Amazonitic alkali feldspar from the Tanakami Granitic pegmatite, southwest Japan

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This is the first detailed description of amazonitic alkali feldspar in Japan. The amazonitic feldspar is from pegmatite in the Tanakami Granite, southwest Japan. Macroscopically, the feldspar is characterized by the coexistence of pale blue and white parts. The two parts of microperthite are distinctly different in terms of their microscopic texture. The pale blue part has clear crosshatched twin patterns, albite laths, and few albite patches with relatively few micropores. In contrast, the white part has unclear twin patterns, few albite laths, and many albite patches with abundant micropores. The pale blue color is due to the host microcline containing 103 ppm of PbO at the maximum, and the white color is due to both the two albite phases and turbid microcline causing strong diffuse reflection. It is deduced that plagioclase laths were first crystallized and then enclosed by pale blue microcline that crystallized later. Crosshatched twins were formed in the microcline during cooling, and albite replaced the microcline forming perthitic patches with many micropores. The composition of plagioclase laths is very close to that of pure albite, which is same as that of albite patches. The microcline part having undergone extensive albitization appear white to the naked eye; the part that did not undergo albitization has retained its pale blue color. The amazonitic microcline crystallization and albitization are estimated to have occurred at very low temperatures around 200 °C.

Keywords: Amazonite, Color, Lead, Water, Hydrothermal, Replacement, Tanakami Granite

INTRODUCTION

Pegmatite environments are highly variable (Černý, 1993, 1994) and many problems associated with their formation processes still exist (London, 2005). Feldspar microtextures give valuable information on thermal and chemical reactions in various host rocks (Smith and Brown, 1988; Brown and Parsons, 1994; Deer et al., 2001). The evolution of pegmatite feldspars from the crystallization stage to the low-temperature hydrothermal stage has been outlined by Černý et al. (1984) and Černý (1994). Recently, Nakano et al. (2001) and Kohno et al. (2008) clarified the low-temperature multistage events in the formation of pegmatite alkali feldspar that is not amazonite, from their microtextures. However, much more studies on pegmatite feldspars are required to clarify a variety of pegmatite environments and their formation processes.

Amazonites, which are widely known as a blue-

green variety of alkali feldspar (microcline or orthoclase), mostly occur in pegmatites (Cech et al., 1971; Hofmeister and Rossman, 1983, 1985; Smith and Brown, 1988; Deer et al., 2001). Their colors have been the main subject of many studies to date. The color is considered to be controlled by not only the amount of Pb but also the amount of water and radioactive irradiation (Hofmeister and Rossman, 1983). However, the characterization of their microtextures has hardly been carried out, except for the study of galena inclusions in the Broken Hill amazonite (Murakami et al., 2000). Several papers on studies on amazonite reported only the existence of microperthites or showed only their photographs without interpretations (Foord and Martin, 1979; Pivec et al., 1981; Stevenson and Martin, 1986, 1988; Ostrooumov and Banerjee, 2005).

In this study, we characterize microtextures, especially microperthites of Or-rich host and Ab-rich guest phases, of amazonitic alkali feldspar from pegmatite of the Tanakami Granite pluton, Japan, with respect to its

macroscopic color variation. The sample shows pale blue and white parts. The former part is amazonite, but the latter is not amazonite; however, alkali feldspar is recognized to be amazonitic as a whole in this study. The term “amazonitic” was first used for amazonite coexisting with white alkali feldspar by Stevenson and Martin (1988). This term is now used in a broad sense for blue-green colored alkali feldspars, regardless of paragenesis and texture (Martin et al., 2008). The occurrence of amazonites or amazonitic alkali feldspars in Japan has been reported (Nagashima et al., 1975; Kobayashi, 1989; Matsumura, 2003; etc.); however, this is the first time that their detailed description is being reported. This paper should provide new insight into amazonitic alkali feldspars.

GEOLOGICAL BACKGROUND AND EXAMINED SAMPLE

Many Cretaceous granitic plutons are widely distributed in the inner zone of southwest Japan. Several granite plutons among them are distributed around Lake Biwa, the biggest lake in Japan. The Tanakami Granite pluton of dimensions ca. 15 km $\times$ 20 km is situated to the southeast of Lake Biwa (Collaborative Research Group for the Granites around Lake Biwa, 2000; Nakano and Hara-yama, 2003). It belongs to the ilmenite-series granites (Ishihara, 1977). Ishihara et al. (2005) reported that the Tanakami Granite is rich in radioactive elements such as U (3.1–6 ppm) and Th (18–30 ppm) as well as F (max. 1550 ppm) and rare-earth elements (179–290 ppm) as compared to other Japanese granites.

There are many pegmatite cavities in the western margin of the Tanakami Granite pluton (Tsuji and Kitahara, 1979). The Tanakami pegmatite is famous for large and beautiful topaz (Dana and Ford, 1959), beryl, and zinnwaldite crystals. Many beautiful smoky and black rock crystals are found to exist along with abundant feldspar crystals as major minerals. Alkali feldspars are generally reddish, and plagioclases (albite) are generally white. In addition, around 40 minerals have been reported to be obtained from the pegmatites (Tsuji and Kitahara, 1979), for example, euxenite, yttrotantalite, fergusonite, samarskite, columbite, cassiterite, fluorite, gadolinite, zircon, and garnet.

Amazonitic alkali feldspars occur in the Tanakami pegmatite. The present sample is the largest one among them, with dimensions of approximately 3 cm $\times$ 2 cm $\times$ 5 cm. Macroscopically, this sample shows a combination of white and pale blue parts. To our regret, however, its precise locality and occurrence are unknown, because late Mrs. Kobayashi found it more than 40 years ago in the western margin of the Tanakami Granite pluton (around

135°58'E, 34°56'N), Otsu City, Shiga Prefecture.

ANALYTICAL METHODS

A BRC112E spectrometer (B&W Tek, Inc., USA) was used for color measurement. The naturally plain (110) surface of the sample was illuminated vertically by incandescent electric light (Fig. 1). The scattered light was detected at a catch angle of 45° by the acceptor of diameter 0.1 mm that was attached to the CCD detector body. The intensity of scattered light for different wavelengths (0.6-nm step in the range of 400–800 nm) was recorded by using the BWSpec 3.23 software installed in a connected PC. The data were calibrated by taking into account several factors such as dark compensation for the CCD detector and reference data of source light.

Thin sections of the sample were examined under an optical microscope and by using a JEOL JXA 8800M electron probe microanalyzer (EPMA) at Shiga University. The analytical conditions were as follows: accelerating voltage = 15 kV, probe current = 0.05 μ A (mapping) and 0.02 μ A (quantitative analyses), and the beam was focused for mapping and defocused to diameters of 5 μ m for phase compositions and 50 μ m for local bulk compositions. The mapping was carried out using a stage scan under the following settings: resolution = 500 $\times$ 500 pixels and dwell time = 180–200 ms. Quantitative analyses of major elements were carried out by using Bence and Albee's procedure (1968), which is as follows. The bulk composition of the feldspar sample was estimated by averaging the local-bulk composition ($n = 435$). The Pb concentration was determined by using a synthetic glass standard (55.62 wt% PbO) under the following conditions: peak counting time = 500 s, background counting time = 500 s, and probe current = 0.05 μ A.

The sample was also investigated by FT-IR and XRD analyses. The FT-IR analysis was carried out using a Janssen MFT-2000 spectrometer at Shinshu University. The analytical conditions were the same as those in a previous study (Nakano et al., 2001), and the beam diameter was 100 μ m. The XRD analyses were carried out to determine the feldspar obliquity (Goldsmith and Laves, 1954) by using a Rigaku X-ray diffractometer at Shiga University. The operating conditions were 35 kV, 15 mA, and a scan speed of 0.5° per minute.

FELDSPAR COLORS DETECTABLE TO THE NAKED EYE

The feldspar shows several well-developed facets (Fig. 1). The development of the (110) facet is characteristic (Fig. 1), probably comparable to the adularia habit (Černý and

Figure 1. Photographs of amazonitic alkali feldspar from the Tanakami pegmatite. (a) Feldspar grain consisting of pale blue feldspar (PBF) part and white feldspar (WF) part. The inset shows a close-up of the rectangular part. The cross in the inset shows the position for which the color data are shown in Figure 2. (b) Complex color combination of PBF and WF parts on (001) section, which was cut from grain shown in (a). (c) Textural contrast between PBF and WF parts under crossed polarizers on (001) section obtained from chip shown in (b). Crosshatched twin patterns are clear in the PBF part, but almost absent in the WF part. Perthitic textures of the Or-rich host and Ab patches are present in the WF part.

Figure 2. Color characterization of amazonitic alkali feldspar from the Tanakami Granite. (a) Typical spectral pattern of PBF obtained by using BRC112E spectrometer for the position shown in Figure 1a. (b) a^* - b^* plot on the $L^*a^*b^*$ color coordinate system, obtained from data shown in (a). (c) Corresponding x - y plot on the xyz color coordinate system.

Chapman, 1984). It is notable that the present crystal facets are undulated, with small pits and grooves at some places.

The feldspar consists of two parts that appear pale blue (hereafter referred to as PBF) and white (hereafter referred to as WF) in color to the naked eye (Figs. 1a and 1b). The former part is translucent, but the latter is opaque. Close inspections with the naked eye reveal the combination of PBF and WF to be complex (Figs. 1a and 1b). The WF part in the PBF part appears in the form of small veins, bands, patches, or domains. The PBF part in the WF part is enclosed as irregular domains of various sizes. Texturally, it appears that the WF part projects into and/or encloses the PBF part.

Spectral patterns and corresponding digital data of colors obtained from different positions are nearly the same for any examined area of the (110) facet. A typical spectral pattern is shown in Figure 2. The digital data

were converted to parameters of the $L^*a^*b^*$ color coordinate system and the xyz color coordinate system as the international color coordinate systems, using the software supplied with the present spectrometer. The obtained color data are $L^* = 82.61$, $a^* = -5.77$, and $b^* = 6.41$, where L^* indicates the brightness value and a^* and b^* indicate hues. The negative value of a^* indicates a green tint, and the positive value of b^* indicates a yellow tint. The two parameters combined together show a pale (grey) yellow-green tint (Fig. 2b). In Figure 2c, the parameters $x = 0.3164$ and $y = 0.3472$ ($z = 0.3364$) are plotted in the region of a bright (white) yellow-green tint.

FELDSPAR MICROTEXTURES

The two parts of the feldspar are macroscopically different in color and have distinct microtextures, especially the (001) section (Figs. 1c, 3, and 4), although they are patch

Figure 3. Microphotographs showing distinct textures of (a) WF and (b) PBF parts: (a1) and (b1) with one polarizer and (a2) and (b2) with crossed polarizers. The WF part is highly turbid due to the presence of many micropores and minute alteration materials in the well-developed perthitic texture. The PBF part is rather clear and shows two types (fine and coarse) of crosshatched twin patterns.

micropertthites of an Or-rich host and an Ab-rich guest. Figure 1c shows their textural differences on a macroscopic scale, and Figures 3 and 4 show the differences on a microscopic scale.

Ab-rich laths and Ab-rich patches are scattered in the PBF part. However, the latter occur in considerably lesser quantities in the PBF part than in the WF part. The PBF part is relatively clear due to a small quantity of micropores that are developed in and around the Ab-rich patches (Fig. 4). These patches have the same crystallographic orientation over the grains. On the other hand, the Ab-rich laths of variable sizes are scattered with different orientations, both elongation and optical orientations. In

addition, crosshatched twins are distinctly formed in the PBF part. Fine and coarse crosshatched twin patterns are recognized in the Or-rich host (Fig. 3). The former is a combination of albite and pericline polysynthetic twins of 2–20 μm in width. These fine-scale twins are formed as broad bands of several hundred micrometers in width along the b-axis at intervals of several hundred micrometers. The crosshatched twin pattern corresponds to the crosshatched pattern shown in Figure 1.

Many Ab-rich patches of various sizes are distributed in the WF part, but Ab-rich laths are almost absent in this part. The WF part is turbid due to a large number of micropores in and around the Ab patches. Furthermore,

Figure 4. (a1) and (b1) Backscattered electron images (BEIs) and (a2) and (b2) secondary electron images (SEIs) images of PBF and WF parts of the present amazonitic feldspar. Ab-rich patches are very weakly aligned in the PBF part. The Ab-rich patches are aligned along the *b*- and *a*-axes in the WF part.

the Ab patches tend to be aligned roughly along the *a*- and *b*-axes in the WF part, especially in the boundary areas with the PBF part. It is notable that many grains of alteration materials are present in some regions in the WF part (Fig. 3). These materials have not been identified, although muscovite flakes and many opaque particles are found to be scattered. The crosshatched twin patterns in the WF part become very blurred or disappear, which may have been caused by the formation of many Ab-rich patches and the presence of micropores and alteration materials.

ELEMENT DISTRIBUTIONS

Distribution patterns of Na, K, and Ca obtained by EPMA mapping clearly resolved the textural difference between the PBF and WF parts (Figs. 5 and 6). Moreover, they revealed the characteristic feature of their distributions: there are minor compositional fluctuations in the both Or-rich host and Ab-rich guest phases (patches and laths) (Fig. 5). However, some compositional contrast is recognized in the Or-rich host of the WF part (Fig. 6). Halo-like regions depleted in Ab components appear to develop around the Ab-rich patches. The Ab-rich patches and laths are completely depleted in Ca over the grains (Figs. 5 and 6) as compared to other pegmatite alkali feldspars from Japan (Nakano, 1997; Kohno et al., 2008).

From Pb mapping of the PBF and WF parts, it is clear that the Or-rich host is relatively rich in Pb, but the Ab-rich patches or laths are depleted in Pb (Figs. 5 and 6).

The average Pb content of the mapping regions appears to be consistent with the proportion of the Or-rich phase to the Ab-rich phase in the examined alkali feldspar.

COMPOSITIONAL FEATURES

The bulk composition is found to be $\text{Or}_{77}\text{Ab}_{23}\text{An}_{0.035}$ ($n = 435$), which was obtained by the so-called traverse method using a 50- μm electron beam. The local bulk composition fluctuates from Or_{60} to Or_{88} .

Selected phase compositions are listed in Table 1. The compositions of Ab-rich patches and laths are very close to those of the end member; the Ab-rich patches and laths are found to be depleted in Ca as already mentioned. Therefore, these are hereafter referred to as Ab patches and Ab laths, respectively. The composition of the Or-rich host is also close to that of the end member. The Or-rich host is predominantly consists of Or_{98} and subordinately of the Or-poor compositions Or_{92-96} . The compositional range (Or_{92-98}) of the host is much narrower than that of other Tanakami samples (Or_{84-98}) (Kohno et al., 2008) and Nango and Ishikawa samples (Or_{73-98}) (Nakano, 1997).

The Or-rich host has a small amount of Pb, and the Ab phases (both laths and patches) are depleted in Pb (Fig. 5). The maximum PbO content of the Or-rich host is 103 ppm (Pb = 96 ppm), and the average PbO content is 68 ppm (Pb = 63 ppm). The PbO content of the Ab patches and laths is below the detection limit (54 ppm).

Figure 5. Element distribution maps and textural image for PBF part, obtained by EPMA. It is notable that compositional fluctuations are very small in both the Or-rich host and the Ab-rich laths and patches. Ca is almost absent in the Or-rich host and Ab-rich laths and patches. The Pb content of the Ab-rich phases is the same as the background level. The scale bars are 200 μm .

Figure 6. Element distribution maps and textural image for WF part, obtained by EPMA. There is some compositional fluctuation in the Or-rich host and very small fluctuations in the Ab-rich patches. Ca is almost absent in the PBF part. The Pb content of the Ab-rich phases is the same as the background level. The scale bars are 200 μm .

WATER ALLOCATION

Absorption spectra of the feldspar were measured with unpolarized IR light to examine water allocation (Nakano et al., 2001). The FT-IR spectra of the PBF and WF parts recorded between 3000 cm^{-1} and 4000 cm^{-1} (Fig. 7) are very similar to those of both the clear featureless and turbid micropertthitic parts in the alkali feldspar from the Hanazono Pegmatite examined by Nakano et al. (2001). The spectra could be separated into three bands with peaks around 3250 , 3450 , and 3600 cm^{-1} , according to the procedure described by Nakano et al. (2001). By compari-

son with the case of the Hanazono alkali feldspar (Nakano et al., 2001), from the textural and spectral similarities of the two samples, it can be estimated that a small amount of structural water (around 3600 cm^{-1}) and additional molecule water (around 3250 and 3450 cm^{-1}) are trapped in both the Or-rich host feldspars. The WF part contains a larger amount of water than the PBF part.

Si-Al ORDERING

The PBF and WF parts were examined by using the Rigaku X-ray powder diffractometer at Shiga University.

Table 1. Representative chemical composition of the Tanakami amazonitic alkali feldspar

	Or-rich host		Ab-patch		Ab-lath	
Oxide compositions (wt%)						
SiO ₂	64.1	64.3	68.5	68.3	68.0	68.1
Al ₂ O ₃	18.4	18.4	20.0	19.9	19.3	19.9
FeO	0.00	0.01	0.00	0.00	0.03	0.02
CaO	0.00	0.00	0.01	0.00	0.00	0.01
Na ₂ O	0.66	0.44	11.9	11.4	11.6	11.8
K ₂ O	15.7	16.3	0.12	0.13	0.15	0.10
BaO	0.13	0.02	0.01	0.06	0.04	0.00
Total	99.0	99.5	100.5	99.8	99.1	99.9
Atomic proportions (O=8)						
Si	2.989	2.992	2.978	2.985	2.998	2.977
Al	1.014	1.008	1.026	1.027	1.000	1.027
Fe	0.000	0.000	0.000	0.000	0.001	0.001
Ca	0.000	0.000	0.001	0.000	0.000	0.001
Na	0.059	0.040	1.001	0.969	0.995	1.004
K	0.935	0.969	0.007	0.007	0.009	0.005
Ba	0.002	0.000	0.000	0.001	0.001	0.000
Total	4.999	5.009	5.013	4.989	5.004	5.015
Or-Ab-An ternary feldspar compositions (mol%)						
An	0.0	0.0	0.0	0.0	0.0	0.1
Ab	6.0	4.0	99.3	99.2	99.2	99.4
Or	94.0	96.0	0.7	0.8	0.8	0.5

Figure 7. Micro FT-IR spectra for Or-rich hosts of (a) PBF and (b) WF parts. Peak separation was carried out by using the method described by Nakano et al. (2001). **Figure 8.** Plot of Pb content against order parameters showing color variation in amazonites, which was proposed by Hofmeister and Rossman (1985). Feldspar obliquity is used for the present pale blue microcline, instead of the original order parameter obtained from IR data. The average Pb content (63 ppm) is used for the microcline.

It was confirmed that the feldspars in both the PBF and WF parts consist mainly of microcline and albite, although the feldspars appear different in terms of their microtextures. The feldspar obliquity (Goldsmith and Laves, 1954) of the microcline was found to be 0.79 and 0.75 in the PBF part and in the WF part, respectively.

DISCUSSION

Reason behind color variation in feldspar

Hofmeister and Rossman (1985) have clarified that for alkali feldspars to have a blue-green color, not only an appropriate amount of Pb content but also a certain level of irradiation and some amount of water are required. They pointed out that lead and water occur in a 1:1 ratio at the color center and water plays a catalytic role in the irradiative transfer of Pb^{2+} to the amazonite chromophore (Pb^{3+}). As a result, the presence of a small amount of Pb (in ppm) leads to the pale blue color of the alkali feldspar. They found that the minimum Pb content required for this color is approximately 60 ppm. An increase in the Pb content of amazonites changes their colors from blue to green through blue-green color.

Foord and Martin (1979) studied the occurrence of amazonites at Pikes Peak, Colorado, USA, and reported the overgrowth of white-colored feldspars on the amazonites. Stevenson and Martin (1986) reported the coexistence of amazonitic and white alkali feldspars in the same pegmatite or in the same grain from the Geco pegmatites of Canada, as follows. "There are also individual grains of amazonite that vary in color from white to green. This

zonation is never concentric, but up to half the crystal may be green and may grade to white in the other half. In a few cases, the amazonite is mottled green and white.” On the basis of some overlaps in the variation range of the Pb content of amazonites and non-amazonites, they suggested that the lack of color could stem either from insufficient or excess natural irradiation or from the lack of Pb-H₂O pairs. They could not explain the coexistence of these two feldspars. Stevenson and Martin (1988) studied alkali feldspars in the Portman Lake granodiorite (not pegmatite) and reported that the Pb content of the amazonite exceeds 14,800 ppm and that in the coexisting white feldspar is less than 300 ppm as a rule.

The present host microcline (obliquity = 0.75–0.79) contains a small amount of Pb (63 ppm on an average) regardless of its occurrence. The microcline in the PBF part contains a trace amount of structural water (Fig. 7). In addition, the Tanakami Granite is rich in radioactive elements (Ishihara et al., 2005), as collaborated by the common occurrence of smoky or black quartz in the pegmatite cavities. These two observations are sufficient evidence for attributing the pale blue color to the clear host microcline. The pale blue color of the microcline is characterized, as shown in Figure 8, on the basis of the figure presented by Hofmeister and Rossman (1985), although the methods used by them for measuring the obliquity of alkali feldspars was different. Hofmeister and Rossman (1986) also considered the same mechanism for blue coloring of plagioclase. However, the present two types of Ab phases are too low in Pb to contribute to pale-blue coloring.

On the basis of the above conclusions, the macroscopic color variation from the PBF part to the WF part is interpreted as follows. Many micropores along with minute alteration materials are scattered through out both the microcline and Ab patches in the turbid patch micropertthite (WF). As a result, macroscopically, the pale blue color is completely lost in the turbid micropertthitic part. The presence of a large number of micropores (or micro-inclusions such as fluid inclusions) in micropertthites causes strong diffuse reflection that leads to microscopic turbidity and macroscopic whiteness (Worden et al., 1990; Walker et al., 1995). A close inspection reveals complex blending patterns of pale blue and white colors in the sample, which are like irregular veins, patches, and domains (Figs. 1a and 1b). These patterns correspond fundamentally to the distribution patterns of micropertthitic Ab patches observed under a microscope (Figs. 1c, 3, and 4). It is concluded that the distribution of Ab components controls the macroscopic color variation from pale blue to white in the feldspar.

Figure 9. Schematic model for microtextural formation of the Tanakami amazonitic alkali feldspar.

Figure 10. Na distribution map of large albite grain connected to albite veins or patches in WF part, forming perthitic texture. This map corresponds to the lower left end of the feldspar shown in Figures 1b and 1c.

Textural evolution during cooling

Černý et al. (1984) clarified the compositional variation in alkali feldspars in magmatic rocks to low-temperature hydrothermal stages within a pegmatite from Vezna. Further, Černý (1994) summarized that the perthite evolution of pegmatite alkali feldspars takes place by exsolution, coarsening, and recrystallization. Many recent studies on microtextures of alkali feldspars from syenites (Parsons, 1978; Parsons and Brown, 1984; Brown and Parsons, 1994; Nakano et al., 2005; etc.) and granites (Lee et al., 1995; Lee and Parsons, 1997; Hashimoto et al., 2005) have shown that patch micropertthites are formed along with many micropores by hydrothermal coarsening leading to microscopic turbidity. Černý (1994) also pointed out that the coarsening and segregation of perthite components proceed much farther in pegmatites than in any other geological environment.

The PBF part, which includes many Ab laths and is associated with distinct crosshatched twin patterns, has a small number of Ab patches and micropores; hence, it is clear microscopically. The WF part is texturally different

from the PBF part. Crosshatched twin patterns are not clear in the former. Although the WF part has only a few Ab laths, it has many Ab patches with a large number of micropores; hence, it is turbid microscopically. The formation of these textural contrasts can be explained by the following scenario (Fig. 9).

The laths must have been first formed in the pegmatite melt or fluid (stage I), because they are randomly scattered with not only elongated orientations but also crystallographic orientations. Then, they were enclosed in crystallized pale blue microcline (PBF) that crystallized later on (stage II). Crosshatched twins were formed during the successive temperature decrease (stage III). After this transition, the hydrothermal solution-feldspar interaction induced the formation of many Ab patches and a large number of micropores in the PBF part, resulting in the formation of the WF part (stage IV). This change might have been promoted by solution redeposition (Waldron et al., 1993); hence, even if preexisting exsolution perthites had formed, they would have been completely modified. This reaction caused the compositional reorganization of the perthite components with composition very close to the composition of the end members (albitization and K-feldspathization). The change might have been promoted by the metasomatically moving albite from the outside (Fig. 10). The twin patterns became blurred at this stage. Further, the feldspar-solution interaction induced more extensive local changes in the WF part (stage V), which increased the turbidity.

From the compositional pair Or_{94-96} and Ab_{99} of the micropertthites (Table 1) plotted on the Ab-Or binary phase diagram (Brown and Parsons, 1989), both the microcline crystallization and albitization in the present amazonitic alkali feldspar are estimated to have occurred around 200 °C. The precise crystallization temperature of Ab laths could not be found out, because their original composition is unknown. Nevertheless, very low-temperature reactions occurred extensively in the pegmatite environment around 200 °C, which is consistent with the results of other studies (Černý et al., 1984; London, 1996, 2005; Kohno et al., 2008). Such very low-temperature albitization and K-feldspathization have been also found to occur in alkali feldspars from syenites (Nakano et al., 1997; Nakano, 1998) and granites (Lee and Parsons, 1997; Hashimoto et al., 2005).

Geological implication of amazonitic feldspar from the Tanakami pegmatite

The occurrence of amazonite-bearing pegmatites is restricted to two different geological locations (Martin and De Vito, 2005; Martin et al., 2008). Martin et al. (2008)

stressed that such plumbean K-feldspar is found in two distinct contexts: (1) NYF-type granitic pegmatites and related intrusive products of anorogenic magmatism, emplaced during periods of tectonic quiescence and distension of the crust, and (2) granite pegmatites developed in metamorphosed massive sulfide deposits, such as at Broken Hill, Australia. In the former, the presence of amazonitic K-feldspar indicates the addition of Pb, U, Th, and alkalis to the source prior to anatexis during the period of distension after a major orogenic disturbance. This process is closely related to anorogenic A-type granite magmatism (Martin et al., 2008). It is not clear at present whether the Tanakami pegmatite belongs to the above-mentioned NYF-type, but it is obvious that it was formed by magmatism at the margin of the Asian Continent at the end of the Cretaceous period before the extension forming the Japan Sea (Kutsukake, 1993). The occurrence of amazonitic alkali feldspars in Japan suggests that amazonites or amazonitic alkali feldspars may occur widely in other places or regions where they have been not found yet.

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