

PAKHOMOVSKYITE, $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, A NEW MINERAL SPECIES FROM KOVDOR, KOLA PENINSULA, RUSSIA

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ABSTRACT

Pakhomovskiyte, $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, 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, bobierite, magnetite, kovdorskite, rimkorolgitte, juonniite, norsethite, chalcopyrite, phlogopite, pyrrhotite and pyrite. Pakhomovskiyte 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 $2.71(2) \text{ g/cm}^3$ (measured using heavy liquids) and 2.71 g/cm^3 (calculated). Pakhomovskiyte is biaxial (+), $\alpha 1.581(2)$, $\beta 1.600(2)$, $\gamma 1.631(2)$ (589 nm), $2V$ (meas.) $75\text{--}80^\circ$, $2V$ (calc.) 77° . The dispersion is weak, $r < v$. Optical orientation: $X = b$, $Y \wedge c$ in the range $22\text{--}23^\circ$ 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 $\text{Co} + \text{Mg} + \text{Mn} + \text{Ni} + \text{Fe} + \text{P} = 5$ is $(\text{Co}_{2.38}\text{Mg}_{0.38}\text{Mn}_{0.17}\text{Ni}_{0.04}\text{Fe}_{0.03}^{2+})_{\Sigma 2.99}(\text{PO}_4)_{2.01} \cdot 8.35\text{H}_2\text{O}$. The simplified formula is $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. According to X-ray-diffraction studies, pakhomovskite is monoclinic, $C2/m$, $a 10.034(4)$, $b 13.341(3)$, $c 4.670(3) \text{ \AA}$, $\beta 105.02(2)^\circ$, $V 603.8 \text{ \AA}^3$, $Z = 2$. The strongest six lines in the X-ray powder-diffraction pattern [$d_{\text{obs}}(\text{Å})$ (I_{obs}/hkl)] are: 6.67(100)(020), 3.195(60)(131), 2.948(70)(311), 2.691(70)(221), 2.521(60)(241), 2.408(60)(401). Pakhomovskiyte, a new member of the vivianite group, is an analogue of synthetic $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. Pakhomovskiyte 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 Ya. A. Pakhomovsky, who has made significant contributions to the mineralogy of the alkaline massifs of the Kola Peninsula.

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

SOMMAIRE

La pakhomovskiyte, $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, 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 sphérolites 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 bakhchisaraitsevite, bobierite, magnétite, kovdorskite, rimkorolgitte, juonniite, norsethite, chalcopyrite, phlogopite, pyrrhotite et pyrite. La pakhomovskiyte est rose brillant, avec un éclat mat en agrégats et un éclat nacré en feuillets distincts. La rayure est rose. Les sphérolites 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 pakhomovskiyte est biaxe (+), $\alpha 1.581(2)$, $\beta 1.600(2)$, $\gamma 1.631(2)$ (589 nm), $2V$ (meas.) $75\text{--}80^\circ$, $2V$ (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 $\text{Co} + \text{Mg} + \text{Mn} + \text{Ni} + \text{Fe} + \text{P} = 5$ serait $(\text{Co}_{2.38}\text{Mg}_{0.38}\text{Mn}_{0.17}\text{Ni}_{0.04}\text{Fe}_{0.03}^{2+})_{\Sigma 2.99}(\text{PO}_4)_{2.01} \cdot 8.35\text{H}_2\text{O}$. La formule simplifiée est $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. Selon les données en diffraction X, la pakhomovskite est monoclinic, $C2/m$, $a 10.034(4)$, $b 13.341(3)$, $c 4.670(3) \text{ \AA}$, $\beta 105.02(2)^\circ$, $V 603.8 \text{ \AA}^3$, $Z = 2$. Les six raies les plus

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intenses du spectre de diffraction (méthode des poudres) [$d_{\text{obs}}(\text{Å})(I_{\text{obs}})hkl$] 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 pakhomovskiyte, nouveau membre du groupe de la vivianite, est un analogue du composé synthétique $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. La pakhomovskiyte 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 Ya. A. Pakhomovsky pour ses contributions à la minéralogie des massifs alcalins de la péninsule de Kola.

(Traduit par la Rédaction)

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

INTRODUCTION

Pakhomovskiyte, $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, is a new mineral species from Kovdor alkaline massif, Kola Peninsula, Russia. It was found in 2001 and identified by X-ray powder-diffraction pattern, which demonstrated its equivalence to $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, a synthetic cobalt orthophosphate octahydrate known since 1989 (Riou *et al.* 1989). Pakhomovskiyte is the Co-dominant analogue of vivianite, bari_ite 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 pakhomovskiyte 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 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, tinguaitite, 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, bari_ite, kovdorskite, bakhchisaraitsevite, cattite and pakhomovskiyte.

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, rimkorolite, bakhchisaraitsevite, pakhomovskite 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.

Pakhomovskite 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,

rimkorolite, juonniite, norsethite, gladiusite, pyrite and chalcopyrite incrust small cavities in the axial zone of the vein. Pakhomovskite 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 pakhomovskite 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. Pakhomovskite 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 $2.71(2) \text{ g cm}^{-3}$; $D_{calc} = 2.71 \text{ g cm}^{-3}$. In immersion liquids, the mineral is pale pink, with pleochroism from pale pink on Y to pinkish grey on Z . Optical orientation: $X = b$, $Y \wedge c = 22-23^\circ$ in the obtuse β angle. Pakhomovskite is biaxial, positive,

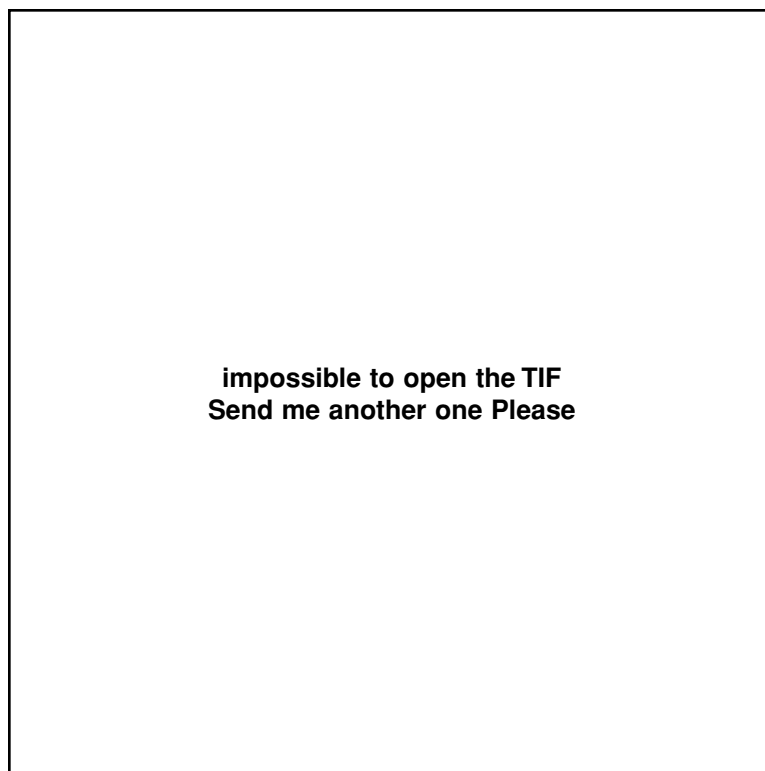


FIG. 1. Coarse-grained dolomite carbonatite cutting phoscorite of the Kovdor Iron-Ore Complex, Kola peninsula, Russia. The 180-cm-high person standing in front of the cliff face is Dr. Anatoly Zaitsev (St. Petersburg State University).



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

with α 1.581(2), β 1.600(2), γ 1.631(2) (589 nm), $2V$ (meas.) $75\text{--}80^\circ$, $2V$ (calc.) 77° . Dispersion is weak, $r < v$. The compatibility index is 0.048 (good).

The physical and optical properties of pakhomovskiyite are compared with those of other minerals of the vivianite group and of synthetic $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$ in Table 1. In a hand specimen, pakhomovskiyite can be fairly similar to erythrite, but the optical properties, density and (micro)habit of these minerals are quite different. The tabular shape of pakhomovskiyite 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 pakhomovskiyite were undertaken using a Cameca MS-46 electron microprobe operating at 20 kV and 20 nA, with a $30\ \mu\text{m}$ 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 concentra-

tion of H_2O was determined by Penfield's method. The empirical formula, calculated on the basis of $\text{Co} + \text{Mg} + \text{Mn} + \text{Ni} + \text{Fe} + \text{P} = 5$, is: $(\text{Co}_{2.38}\text{Mg}_{0.38}\text{Mn}_{0.17}\text{Ni}_{0.04}\text{Fe}^{2+}_{0.03})_{\Sigma 2.99}(\text{PO}_4)_{2.01} \cdot 8.35\text{H}_2\text{O}$. A simplified formula $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, which requires: CoO 44.00, P_2O_5 27.78, H_2O 28.22, total 100.00 wt.%. Pakhomovskiyite is easily soluble in diluted cold 10% HCl.

CRYSTALLOGRAPHY

X-ray powder-diffraction data for pakhomovskiyite (Table 3) were recorded using 114.6 mm diameter camera with a $\text{FeK}\alpha$ 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 Å³, $Z = 2$ and space group $C2/m$, 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 $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. Pakhomovskiyite 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

TABLE 1. COMPARISON OF PAKHOMOVSKYITE WITH SYNTHETIC $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, VIVIANITE, ARUPITE AND BARIČITE

Property	Pakhomovskiyte ¹ $\text{Co}_3[\text{PO}_4]_2 \cdot 8\text{H}_2\text{O}$	Synthetic ² $\text{Co}_3[\text{PO}_4]_2 \cdot 8\text{H}_2\text{O}$	Vivianite ³ $\text{Fe}^{2+}_3[\text{PO}_4]_2 \cdot 8\text{H}_2\text{O}$	Arupite ³ $\text{Ni}_3[\text{PO}_4]_2 \cdot 8\text{H}_2\text{O}$	Baričite ³ $\text{Mg}_3[\text{PO}_4]_2 \cdot 8\text{H}_2\text{O}$	Erythrite ³ $\text{Co}_3[\text{AsO}_4]_2 \cdot 8\text{H}_2\text{O}$
Symmetry	monoclinic	monoclinic	monoclinic	monoclinic	monoclinic	monoclinic
Space group	$C2/m$	$C2/m$	$C2/m$	$I2/m$	$C2/m$	$C2/m$
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
$2V$ °	75–80	not measured	64–84	not measured	55–60	very large to 90°
Orientation	$X = b$, $Z \wedge c 22\text{--}23^\circ$	not measured	$X = b$, $Z \wedge c 28.5^\circ$	not measured	$X = b$, $Z \wedge c 28\text{--}30^\circ$	$X = b$, $Z \wedge c 30\text{--}36^\circ$
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

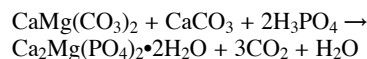
1) This work, 2) Riou *et al.* (1989), 3) Anthony *et al.* (2000).

TABLE 2. CHEMICAL COMPOSITION OF PAKHOMOVSKYITE

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

hydrothermal solutions, infiltrating alkaline rocks and fluorapatite-rich phosphorite, 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:

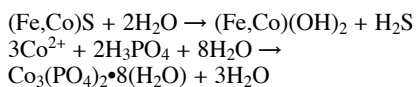


Other elements such as Fe (extracted from magnetite, pyrrhotite, *etc.*), Sc (extracted from baddeleyite), Ba and Sr (extracted from carbonates) are incorporated into vivianite, bari_ite, gladiusite, juonniite, krasnovite, rimkorolgitite, strontiowhitlockite, among others.

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

TABLE 3. X-RAY POWDER-DIFFRACTION DATA FOR PAKHOMOVSKYITE, SYNTHETIC $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$ AND BARIČITE

Pakhomovskiyte				Synthetic $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$ ICDD 41-375				Baričite ICDD 29-705			Pakhomovskiyte				Synthetic $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$ ICDD 41-375				Baričite ICDD 29-705		
<i>hkl</i>	<i>l</i>	<i>d</i> _{meas}	<i>d</i> _{calc}	<i>l</i>	<i>d</i> _{calc}	<i>hkl</i>	<i>l</i>	<i>d</i> _{meas}	<i>hkl</i>	<i>l</i>	<i>d</i> _{meas}	<i>d</i> _{calc}	<i>l</i>	<i>d</i> _{calc}	<i>hkl</i>	<i>l</i>	<i>d</i> _{meas}				
110	3	7.84	7.839	30	7.835	110	25	7.90	53T	1	1.803	1.8053	3	1.8035							
020	10	6.67	6.670	100	6.666	020	100	6.71	222				1	1.7985			1.8009				
200	4	4.85	4.844	30	4.842	200	20	4.87	530				2	1.7762			1.7755				
001	2	4.53	4.511	14	4.516	001	5	4.51	261				0	1.7739			1.7739				
11T	1	4.29	4.321	4	4.321	11T	15	4.33	351				4	1.7647			1.7651				
130	1	4.02	4.041	12	4.039	130	10	4.07	17T				1	1.7587		17T	10	1.768			
220			3.919	0	3.918				152	1	1.757	1.7567	4	1.7569				1.7569			
20T	4	3.84	3.833	25	3.830	20T	20	3.83	171				0	1.6975				1.6972			
021			3.736	1	3.739				512				0	1.6903				1.6885			
111	1	3.54	3.597	4	3.602	111	5	3.61	441				1	1.6743				1.6743			
040			3.3350	0	3.3327				080	4	1.668	1.6675	7	1.6664		080	30	1.676			
22T	1	3.31	3.3235	2	3.3209	22T	1	3.34	60T				9	1.6612				1.6612			
13T	6	3.195	3.1859	33	3.1849	13T	40	3.196	352				1	1.6615		352	10	1.667			
310			3.1385	2	3.1374				442				1	1.6618				1.6604			
31T	7	2.948	2.9477	26	2.9443	31T	60	2.956	312				1	1.6475				1.6475			
201			2.9424	19	2.9462				370				0	1.6412				1.6402			
131	2	2.870	2.8601	1	2.8618				152	2	1.642	1.6407	9	1.6418				1.6418			
240	1	2.769	2.7469	4	2.7453				460				0	1.6370		460	15	1.648			
221	7	2.691	2.6921	26	2.6947	221	70	2.699	46T				0	1.6326				1.6326			
041			2.6816	19	2.6816				242				1	1.6295				1.6311			
330	1	2.620	2.6128	11	2.6117	330	10	2.626	511				0	1.6212				1.6221			
150			2.5722	3	2.5706				600				2	1.6146				1.6140			
24T	6	2.521	2.5161	16	2.5142	24T	50	2.526	62T				0	1.6136				1.6119			
33T			2.4996	7	2.4971				37T				0	1.6120				1.6107			
400			2.4218	1	2.4210				262				0	1.5930				1.5925			
40T	6	2.408	2.4098	18	2.4070	40T	35	2.418	532				2	1.5912				1.5896			
311	2	2.318	2.3171	0	2.3193				55T	2	1.591	1.5876	6	1.5861		55T	10	1.593			
15T			2.3037	12	2.3026	15T	15	2.311	062				1	1.5833				1.5837			
112			2.2992	3	2.3007				280				1	1.5757				1.5757			
202			2.2834	1	2.2836				620	2	1.572	1.5692	4	1.5687				1.5687			
420			2.2764	1	2.2756				550				6	1.5670		550	25	1.576			
42T	1	2.275	2.2664	4	2.2639	42T	5	2.275	081				1	1.5640				1.5633			
002			2.2552	0	2.2579				203				1	1.5545				1.5555			
060			2.2233	0	2.2218				332				1	1.5537				1.5553			
241	3	2.206	2.2064	13	2.2073	241	30	2.217	113	1	1.536	1.5374	0	1.5388		113	5	1.539			
151	3	2.170	2.1711	11	2.1712	151	10	2.179	531				3	1.5338				1.5338			
222			2.1603	4	2.1603				28T				2	1.5291				1.5280			
022			2.1364	2	2.1386				223				0	1.5139		223	5	1.514			
312			2.0990	1	2.0980				313				0	1.5125				1.5126			
331			2.0796	2	2.0810				602	1	1.510	1.5112	4	1.5094				1.5094			
132			2.0667	1	2.0675				003				2	1.5053				1.5053			
350	3	2.061	2.0568	10	2.0557	350	20	2.066	64T				4	1.4882		64T	1	1.494			
112			2.0558	1	2.0587				371				0	1.4809				1.4809			
260			2.0206	1	2.0194				172				1	1.4862				1.4760			
35T	1	2.001	2.0002	2	1.9984				622	2w	1.475	1.4738	1	1.4722				1.4722			
061			1.9942	2	1.9936	061	5	2.001	402				6	1.4731		402	15	1.477			
440			1.9596	1	1.9587				023				1	1.4667				1.4683			
51T			1.9542	2	1.9520				190				1	1.4652				1.4642			
44T	1	1.946	1.9533	1	1.9513	44T	5	1.959	133				3	1.4617				1.4628			
401			1.9349	1	1.9364				461				0	1.4596				1.4598			
26T			1.9233	2	1.9219				403				1	1.4578				1.4574			
332			1.9177	8	1.9167				640				1	1.4532				1.4526			
510	1	1.918	1.9173						462				1	1.4517				1.4506			
402			1.9167	7	1.9150				281				3	1.4507		281	10	1.459			
132	2w	1.880	1.8845	8	1.8866	132	5	1.886	333				1	1.4402				1.4402			
242			1.8841	0	1.8838					1	1.422		1								
170			1.8699	1	1.8686	170	1	1.878		1	1.407		1								
042			1.8682	0	1.8693					1	1.371		1								
202			1.8676	5	1.8704					4	1.337		1				25	1.341			
421			1.8583	1	1.8595												10	1.236			
422			1.8421	0	1.8406												5	1.222			



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 $\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$ at room temperature from aqueous solutions. By analogy, we suggest that pakhomovskiyite crystals grew from cold Co-bearing phosphate solutions in fissures of dolomite carbonatite that serve as a geochemical barrier. This hypothesis is supported by the presence of cattiiite, $\text{Mg}_3(\text{PO}_4)_2 \cdot 22\text{H}_2\text{O}$, and nastrophite, $\text{NaSr}(\text{PO}_4) \cdot 9\text{H}_2\text{O}$, in surrounding carbonatite veins (Britvin *et al.* 2002). The presence of nastrophite reveals a high alkalinity of residual solutions, and cattiiite could have formed only at low temperatures (5–20%). Therefore, pakhomovskiyite 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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