Protoanthophyllite from three metamorphosed serpentinites

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ABSTRACT

This is the first report of a natural Mg-rich protoanthophyllite. It is common in metamorphosed serpentinites from three Japanese ultramafic complexes, and some crystals contain anthophyllite (Pnma) lamellae. The Mg/(Mg + Fe) ratios of the Hayachine, Tari-Misaka, and Takase protoanthophyllites are 0.90, 0.92, and 0.91, respectively. The samples have identical optical properties: X = a, Y = b, Z = c, and 2Vr = 64 ± 5°. Their space group is Pnma (or Pn2n), as revealed by systematic extinctions in selected-area electron-diffraction patterns. The protoanthophyllite and anthophyllite have similar compositions and orthorhombic symmetry. They are difficult to distinguish using optical, microanalytical, and powder X-ray diffraction measurements. This problem raises the possibility that some of the published data on geological and synthetic anthophyllite samples may be of misidentified materials, potentially leading to errors in the published stability relations of anthophyllite. We provide a method to identify protoanthophyllite and differentiate it from its polymorphs using selected-area electron diffraction and high-resolution transmission electron microscopy methods.

INTRODUCTION

Members of the anthophyllite–gedrite amphibole series are significant minerals for petrological studies of metamorphic rocks. They occur in metamorphosed ultramafic rocks, in reaction zones between ultramafic and country rocks, in low-Ca amphibolites, and in iron formations (Robinson et al. 1982; Deer et al. 1997). When ultramafic rocks are incorporated into orogenic belts by obduction or subduction, they commonly are hydrated to serpentinite and then recrystallized under various metamorphic conditions (Spear 1993). Anthophyllite occurs in Alpine-type peridotites (e.g., Evans and Trommsdorff 1970; Trommsdorff and Evans 1972), and anthophyllite and gedrite are essential components in cordierite-anthophyllite rocks, which contain assemblages that are characteristic of specific P-T conditions (Spear 1993). The association of kyanite or sillimanite with Al-bearing anthophyllite or gedrite represents moderately high-pressure metamorphic conditions (>5 kbar) (Spear 1993), and Liu and Liou (1995) reported a high-pressure kyanite and Al-bearing anthophyllite schist that is associated with the Dabie Mountains ultrahigh-pressure metamorphic rocks in China.

Metamorphic reactions of serpentinites have been studied extensively. With increasing temperature, there are associations of serpentine–brucite ± diopside, serpentine–olivine ± diopside, serpentine–olivine ± tremolite, olivine–talc ± tremolite, olivine–anthophyllite ± tremolite, olivine–enstatite ± tremolite, and olivine–enstatite ± diopside (Evans and Trommsdorff 1970; Tracy and Frost 1991; Spear 1993). As shown by Evans and Trommsdorff (1970), anthophyllite can be produced by the reaction:

\[ 4 \text{olivine} + 9 \text{talc} = 5 \text{anthophyllite} + 4 \text{H}_2\text{O} \] (1)

The reaction:

\[ \text{anthophyllite} + \text{olivine} = 9 \text{enstatite} + \text{H}_2\text{O} \] (2)

marks the upper thermal stability of anthophyllite. Both reactions have steep slopes in the P-T diagram, making them good indicators of temperature (−600–700 °C) (Evans and Trommsdorff 1970; Tracy and Frost 1991).

The structure of anthophyllite \([\{(\text{Mg,Fe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2]\] like that of other amphiboles, can be viewed as consisting of bands of SiO₄ tetrahedra and (Mg, Fe)-centered octahedra parallel to c. These bands can be understood in terms of the I-beam model of Papke and Ross (1970) and Thompson (1970). Two tetrahedral and one octahedral band comprise an I-beam. The arrangement of I-beams forms alternating layers of tetrahedra and octahedra parallel to (100). The octahedral layers can have either of two orientations, with one related to the other by a half-rotation around the c axis. Different octahedral orientations between adjacent tetrahedral layers cause different stacking sequences. The stacking vector between neighboring tetrahedral layers is \(+c/3\) or \(-c/3\) or, more simply, \(+c\) or \(-c\) (Hawthorne 1981). In anthophyllite, like in other \(Pnma\) amphiboles, the stacking vector in alternate paired tetrahedral layers reverses (\(+c\) or \(-c\)).

The various combinations of stacking vectors along the a axis results in different amphibole polymorphs (Fig. 1, left column). The same orientation (\(++...\) or \(...--...\)) of tetrahedral layers produces the clinoamphibole structure with...