Bennesherite, Ba$_2$Fe$^{2+}$Si$_2$O$_7$: A new melilite group mineral from the Hatrurim Basin, Negev Desert, Israel

ARKADIUSZ KRZĄTAŁA$^{1,*}$, BILJANA KRÜGER$^2$, IRINA GALUSKINA$^1$, YEVENY VAPNIK$^3$, AND EYVENY GALUSKIN$^1$

$^1$Institute of Earth Sciences, Faculty of Natural Sciences, University of Silesia, Będziniska 60, 41-200 Sosnowiec, Poland
$^2$Institute of Mineralogy and Petrography, University of Innsbruck, Innrain 52, 6020 Innsbruck, Austria
$^3$Department of Geological and Environmental Sciences, Ben-Gurion University of the Negev, POB 653, Beer-Sheva 84105, Israel

**Abstract**

The first barium member of the melilite group, bennesherite Ba$_2$Fe$^{2+}$Si$_2$O$_7$ [P4$_2$12$_m$, Z = 2, a = 8.2334(14) Å, c = 5.2854(8) Å, V = 359.29(13) Å$^3$], was discovered in thin veins of rankinite paralava within pyrometamorphic gehlenite hornfels at Gurim Anticline, Hatrurim Basin, Negev Desert, Israel. Bennesherite occurs in small intergranular spaces between large crystals of rankinite, gehlenite, and garnet together with other Ba-minerals such as fresnoite, walstromite, zadovite, gurimite, hexacelsian, and celsian. It forms transparent, light yellow to lemon-colored crystals with a white streak and a vitreous luster. They exhibit good cleavage on (001), a brittle tenacity, and a conchoidal fracture. The estimated Mohs hardness is 5. Bennesherite has a melilite-type structure with the layers composed of disilicate ([Si$_2$O$_7$]$^{6-}$ groups and (Fe$^{2+}$O$_4$)$^{6-}$ tetrahedra, connected by large eightfold-coordinated Ba atoms. In some grains, epitaxial intergrowths of bennesherite and fresnoite are observed. The structure of the fresnoite, Ba$_2$TiO(Si$_2$O$_7$) with a P4$_2$hm space group and unit-cell parameters a = 8.5262(5) Å, c = 5.2199(4) Å, is closely related to the structure of bennesherite. Among all the known minerals of the melilite group, bennesherite has a structure characterized by the lowest misfit degree between the tetrahedral (T1 and T2 sites) and polyhedral (X-site) layers, as it was shown in both natural and synthetic melilite-type phases.

**Keywords:** Bennesherite, new mineral, melilite group, crystal structure, Raman, fresnoite, paralava, Hatrurim, Israel

**Introduction**

A new mineral of the melilite group, bennesherite, Ba$_2$Fe$^{2+}$Si$_2$O$_7$ (IMA 2019-068), was found in thin veins of rankinite paralava in gehlenite hornfels of the pyrometamorphic Hatrurim Complex in the Negev Desert, Israel. Paralava with bennesherite was found in the immediate vicinity of Ben Neshet Mount, from which the mineral name derives. This rankinite paralava is a source of several new minerals, among which Ba-bearing minerals are predominant, such as zadovite = BaCa$_2$[Si$_2$O$_7$(PO$_4$)](PO$_4$)$_2$F; aradite = BaCa$_2$[Si$_2$O$_7$(VO$_4$)](VO$_4$)$_2$F; hexacelsian = BaAl$_2$Si$_2$O$_7$ and gurimite = Ba$_4$O$_4$Al$_2$(Galuskin et al. 2015; Galuskina et al. 2017a).

Bennesherite is the first barium member of the melilite group combining seven OH-free minerals and one OH-bearing (Table 1). In a melilite structure with the general formula $X_7$T$1_1$(T$2_2$O$_7$)$_2$ (Bindi et al. 2001; Table 1), layers composed of eightfold-coordinated cations, where X = Ca, Na, Sr, K, Ba, $\square$ (vacancy), intercalate with layers formed by a tetrahedrally coordinated T1 and T2, where $T_1$ = Mg, Al, Fe$^{2+}$, Fe$^{3+}$, Be, Zn, B, Si; and T2 = Si, Al, B, Be. Two T2 tetrahedra are linked and form (T2)O$_2$ dimers.

It should be underlined that very small (~10 µm) mineral grains with the empirical formula (Ba$_2$O$_7$Si$_2$Ca$_2$)FeSi$_3$O$_7$, i.e., with a chemical composition close to bennesherite, were detected in leucitic- and melilite-bearing nephelinite from Nyiragongo in the Virunga volcanic province, Democratic Republic of Congo (Andersen et al. 2014). These rocks contain the other rare barium sorosilicate–andrémeyerite, BaFe$^{2+}$Si$_2$O$_7$, composed of the same chemical constituents as bennesherite, but with a different Ba:Fe$^{2+}$ atomic ratio. This different ratio is related to the different structural arrangements of these two phases (Sahama et al. 1973).

Bennesherite has synthetic structural analogs: Ba$_2$MgSi$_2$O$_7$ (Shimizu et al. 1995), Ba$_2$CoSi$_2$O$_7$ (El Bali and Zavali 2003), Ba$_2$CuSi$_2$O$_7$ (Du et al. 2003), and Ba$_2$MnSi$_2$O$_7$ (Sale et al. 2019). Ito and Hafner (1974) also used synthetic Ba$_2$Fe$^{2+}$Si$_2$O$_7$ as a standard for Mössbauer measurements of gadolinite spectra. Synthetic “barium ferroåkermanite,” Ba$_2$Fe$^{2+}$Si$_2$O$_7$, was used for the study of the valence changing and structural state of iron during melting experiments with the help of Mössbauer spectroscopy (Bychkov et al. 1992).

In rankinite paralava, bennesherite intergrows with structurally related fresnoite, Ba$_2$TiO(Si$_2$O$_7$). The main difference between the structures of these minerals is that the T1 (Fe$^{2+}$O$_4$)$^{6-}$ tetrahedron in the tetrahedral layer of the bennesherite structure is replaced by (TiO$_4$)$^{6-}$ tetragonal pyramid in the fresnoite structure (Moore and Louisnathan 1969; Bindi et al. 2006). Fresnoite is a rare mineral discovered in sanbornite-bearing metamorphic rocks from the Rush Creek deposit, eastern Fresno County, California, U.S.A., (Alfors et al. 1965) and later found in several localities (Chukanov et al. 2011; Andersen et al. 2014; Solovova et al. 2006; Peretyazhko et al. 2018).

In this paper, we describe the new mineral bennesherite, as