x30; (i) ilmenite fragments, reflected light: section of horizontally-oriented fragment (1), clear polygonal outlines and inclusions of barren mineral (2), x30; (j) hydrogoethite fringes (1) around quartz fragments (2), reflected light, x70; (k) occurrence of ore accessories in phosphorites, reflected light: pyrite (1), x50 complex fragment of magnetite (2) and hematite (3), x75

Plagioclases are mixed crystals of sodium feldspar and potassium feldspar of ternary system $K[AlSi_3O_8]-Na[AlSi_3O_8]-Ca[Al_2Si_2O_8]$. Depending on the chemical composition, aluminosilicates form solid solutions. In the phosphorous ore, microstructure plagioclases were discovered as free fragments with poor rounding.

Pure calcite $CaCO_3$ is white, but, depending on the impurity elements, it may be of various colours. Calcite has a hardness rating of 3 on the Mohs scale, and its density is 2.6-2.8 g/cm^3 .

In the studied phosphorite samples, calcite is represented by the components of paleontological remains with the presence of phosphorous.

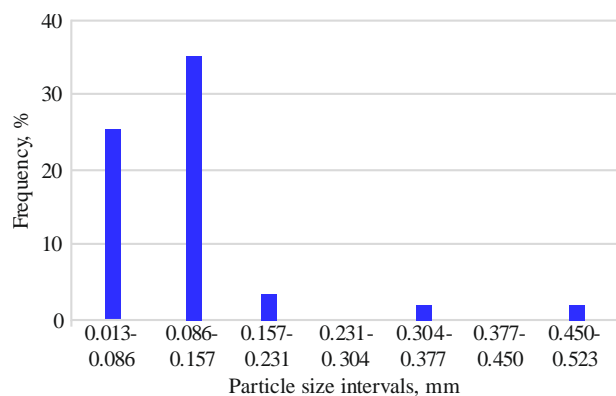


Figure 5. Distribution of quartz section dimensions in the microscopic section plane

Among the other mineral formations in the studied samples of phosphorite, the presence of individual hydrobiotite grains was detected $(K, H_2O)(Mg, Fe^{3+}, Mn)_3[(OH, H_2O)_2AlSi_3O_{10}]$. The latter is formed by way of biotite $K(Mg, Fe^{3+}, Mn)_3[(OH, F)_2(Al, Fe^{3+})Si_3O_{10}]$ and chlorite weathering. Chlorite is a mineral of a group of aluminosilicates Mg, Fe and Al of bedded structure with the general formula $(Mg, Fe)_{6-n}(Al, Fe^{2+})_n(OH)_8Al_nSi_{n-4}O_{10}$, where $n = 0.6-2.0$. Chlorites have a hardness of 2-2.5 on the Mohs scale, the density being 2.5-3.3.

When studying the non-transparent microscopic sections of phosphorite ore samples in reflected light, the following minerals were discovered: ilmenite $FeO \cdot TiO_2$, hydrogoethite $FeOOH \cdot nH_2O$, pyrite FeS_2 , magnetite Fe_3O_4 and hematite Fe_2O_3 , among which ilmenite is the most frequent. As a rule, ilmenite is represented by free elongated fragments ranging from 0.013×0.039 to 0.065×0.091 mm, averagely 0.026×0.065 mm.

Hydrogoethite is marked as the local sections in phosphorite cement that develop in the cracks; there are also hydrogoethite fringes around quartz fragments. Pyrite was discovered as individual free fragments of 0.065-0.091 mm. Magnetite and hematite are found in the form of individual complex fragments (signed quantity).

The statistical processing of the data received from determination of the volume content of various mineral formations in the phosphorite ore samples allowed to build the following hierarchy of minerals by their occurrence frequency (vol. %): quartz – 46.4; francolite – 27.9; glauconite – 17.6; calcite – 5.1; plagioclase – 1.4; ilmenite – 0.9; hydrogoethite – 0.3. The content of the other discovered minerals (hydrobiotite, chlorite, magnetite, hematite, pyrite) is not more than 0.1 % vol.

4. Conclusions

In the paper, the geological exploration data on the characteristics of the group of phosphorites from Malokamyshevske, Iziumske and Sinichino-Yaremovske deposits (Kharkiv oblast) have been generalized and analysed. It has been stated, that, according to the phosphate level content, these phosphorites, apart from fertilizer production, can be considered as minerals for ferrophosphorus smelting. Depending on the conditions of phosphate occurrence, there are 4 main areas in Malokamyshevske deposit, among which there is “Peremoha” area with the reserves of P_2O_5 of more than 170000 t.

When exploring “Peremoha” area, it has been revealed that phosphate nodules are rounded mineral formations of

irregular shape; they consist of sand bound with the yellow-brown phosphate cement. The sizes of some nodules may reach 20×30 , 40×40 and 50×60 mm. Grain phosphate classes are represented by micronodules, fragments and aggregates.

The electron microscopic investigation of the microstructure of the phosphorite ore representative samples from “Peremoha” area has been conducted and the quantitative research has been carried out by electron microprobe analysis. The chemical composition of the phosphorites cemented with waste ore mineral formations has been determined. It has been discovered that the ore grade substance is a phosphorus-bearing mineral which, by the element chemical composition, corresponds to fluorocarbon-hydroxyl-apatite with the following content (% wt): 45.23% Ca; 15.67% P; 27.87% O; 3.77% F and 4.05% Si.

The results of the integrated petrographic study of the phosphorite samples from the “Peremoha” ore body are as follows: 17.0% P_2O_5 , 30.91% CaO, 31.30% SiO_2 , 5.05% Fe_2O_3 , 2.45% MgO, 1.72% Al_2O_3 , 1.5% F, 0.69% Na_2O , 6.8% LOI.

The findings of the complex research into the mineral composition of phosphate substance and waste phosphorite ore from the ore body of “Peremoha” area indicate that the main components are represented by oxides P_2O_5 , CaO, and SiO_2 . This necessitates a certain flow chart for dressing, possibly by means of the ore heat treatment and the subsequent increase in the phosphorus oxide content.

Acknowledgements

The authors express special gratitude to Oliinyk Tetiana Anatoliivna, Doctor of Technical Sciences, Professor, Head of the Department of Mineral Processing and Chemistry at Kryvyi Rih National University for valuable guidance and invaluable assistance in preparing materials for the paper, as well as to Rudyi Mykola Hryhorovych, Head of the Kharkiv Integrated Geological Exploration Party, for his assistance in the selection and preparation of phosphate ore samples from “Peremoha” area.

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Дослідження мінерального складу фосфатної речовини і порожньої породи фосфоритової руди

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Мета. Теоретичні й експериментальні дослідження хімічного, мінерального складу, особливостей структури фосфоритів українських родовищ для надання оцінки ступеня їх придатності в інших галузях.

Методика. Хімічний склад руди визначали традиційним хімічним (мокрим) аналізом з використанням стандартних сертифікованих хімреактивів. Мінеральний склад досліджували на растровому електронному мікроскопі, оснащеному приставкою для проведення енергодисперсійного рентгеноспектрального мікроаналізу (РСМА). Петрографічний аналіз проводили традиційними методами підготовки шліфа і наступною ідентифікацією мінералів та їх описом. Мікроскопічні дослідження вихідних проб руди проводили на оптичному мікроскопі фірми "Nu" (Німеччина) в прохідному і відбитому світлі. Як зразки використовували приготовані прозорі й поліровані шліфи. Метод магнітного збагачення фосфоритів у лабораторних умовах виконували в полях різної інтенсивності. Експерименти в слабкому полі моделювалися на магнітному аналізаторі; в сильному полі – на сепараторі роторного типу. Дослідження флотаційного методу збагачення здійснювали в лабораторній флотомашині механічного типу.

Результати. Встановлено, що фосфатна речовина (фосфатні жовна) представляють собою округлі неправильної форми мінеральні утворення, що складаються з піщаного матеріалу, пов'язаного жовтувато-бурым фосфатним цементом. Рудна корисна речовина являє собою фосфоровмісний мінерал, за елементним хімічним складом відповідний складу фторкарбонгидроксилапатиту, де за вмістом переважає Са (45.23%); Р (15.67%); О (27.87%). Наведено результати комплексного петрографічного дослідження проби фосфорита з рудного пласта ділянки "Перемога".

Наукова новизна. Виявлено, що фосфоровмісна речовина в пробах фосфориту представлена масою, цементуючою нерудні мінерали (переважно кварц, глауконіт кальцит і плагіоклаз).

Практична значимість. За рівнем вмісту фосфатної речовини фосфорити Малокамишевського, Ізюмського та Синичине-Яремівського родовищ можуть розглядатися як мінеральна сировина для виплавки феррофосфору.

Ключові слова: феррофосфор, рудна речовина, фосфорит, мінеральні різновиди, петрографія, апатит

Исследования минерального состава фосфатного вещества и пустой породы фосфоритовой руды

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Цель. Теоретические и экспериментальные исследования химического, минерального состава, особенностей структуры фосфоритов украинских месторождений для дачи оценки степени их пригодности в других отраслях.

Методика. Химический состав руды определяли традиционным химическим (мокрым) анализом с использованием стандартных сертифицированных химреактивов. Минеральный состав исследовали на растровом электронном микроскопе, оснащённом приставкой для проведения энергодисперсионного рентгеноспектрального микроанализа (РСМА). Петрографический анализ проводили традиционными методами подготовки шлифа и последующей идентификацией минералов, и их описанием. Микроскопические исследования выходных проб руды проводили на оптическом микроскопе фирмы "Nu" (Германия) в проходящем и отраженном свете. В качестве образцов использовали приготовленные прозрачные и полированные шлифы. Метод магнитного обогащения фосфоритов в лабораторных условиях выполняли в полях различной интенсивности. Эксперименты в слабом поле моделировались на магнитном анализаторе; в сильном поле – на сепараторе роторного типа. Исследование флотационного метода обогащения осуществляли в лабораторной флотомашине механического типа.

Результаты. Установлено, что фосфатное вещество (фосфатные желваки) представляют собой округлые неправильной формы минеральные образования, состоящие из песчаного материала, связанного желтовато-бурым фосфатным цементом. Рудное полезное вещество представляет собой фосфорсодержащий минерал, по элементному химическому составу соответствующий составу фторкарбонгидроксилапатиту, где по содержанию преобладает Са (45.23%); Р (15.67%); В (27.87%). Приведены результаты комплексного петрографического исследования пробы фосфорита из рудного пласта участка "Победа".

Научная новизна. Виявлено, що фосфорсодержащие вещества в пробах фосфоритов представлены массой, цементирующей нерудные минералы (преимущественно кварц, глауконит кальцит и плагиоклаз).

Практическая значимость. По уровню содержания фосфатного вещества фосфориты Малокамишевского, Изюмского и Синичине-Яремівського месторождений могут рассматриваться как минеральное сырье для выплавки феррофосфора.

Ключевые слова: феррофосфор, рудное вещество, фосфорит, минеральные разновидности, петрография, апатит