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The crystal chemistry of the sakhaite–harkerite solid solution

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Abstract

Sakhaite, ca. $Ca_{48}Mg_{16}(BO_3)_{32}(CO_3)_{16}(HCl,H_2O)_2$, is a rare rock-forming borate-carbonate mineral typically occurring in high-temperature, low-pressure calcareous skarns. It forms a complete solid solution with harkerite, ca. $Ca_{48}Mg_{16}[AlSi_4(O,OH)_{16}]_4(BO_3)_{16}(CO_3)_{16}(HCl,H_2O)_2$. The solid solution can be described with the general formula

$$Ca_{48}(Mg,Fe,Mn)_{16}(CO_3)_{16}[Al_aSi_{5-a}(O,OH)_{16}]_y(BO_3)_{32-4y}(HCl,H_2O)_n$$

where $y_{max} = 8$ and $n_{max} = 16 - y$. In this study, we examine samples of sakhaite and harkerite from four localities worldwide: Titovskoye deposit, Sakha Republic, Russia (type locality for sakhaite); Solongo B deposit, Buryatia Republic, Russia; Camas Malag, Skye, Scotland (type locality for harkerite); as well as a sakhaite-like mineral from the Kombat Mine, Tsumeb. The Si:B ratios of the samples ranged from that of end-member sakhaite (containing B only) to that of end-member harkerite (Si:B = 1:1), with several intermediate compositions. All samples were deficient in B relative to the ideal composition, implying significant substitution for borate groups. The Si:Al ratio of silicate-containing samples ranged from the ideal 4:1 to 4:1.5, implying substitution of Al at the Si site. The cubic unit-cell parameter was found to increase linearly with increasing Si content, except for the sakhaite-like mineral from Tsumeb. This mineral was found to have significant substitution of Pb for Ca (0.4–0.5 apfu) and was poor in Cl, which in most sakhaite and harkerite samples occupies the interstitial site surrounded by four borate groups. This interstitial site in the Tsumeb samples appears to be, instead, mainly occupied by H_2O, which may qualify the mineral as a distinct species.

Keywords: Sakhaite, harkerite, solid solution, crystal structure; Lithium, Beryllium, and Boron: Quintessentially Crustal