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MICROSTRUCTURE OF PERTHITES IN SYENITES FROM THE YAMATO MOUNTAINS, EAST ANTARCTICA

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Abstract: Cryptoperthites in intrusive syenite from the Yamato Mountains were studied by transmission electron microscopy. They consist of two domains, one being narrow Albite- twinned plagioclase, the other a triclinic K-feldspar. The crystal symmetry of the majority of K-feldspars from the Yamato Mountains is triclinic; while monoclinic symmetry is rare. The triclinicity of K-feldspar ranges from 0.34 to 0.59. There is no difference in triclinicity between K-feldspar from the northern and southern Yamato Mountains. The exsolution lamelae do not develop a zig-zag pattern in either area. This fact suggests that the cooling rate of intrusive syenites from the Yamato Mountains is not very slow.

Plagioclase in myrmekite, perthite and antiperthite in syenite from the southern Yamato Mountains is oligoclase ($An_{19.6}Ab_{79.7}Or_{0.7}$~ $An_{14.9}Ab_{68.9}Or_{16.2}$) with low Or content, whereas plagioclase of composition $An_{0.3}Ab_{99}Or_{0.7}$~$An_{0.3}Ab_{82}Or_{17.7}$ occurs as patches and wavy strings in perthite from the northern area. Although plagioclase is more anorthitic in syenite from the south than from the north, the chemical composition of K-feldspar is similar in both areas.

key words: Albite-twin, alkali feldspar, cryptoperthite, K-feldspar, perthite, syenite

1. Introduction

K-feldspar is an essential mineral in syenitic rocks. K-feldspar of syenitic rocks from the Yamato Mountains was first described in detail by OHTA and KIZAKI (1966). They described three different types of K-feldspar: dusty mosaic grains, schiller porphyroblasts and pink, fine-grained matrix. In the experiments reported by OBA and SHIRAISHI (1993, 1994), K-feldspar from the Yamato syenites appears during crystallization from liquidus to solidus and the chemical composition of K-feldspar varies with decreasing temperature. OBA and SHIRAISHI (1993, 1994) reported that K-feldspar forms perthtie lamellae with plagioclase below the solvus.

A variety of perthite structures is a characteristic feature in syenitic rocks (ALLING, 1938; BROWN and PARSONS, 1988; NAKANO and SUWA, 1995). The shape and width of the perthite lamellae reflects the cooling history of the rocks as well as bulk chemical composition. YUND *et al.* (1974) reported that the coarsening of the perthite lamellae increases with increasing annealing time and temperature. YUND and DAVIDSON (1978) estimated the cooling rate on the basis of the coarsening rate in annealing experiments between 560°C and 470°C . BROWN and PARSONS (1984) reported that the primary coarsening is stopped by the development of Albite twins in the Ab-rich phase. They found, in the Klokken layered syenite intrusion, that the microtexture of cryptoperthite changes from continuous zig-zag lamellar texture near the top of the intrusion to lozenge-shaped texture in the lower part. They thought that the different microtextures of cryptoperthite depend on the cooling rates at different depths. They considered that the interaction of plagioclase and K-feldspar transformations during slow cooling produced a great variety of cryptoperthite microtextures. It cannot be ascribed to coarsening alone.

Therefore, the microperthite texture of perthites is considered to be a useful indicator of the cooling process in syenitic bodies.

The authors have been studying the emplacement depth of the Yamato syenite in terms of the experimental study of Ca-amphibole (OBA and SHIRAISHI, 1993, 1994). In the present study, we try to examine the emplacement depth through observation of the cryptoperthite in the Yamato syenites by transmission electron microscopy (TEM). The nomenclature of perthites is after ALLING (1938).

2. Petrography

The syenitic rocks in the Yamato Mountains occur as isolated masses and nunataks scattered over a distance of 50 km. SHIRAISHI *et al.* (1983) classified these syenites into three types on the basis of mode of occurrence and petrography: two-pyroxene syenite, clinopyroxene syenite and clinopyroxene-quartz monzosyenite. The mineral compositions of the syenites are essentially identical: K-feldspar, plagioclase, quartz, biotite, Ca-amphibole, clinopyroxene with or without orthopyroxene, sphene and ilmenite. Emplacement of the first two syenite types is thought to have taken place during or in the waning stage of the latest Proterozoic to early Cambrian granulite facies metamorphism; the third type is younger, being intrusive into the first two. The porphyritic type occurs as layers within the clinopyroxene syenite in the northern part and as isolated masses in the central part, while the even-grained type is from the southern most part of the Yamato Mountains (SHIRAISHI *et al.*, 1983). Some rocks, especially in the central and southern Yamato Mountains, show recrystallization and deformation textures, such as equigranular aggregates of pyroxene, quartz and plagioclase (An 23-32) between the K-feldspar phenocrysts. Plagioclase and K-feldspar as perthite are common throughout the Yamato Mountains and show myrmekitic textures in the syenite of the southern part.

Therefore, finding the areal difference of the emplacement depth of the syenite bodies, we selected six medium-grained non-porphyritic rocks from the northern and southern Yamato Mountains. Samples Y405, Y406 and Y904 are clinopyroxene syenite from the northern Yamato Mountains, and samples Y34A and Y556 of two-pyroxene syenite and Y557 of clinopyroxene-quartz syenite are from the southern Yamato Mountains.

Figures 1a, b and c show occurrences of perthite in syenites Y405, Y406 and Y904 from the northern Yamato Mountains. Plagioclase occurs in perthite as plume and rods. Slight differences in orientation are observed within a set of strings oriented in the same general direction. The strings of plagioclase extend to the grain boundary. The majority of sodic plagioclase usually occurs as patches or strings in perthite or as small blobs along the grain boundaries of K-feldspar from Y405 and Y904. The chemical compositions of plagioclase ranges from $An_{0.3}Ab_{99}Or_{0.7}$ to $An_{0.3}Ab_{82}Or_{17.7}$.

In contrast, K-feldspar and plagioclase in syenites Y34A, Y556 and Y557 from the

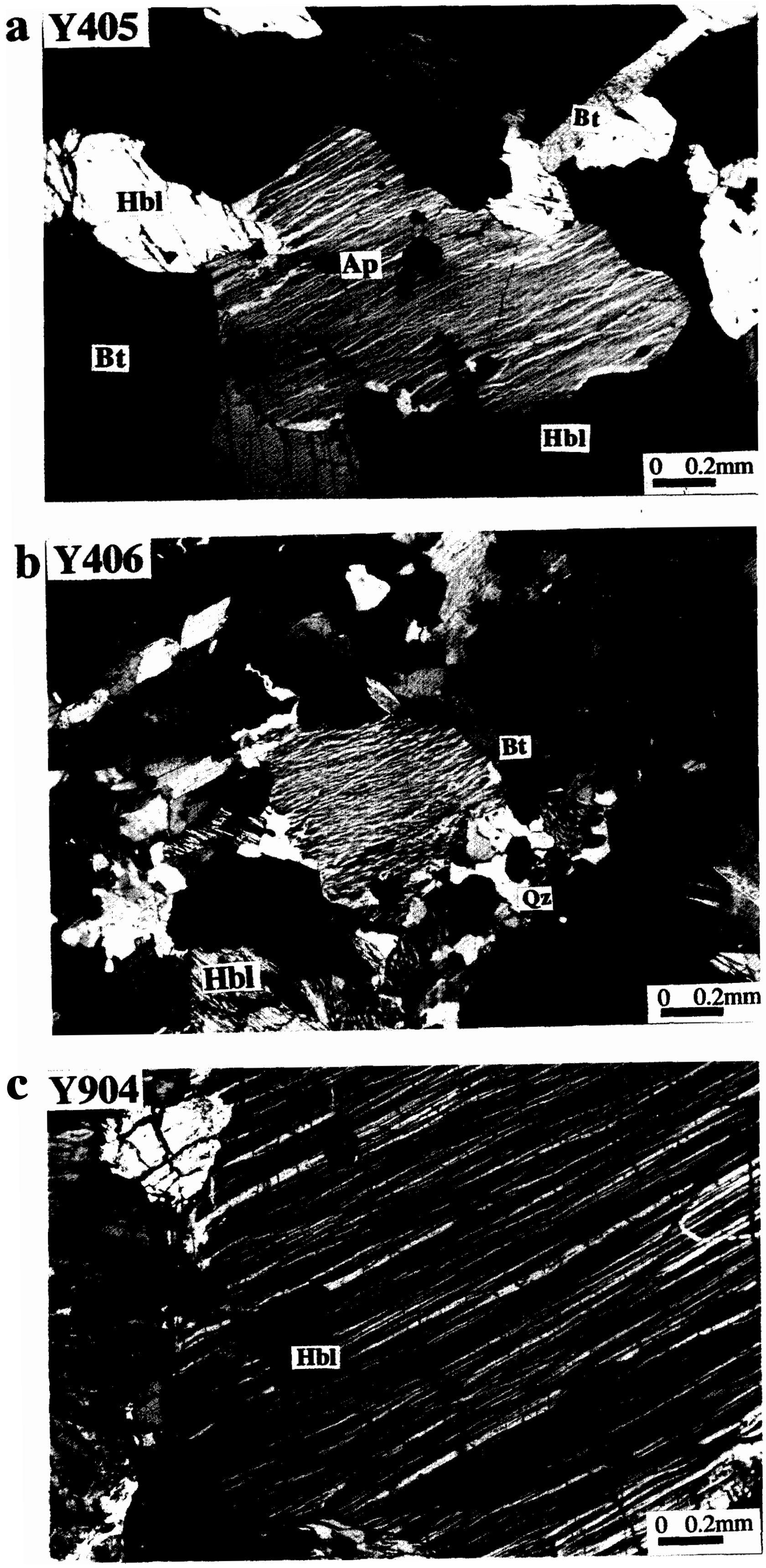

Fig. 1. Photomicrographs showing plagioclase blobs in K-feldspar host.
a, b and c: Plume perthite in Y405, Y406 and Y904 from the northern Yamato Mountains.

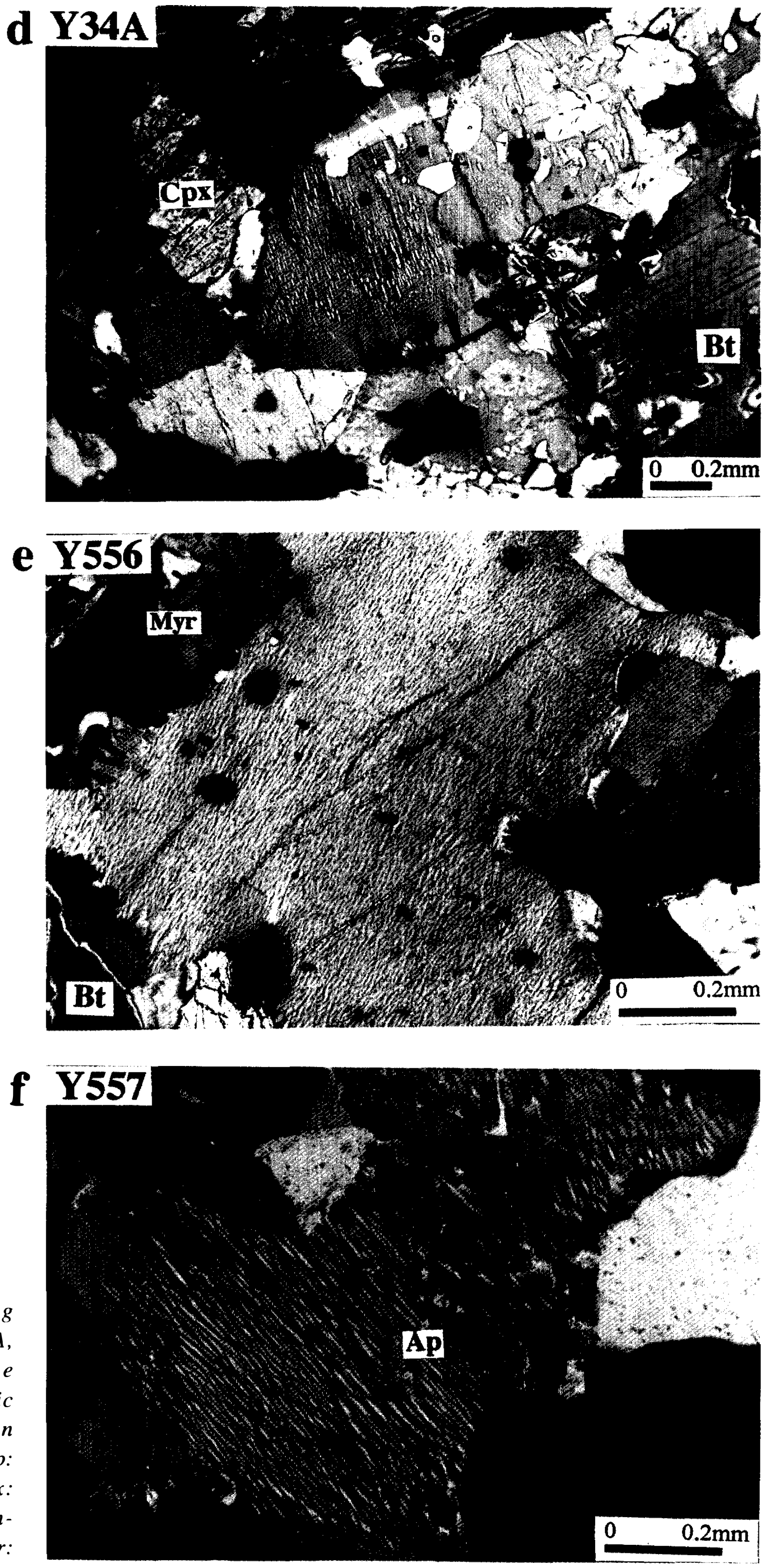

Fig. 1. (Continued)
d, e and f: Stringlet, string and rod perthite in Y34A, Y556 and Y557 from the southern area. Myrmekitic texture within or at grain boundary of K-feldspar. Ap: Apatite, Bt: Biotite, Cpx: Clinopyroxene, Hbl: Hornblende, Pl: Plagioclase, Myr: Myrmekite.

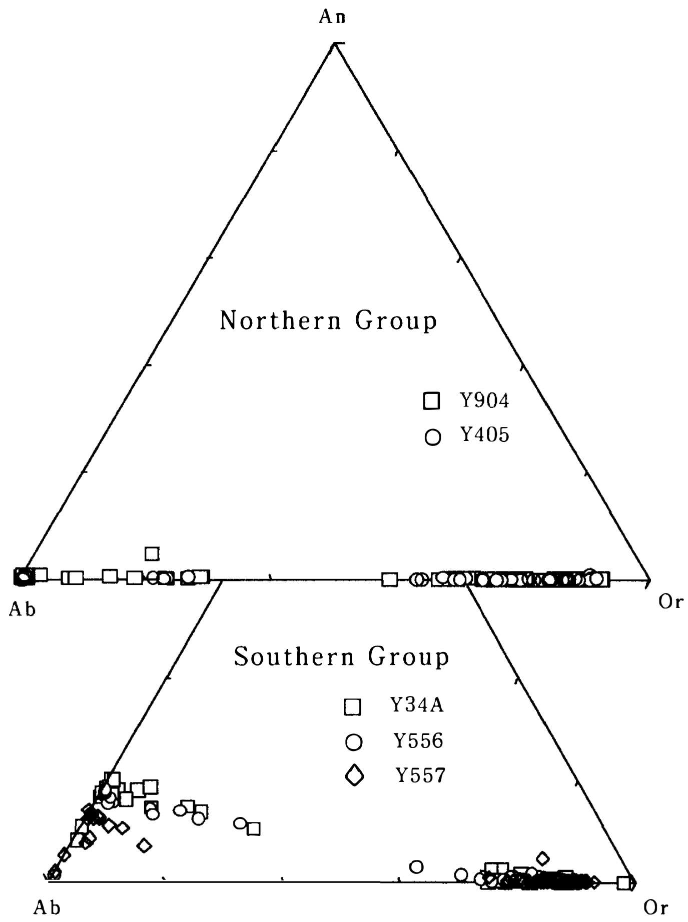

Fig. 2. Plots of the chemical compositions of plagioclase and K-feldspar in syenites from the northern and southern Yamato Mountains in the feldspar ternary system.

southern Yamato Mountains occur as perthite and antiperthite, respectively. Perthite is the stringlet to the rod of ALLING (1938) (Figs. 1d, e and f). Grain margins of K-feldspar are non-perthitic. A small amount of grained-sodic plagioclase along the grain boudaries of other minerals has no antiperthite texture. In syenites Y34A and Y556, there is sometimes myrmekitic texture with wormy plagioclase at one side of an K-feldspar host (Fig. 1e). Uncommonly, large (2 mm long) subhedral K-feldspar, grains in Y556, are zoned, having non-perthitic cores and plagioclase and clinopyroxene inclusions in the margins. However, the chemical composition of K-feldspar varies little. A few plagioclases in Y556 contain irregular perthite inclusions. Plagioclases of antiperthite and perthite in Y34A and Y556 are oligoclase ($An_{19.6}Ab_{79.7}Or_{0.7}$ to $An_{14.9}Ab_{68.9}Or_{16.2}$), and in Y557 are $An_{14}Ab_{86}$ to $An_{5.3}Ab_{77.2}Or_{17.5}$ (Fig. 2).

3. X-ray and Electron Microscopic Observations

TEM images of cryptoperthite from Y904, Y556 and Y405 are shown in Figs. 3 and 4. The boundary between a narrow plagioclase domain and K-feldspar in Y904 is straight

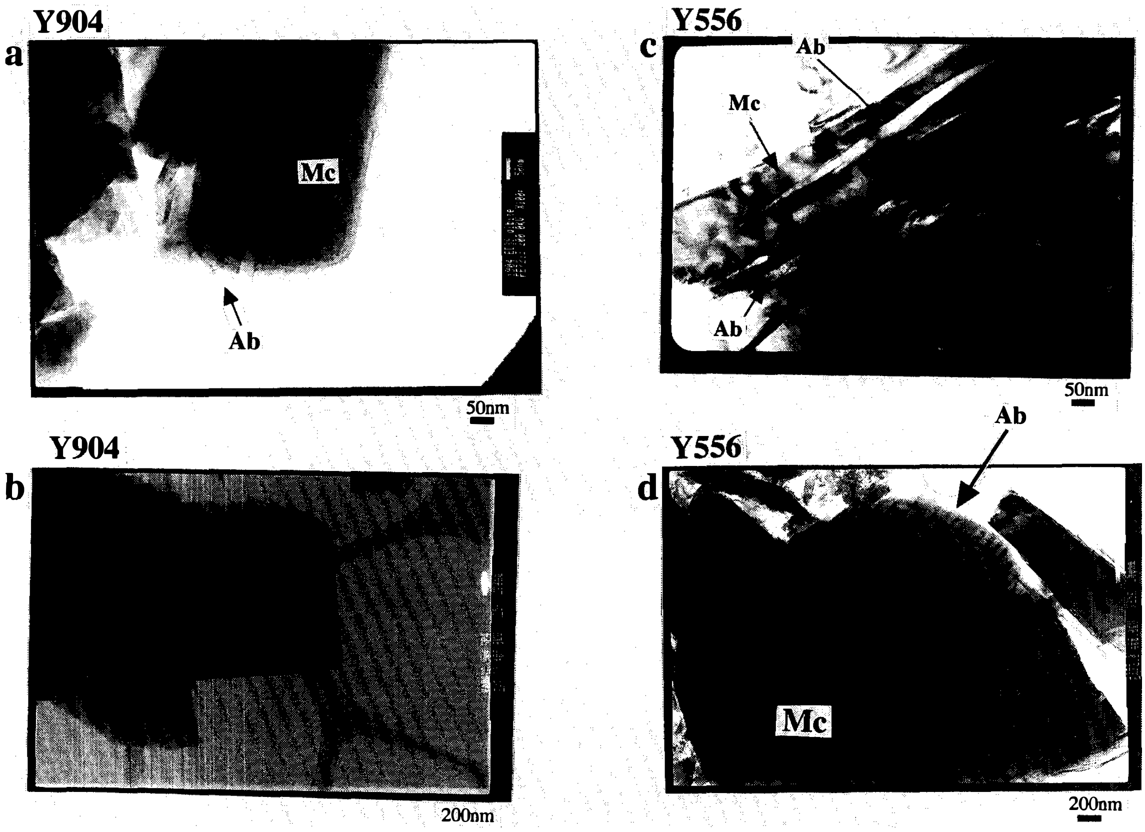

Fig. 3. TEM images of cryptoperthite in syenites Y904 and Y556. a: Straight albite domain in K-feldspar from Y904. b: Albite twin from Y904. c: Albite-twinned albite rods in K-feldspar from Y556. d: Albite twin from Y556. Ab: albite, Mc: microcline.

(Fig. 3a), and Albite twins are illustrated in Fig. 3b. The lamellae in Y556 from the southern part are straight to slightly wavy, as shown in Fig. 3c. The periodicity of the perthitic lamellae is about 200 nm. The exsolution lamellae do not develop a zig-zag pattern, although the sodic phase is Albite twins, as shown in Fig. 3d. The lamellae in Y405 from the northern Yamato Mountains are straight (Fig. 4b).

Images of perthite and parts of the electron diffraction patterns of albite and microcline in Y405 are shown in Fig. 4. The width of the albite domain is about 100–200 nm. The double spots in Fig. 4a indicate Albite twins, the lamellae being developed along the $(\bar{4}01)$ plane. The lamellae orientation is not consistent with the exsolution boundary of $(\bar{6}01)$ and $(\bar{8}01)$ planes reported by many investigators (Yund and Chapple, 1980; Christoffersen and Schedl, 1980; Nakano and Akai, 1992). The diffraction pattern of Fig. 4c shows that the angles between (020) and $(\bar{3}\bar{1}1)$, $(\bar{3}11)$ are 79°and 76°. As compared with 77.60° and 77.60° for sanidine, they are similar to 79.78° and 75.36° for microcline.

To determine the crystal symmetry, the triclinicity of K-feldspar was determined by Goldsmith and Laves' method (1954). The equation of triclinicity is as follows: $\Delta = 12.5\ (d_{131}-d_{1\bar{3}1})$. We used the samples from this study and that of Shiraishi *et al.* (1983). The triclinicities of Y904, 73120606 and 73120304 from the northern Yamato Mountains are 0.44, 0.59 and 0.36, whereas on the other hand those of Y556, Y557, Y34A, 74121803

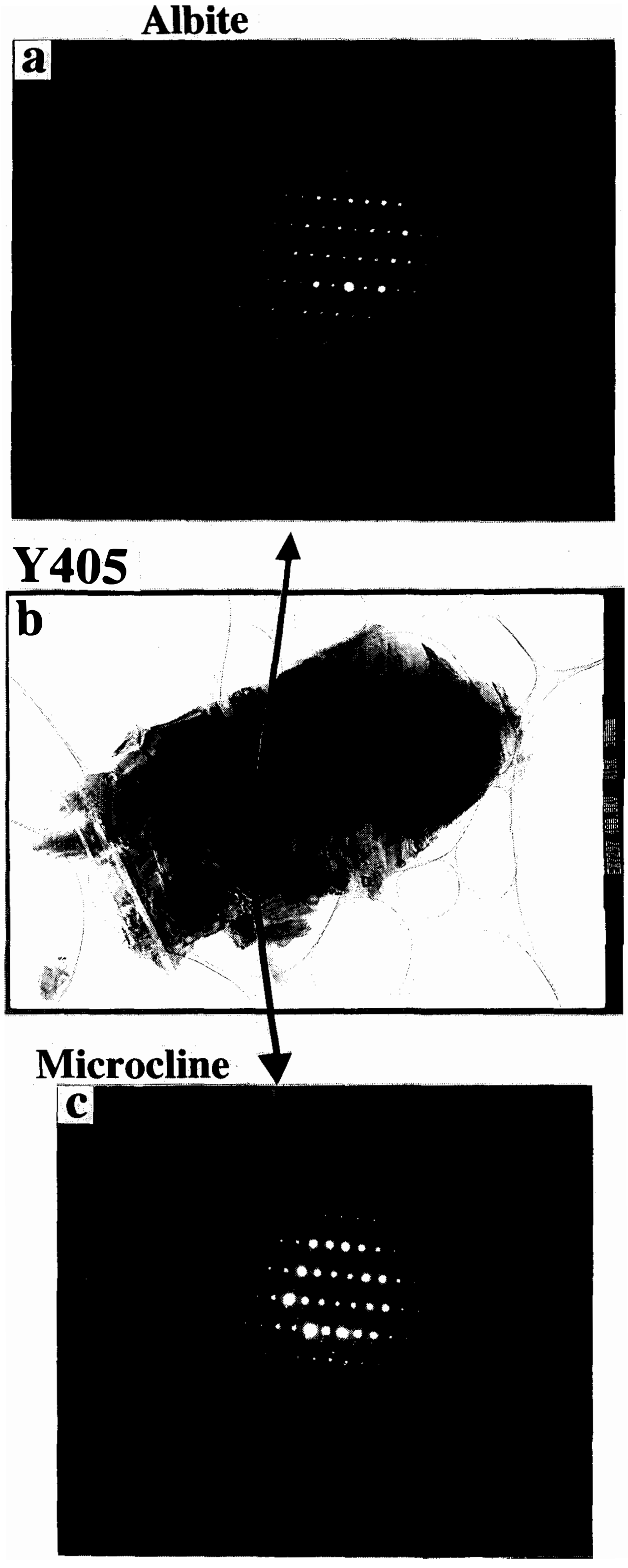

Fig. 4. TEM image and diffraction patterns of albite and K-feldspar in cryptoperthite from Y405. a: Double spots of Albite twin. b: Albite domain in K-feldspar. c: Diffraction pattern of microcline.

and Y80A122 from the southern areas are 0.44, 0.34, 0.44, 0.35 and 0. Except for Y80A122, triclinicities in the northern and southern samples are similar.

4. Discussion

BROWN and WILLAIME (1974) suggested an explanation for the microstructure of lamellae. Figure 5 is modified from BROWN and WILLAIME (1974), BROWN and PARSONS

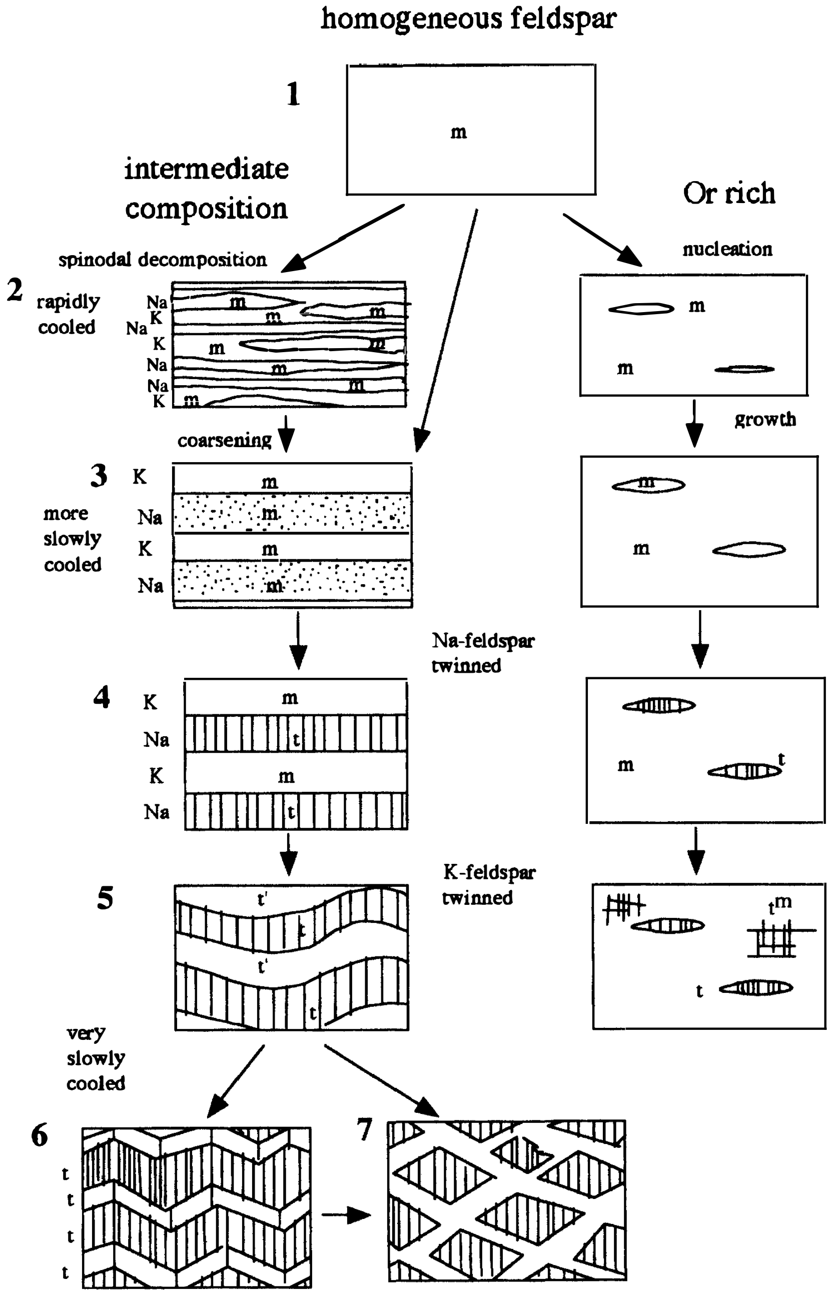

Fig. 5. Scheme for the formation of microtexture of perthites (modified from BROWN and WILLAIME, 1974; BROWN and PARSONS, 1984; NAKANO, 1992b). Symbols m and t are monoclinic and triclinic, respectively. t' is incipient twinning in K-feldspar. t^m indicates microcline twinning.

(1984) and NAKANO (1992b). Above 560°C, original homogeous crystals grow with monoclinic symmetry (stage 1). When they start to exsolve, both Na and K-rich phases are monoclinic (stage 2). Exsolution occurs initially on $(\bar{6}01)$ (stage 3), and this is followed by inversion of the Na-rich phase and formation of Albite twins (stage 4). The primary coarsening of albite is stopped by the development of Albite twins. The boundary remains parallel to $(\bar{6}01)$ until the K-rich phase becomes triclinic and twinned (stage 5). The interface changes to $(\bar{6}\bar{6}1)$ because this orientation has a lower elastic strain energy when both phases are triclinic (stage 6). Initial spinodal unmixing on $(\bar{6}01)$ is followed by coarsening and development of low-energy interfaces, creating a zig-zag pattern. finally, the microcline lamellae develop lozenge-shaped albite domains (stage 7).

In the syenites from the Yamato Mountains, the lamellar textures and the symmetries of both feldspar phases indicate stage 5 (Fig. 5). BROWN and PARSONS (1984) suggested that the important factors in determining periodicity and morphology of cryptoperthite are composition and cooling rate. The experimental results reported by OBA and SHIRAISHI (1994) showed that the chemical composition of K-feldspar at the critical point of the solvus is $Or_{50}Ab_{50}$ to $Or_{65}Ab_{35}$. The scheme in Fig. 5 shows the stages during cooling of alkali feldspar in the compositional range Or_{25} to Or_{60} with <6% An. The bulk composition of the alkali feldspar allows the cooling rate of intrusive syenites from the Yamato Mountains to be modeled using the scheme in Fig. 5.

BROWN and PARSONS (1984) calculated curves for cooling of the Klokken intrusion from a magmatic temperature of 850°C to 400°C by using the method of JAEGER (1968). The cooling curves, calculated for 200 m and 1 km from the margin of the intrusion (assuming it to be a sphere of radius 2 km), pass through the stability field of the zig-zag lamellae and the lozenge-shaped albite domains of stages 6 and 7, respectively. Stage 4 is indicated by a K-rich phase with monoclinic symmetry and straight lamellae of cryptoperthite grown on the cooling paths for rapidly cooled bodies such as a 5 m-thick rhyolite dyke (CHRISTOFFERSEN and SCHEDL, 1980) and 60 m-thick lava flows (YUND and CHAPPLE, 1980). NAKANO (1992a) observed perthitic lamellae of plagioclase in sanidine from trachyte lava of Oki-Dogo island, Japan; the periodicity of the lamellae is below 10 nm. The width of albite domains in the Yamato Mountains is about 100–200 nm. Thus cooling rates of the syenite intrusions of the Yamato Mountains were faster than those of the Klokken intrusion. Judging from the cooling rate, if the Yamato Mountains intrusions are of similar size to the Klokken intrusion, they crystallized at shallower depth than Klokken.

The chemical composition of plagioclase from the southern Yamato Mountains has a higher An content than that from the northern area, but K-feldspars from both areas are indistinguishable chemically. Also, the microtexture of cryptoperthites from the northern and southern Yamato Mountains is similar. Hence the syenite intrusions of both areas cooled at similar rates. OBA and SHIRAISHI (1993, 1994) concluded on the basis of the stability of amphibole in the experiment that the syenites in the southern Yamato Mountains crystallized at pressures lower than 0.3 Gpa (about 10 km). If the sizes of the southern and northern Yamato Mountain intrusions are similar, the microstructure of perthite suggested that the syenites from the northern Yamato Mountains also intruded in a shallow crust.

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