Winchite from Mt. Hiei contact aureole, Kyoto, Japan

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Sodic-calcic amphibole closely associated with aegirine-augite was newly found from a sandy hornfels at Mt. Hiei contact aureole, Kyoto, Japan. The amphibole shows a pleochroism of X=colorless, Y=blue and Z=light blue and is winchite with significant amounts of TiO₂ (1.5–2.5 wt.%) and of Mg-Fe-Mn-Li amphibole component at B site (ca. 0.1–0.4 cations for O=23 basis). The chemical composition and the coexisting phases of the winchite in this study are similar to those in the alkaline igneous complex.

Introduction

Winchite, one of the end members of the sodic-calcic amphibole (Leake et al., 1997), was originally found from Kajlidongri mine, Madhya Pradesh, India, in the beginning of the 20th century (see Nayak and Leake, 1975). Since then, this mineral has been reported from various geological settings, such as a) metamorphosed Mn-ore deposits (e.g., Bilgrami, 1955; Nambu et al., 1980), b) high-pressure metamorphic rocks (e.g., Maresch et al., 1982; Smelik and Veblen, 1989; Otsuki and Banno, 1990) and c) alkaline igneous complex (e.g., Strong and Taylor, 1984). The present study reports a new occurrence of winchite closely associated with aegirine-augite in a sandy hornfels from Mt. Hiei contact aureole, Kyoto, Japan. In this contribution, the mode of occurrence and chemical character of the winchite will be described and its petrological significance will be briefly discussed.

Geological outline

The winchite was found in a sandy hornfels from the western slope of Mt. Mizui, which occupies the northern part of the Hiei Mountains bounded by two active faults with NNE–SSW trend, i.e., Hanaore Fault and Hiei Fault (Fig. 1). The main constituent of the Hiei Mountains is the Jurassic accretionary sediment of the Tamba Group and late Cretaceous granitoids. The granitoids in this area are subdivided into Ohgi tonalite and Hiei granite with radiometric ages ranging from 73 to 99 Ma (Hayase and Ishizaka, 1967; Kawano and Ueda, 1966; Sawada and Itaya, 1993). The major mafic phases in the granitoids are hornblende and biotite. Clinopyroxene is rarely recognized in the Ohgi tonalite (Kimura et al., 1998).

The intrusion of the late Cretaceous granitoids caused contact metamorphism to the surrounding sediments of the Tamba Group. The three mineral zones, i.e., cordierite, biotite and chlorite zones with descending order of the metamorphism, were established in the southern margin of the contact aureole of the Hiei granite. The metamorphic zoning was defined by the appearance of index minerals in metapelite and by the graphitization degree of carbonaceous materials by Nakamura (1995).

The recent petrological study in the Hiei Mountains by our group reveals that the muddy hornfels of the

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Figure 1. Geologic map with the locality of index metamorphic minerals around Mt. Hiei contact aureole. Lithologic distribution mainly follows Kimura et al. (1998). Metamorphic zoning to the south of the Hiei granite quotes Nakamura (1995). Crd, cordierite; Bt, biotite; Kfs, K-feldspar; Ms, muscovite; Chl, chlorite.

Tamba Group located between Hiei granite and Ohgi tonalite contains cordierite and/or biotite. This fact suggests that the Tamba Group in the relevant area suffered the cordierite or biotite grade contact metamorphism (Fig. 1).

The sandy hornfels with winchite was found in the western slope of Mt. Mizui, about 500 m above sea level. As far as we observed more than 200 thin sections of muddy and sandy hornfels in the Hiei Mountains, winchite was not found from the other studied specimens. The sandy hornfels with winchite is intercalated with muddy hornfels, which contains tiny and abundant biotite. Although cordierite was not found from this locality, the outcrop of the winchite-bearing sandy hornfels is located near the cordierite-in isograd (Fig. 1). This suggests that the rock was heated to temperatures slightly less than 510°C at 2–2.3 kbar (Nakamura, 1995). Another remarkable feature in this outcrop is the development of quartz or quartz-feldspathic veins in the hornfels. A quartz-feldspathic vein contains amphiboles with high-alkali and Ti contents ($\text{Na}_2\text{O} + \text{K}_2\text{O} = 5.6\text{--}7.1 \text{ wt.}\%$ and $\text{TiO}_2 = 3.5\text{--}4.8 \text{ wt.}\%$, Okamoto, 1999).

Petrography and chemical composition

The sandy hornfels is mainly composed of detrital grains of quartz, K-feldspar and plagioclase with ca. 1 mm diameter in average. Along their grain boundaries, thermal metamorphic minerals (up to 0.3 mm in diameter) are well developed (Fig. 2). The main metamorphic minerals are biotite, muscovite, blue amphibole and green clinopyroxene. Subordinate amounts of titanite, monazite, zircon and opaque minerals are also observed.

Both the blue amphibole and the green clinopyroxene occur as small prismatic crystals 0.05–0.30 mm in length (Fig. 2). The blue amphibole shows a pleochroism of X=colorless, Y=blue, and Z=light blue.

Chemical analyses of the blue amphibole and the green clinopyroxene were performed by an electron microprobe (Hitachi S-550) with Kevex energy dispersion system (Quantum detector) at Kyoto University. The procedure follows that of Mori and Kanehira (1984) and Hirajima and Banno (1991). Table 1 shows representative chemical analyses of amphibole and clinopyroxene. The nomenclature of amphibole follows Leake et al. (1997).

Amphibole

The amphibole is homogeneous in each grain but slightly changes its composition from a grain to another.

Figure 2. (a) Photomicrograph of winchite (Win) developing along the grain boundary of quartz (Qtz) and feldspar (Fs) grains. Scale bar is 0.1 mm. Opened Nicol. (b) Photomicrograph of winchite (Win) and aegirine-augite (Aeg) developing along the grain boundary of quartz (Qtz) and feldspar (Fs) grains. Scale bar is 0.1 mm. Opened Nicol.

Because the amphibole is closely associated with aegirine-augite, we need to estimate Fe^{3+} content in the amphibole. There is no explicit way of the $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratio estimation for amphiboles formed in the low-pressure conditions. We tentatively adopted a charge balance method following Leake et al. (1997). In Table 1, two chemical formulae (1: all iron as FeO and 2: averaging the minimum and maximum ferric estimation or normalizing Si as 8.0 by Leake et al. (1997), see their Appendix 2: Table 2) are shown for comparison. Microprobe data of the amphibole are summarized as follows: a) the tetrahedral site is mainly occupied by Si, b) the sum of Ca and Na in B site is larger than 1.5 and less than 1.7, c) Ca/Na ratio in B site is almost 1, and d) the sum of Na and K in A site is less than 0.2, suggesting that the analyzed amphibole is winchite. The winchite contains a significant amount of TiO_2 (1.5–2.5 wt.%). On the behavior of Ti in amphibole, following ideas are proposed by many workers: Ti^{4+} coordinates in A) tetrahedral site (e.g., Della Ventura et

Table 1. EPMA data of blue amphibole and green clinopyroxene in sandy hornfels (MS14)

Amphibole							Clinopyroxene		
winchite 1		winchite 2		winchite 3			pyroxene 1		
SiO ₂	53.06		53.94		55.11		SiO ₂	54.64	
TiO ₂	1.52		1.61		2.16		TiO ₂	0.47	
Al ₂ O ₃	0.85		1.08		0.75		Al ₂ O ₃	0.19	
FeO*	19.63		19.09		17.85		FeO*	18.12	
MnO	0.31		0.21		0.52		MnO	0.37	
MgO	11.2		11.72		11.31		MgO	7.49	
CaO	4.87		4.98		4.83		CaO	14.52	
Na ₂ O	2.98		3.18		2.86		Na ₂ O	4.60	
K ₂ O	0.45		0.46		0.40		K ₂ O	0.00	
Total	94.87		96.27		95.79		Total	100.40	
O	23		23		23		O	6	
	All Fe ²⁺	Ave*	All Fe ²⁺	Ave*	All Fe ²⁺	Si=8.0		All Fe ²⁺	Cation=4.0
Si	8.046	7.996	8.028	7.984	8.150	8.000	Si	2.089	2.056
Al ^(IV)	0.000	0.004	0.000	0.016	0.000	0.000	Al ^(IV)	0.000	0.000
Sum	8.046	8.000	8.028	8.000	8.150	8.000	Sum	2.089	2.056
Al ^(VI)	0.152	0.147	0.189	0.173	0.104	0.128	Al ^(VI)	0.009	0.008
Ti	0.173	0.172	0.180	0.179	0.207	0.236	Ti	0.014	0.013
Fe ³⁺		0.283		0.251		0.933	Fe ³⁺		0.189
Mg	2.532	2.516	2.600	2.586	2.562	2.448	Mg	0.417	0.420
Fe ²⁺	2.143	1.881	2.030	1.811	2.127	1.255	Fe ²⁺	0.560	0.370
Sum	5.000	5.000	5.000	5.000	5.000	5.000	Sum	1.000	1.000
Fe ²⁺	0.346	0.310	0.346	0.301	0.103	0.000	Fe ²⁺	0.019	0.011
Mn	0.040	0.040	0.026	0.026	0.060	0.064	Mn	0.012	0.012
Ca	0.791	0.786	0.794	0.790	0.731	0.751	Ca	0.595	0.585
Na	0.823	0.864	0.833	0.883	0.979	0.805	Na	0.341	0.336
Sum	2.000	2.000	2.000	2.000	1.873	1.620	Sum	0.967	0.944
Na	0.054	0.007	0.084	0.030	0.000	0.000			
K	0.087	0.087	0.087	0.087	0.117	0.074			
Sum	0.141	0.093	0.172	0.117	0.117	0.074			
Total	15.186	15.093	15.200	15.117	15.139	14.694	Total	4.064	4.000

Ave*: average ferric estimation follows Leake et al. (1997).

Si=8.0: ferric estimation for normalizing Si=8.0 follows Leake et al. (1997)

al., 1991) and B) octahedral site (e.g., Kitamura et al., 1975; Hawthorne et al., 1998). As the studied amphiboles show Si $\approx$ 8.00 for O=23, Ti may occupy the octahedral site in them. The other common character for the studied amphiboles is that significant amounts of Mg-Fe-Mn-Li amphibole component (0.1–0.4 cations for O=23) occupy B site. Some winchite (e.g., winchite 3 in Table 3) is in shortage of total cations in B site. The incorporation of Li in the studied amphibole is one of the explanations for the shortage of total cations in B site.

Clinopyroxene

Green clinopyroxene is also homogeneous in each grain

but slightly changes its composition from a grain to another. It is aegirine-augite with acmite content ($=(\text{Na}-\text{Al})/(\text{Ca}+\text{Na})$) from 0.25 to 0.30 and is almost free from jadeite component ($=\text{Al}/(\text{Ca}+\text{Na})<0.01$) (Table 1).

Discussion

Characteristic features of winchite according to their mode of occurrences

Some blue or bluish-green amphiboles (e.g., glaucophane, crossite and barroisite) are one of the diagnostic minerals for the high-pressure and low-temperature (HP/LT) metamorphism. However, other blue am-

phiboles (e.g., riebeckite and winchite) occur in alkaline igneous rocks, metamorphosed Mn-ore deposits and authigenic environments as well as in the HP/LT metamorphic rocks.

The chemistry of winchite reflects both the P-T conditions of its formation and the host rock compositions as follows. Winchites in the HP/LT metamorphic rocks are generally free from TiO_2 (e.g., in basic schists of the Sanbagawa belt by Higashino et al., 1982; in blueschist of Vermont, Smelik and Veblen, 1989; in eclogite of Venezuela, Maresch et al., 1982, and of Spitsbergen, Hirajima et al., 1988) and they contain significant amounts of Al_2O_3 (e.g., 1.5–4.5 wt.% in the Sanbagawa belt and 7.0–8.0 wt.% in Venezuela and Spitsbergen) as a glaucophane component. Winchite from Mn-ore deposits is characterized by a high content of MnO (ca. 2.0–15.4 wt.%, e.g., Nambu et al., 1980) and is closely associated with other Mn-rich phases, such as manganocummingtonite (former tirodite), judite, braunite etc. (Bilgrami, 1955; Nayak and Leake, 1975). Winchite from alkaline igneous rocks is characterized by high TiO_2 (e.g., 0.3–1.6 wt.%) and low Al_2O_3 (e.g., 0.7–1.3 wt.%) and is closely associated with aegirine/aegirine-augite, K-feldspar and plagioclase (Strong and Taylor, 1984). The chemical composition of the winchite in this study ($\text{TiO}_2 = 1.5\text{--}2.3$ wt.% and $\text{Al}_2\text{O}_3 = 0.6\text{--}1.1$ wt.%) and its associated minerals are very similar to those in the alkaline igneous complex.

Why winchite developed in sandy hornfels?

What is the main reason for the development of winchite and aegirine-augite in the sandy hornfels? If the studied rock originally had a peculiar chemical composition with high-Na, Fe^{3+} and Ti contents rather than the common composition of sandstone in the Tamba Group, the formation of winchite and aegirine-augite should be expected in the biotite or cordierite grade contact metamorphism.

Strong and Taylor (1984) pointed out that the fluid chemistry is also important in controlling the chemical characteristics of amphiboles in per-alkaline intrusive and volcanic rocks, along with host-rock compositions. Czamanske and Atkin (1985) reported the metasomatic origin of acmite and sodic amphiboles with unusual Ti content in lithic-wacke inclusions within the alkalic ultramafic diatreme. The development of quartz and quartz-feldspathic veins is an evidence of igneous activity at the outcrop of the studied rock. Many thin veins (<1–2 mm in width) radiate from the quartz-feldspathic vein (a few cm in width) with the high-alkali and Ti amphibole. Therefore, another possible cause for the

formation of winchite and aegirine-augite in the present study is the enrichment of Na, Fe^{3+} and Ti by a vein forming fluid

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