American Mineralogist, Volume 84, pages 1304–1318, 1999

Hydrothermal synthesis of amphiboles along the tremolite-pargasite join and in the ternary system tremolite-pargasite-cummingtonite

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ABSTRACT

We report here an investigation of amphibole synthesis within the ternary system $Ca_2Mg_5Si_8O_{22}(OH)_2$-$NaCa_2Mg_4Al_3Si_6O_{22}(OH)_2$-$Mg_7Si_8O_{22}(OH)_2$ (= TR-PG-MC) to define better the limits of solid solution for amphiboles formed along and near the join tremolite-pargasite. Hydrothermal syntheses were conducted in the range of 750–1000 °C and 1–6 kbar. Syntheses at 10 mol% compositional intervals along the TR-PG join produced incomplete yields of amphibole, and the resultant amphiboles were found to be associated with varying amounts of accessory clinopyroxene, plagioclase, and gehlenite. Syntheses of end-member pargasite with progressively greater amounts of the MC component produced a very good amphibole yield for a pargasite composition containing 2.5 mol% MC. The persistence of clinopyroxene or gehlenite and the improved yield of pargasitic amphibole with minor addition of the MC component indicate a shift toward MC enrichment for amphiboles made from bulk compositions directly on the TR-PG join. Syntheses within the TR-PG-MC ternary system suggest that the Ca-rich limit of solid solution is a slightly curved field in the TR-PG-MC field. Amphiboles made along this join showed a very systematic change in the (151) and ($\bar{3}$31) peak spacing with mol% PG, providing a simple technique for deducing the composition of amphiboles made near the tremolite-pargasite join. Electron microprobe analysis confirms that the amphiboles for the most part conform to the "pargasite" substitution. The one exception being amphiboles formed near 80–90 mol% PG compositions, which proved both difficult to synthesize (~75 wt% amphibole yield) and displayed a small, but significant, excess of Na in their structure. High yields of amphibole could be formed from this same bulk composition with the use of a dilute NaOH solution instead of pure water, suggesting that there was insufficient Na in the starting mixture to allow complete amphibole formation. Structural refinements using X-ray diffraction (XRD) Rietveld refinement confirmed the high Na content for this sample and also revealed a non-linear trend in the unit-cell volume with composition, with a maximum at the 80 mol% PG bulk composition. The difficulty in synthesizing amphiboles near this bulk composition and its unusually high volume suggest that immiscibility in natural hornblendes may initiate with increasing pressure for pargasite-rich bulk compositions.