Assessment of cation substitutions along the gallium and fluorine analogue of the tremolite-glaucophane join

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ABSTRACT

Assessment of the glaucophane substitution, $[\text{VI}] \text{Ca} + [\text{IV}] \text{Mg} \leftrightarrow [\text{VI}] \text{Na} + [\text{VI}] \text{Al}$, along the Ga and F analogue of the tremolite-glaucophane join, $[\text{VI}] \text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}\text{F}_2$–$[\text{VI}] \text{Na}_2\text{Mg}_3\text{Ga}_3\text{Si}_8\text{O}_{22}\text{F}_2$ (f–Ga–glauc), was conducted at 900 °C and 1.5 GPa in 10 mol% increments. Several chemical exchanges deviating from the glaucophane substitution were identified, namely the “edenite” substitution $[\text{VI}] \text{Na} + [\text{IV}] \text{Ga} \leftrightarrow [\text{VI}] \text{Na} + [\text{IV}] \text{Ga}$ toward F-Ga-nyböite, the $[\text{VI}] \text{Na} + [\text{IV}] \text{Ga} \leftrightarrow [\text{VI}] \text{Na} + [\text{VI}] \text{Mg}$ toward F-Ga-richterite exchange toward F-Ga-nyböite–magnesiokatophorite, and the [A] $[\text{VI}] \text{Ga}$ exchange toward F-Ga-nyböite–magnesiokatophorite–cummingtonite. Minor displacements from the join due to the $[\text{VI}] \text{Na} + [\text{IV}] \text{Ga} \leftrightarrow [\text{VI}] \text{Na} + [\text{VI}] \text{Mg}$ exchange toward “cummingtonite” and the richterite exchange $[\text{VI}] \text{Na} + [\text{VI}] \text{Mg}$ exchange toward F-Ga-nyböite–magnesiokatophorite–cummingtonite were also observed. Amphibole syntheses with low F-Ga-glauc contents (≤60 mol%) were primarily influenced by the “edenite” exchange, while those with high F-Ga-glauc contents (>70 mol%) were dominated by the “glaucophane” substitution. Powder X-ray diffraction Rietveld refinements were obtained without restrictions for the amphiboles formed in the range 0–40 mol% F-Ga-glauc. Refinements for samples in the ranges of 50–70 and 100 mol% F-Ga-glauc were possible only after applying some restrictions to the A- and M4-site occupancies because of the appearance of a layered silicate and an unidentified Ga-rich phase that complicated the refinement. The successful refinements indicated that amphibole exhibits $[\text{VI}] \text{Ga}$ ordering at the M2 site and $[\text{IV}] \text{Ga}$ ordering at the end-member composition. Initial investigations (Ernst 1961, 1963; Maresch 1973) generally yielded an amphibole similar to alumino-eyckenmanite $[\text{Na}_2\text{Mg}_3\text{Al}_2\text{Si}_8\text{O}_{22}(\text{OH})_2]$. Pawley (1992) attempted to obtain thermodynamic data for glaucophane by synthesizing nyböite $[\text{Na}_2\text{Mg}_3\text{Al}_2\text{Si}_8\text{O}_{22}(\text{OH})_2]$, which is related to glaucophane by the edenite exchange $[\text{VI}] \text{Na} + [\text{IV}] \text{Ga} \leftrightarrow [\text{VI}] \text{Na} + [\text{VI}] \text{Mg}$, but was never achieved, instead an amphibole of quaternary composition (nyböite–glaucophane–Na-magnesiokatophorite–cummingtonite) was synthesized in the absence of quartz, and an amphibole of ternary composition (nyböite–glaucophane–Na-magnesiokataphorite–cummingtonite) was synthesized in the presence of quartz. Note, we use the term Na-magnesiokataphorite–cummingtonite to describe the hypothetical amphibole $[\text{Na}_2\text{Al}_2\text{Si}_8\text{O}_{22}(\text{OH})_2]$, which was previously defined by Welch and Graham (1992) as Mg-kataphorite, as being more consistent with current IMA nomenclature (Leake et al. 1997). Welch and Graham (1992) pursued the synthesis of end-member glaucophane using the F-analogue system, $\text{Na}_2\text{O}-\text{MgO}-\text{Al}_2\text{O}_3-\text{Si}_2\text{O}_5\text{Si}_2\text{F}_2$ (NMASH). They concluded that the NMASH system was analogous to the NMASH system studied by Koons (1982) and Carman and Gilbert (1983). Welch and Graham (1992) synthesized amphiboles that again deviated from F-glaucophane composition, forming in the quaternary system nyböite–glaucophane–Na-magnesiokataphorite–cummingtonite.

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INTRODUCTION

The occurrence of glaucophane $[\text{VI}] \text{Na}_2\text{Mg}_3\text{Al}_2\text{Si}_8\text{O}_{22}(\text{OH})_2]$ is indicative of blueschist terranes, that is high-pressure and low-temperature metamorphic conditions. The ability to define the $P$-$T$ stability field of glaucophane would enable geologists to better define $P$-$T$ conditions achieved during blueschist metamorphism. Two approaches have been taken toward this goal: (1) calculation of the stability field of end-member glaucophane derived from phase equilibria and calorimetric studies of natural Fe-bearing glaucophane (Maruyama et al. 1986; Holland 1988; Evans 1990), and (2) the investigation of Fe-free end-member glaucophane, which is the focus of this study. Previous attempts to experimentally synthesize glaucophane have resulted in amphibole compositions that deviate from the end-member composition. Initial investigations (Ernst 1961, 1963; Maresch 1973) generally yielded an amphibole that was displaced, in some cases considerably, from ideal glaucophane toward such compositions as Mg-rich richterite $[\text{Na}_2\text{Mg}_3\text{Si}_8\text{O}_{22}(\text{OH})_2]$ at low pressures and toward cummingtonite $[\text{Mg}_2\text{Si}_8\text{O}_{22}(\text{OH})_2]$ at high pressures (Maresch 1977). Koons (1982) and Carman and Gilbert (1983) were unable to synthesize a 100% yield of glaucophane; instead, they formed an amphibole similar to alumino-eyckenmanite $[\text{Na}_2\text{Mg}_3\text{Al}_2\text{Si}_8\text{O}_{22}(\text{OH})_2]$. Pawley (1992) attempted to obtain thermodynamic data for glaucophane by synthesizing nyböite $[\text{Na}_2\text{Mg}_3\text{Al}_2\text{Si}_8\text{O}_{22}(\text{OH})_2]$, which is related to glaucophane by the edenite exchange $[\text{VI}] \text{Na} + [\text{IV}] \text{Ga} \leftrightarrow [\text{VI}] \text{Na} + [\text{VI}] \text{Mg}$, but was never achieved, instead an amphibole of quaternary composition (nyböite–glaucophane–Na-magnesiokataphorite–cummingtonite) was synthesized in the absence of quartz, and an amphibole of ternary composition (nyböite–glaucophane–Na-magnesiokataphorite–cummingtonite) was synthesized in the presence of quartz. Note, we use the term Na-magnesiokataphorite–cummingtonite to describe the hypothetical amphibole $[\text{Na}_2\text{Al}_2\text{Si}_8\text{O}_{22}(\text{OH})_2]$, which was previously defined by Welch and Graham (1992) as Mg-kataphorite, as being more consistent with current IMA nomenclature (Leake et al. 1997). Welch and Graham (1992) pursued the synthesis of end-member glaucophane using the F-analogue system, $\text{Na}_2\text{O}-\text{MgO}-\text{Al}_2\text{O}_3-\text{Si}_2\text{O}_5\text{Si}_2\text{F}_2$ (NMASH). They concluded that the NMASH system was analogous to the NMASH system studied by Koons (1982) and Carman and Gilbert (1983). Welch and Graham (1992) synthesized amphiboles that again deviated from F-glaucophane composition, forming in the quaternary system nyböite–glaucophane–Na-magnesiokataphorite–cummingtonite.

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