American Mineralogist, Volume 108, pages 2142–2150, 2023

Yakubovichite, $CaNi_2Fe^{3+}(PO_4)_3$, a new nickel phosphate mineral of non-meteoritic origin

Sergey N. Britvin[1,2,*], **Mikhail N. Murashko**[1], **Maria G. Krzhizhanovskaya**[1], **Yevgeny Vapnik**[3], **Natalia S. Vlasenko**[4], **Oleg S. Vereshchagin**[1,†], **Dmitrii V. Pankin**[5], **Anatoly N. Zaitsev**[1], and **Anatoly A. Zolotarev**[1]

[1]Institute of Earth Sciences, Saint-Petersburg State University, Universitetskaya Nab. 7/9, St. Petersburg, 199034, Russia
[2]Nanomaterials Research Center, Kola Science Center, Russian Academy of Sciences, Fersman Str. 14, Apatity, 184200, Russia
[3]Department of Geological and Environmental Sciences, Ben-Gurion University of the Negev, POB 653, Beer-Sheva, 84105, Israel
[4]Geomodel Resource Center, Saint-Petersburg State University, Ulyanovskaya Str. 1, St. Petersburg, 198504, Russia
[5]Center for Optical and Laser Materials Research, St. Petersburg State University, Ulyanovskaya Str. 5, St. Petersburg, 199034, Russia

Abstract

Yakubovichite, $CaNi_2Fe^{3+}(PO_4)_3$, a new mineral containing up to 20 wt% NiO, represents a novel type of terrestrial phosphate mineralization featuring an extreme enrichment in Ni. The mineral was discovered in the Hatrurim Formation (Mottled Zone)—pyrometamorphic complex whose outcrops are exposed in Israel and Jordan in the area coincident with the Dead Sea Transform fault system. Nickel-rich minerals in these assemblages also include Ni phosphides: halamishite Ni_5P_4, negevite NiP_2, transjordanite and orishchinite—two polymorphs of Ni_2P, nazarovite $Ni_{12}P_5$, polekhovskyite $MoNiP_2$; Ni-spinel trevorite $NiFe_2O_4$, bunsenite NiO, and nickeliferous members of the hematite-eskolaite series, Fe_2O_3-Cr_2O_3 containing up to 2 wt% NiO. Yakubovichite forms polycrystalline segregations up to 0.2 mm in size composed of equant crystal grains, in association with crocobelonite, hematite, other phosphates, and phosphides. It has a deep yellow to lemon-yellow color, is transparent to translucent with vitreous luster, and has no cleavage. Mohs hardness = 4. Yakubovichite is orthorhombic, *Imma*, unit-cell parameters of the holotype material: a = 10.3878(10), b = 13.0884(10), c = 6.4794(6) Å, V = 880.94(2) Å^3, Z = 4. Chemical composition of holotype material (electron microprobe, wt%): Na_2O 1.82, K_2O 1.76, CaO 6.37, SrO 0.49, BaO 1.37, MgO 2.13, NiO 21.39, CuO 0.16, Fe_2O_3 18.80, Al_2O_3 1.06, V_2O_3 0.44, Cr_2O_3 0.15, P_2O_5 44.15, total 100.09. The empirical formula calculated on the basis of 12 O atoms per formula unit is $(Ca_{0.55}Na_{0.29}K_{0.18}Ba_{0.04}Sr_{0.02})_{1.08}(Ni_{1.39}Mg_{0.26}Fe^{3+}_{0.24}V^{3+}_{0.03}Cu_{0.01}Cr_{0.01})_{\Sigma1.94}(Fe^{3+}_{0.90}Al_{0.10})_{\Sigma1}P_{3.02}O_{12}$. D_{calc} = 3.657 g cm^{-3}. The strongest lines of powder XRD pattern [d(Å)(I)(hkl)]: 5.82(44)(011), 5.51(73)(101), 5.21(32)(200), 4.214(34)(121), 2.772(97)(240), 2.748(100)(202), 2.599(38)(400). Yakubovichite is the first mineral that crystallizes in the α-$CrPO_4$ structure type. It has a direct synthetic analog, $CaNi_2Fe^{3+}(PO_4)_3$. Since yakubovichite is the first natural Ni-phosphate of non-meteoritic origin, the possible sources of Ni in the reported mineral assemblages are discussed. Pyrometamorphic rocks of the Hatrurim Formation were formed at the expense of the sediments belonging to a Cretaceous-Paleogene (Cretaceous-Tertiary) boundary (~66 Ma age). This geological frame marks the event of mass extinction of biological species on Earth that was likely caused by the Chicxulub impact event. The anomalous enrichment of pyrometamorphic assemblages in Ni may be related to metamorphic assimilation of Ni-rich minerals accumulated in the Cretaceous-Paleogene layer, which was formed due to a Chicxulub collision.

Keywords: Nickel, phosphate, phosphide, trevorite, bunsenite, eskolaite, crystal structure, pyrometamorphism, Dead Sea Transform Fault, Hatrurim Formation, Cretaceous-Paleogene boundary