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PAKHOMOVSKYITE, $Co_3(PO_4)_2 \cdot 8H_2O$, A NEW MINERAL SPECIES FROM KOVDOR, KOLA PENINSULA, RUSSIA

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Abstract

Pakhomovskyite, $Co_3(PO_4)_2 \cdot 8H_2O$, is a new mineral species found in dolomite carbonatite cutting phoscorites in the Iron-Ore Complex, Kovdor, Kola Peninsula, Russia. The mineral was found as groups (up to 3 × 2 cm) of small spherulites (up to 0.5 mm diameter) and rosettes (up to 0.05 mm diameter) of well-shaped tabular crystals growing on walls of leached fissures in dolomitic carbonatite. The associated minerals are bakhchisaraitsevite, bobierrite, magnetite, kovdorskite, rimkorolgite, juonniite, norsethite, chalcopyrite, phlogopite, pyrrhotite and pyrite. Pakhomovskyite is bright pink, with a dull luster in aggregates, and pearly luster in separate flakes. The streak is pink. The spherulites are translucent, non-fluorescent. The Mohs hardness is about 2. The mineral is flexible in thin flakes. Cleavage is perfect on {010}, and the fracture is stepped. Density is 2.71(2) g/cm^3 (measured using heavy liquids) and 2.71 g/cm^3 (calculated). Pakhomovskyite is biaxial (+), α 1.581(2), β 1.600(2), γ 1.631(2) (589 nm), 2*V* (meas.) 75–80°, 2*V* (calc.) 77°. The dispersion is weak, $r < v$. Optical orientation: $X = b$, $Y \wedge c$ in the range 22–23° in the obtuse β angle, with pleochroism from pale pink on *Y* to pinkish grey on *Z*. Chemical analysis with an electron microprobe gave (wt%): CoO 34.88, MgO 2.97, MnO 2.41, FeO 0.40, NiO 0.53, P_2O_5 27.95, H_2O (by the Penfield method) 29.50, total 98.64. The empirical formula calculated on the basis of Co+Mg+Mn+Ni+Fe+P = 5 is $(Co_{2.38}Mg_{0.38}Mn_{0.17}Ni_{0.04}Fe^{2+}_{0.03})_{\Sigma 2.99}(PO_4)_{2.01} \cdot 8.35H_2O$. The simplified formula is $Co_3(PO_4)_2 \cdot 8H_2O$. According to X-ray-diffraction studies, pakhomovskyite is monoclinic, *C*2/*m*, *a* 10.034(4), *b* 13.341(3), *c* 4.670(3) Å, β 105.02(2)°, *V* 603.8 Å^3, *Z* = 2. The strongest six lines in the X-ray powder-diffraction pattern [d_{obs}(Å)(I_{obs})*hkl*] are: 6.67(100)(020), 3.195(60)(13$\bar{1}$), 2.948(70)(31$\bar{1}$), 2.691(70)(221), 2.521(60)(24$\bar{1}$), 2.408(60)(40$\bar{1}$). Pakhomovskyite, a new member of the vivianite group, is an analogue of synthetic $Co_3(PO_4)_2 \cdot 8H_2O$. Pakhomovskyite is the latest low-temperature hydrothermal mineral to form, as a result of dissolution of primary ore minerals by alkaline phosphate-bearing solutions. The mineral is named in honor of Yakov A. Pakhomovsky, who has made significant contributions to the mineralogy of the alkaline massifs of the Kola Peninsula.

Keywords: pakhomovskyite, new mineral species, vivianite group, carbonatite–phoscorite complex, Kovdor massif, Kola Peninsula, Russia.

Sommaire

La pakhomovskyite, $Co_3(PO_4)_2 \cdot 8H_2O$, est une nouvelle espèce minérale découverte dans une carbonatite à dolomite recoupant les phoscorites du complexe à minerai de fer, massif de Kovdor, péninsule de Kola, en Russie. Le minéral se présente en groupes de petites sphérules atteignant 3 × 2 cm, chacune jusqu'à 0.5 mm de diamètre, et en rosettes de cristaux tabulaires bien formés jusqu'à 0.05 mm de diamètre, tapissant les parois de fissures lessivées dans la carbonatite dolomitique. Lui sont associés bakhchisaraïtsévite, bobierrite, magnétite, kovdorskite, rimkorolgite, juonniite, norsethite, chalcopyrite, phlogopite, pyrrhotite et pyrite. La pakhomovskyite est rose brillant, avec un éclat mat en aggrégats et un éclat nacré en feuillets distincts. La rayure est rose. Les sphérulites sont translucides et non fluorescentes. La dureté de Mohs est environ 2. Le minéral est flexible en feuillets minces. Le clivage est parfait sur {010}, et la fracture est en escalier. La densité mesurée avec liqueurs denses est 2.71(2), et la densité calculée est 2.71 g/cm^3. La pakhomovskyite est biaxe (+), α 1.581(2), β 1.600(2), γ 1.631(2) (589 nm), 2*V* (mes.) 75–80°, 2*V* (calc.) 77°. La dispersion est faible, $r < v$. Orientation optique: $X = b$, $Y \wedge c$ entre 22 et 23° dans l'angle β obtus, avec pléochroïsme allant de rose pâle sur *Y* à gris rosâtre sur *Z*. Une analyse chimique effectuée avec une microsonde chimique a donné (en %, poids): CoO 34.88, MgO 2.97, MnO 2.41, FeO 0.40, NiO 0.53, P_2O_5 27.95, H_2O (méthode de Penfield) 29.50, pour un total de 98.64. La formule empirique calculée sur une base de Co+Mg+Mn+Ni+Fe+P = 5 serait $(Co_{2.38}Mg_{0.38}Mn_{0.17}Ni_{0.04}Fe^{2+}_{0.03})_{\Sigma 2.99}(PO_4)_{2.01} \cdot 8.35H_2O$. La formule simplifiée est $Co_3(PO_4)_2 \cdot 8H_2O$. Selon les données en diffraction X, la pakhomovskyite est monoclinique, *C*2/*m*, *a* 10.034(4), *b* 13.341(3), *c* 4.670(3) Å, β 105.02(2)°, *V* 603.8 Å^3, *Z* = 2. Les six raies les plus intenses du spectre

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de diffraction (méthode des poudres) [d_{obs}(Å)(I_{obs})*hkl*] sont: 6.67(100)(020), 3.195(60)(13$\bar{1}$), 2.948(70)(31$\bar{1}$), 2.691(70)(221), 2.521(60)(24$\bar{1}$), et 2.408(60)(40$\bar{1}$). La pakhomovskyite, nouveau membre du groupe de la vivianite, est un analogue du composé synthétique $Co_3(PO_4)_2$•$8H_2O$. La pakhomovskyite est le dernier minéral à se former durant l'évolution hydrothermale, et résulte de la dissolution de minerais primaires par des solutions alcalines phosphatées. Le nom choisi honore Yakov A. Pakhomovsky pour ses contributions à la minéralogie des massifs alcalins de la péninsule de Kola.

(Traduit par la Rédaction)

Mots-clés: pakhomovskyite, nouvelle espèce minérale, groupe de la vivianite, complexe de carbonatite–phoscorite, massif de Kovdor, péninsule de Kola, Russie.

Introduction

Pakhomovskyite, $Co_3(PO_4)_2$•$8H_2O$, is a new mineral species from the Kovdor alkaline massif, Kola Peninsula, Russia. It was found in 2001 and identified by X-ray powder-diffraction pattern, which demonstrated its equivalence to $Co_3(PO_4)_2$•$8H_2O$, a synthetic cobalt orthophosphate octahydrate known since 1989 (Riou *et al.* 1989). Pakhomovskyite is the Co-dominant analogue of vivianite, barićite and arupite, and a P-dominant analogue of erythrite. So far, it is the third phosphate of the vivianite group found within the Kovdor hydrothermal veins.

The mineral is named in honor of Dr. Yakov A. Pakhomovsky (b. 1948), a mineralogist at the Geological Institute of the Kola Science Centre, Russian Academy of Sciences, who has made a significant contribution to mineralogy of the Kola alkaline massifs. Both the species and the name have been approved by the Commission on New Minerals and Mineral Names of the International Mineralogical Association (IMA) (proposal 2004–021). Type material of pakhomovskyite is deposited in the Mineralogical Museum of St. Petersburg State University, Russia, and in the Geological and Mineralogical Museum of Geological Institute of the Kola Science Center of the Russian Academy of Sciences, Apatity, Russia.

Geological Setting

The Kovdor massif of ultrabasic alkaline rocks and carbonatites is a central-type multiphase igneous intrusion (67°33' North, 30°31' East) in the Kola Peninsula, Russia. It was emplaced into Archean biotite- and hornblende-biotite gneisses and granitic gneiss of the Belomorsky block of the Baltic shield 360–420 million years ago (Kramm *et al.* 1993, Bayanova *et al.* 1997). The massif has a distinct concentrically zoned structure and contains three pronounced ring-shaped complexes (Ivanyuk *et al.* 2002).

Moving from the center toward the outer part of the massif, these are: (1) olivinite, (2) metasomatic rocks, containing phlogopite, diopside and melilite, among others, (3) turjaite and melteigite–urtite. Both the main rocks of the massif and the host fenitized gneiss are penetrated by dykes of nepheline and cancrinite syenite, ijolite, tinguaite, alnoite, shonkinite and calcite carbonatite. At the contact of olivinite and feldspathoid-bearing intrusions in the west, the massif is intruded by a concentric zoned stock of phoscorites in the outer zone and magnetite–carbonate rocks in the central zone. These rocks form the bulk of the Iron-Ore Complex. In turn, a stockwork of veins of dolomite carbonatite, picrite dykes and numerous explosion-pipes containing various breccias are concentrated within the Iron-Ore Complex.

The Iron-Ore Complex contains phoscorites (apatite–forsterite, forsterite–magnetite, apatite – forsterite – magnetite and forsterite rocks), magnetite–carbonate rocks (forsterite – calcite – magnetite, phlogopite – calcite – magnetite, magnetite–calcite and magnetite–dolomite rocks), carbonatites and phlogopitic glimmerites. The magnetite–silicate varieties are clearly concentrated at the periphery of the columnar orebody, and the magnetite–carbonate rocks occur within the central zone. This zonation is emphasized by the development of magnetite-free apatite–forsterite rocks at the outer boundary of the orebody and by the presence of calcite–magnetite rocks with a high pyrochlore content (called "anomalous" ore owing to their higher radioactivity) in the axial zone of the orebody. The final stage of formation of the Iron-Ore Complex was the intrusion of dykes of dolomitic carbonatite and the formation of hydrothermal veins related to the dolomite carbonatite. The veins contain hydroxylapatite, bobierrite, vivianite, barićite, kovdorskite, bakhchisaraitsevite, cattiite and pakhomovskyite.

Occurrence, Physical and Optical Properties

Dikes of dolomite carbonatite (up to 2 m wide) are mostly concentrated in the central part of the Iron-Ore Complex, within the "Anomalous" ore. Their contacts with host phoscorites, magnetite–carbonate rocks, magnetite-free calcite carbonatite, pyroxenite, and fenite are sharp; no alteration zones are developed around the dikes. The dolomite carbonatite is a white or cream-colored, massive medium- or coarse-grained rock, almost entirely made of equant grains of dolomite. The dike rock contains occasional newly formed calcite (up to 20 vol. %). Characteristic accessory minerals are richterite, pyrrhotite, zircon, brown phlogopite and tetra-ferriphlogopite, hydroxylapatite and magnetite.

The veins contain rare irregularly distributed voids encrusted by rhombohedral crystals of dolomite overgrown by various hydrothermal minerals: collinsite, bobierrite, vivianite, kovdorskite, rimkorolgite, bakhchisaraitsevite, pakhomovskyite and other rare phosphate minerals; these are associated with magnesite, strontianite, barite, henrymeyerite and pyrite where a dolomite vein cuts phoscorite or magnetite–carbonate rocks. An assemblage including catapleiite, labuntsovite-group minerals, natrolite, anatase, edingtonite and pyrite occurs where the dolomite vein cuts foidolite or alkaline diopsidite.

Pakhomovskyite was found in a dike (up to 0.8 m wide) of coarse-grained dolomite carbonatite cutting phoscorite of the Iron-Ore Complex (Fig. 1). In marginal parts of the vein, there are numerous inclusions of corroded cavernous tabular crystals of Co-bearing pyrrhotite, whereas crystals of dolomite, bakhchisaraitsevite, bobierrite, magnetite, kovdorskite, rimkorolgite, juonniite, norsethite, gladiusite, pyrite and chalcopyrite incrust small cavities in the axial zone of the vein. Pakhomovskyite forms groups (up to 3 × 2 cm) of small spherulites (up to 0.5 mm in diameter) and rosettes (up to 0.05 mm diameter) of single well-shaped tabular crystals (up to 0.05 mm in diameter) growing on walls of leached fissures in dolomite carbonatite (Fig. 2).

Aggregates of pakhomovskyite are bright pink (like erythrite), with a pink streak and a dull (in aggregates) to pearly (in separate flakes) luster. Separate spherulites are translucent, and thin flakes are transparent. No fluorescence was observed. Pakhomovskyite aggregates are very soft; the Mohs hardness is approximately 2. The mineral is flexible in thin flakes. The cleavage is perfect on {010}; its fracture is stepped. No twinning was observed. The density measured by flotation in a dilute Clerici–water solution is 2.71(2) g cm^{-3}; D_{calc} = 2.71 g cm^{-3}. In immersion liquids, the mineral is pale pink, with pleochroism from pale pink on *Y* to pinkish grey on *Z*. Optical orientation: $X = b$, $Y \wedge c$ = 22–23° in the obtuse β angle. Pakhomovskyite is biaxial, positive, with α 1.581(2), β 1.600(2) , γ 1.631(2) (589 nm), 2*V* (meas.) 75–80°, 2*V* (calc.) 77°. Dispersion is weak, $r < v$. The compatibility index is 0.048 (good).

The physical and optical properties of pakhomovskyite are compared with those of other minerals of the vivianite group and of synthetic $Co_3(PO_4)_2 \bullet 8H_2O$ in Table 1. In a hand specimen, pakhomovskyite can be fairly similar to erythrite, but the optical properties, density and (micro)habit of these minerals are quite different. The tabular shape of pakhomovskyite crystals as well as their bright pink color contrast with the blue color and prismatic habit of vivianite and arupite.

Chemical Composition

Chemical analyses of fourteen spherulites and separate crystals of pakhomovskyite were undertaken using a Cameca MS–46 electron microprobe operating at 20 kV and 20 nA, with a 30 μm beam diameter (Table 2). The beam diameter used in this study is rather large, as the mineral is unstable under the electron beam. Every analysis is an average result of the 6–10 points. The following standards were used: cobalt (Co), pyrope (Mg), synthetic $MnCO_3$ (Mn), hematite (Fe), nickel (Ni), apatite (P). Analytical difficulties due to the mineral instability under the electron beam were partially overcome by defocusing the beam and moving it slowly during the analysis. The concentration of H_2O was determined by Penfield's method. The empirical formula, calculated on the basis of Co + Mg + Mn + Ni + Fe + P = 5, is: $(Co_{2.38}Mg_{0.38}Mn_{0.17}Ni_{0.04}Fe^{2+}_{0.03})_{\Sigma 2.99}(PO_4)_{2.01} \bullet 8.35H_2O$. A simplified formula is $Co_3(PO_4)_2 \bullet 8H_2O$, which requires: CoO 44.00, P_2O_5 27.78, H_2O 28.22, total 100.00 wt.%. Pakhomovskyite is easily soluble in dilute (10%) cold HCl.

Crystallography

X-ray powder-diffraction data for pakhomovskyite (Table 3) were recorded using a 114.6-mm-diameter camera with a Fe*K*α radiation. The data were indexed and refined on the basis of a monoclinic unit-cell with *a* 10.034(4), *b* 13.341(3), *c* 4.670(3) Å, β 105.02(2)°, *V* 603.8 $Å^3$, Z = 2 and space group *C*2/*m*, which we obtained as a result of single-crystal X-ray studies with the precession method. The data are in agreement with the data reported by Riou *et al.* (1989) for synthetic $Co_3(PO_4)_2 \bullet 8H_2O$. Pakhomovskyite is isotypic with vivianite.

Genesis

Hydrothermal mineralization of carbonatite veins of the Kovdor massif is similar to that in Na-carbonate-bearing hydrothermal veins within the Khibiny alkaline massif (Goryainov *et al.* 1998). Low-temperature hydrothermal solutions, infiltrating alkaline rocks and fluorapatite-rich phoscorite, become enriched in P and F. Such solutions can extract Fe, Mg, Ba, Sr, Si, Zr, Al, Sc, the rare earths, and other chemical elements, including Co, from the host rocks. By reaction with dolomite, the alkaline-phosphate-bearing solution produces Ca- and Mg-phosphates, *e.g.*, collinsite:

$$CaMg(CO_3)_2 + CaCO_3 + 2H_3PO_4 \rightarrow Ca_2Mg(PO_4)_2 \bullet 2H_2O + 3CO_2 + H_2O$$

Other elements such as Fe (extracted from magnetite, pyrrhotite, *etc.*), Sc (extracted from baddeleyite), Ba

FIG. 1. Coarse-grained dolomite carbonatite cutting phoscorite of the Kovdor Iron-Ore Complex, Kola Peninsula, Russia. The 180-cm-high person standing in front of the cliff face is Dr. Anatoly Zaitsev (St. Petersburg State University).

FIG. 2. Pink crystals of pakhomovskyite on the matrix (a) and their SEM photo (b).

TABLE 1. COMPARISON OF PAKHOMOVSKYITE WITH SYNTHETIC $Co_3(PO_4)_2{\cdot}8H_2O$, VIVIANITE, ARUPITE AND BARIĆITE

Property	Pakhomovskyite[1] $Co_3[PO_4]_2{\cdot}8H_2O$	Synthetic[2] $Co_3[PO_4]_2{\cdot}8H_2O$	Vivianite[3)] $Fe^{2+}{}_3[PO_4]_2{\cdot}8H_2O$	Arupite[3)] $Ni_3[PO_4]_2{\cdot}8H_2O$	Barićite[3)] $Mg_3[PO_4]_2{\cdot}8H_2O$	Erythrite[3)] $Co_3[AsO_4]_2{\cdot}8H_2O$
Symmetry	monoclinic	monoclinic	monoclinic	monoclinic	monoclinic	monoclinic
Space group	C2/*m*	C2/*m*	*C*2/*m*	*I*2/*m*	C2/*m*	C2/*m*
a Å	10.03	10.02	10.09	9.89	10.08	10.25
b Å	13.34	13.33	13.47	13.23	13.42	13.45
c Å	4.67	4.67	4.70	4.65	4.67	4.67
β °	105.0	104.9	104.3	102.4	104.5	105.0
Z	2	2	2	2	2	2
Strongest lines in powder pattern	6.67 (100), 3.195 (60), 2.948 (70), 2.691 (70), 2.521 (60), 2.408 (60)	7.835 (30), 6.666 (100), 4.842 (30), 3.1849 (33), 2.9443 (26), 2.6947 (26)	7.93 (13), 6.73 (100), 4.90 (12), 4.081 (12), 3.210 (16), 2.985 (10)	7.878 (26), 6.624 (100), 4.818 (24), 3.805 (21), 3.152 (24), 2.922 (23)	6.71 (100), 3.196 (40), 2.956 (60), 2.699 (70), 2.526 (50), 2.418 (35)	6.65 (100), 3.34 (8), 3.22 (12), 2.70 (8), 2.32 (8), 1.677 (14)
Density g/cm^3	2.71	2.78	2.68	2.85	2.42	3.06
Mohs hardness	2	not measured	2	2	2	2
Color	bright pink	pink	colorless, blue to black and brown	turquoise blue to sky blue	colorless to pale blue	pink, crimson
Optical character	biaxial (+)	biaxial (+)	biaxial (+)	biaxial (+)	biaxial (+)	biaxial (+/–)
α	1.581	not measured	1.616	1.635	1.554	1.629
β	1.600	not measured	1.656	not measured	1.564	1.663
γ	1.631	not measured	1.675	1.680	1.595	1.701
2*V* °	75–80	not measured	64–84	not measured	55–60	very large to 90°
Orientation	*X* = *b*, *Z* ∧ *c* 22–23°	not measured	*X* = *b*, *Z* ∧ *c* 28.5°	not measured	*X* = *b* *Z* ∧ *c* 28–30°	*X* = *b* *Z* ∧ *c* 30–36°
Dispersion	*r* < *v*, weak	not measured	*r* < *v*, weak	not measured	*r* < *v*, weak	*r* < *v*
Pleochroism	*Y* pale pink, *Z* pinkish grey	not measured	*X* deep blue, *Y*, *Z* pale yellow	*X* blue, *Z* colorless	*X* blue, *Y*, *Z* colorless	*X*, *Y* pale pink, *Z* deep red
Habit	tabular crystals	plate-like crystals	prismatic to acicular crystals	short prismatic crystals	thick plates	flattened on [010] prismatic crystals
Cleavage	{010} perfect	not reported	{010} perfect	not reported	{010} perfect	{010} perfect, {100} and {$\bar{1}$02} poor

1) This work, 2) Riou *et al.* (1989), 3) Anthony *et al.* (2000).

TABLE 2. CHEMICAL COMPOSITION OF PAKHOMOVSKYITE

	Mean	Stand. dev.		Mean	Stand. dev.
CoO wt%	34.88	0.4	NiO	0.53	0.02
MgO	2.97	0.1	P_2O_5	27.95	0.5
MnO	2.41	0.05	H_2O*	29.5	0.5
FeO	0.4	0.02			
			Total	98.64	

and Sr (extracted from carbonates) are incorporated into vivianite, barićite, gladiusite, juonniite, krasnovite, rimkorolgite, strontiowhitlockite, among others.

The Co content of pyrrhotite of pakhomovskyite-bearing carbonatite vein is up to 0.1 wt.%, whereas in pentlandite from a phoscorite of the Anomalous Zone, it is up to 1.1 wt. % (Ivanyuk *et al.* 2002). Pakhomovskyite may well form according to the following reactions:

$$(Fe,Co)S + 2H_2O \rightarrow (Fe,Co)(OH)_2 + H_2S$$

$$3Co^{2+} + 2H_3PO_4 + 8H_2O \rightarrow Co_3(PO_4)_2{\cdot}8H_2O + 6H^+$$

The character of pyrrhotite dissolution, shown in detail by Liferovich *et al.* (2000), as well as the usual presence of vivianite and gladiusite in the same vein, support such suggestion.

Riou *et al.* (1989) prepared crystals of synthetic $Co_3(PO_4)_2{\cdot}8H_2O$ at room temperature from aqueous solutions. By analogy, we suggest that pakhomovskyite crystals grew from cold Co-bearing phosphate solutions in fissures of dolomite carbonatite that serve as a

TABLE 3. X-RAY POWDER-DIFFRACTION DATA FOR PAKHOMOVSKYITE, SYNTHETIC $Co_3(PO_4)_2$•$8H_2O$ AND BARIĆITE

Pakhomovskyite				Synthetic $Co_3(PO_4)_2$•$8H_2O$ ICDD 41-375		Barićite ICDD 29-705		
hkl	*I*	d_{meas}	d_{calc}	*I*	d_{calc}	*hkl*	*I*	d_{meas}
110	3	7.84	7.839	30	7.835	110	25	7.90
020	10	6.67	6.670	100	6.666	020	100	6.71
200	4	4.85	4.844	30	4.842	200	20	4.87
001	2	4.53	4.511	14	4.516	001	5	4.51
$11\bar{1}$	1	4.29	4.321	4	4.321	$\bar{1}11$	15	4.33
130	1	4.02	4.041	12	4.039	130	10	4.07
220			3.919	0	3.918			
$20\bar{1}$	4	3.84	3.833	25	3.830	$\bar{2}01$	20	3.83
021			3.736	1	3.739			
111	1	3.54	3.597	4	3.602	111	5	3.61
040			3.3350	0	3.3327			
$22\bar{1}$	1	3.31	3.3235	2	3.3209	$\bar{2}21$	1	3.34
$13\bar{1}$	6	3.195	3.1859	33	3.1849	$\bar{1}31$	40	3.196
310			3.1385	2	3.1374			
$31\bar{1}$	7	2.948	2.9477	26	2.9443	$\bar{3}11$	60	2.956
201			2.9424	19	2.9462			
131	2	2.870	2.8601	1	2.8618			
240	1	2.769	2.7469	4	2.7453			
221	7	2.691	2.6921	26	2.6947	221	70	2.699
041			2.6816	19	2.6816			
330	1	2.620	2.6128	11	2.6117	330	10	2.626
150			2.5722	3	2.5706			
$24\bar{1}$	6	2.521	2.5161	16	2.5142	$\bar{2}41$	50	2.526
$33\bar{1}$			2.4996	7	2.4971			
400			2.4218	1	2.4210			
$40\bar{1}$	6	2.408	2.4098	18	2.4070	$\bar{4}01$	35	2.418
311	2	2.318	2.3171	0	2.3193			
$15\bar{1}$			2.3037	12	2.3026	$\bar{1}51$	15	2.311
$11\bar{2}$			2.2992	3	2.3007			
$20\bar{2}$			2.2834	1	2.2836			
420			2.2764	1	2.2756			
$42\bar{1}$	1	2.275	2.2664	4	2.2639	$\bar{4}21$	5	2.275
002			2.2552	0	2.2579			
060			2.2233	0	2.2218			
241	3	2.206	2.2064	13	2.2073	241	30	2.217
151	3	2.170	2.1711	11	2.1712	151	10	2.179
$22\bar{2}$			2.1603	4	2.1603			
022			2.1364	2	2.1386			
$31\bar{2}$			2.0990	1	2.0980			
331			2.0796	2	2.0810			
$13\bar{2}$			2.0667	1	2.0675			
350	3	2.061	2.0568	10	2.0557	350	20	2.066
112			2.0558	1	2.0587			
260			2.0206	1	2.0194			
$35\bar{1}$	1	2.001	2.0002	2	1.9984			
061			1.9942	2	1.9936	061	5	2.001
440			1.9596	1	1.9587			
$51\bar{1}$			1.9542	2	1.9520			
$44\bar{1}$	1	1.946	1.9533	1	1.9513	$\bar{4}41$	5	1.959
401			1.9349	1	1.9364			
$26\bar{1}$			1.9233	2	1.9219			
$33\bar{2}$	1	1.918	1.9177	8	1.9167	$\bar{3}32$	10	1.922
510			1.9173					
$40\bar{2}$			1.9167	7	1.9150			
132	2w	1.880	1.8845	8	1.8866	$\bar{2}42$	5	1.886
$24\bar{2}$			1.8841	0	1.8838			
170			1.8699	1	1.8686	170	1	1.878
042			1.8682	0	1.8693			
202			1.8676	5	1.8704			
421			1.8583	1	1.8595			
$42\bar{2}$			1.8421	0	1.8406			

Pakhomovskyite				Synthetic $Co_3(PO_4)_2$•$8H_2O$ ICDD 41-375		Barićite ICDD 29-705		
hkl	*I*	d_{meas}	d_{calc}	*I*	d_{calc}	*hkl*	*I*	d_{meas}
$53\bar{1}$	1	1.803	1.8053	3	1.8035			
222			1.7985	1	1.8009			
530			1.7762	2	1.7755			
261			1.7739	0	1.7739			
351			1.7647	4	1.7651			
$17\bar{1}$			1.7587	1	1.7577	$\bar{1}71$	10	1.768
$15\bar{2}$	1	1.757	1.7567	4	1.7569			
171			1.6975	0	1.6972			
$51\bar{2}$			1.6903	0	1.6885			
441			1.6736	1	1.6743			
080	4	1.668	1.6675	7	1.6664	080	30	1.676
$60\bar{1}$			1.6630	9	1.6612			
$35\bar{2}$			1.6624	1	1.6615	$\bar{3}52$	10	1.667
$44\bar{2}$			1.6618	1	1.6604			
312			1.6455	1	1.6475			
370			1.6412	0	1.6402			
152	2	1.642	1.6407	9	1.6418			
460			1.6378	0	1.6370	460	15	1.648
$46\bar{1}$			1.6341	0	1.6326			
242			1.6295	1	1.6311			
511			1.6212	0	1.6221			
600			1.6146	2	1.6140			
$62\bar{1}$			1.6136	0	1.6119			
$37\bar{1}$			1.6120	0	1.6107			
$26\bar{2}$			1.5930	0	1.5925			
$53\bar{2}$			1.5912	2	1.5896			
$55\bar{1}$	2	1.591	1.5876	6	1.5861	$\bar{5}51$	10	1.593
062			1.5833	1	1.5837			
280			1.5767	1	1.5757			
620	2	1.572	1.5692	4	1.5687			
550			1.5677	6	1.5670	550	25	1.576
081			1.5640	1	1.5633			
$20\bar{3}$			1.5545	1	1.5555			
332			1.5537	1	1.5553			
$11\bar{3}$	1	1.536	1.5374	0	1.5388	113	5	1.539
531			1.5331	3	1.5338			
$28\bar{1}$			1.5291	2	1.5280			
$22\bar{3}$			1.5139	0	1.5146	$\bar{2}23$	5	1.514
$31\bar{3}$			1.5125	0	1.5126			
$60\bar{2}$	1	1.510	1.5112	4	1.5094			
003			1.5035	2	1.5053			
$64\bar{1}$			1.4882	4	1.4868	$\bar{6}41$	1	1.494
371			1.4809	0	1.4809			
$17\bar{2}$			1.4862	1	1.4760			
$62\bar{2}$	2w	1.475	1.4738	1	1.4722			
402			1.4712	6	1.4731	402	15	1.477
023			1.4667	1	1.4683			
190			1.4652	1	1.4642			
$13\bar{3}$			1.4617	3	1.4628			
461			1.4596	0	1.4598			
$40\bar{3}$			1.4578	1	1.4574			
640			1.4532	1	1.4526			
$46\bar{2}$			1.4517	1	1.4506			
281			1.4507	3	1.4504	281	10	1.459
$33\bar{3}$			1.4402	1	1.4402			
	1	1.422		1				
	1	1.407		1				
	1	1.371		1				
	4	1.337		1			25	1.341
							10	1.236
							5	1.222

geochemical barrier. This hypothesis is supported by the presence of cattiite, $Mg_3(PO_4)_2$•$22H_2O$, and nastrophite, $NaSr(PO_4)$•$9H_2O$, in surrounding carbonatite veins (Britvin *et al.* 2002). The presence of nastrophite reveals a high alkalinity of residual solutions, and cattiite could have formed only at low temperatures (5–20ºC). Therefore, pakhomovskyite can be considered as a mineral that formed as a result of the latest low-temperature stage of hydrothermal activity within the phoscorites of the Kovdor Iron-Ore Complex.

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