

МИНЕРАЛЫ И ПАРАГЕНЕЗИСЫ МИНЕРАЛОВ

**BARICITE, $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, FROM THE IMILAC PALLASITE:
THE FIRST EXAMPLE OF HYDRATION OF ANHYDROUS METEORITIC
PHOSPHATE, FARRINGTONITE $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2$**

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Abstract. Barićite $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, the Mg-dominant analogue of vivianite $\text{Fe}_3^{2+}(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, has been identified in the Imilac meteorite, a member of the main-group pallasites (PMG). Associated minerals are olivine ($\text{Fa}_{12.9}$), (Fe,Ni) metal, chromite, troilite, phosphides of schreibersite–nickelphosphide series Fe_3P – Ni_3P , and anhydrous phosphates typical of pallasites: stanfieldite $\text{Ca}_7(\text{Mg}, \text{Ca})_2\text{Mg}_9(\text{PO}_4)_{12}$, merrillite $\text{Ca}_9\text{MgNa}(\text{PO}_4)_7$, and farringtonite $\text{Mg}_3(\text{PO}_4)_2$. Barićite appears as aggregates of tan-colored submicrometer-sized lamella infilling the fractures in the weathered farringtonite grain. Chemical composition (wt. %, electron microprobe, H_2O by stoichiometry): MgO 26.28, FeO 4.74, P_2O_5 32.96, SiO_2 0.33, H_2O 34.05, Total 98.36. The empirical formula calculated based on 8 oxygen atoms per anhydrous part of the formula unit is $(\text{Mg}_{2.76}\text{Fe}_{0.28}^{2+})_{3.04}(\text{P}_{1.97}\text{Si}_{0.02})\text{O}_8 \cdot 8\text{H}_2\text{O}$. Barićite is monoclinic, space group $C2/m$, unit-cell parameters obtained by the Rietveld refinement are: $a = 10.051(2)$, $b = 13.444(2)$, $c = 4.652(1)$ Å, $\beta = 105.04(1)$, $V = 607.1(2)$ Å³, $Z = 2$. Calculated density is 2.27 g/cm³. Strongest lines of powder X-ray diffraction pattern [d in Å (hkl)]: 7.91(44)(110); 6.76(100)(020); 4.33(12)($\bar{1}11$), 2.950(32)($\bar{3}11, 201$); 2.694(26)(221, 041); 2.521(16)($\bar{2}41$); 2.423(17)(400, $\bar{4}01$). The absence of ~ 14 Å reflection in the XRD pattern evidences that the mineral is barićite rather than its polymorphic modification, bobierite. The assemblage of barićite in Imilac evidences that the mineral is a product of aqueous alteration of farringtonite, $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2$. In contrast to the previously described occurrence of newberyite, $\text{Mg}(\text{HPO}_4) \cdot 3\text{H}_2\text{O}$, in the Springwater pallasite, barićite in Imilac was formed through a simple hydration process of farringtonite, according to the equation: $\text{Mg}_3(\text{PO}_4)_2 + 8\text{H}_2\text{O} = \text{Mg}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. This is the first example of hydration of anhydrous meteoritic phosphate.

Keywords: barićite, newberyite, vivianite, farringtonite, phosphate, meteorite, pallasite PMG, aqueous alteration, hydration

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INTRODUCTION

Pallasites is a class of metal-rich (stony-iron) meteorites incorporating about 200 names (Grady, 2000). Since the recognition of the prototype member, the Krasnojarsk mass (Pallas Iron) (Pallas, 1776), pallasites play a significant role in the studies of evolution of metal-rich planetesimals (Buseck, 1977; Scott, 1977a, b; Hsu, 2003; Wasson, Choi, 2003; Poitrasson et al., 2005; Boesenberg et al., 2012; McKibbin et al., 2019). At the same time, their own origin is still a matter of considerable debates (Walte, Golabek, 2022; Mittlefehldt et al., 2024). Pallasites consist of centimeter-sized olivine (ferroan forsterite) crystals embedded into the metal matrix, with approximately equal olivine/metal mass ratio (Buseck, Goldstein, 1969). In the small group of pyroxene pallasites, the dominant silicate is enstatite (Boesenberg et al., 2000). The metal is comprised by α -(Fe,Ni) (kamacite) and γ -(Fe,Ni) (taenite), and frequently exhibits the Widmanstätten pattern reminiscent of fine- to medium-structured octahedrites. Subordinate and accessory phases are chromite, troilite and phosphides, including schreibersite–nickelphosphide Fe_3P – Ni_3P (Britvin et al., 2021b), barringerite $(\text{Fe}, \text{Ni})_2\text{P}$ (Buseck, 1969; Zucchini et al., 2018), and nazarovite Ni_{12}P_5 (Britvin et al., 2022). A characteristic feature of pallasite mineralogy is a suite of phosphates: merrillite $\text{Ca}_9\text{MgNa}(\text{PO}_4)_7$ formerly referred to as whitlockite (Buseck, Holdsworth, 1977), stanfieldite $\text{Ca}_7(\text{Mg}, \text{Ca})_2\text{Mg}_9(\text{PO}_4)_{12}$ (Fuchs, 1967; Britvin et al., 2020); farringtonite $\text{Mg}_3(\text{PO}_4)_2$ (Fuchs et al., 1973), and keplerite, $\text{Ca}_9\text{Mg}(\text{Ca}_{0.5}\square_{0.5})(\text{PO}_4)_7$ (Britvin et al., 2021a). The phosphates are considered to be late-stage magmatic cumulates, and like other pallasite minerals, are anhydrous (Buseck, Holdsworth, 1977).

The vast majority of pallasites, being the finds rather than witnessed falls (Grady, 2000), experienced pronounced terrestrial weathering. The processes of aqueous alteration of different meteorites were in the focus of mineralogical research (White et al., 1967; Okada et al., 1985; Buchwald, 1990; Britvin et al., 2001; Pekov et al., 2007; Chukanov et al., 2008; Taddei et al., 2025). However, there is the only work on this topic that relates to pallasites — a brief notice of newberyite, $\text{Mg}(\text{HPO}_4) \cdot 3\text{H}_2\text{O}$, in the Springwater meteorite (Fuchs et al., 1973). In this article, we report the first occurrence of meteoritic baričite, $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, a Mg-dominant analogue of vivianite, $\text{Fe}_3^{2+}(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$ (Sturman, Mandarino, 1976). Baričite is a rare phosphate known across a few localities worldwide, where it has late hydrothermal, sedimentary or organogenic origin (Robertson, 1982; Rodgers, 1987; Liferovich et al., 1999; Klopogge et al., 2003; Hsu et al., 2014; Rothe et al., 2016). The genesis of meteoritic baričite, being substantially different from both terrestrial baričite and newberyite from the Springwater pallasite, is discussed in the present paper.

ANALYTICAL METHODS

Chemical composition of phosphates and olivine was characterized by electron microprobe in the energy-dispersive (EDS) mode, using the detector attached to a Hitachi S-3400N scanning electron microscope. The carbon-coated slab was analyzed at 20 kV accelerating voltage and 1 nA beam current, using the following standards ($K\alpha$ series lines): diopside (Ca, Mg, Si), hematite (Fe), and sidorenkite (Na, Mn, P).

Raman spectroscopy. Recording the micro Raman spectrum was performed by means of a Horiba Jobin-Yvon LabRam HR800 spectrometer equipped with a green diode laser (532 nm) and an Olympus BX41 microscope, using a $50\times$ confocal objective. The attempts were unsuccessful, because of very strong luminescence encountered starting from 200 cm^{-1} .

X-ray powder diffraction was employed for the confirmation of the mineral, because the single-crystal study was impossible owing to a submicrometer size of baričite lamella. The XRD pattern was obtained in Debye-Scherrer geometry using a Rigaku RAXIS imaging plate diffractometer operated with a rotating anode $\text{CoK}\alpha$ tube, at 40 kV, 15 mA and 900 s exposure time. The sample was comprised by a $\sim 100\text{ }\mu\text{m}$ ball prepared from the mineral powder extracted by the needle from the polished slab surface, and pinned onto a thin glass fiber.

The imaging plate to profile data conversion was performed using osc2xrd program (Britvin et al., 2017). Powder X-ray diffraction data were obtained by the Rietveld refinement using TOPAS v.5.0 software (Bruker AXS).

OCCURRENCE AND APPEARANCE

The Imilac meteorite, a member of the main-group pallasites (PMG), was found in 1822 in the Atacama Desert, North Chile (Grady, 2000). Since that, numerous additional fragments of Imilac were recovered across its expected projectile strewnfield, with the total known weight of more than 900 kg (Pinto et al., 2024). Imilac, namely the Ollague fragment, is known as a type locality for barringerite, (Fe, Ni)₂P (Buseck, 1969) — the third most abundant phosphide in meteorites, after the minerals of the schreibersite–nickelphosphide series. The petrology, geochemistry and mineralogy of Imilac is discussed in numerous works (Buseck, 1977; Scott, 1977a, b; Hsu, 2003; Wasson, Choi, 2003; Poitrasson et al., 2005; McKibbin et al., 2019; Chernonozhkin et al., 2021; Walte, Golabek, 2022; Mittlefehldt, 2024). The primary phosphates reported so far are stanfieldite and merrillite; farringtonite was not recorded (Fuchs, 1967; Buseck, Holdsworth, 1977; Steele, Olsen, 1992). In spite of extremely arid climate in this part of Chile (Muñoz et al., 2007), all Imilac fragments are substantially weathered (Pinto et al., 2024). However, hydrous phosphates were not reported in this meteorite (Buseck, Holdsworth, 1977).

Phosphate assemblages were found during the study of a polished section of Imilac from meteorite collection of the Mineralogical Museum of Saint Petersburg State University. This section was preliminary studied under the name of Seymchan (Segoleva, 2023); however, the detailed study of the olivine composition (Table 1) unambiguously evidences that the slab belongs to Imilac (Boesenberg et al., 2012), being erroneously assigned to Seymchan during sorting of the material. The section (Fig. 1a) contains cm-sized rounded olivine crystals embedded into (Fe,Ni) metal matrix; the latter is comprised by α-(Fe,Ni) (kamacite) with centimeter-sized fields of plessite — microstructural intergrowths of α-(Fe,Ni) and γ-(Fe,Ni) (taenite).

Table 1. Chemical composition (in wt.%) of barićite, associated phosphates and olivine

Таблица 1. Химический состав баричита, ассоциирующих фосфатов и оливина

<i>n</i> *	Barićite	Farringtonite	Stanfieldite	Merrillite	Olivine
	4	11	36	13	46
MgO	26.28(0.37)	42.35(0.38)	20.99(0.44)	3.54(0.13)	46.31(0.64)
FeO	4.74(0.11)	3.16(0.12)	2.83(0.26)	0.75(0.36)	12.22(0.30)
MnO	b. d. l. *	b. d. l.	0.42(0.12)	b. d. l.	0.30(0.08)
CaO	b. d. l.	b. d. l.	25.97(0.28)	46.68(0.60)	b. d. l.
Na ₂ O	b. d. l.	b. d. l.	b. d. l.	2.36(0.13)	b. d. l.
P ₂ O ₅	32.96(0.30)	53.64(0.44)	50.58(0.60)	46.41(0.57)	b. d. l.
SiO ₂	0.33(0.11)	b. d. l.	b. d. l.	b. d. l.	41.09(0.54)
(H ₂ O)	34.05*	—	—	—	—
Total	98.36	99.15	100.79	99.74	99.92
Formula amounts calculated on the given number of oxygen atoms					
O	8	8	48	28	4
Mg	2.76	2.82	8.89	0.94	1.71
Fe ²⁺	0.28	0.12	0.67	0.11	0.25
Mn ²⁺	—	—	0.10	—	0.01
Ca	—	—	7.91	8.95	—
Na	—	—	—	0.82	—

Table 1. The end

Таблица 1. Окончание

n^*	Baričite	Farringtonite	Stanfieldite	Merrillite	Olivine
	4	11	36	13	46
P	1.97	2.03	12.17	7.03	—
Si	0.02	—	—	—	1.02
Fe-index****	9.2	4.0	7.0	10.6	12.9

* Number of analytical points. ** b. d. l. — below detection limit. *** Water content was calculated by stoichiometry, assuming $8\text{H}_2\text{O}$ per formula unit. **** Fe-index is $100 \times \text{Fe} / (\text{Fe} + \text{sMg})$ (apfu).

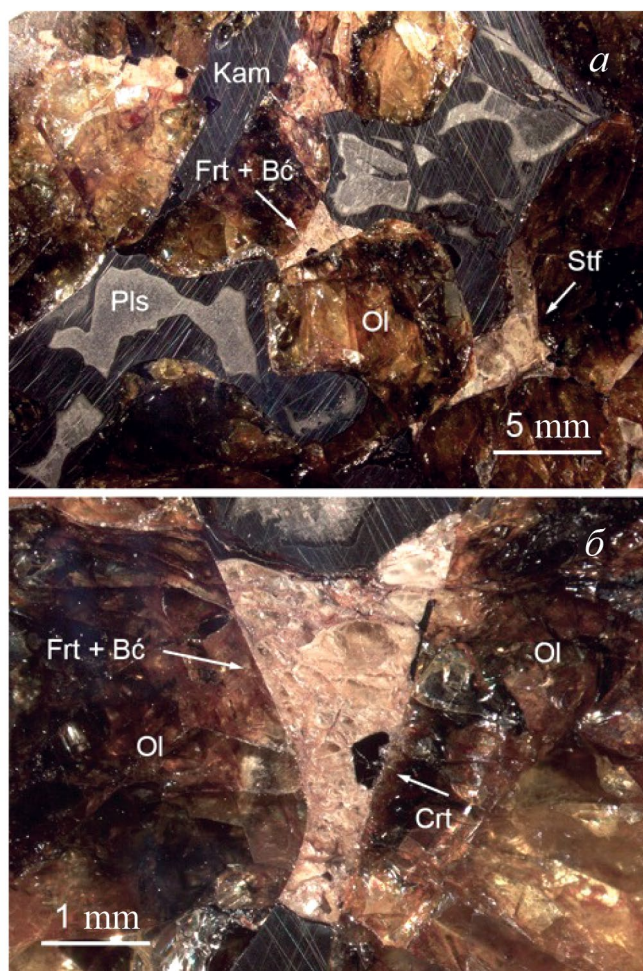


Fig. 1. Baričite in the Imilac meteorite. (a) General view of the polished section containing farringtonite grain with baričite (b) Magnified view of the same area. Ol — olivine, Kam — α -(Fe,Ni) (kamacite), Pls — plessite, Stf — stanfieldite, Crt — chromite, Frt — farringtonite, Bc — baričite

Рис. 1. Баричит в метеорите Imilac. (a) Общий вид полированного шлифа с фаррингтонитом и баричитом. (b) Увеличенное изображение участка. Ol — оливин, Кам — α -(Fe,Ni) (камасит), Плс — плессит, Стф — стэнфилдит, Crt — хромит, Frt — фаррингтонит, Bc — баричит

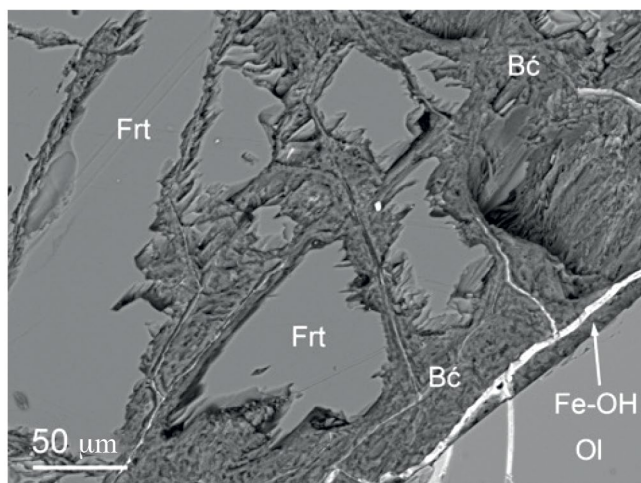


Fig. 2. Baricite infilling fractures within the etched farringtonite grain. SEM BSE image. Ol — olivine, Frt — farringtonite, Bc — baricite, Fe-OH — secondary Fe hydroxides

Рис. 2. Баричит, выполняющий трещины в измененном фаррингтоните. РЭМ фото в обратно рассеянных электронах. Ol — оливин, Frt — фаррингтонит, Bc — баричит, Fe-OH — вторичные гидроксиды Fe

Other common minerals are troilite, phosphides of schreibersite—nickelphosphide series, and chromite. Like the occurrences in other pallasites (Buseck, Holdsworth, 1977), phosphates in Imilac appear as infillings at the interfaces and interstices between olivine crystals and metal matrix (Fig. 1b). The most abundant phosphate is stanfieldite that is exposed on the areas of more than 5 mm in size (Fig. 1b). Farringtonite and merrillite are sporadically scattered as minute grains, typically up to 1 mm, frequently intergrown with stanfieldite. Macroscopically, all phosphates are colorless to tan-colored, transparent to translucent, and are hardly distinguishable by visual examination.

Baricite was detected in a single $\sim 2 \times 4$ mm patch of farringtonite of trapezoidal shape (Fig. 1b, c) infilling the interstice between two olivine crystals (Fig. 1b, c). An euhedral grain of black chromite penetrates the phosphate inclusion (Fig. 1c). Farringtonite, being a primary phosphate, appears as a grid of colorless grains up to 0.5 mm in size, which are dissected by the dense net of subparallel internal fractures (Fig. 1c, 2). Farringtonite grains have heavily etched pinnate rims, whose singular orientation implies that they previously represented a single crystal, which was subsequently fractured and partially weathered. The fractures are infilled with tan-colored baricite. The magnified SEM images (Fig. 2) show that baricite aggregates consist of submicrometer-sized lamellae — a habit typical of the vivianite group minerals (Ralph et al., 2025).

CHEMICAL COMPOSITION

Chemical composition of baricite, associated phosphates and olivine from Imilac is summarized in Table 1. A string with calculated Fe-index, $100 \times \text{Fe}/(\text{Fe} + \text{Mg})$ (atoms per formula unit, *apfu*), is included into the table for comparison purposes. According to Fe-index, all phosphate minerals in the meteorite are depleted in Fe relative to olivine. It is noteworthy that baricite, being a secondary mineral, is substantially enriched in Fe relative to its anhydrous precursor, farringtonite.

X-RAY CRYSTALLOGRAPHY

X-ray single-crystal study of barićite could not be carried out due to very small size and undulated habit of its lamellae (Fig. 2). At the same time, X-ray confirmation of the mineral would be strictly necessary, because both pure Mg₃(PO₄)₂·8H₂O and its partially Fe-substituted varieties can crystallize in two different polymorphous modifications. Barićite, also called polymorph II (Kanazawa et al., 1979; Takagi et al., 1986), is isostructural with vivianite, Fe₃(PO₄)₂·8H₂O (Capitelli et al., 2012), with which it can form a complete series of solid solutions (Sturman, Mandarino, 1976; Liferovich et al., 1999). Another modification, a polymorph I of Mg₃(PO₄)₂·8H₂O (Kanazawa et al., 1979; Takagi et al., 1986) is known as a mineral, bobierrite (Lacroix, 1888), and has a limited ability of Mg for Fe substitution (Liferovich et al., 1999). Structural relationships between barićite and bobierrite are compared in detail by Takagi et al. (1986). From the diagnostic point of view it is essential that the structures of both polymorphs are very similar. However, the *b* parameter of the bobierrite unit cell is doubled relative to that of barićite (Table 2). The latter allows the appearance of strong 020 reflection at ~ 14 Å in the XRD pattern of bobierrite. This reflection would correspond to 010 for barićite, hence it is systematically forbidden and absent in its XRD pattern (Liferovich et al., 1999). The XRD pattern of the secondary phosphate from Imilac (Table 3) does not contain the 14 Å reflection, therefore the mineral can be unambiguously identified as barićite.

Table 2. Unit-cell parameters and Fe-indexes of barićite and bobierrite

Таблица 2. Параметры элементарной ячейки и Fe-индексы баричита и бобьерита

Mineral	Barićite	Barićite	Barićite	Barićite	Bobierrite	Bobierrite
Locality	Imilac meteorite	Yukon, Canada	Kovdor, Russia	Synthetic Mg end-member	Synthetic Mg end-member	Kovdor, Russia
Space group	<i>C2/m</i>	<i>C2/m</i>	<i>C2/m</i>	<i>C2/m</i>	<i>C2/c</i>	<i>C2/c</i>
<i>a</i> , Å	10.051(2)	10.075(4)	10.07(3)	10.034(1)	4.667(1)	4.69(1)
<i>b</i> , Å	13.444(2)	13.416(8)	13.42(2)	13.407(2)	27.926(8)	27.84(6)
<i>c</i> , Å	4.652(1)	4.670(4)	4.68(3)	4.657(1)	10.067(3)	10.07(3)
β, °	105.04(1)	104.87(3)	104.9(2)	105.09(1)	105.01(2)	105.02(1)
<i>V</i> , Å ³	607.1(2)	610.1	610.9	604.9	1267.3	1268.9
<i>Z</i>	2	2	2	2	4	4
Fe-index*	9	45	40	0	0	17
Reference	This work	Sturman, Mandarino, 1976	Liferovich et al., 1999	Takagi et al., 1987	Takagi et al., 1987	Liferovich et al., 1999

* Fe-index is 100 × Fe / (Fe + Mg) (*apfu*); in this table it is rounded to integers.

Table 3. Powder X-ray diffraction data (*d* in Å) for barićite from the Imilac pallasite*

Таблица 3. Порошковые рентгенографические данные (*d* в Å) для баричита из палласита Imilac

<i>I</i> _{obs}	<i>d</i> _{obs}	<i>I</i> _{calc} **	<i>d</i> _{calc}	<i>hkl</i>	<i>I</i> _{obs}	<i>d</i> _{obs}	<i>I</i> _{calc} **	<i>d</i> _{calc}	<i>I</i> _{obs}
44	7.91	26	7.87	110	3	2.327	1	2.317	311
100	6.76	100	6.72	020	4	2.304	4	2.315	–151
10	4.87	9	4.85	200	—	—	1	2.291	–112
12	4.33	8	4.31	–111	4	2.255	1	2.247	002
9	3.959	3	4.069	130	8	2.211	6	2.212	241
—	—	1	3.935	220	3	2.053	3	2.068	350

Table 3. The end

Таблица 3. Окончание

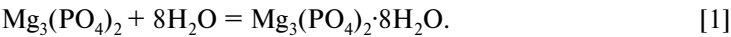
<i>I</i> _{obs}	<i>d</i> _{obs}	<i>I</i> _{calc} **	<i>d</i> _{calc}	<i>hkl</i>	<i>I</i> _{obs}	<i>d</i> _{obs}	<i>I</i> _{calc} **	<i>d</i> _{calc}	<i>I</i> _{obs}
12	3.844	8	3.830	−201	4	1.923	1	1.921	510
10	3.199	15	3.194	−131	4	1.918	2	1.917	−332
9	3.152	3	3.146	310	—	—	2	1.915	−402
32	2.950	9	2.950	−311	5	1.883	3	1.882	132
—	—	10	2.939	201	2	1.676	3	1.680	080
26	2.694	13	2.693	221	2	1.666	3	1.665	−352
—	—	10	2.691	041	3	1.644	3	1.642	152
8	2.634	4	2.623	330	2	1.573	2	1.574	550
16	2.521	14	2.526	−241	4	1.471	2	1.469	402
17	2.423	2	2.427	400	2	1.338	1	1.339	−391
—	—	7	2.413	−401	—	—	—	—	—

* Calculated for CoKα radiation based on the results of the Rietveld profile fitting.

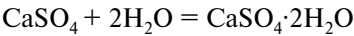
** Reflections with calculated intensities less than 1 have been omitted.

DISCUSSION

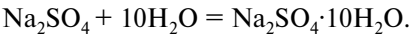
Barićite is not the first secondary phosphate found in meteorites. Vivianite, Fe₃(PO₄)₂·8H₂O, and its nickeloan analogue, arupite Ni₃(PO₄)₂·8H₂O, are the two vivianite-group minerals previously reported from meteorites (Buchwald, 1977, 1990). Minerals of collinsite–cassidyite series, Ca₂Mg(PO₄)₂·2H₂O–Ca₂Ni(PO₄)₂·2H₂O, and lipscombite, Fe²⁺Fe³⁺₂(PO₄)₂(OH)₂, further expand the list of meteoritic secondary phosphates (White et al., 1967; Buchwald, 1977). However, there is a principal genetic difference between the mentioned phosphates and barićite. All minerals listed above are the oxidation products of meteoritic phosphides of schreibersite–nickelphosphide series, Fe₃P–Ni₃P. In this respect, they have the same origin as numerous arsenate minerals formed in the oxidation zone of terrestrial arsenide deposits (e. g., Yakhontova, Zvereva 2000; Pekov et al. 2012; Majzlan et al., 2014; Gritsenko, 2022). Barićite in the Imilac pallasite was formed by another chemical mechanism, not involving oxidation of phosphides. It is a product of hydration of anhydrous magnesium phosphate, farringtonite. From the chemical point of view, this process is a simple addition of water molecules to the anhydrous salt:



The number of reactions of this type in nature is close to the top dozen, although some of them are quite common processes, e. g., hydration of anhydrite, CaSO₄, to yield gypsum (e. g., Zambak and Arthur, 1986)



or hydration of thenardite, to form mirabilite:



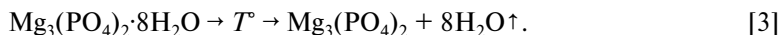
Several other, more exotic examples include post-formational hydration products of anhydrous sulfates and chlorides formed in fumarolic exhalations, such as tolbachite CuCl₂ (Vergasova, Filatov, 1986); chalcocyanite CuSO₄, along with several ill-defined chlorides (e. g., Zambonini, 1935), sulfates of the yavapaiite group (e. g., Hutton, 1959), and hydration

of kokchetavite, a high-pressure polymorph of KAlSi₃O₈, to yield a so-called K-cymrite, KAlSi₃O₈·H₂O (Hwang et al., 2004; Mikhno et al., 2014).

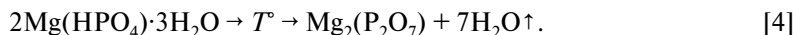
Aqueous alteration of farringtonite was first reported by Fuchs et al. (1973) in the Springwater pallasite. The alteration product was identified by powder XRD as newberyite, MgH-PO₄·3H₂O. In this respect it is noteworthy that the stoichiometry of newberyite, having Mg:P ratio of 1:1, is different from that of farringtonite with Mg:P = 3:2. Therefore, the formation of newberyite in Springwater has been realized via the process different from hydration, namely — the acidic decomposition of farringtonite (bearing an orthophosphate ion, PO₄³⁻) into newberyite (containing hydrogen phosphate, HPO₄²⁻):



with the raised excess of Mg²⁺ being evolved out of the reaction zone. The principal difference between reaction [1] (hydration, in Imilac) and [2] (decomposition, in Springwater) is that the hydration processes are reversible, therefore reverse heating of Mg₃(PO₄)₂·8H₂O to appropriate temperature results in the formation of farringtonite (Pechkovskii et al., 1979; Aramendía et al., 1999; Boonchom, 2010):



In contrast, decomposition of farringtonite into newberyite according to equation [2] is a unidirectional, irreversible reaction, hence the reverse heating of newberyite yields magnesium pyrophosphate instead of farringtonite (Aramendía et al., 1999):



The differences in the processes of aqueous alteration of farringtonite in Springwater and Imilac are apparently caused by the differences in the acidity of aqueous solutions that affected the meteorites. Taking into account severe weathering of the Imilac fragments, the water required for the hydration of farringtonite to barićite was most probably of terrestrial origin. The temperature of barićite formation was higher than 5 °C, since at lower temperatures, another hydrate, cattite Mg₃(PO₄)₂·22H₂O, would have formed (Britvin et al., 2002; Chernyateva et al., 2013).

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Баричит, $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, из палласита Imilac: первый пример гидратации безводного метеоритного фосфата, фаррингтонита $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2$

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Аннотация. Баричит $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, магнезиальный аналог вивианита $\text{Fe}_3^{2+}(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, был обнаружен в метеорите Imilac — представителе палласитов главной группы. Ассоциирующие минералы представлены оливином ($\text{Fa}_{12.9}$), металлом (Fe, Ni), хромитом, троилитом, фосфидами ряда шрейберзит—никельфосфид Fe_3P — Ni_3P , а также безводными фосфатами, характерными для

палласитов: стэнфилдитом $\text{Ca}_7(\text{Mg}, \text{Ca})_2\text{Mg}_9(\text{PO}_4)_{12}$, мерриллитом $\text{Ca}_9\text{MgNa}(\text{PO}_4)_7$ и фаррингтонитом $\text{Mg}_3(\text{PO}_4)_2$. Баричит образует агрегаты субмикронных ламелей кремового цвета, выполняющие трещины в выветрелом зерне фаррингтонита. Химический состав (мас. %, электронно-зондовый анализ, H_2O по стехиометрии): MgO 26.28, FeO 4.74, P_2O_5 32.96, SiO_2 0.33, H_2O 34.05, сумма 98.36. Эмпирическая формула, рассчитанная на 8 атомов кислорода без учета молекулярной воды: $(\text{Mg}_{2.76}\text{Fe}_{0.28}^{2+})_{3.04}(\text{P}_{1.97}\text{Si}_{0.02})\text{O}_8 \cdot 8\text{H}_2\text{O}$. Баричит моноклинный, пространственная группа $C2/m$, параметры элементарной ячейки, полученные методом Ритвельда: $a = 10.051(2)$, $b = 13.444(2)$, $c = 4.652(1)$ Å, $\beta = 105.04(1)^\circ$, $V = 607.1(2)$ Å³, $Z = 2$. Вычисленная плотность 2.27 г/см⁻³. Наиболее сильные линии рентгенограммы порошка [d в Å (I) (hkl)]: 7.91(44)(110); 6.76(100)(020); 4.33(12)(-111), 2.950(32)(-311, 201); 2.694(26)(221, 041); 2.521(16)(-241); 2.423(17)(400, -401). Отсутствие в рентгенограмме рефлекса при ~ 14 Å свидетельствует о том, что минерал является баричитом, а не его полиморфной модификацией — бобьеритом. Ассоциация баричита в метеорите Imilac свидетельствует о том, что минерал является продуктом водного изменения фаррингтонита, $(\text{Mg}, \text{Fe}^{2+})_3(\text{PO}_4)_2$. В противоположность ранее описанному ньюбериту $\text{Mg}(\text{HPO}_4) \cdot 3\text{H}_2\text{O}$ из палласита Springwater баричит в метеорите Imilac образовался путем процесса простой гидратации фаррингтонита, согласно уравнению $\text{Mg}_3(\text{PO}_4)_2 + 8\text{H}_2\text{O} = \text{Mg}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. Это первый пример гидратации безводного метеоритного фосфата.

Ключевые слова: баричит, ньюберит, вивианит, фаррингтонит, фосфат, метеорит, палласит, водное изменение, гидратация