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ELECTRON-MICROSCOPIC INVESTIGATION OF MICROCLINE TWINNING

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ABSTRACT

Fine and coarse twin lamellae of microclines were compared under the polarizing optical microscope and electron microscope. In fine twinned microclines, albite twinning shows a predominant development, whereas pericline twinning is poorly developed and its lamellae are best described in terms of a disordered lattice. Although cross-hatched patterns of polysynthetic albite and pericline twins were observed under the optical microscope, they were not seen under the electron microscope. Microclines with coarse cross-hatching and showing variable extinction angles according to location were composed of wider twinning lamellae in association with finer lamellae, resembling the texture of orthoclase. Microclines with coarse albite twinnings and sharp extinction angles are composed mainly of untwinned microcline with a few finely twinned microcline regions.

INTRODUCTION

Microcline, the stable low-temperature form of $KAlSi_3O_8$ is triclinic, with space group $C\bar{1}$. Al and Si are ordered, occupying crystallographically distinct positions (Bailey and Taylor, 1955). Microcline twins may be formed during growth, by transformation, by recrystallization, by replacement, and by mechanical shear. The occurrence of untwinned microcline with a triclinic morphology as an overgrowth on cross-hatched microcline was recorded by Böggild (1911). Cross-hatched twinnings occur more or less universally in granites and granodiorites and untwinned microclines occur occasionally in pegmatites. Using X-ray and optical methods, Laves (1950) distinguished the following four types of microclines with intermediate states: 1) optically monoclinic, 2) very finely twinned and optically triclinic, 3) optically triclinic without observable twin lamellae but with an extinction angle varying by location, and 4) large areas which are quite clear and with sharp asymmetrical extinction. His inference was that microcline twinnings were the results of complex inversion in an earlier monoclinic state. From the viewpoint of general thermodynamics, Laves (1955) suggested that untwinned areas were formed by recrystallization favoring one of the four microcline twinning positions. Marmo (1955a) and Wones *et al.* (1967) suggested that replacement twinnings can be formed when twinned albite crystals undergo microclinitization in the host rock, and the microcline thus formed inherits the framework of the original albite twins. Marmo (1955a) reported that mechanical twins were found in untwinned microclines occurring in low temperature rock such as pegmatites. An origin of microcline twinnings has been discussed by Marmo (1955b and 1961), Laves (1955), and Schermerhorn (1961). These studies were reviewed by Smith in 1962.

This electron microscopic investigation on microcline textures in microcline-perthites from several localities also presents a consideration of the possible genesis of twinnings and other lamellae in microcline.

Materials

Microcline-perthites having three kinds of microcline were used: 1) with fine cross-hatching, 2) without cross-hatching or with coarse cross-hatching and the extinction angles varying by location, and 3) with coarse albite twins sometimes seen to include a few fine pericline twins and with a sharp extinction angle. Optical properties measured on (001) thin sections are as follows:

a) Microcline from Otome Mine (pale green) and Kinpu-san (milky white), Yamanashi Prefecture, Japan

The microcline is euhedral with the rim without cross-hatching or showing coarse cross-hatching and the core exhibiting finer cross-hatching, all markings distinct in the direction of albite twinning. Chemical compositions of heated specimens calculated from the lattice dimension of $d_{\bar{2}01}$ are $Or_{85}Ab_{15}$ (Otome Mine) and $Or_{80}Ab_{20}$ (Kinpu-san).

b) Microcline from Tanokami-yama, Shiga Prefecture, Japan

Thin rim of the euhedral crystal is without cross-hatching or shows coarse cross-hatching with extinction angles varying in various places; the middle of the crystal showing a finer cross-hatching. The core is composed of orthoclase-perthite. The interzonal boundaries lack sharp distinction. Chemical compositions of heated specimens calculated from lattice dimension are $Or_{86}Ab_{14}$ (rim and middle part) and $Or_{65}Ab_{35}$ (core).

c) Microcline from Amelia (deep green), Virginia and Spruce Pine (white), North Carolina, U.S.A.

These are two types of microclines, one with distinct coarse twins whose extinction angle is sharp and asymmetrical and the other showing fine cross-hatching. A few fine domains are often seen to develop in the direction of pericline twinning in the homogeneous regions between coarse albite twins. Such homogeneous regions appear more frequently in the specimen from Amelia. Chemical compositions of heated specimens calculated from lattice dimensions are $Or_{96}Ab_4$ (Amelia) and $Or_{78}Ab_{22}$ (Spruce Pine).

Precession photographs of these specimens show albite twinning with one set of lamellae more abundant than the other. Distinct pericline twinning is not seen, but diffraction spots ($0k0$) are accompanied by fairly sharp diffuse streaks running in directions normal to the b^* axis.

Methods

For electron microscopic and electron diffraction pattern determination, the planes were etched with 20 percent HF solution or fresh cleavage planes were replicated by the two step carbon replica method.

The carbon replica films contained many thin crystal flakes parallel to the etched plane (a^*b^* plane or (001)) or cleaved plane (001). The thin flakes were then observed under an electron microscope with an accelerating potential of 100kV (Akizuki and Sugawara, 1970).

The b- or b^*-axis was set horizontally for illustrative purposes.

Results

Three types of microcline textures were observed:

1) *Microclines with fine cross-hatching*

Flakes showing strong electron diffraction contrast due to diffraction (hkl) and ($0k0$) were observed. Under the diffraction condition of (hkl) with or without faint ($0k0$) spots, micrographs showed a single linear contrast pattern representing albite twinning (Fig. 1). The

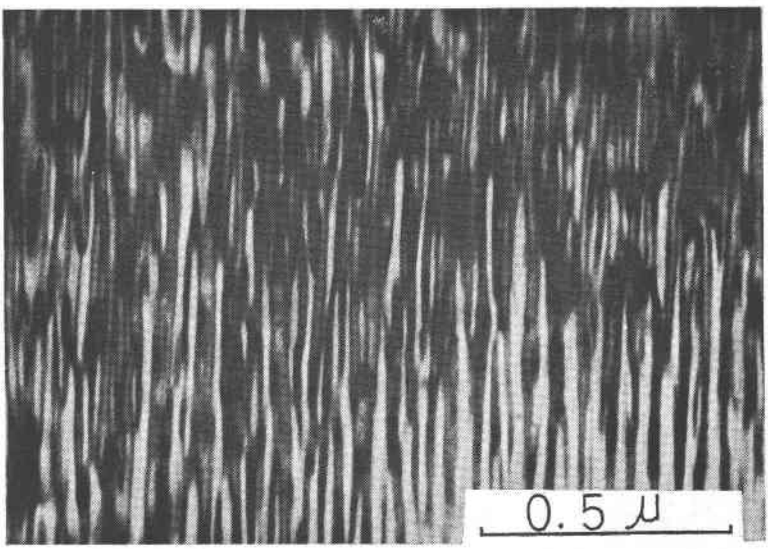

FIG. 1. Electron micrograph of microcline from Otome mine.

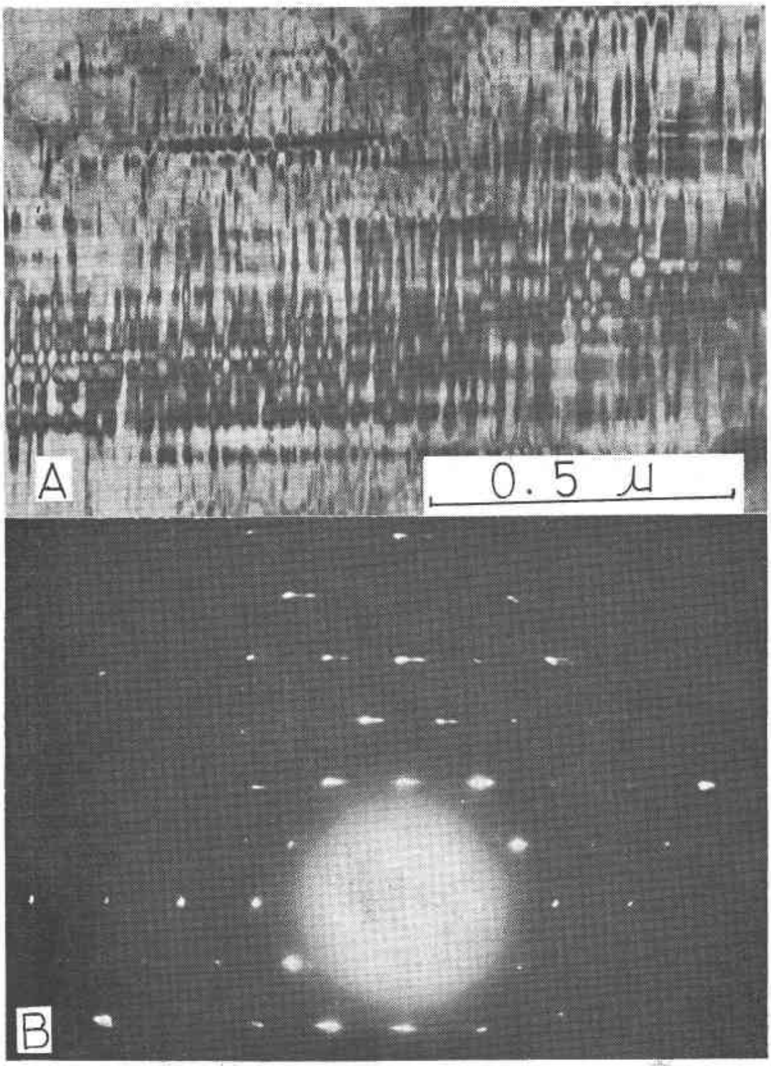

FIG. 2. Electron micrograph and electron diffraction pattern of microcline from Otome mine.

contact planes of the albite individual twin domains were not always parallel to (010) but were finely irregular. With the diffraction contrast of (hkl) and $(0k0)$, cross-hatched patterns with nodes were observed (Fig. 2A), similar to those seen under the polarizing optical microscope. Although the diffraction spots $(0k0)$ showed streaks perpendicular to the b^*-axis (Fig. 2B), the diffraction pattern clearly indicated the existence of albite twinning rather than pericline twinning. Fine cross-hatching without nodes appeared in many cases with (hkl) and ($0k0$) diffraction contrast (Fig. 3A). One direction of the cross-hatches showed albite twinning on the diffraction pattern, while the other direction showed strong diffraction spots of ($0k0$) with streaks perpendicular to the b^*-axis (Fig. 3B). Dark-field image formed by spot (060) showed linear contrast similar to pericline twinning (Fig. 3C).

2) Microclines without or with coarse cross-hatching and extinction angles varying by location

Wider albite twins or varying sizes up to 0.5 μ width were frequently found in the wider rim of the specimen from Tanokami-yama, containing finer lamellae which were roughly parallel to the albite twin (Fig. 4). These finer lamellae did not show split diffraction spots of twins, and were similar to lamellae found in orthoclase undergoing phase transition (Nissen, 1967).

3) Microclines with coarse albite twins, sometimes including a few fine pericline twins, with sharp extinction angle.

The textures of the microclines from Amelia and Spruce Pine characteristically differed from those of other localities, although some parts of the specimens showed a similar texture. The specimen showing asymmetrical extinction angle under the polarizing optical microscope was found to be an untwinned maximum microcline under the electron microscope, although a group of polysynthetic albite twinnings which exhibited banded structures parallel or perpendicular to the albite twin was seen to develop in the untwinned microcline. Most of the banded structures parallel to the albite twins were up to several microns in width (Fig. 5A). Neither side of the band was sharp, and the twins formed lens-like domains in the untwinned host microcline. The domains were thin and short with a gradual decrease toward the margin of the bands (Fig. 6). Bands perpendicular to the albite twin had sharp boundaries with a contrast similar to the pericline twin (Fig. 5B), which did not always show pericline twin spots on the electron diffraction patterns. It may be conjectured, therefore, that the sharp boundaries indicate a single pericline twin, double pericline twins of short range, or other disturbed lattice. Some albite twins were seen to project from these sharp boundaries.

Slightly wider polysynthetic albite and pericline twinnings resulting in two kinds of twins on the diffraction pattern were sometimes observed (Fig. 7). Although seen as cross-hatching under the polariz-

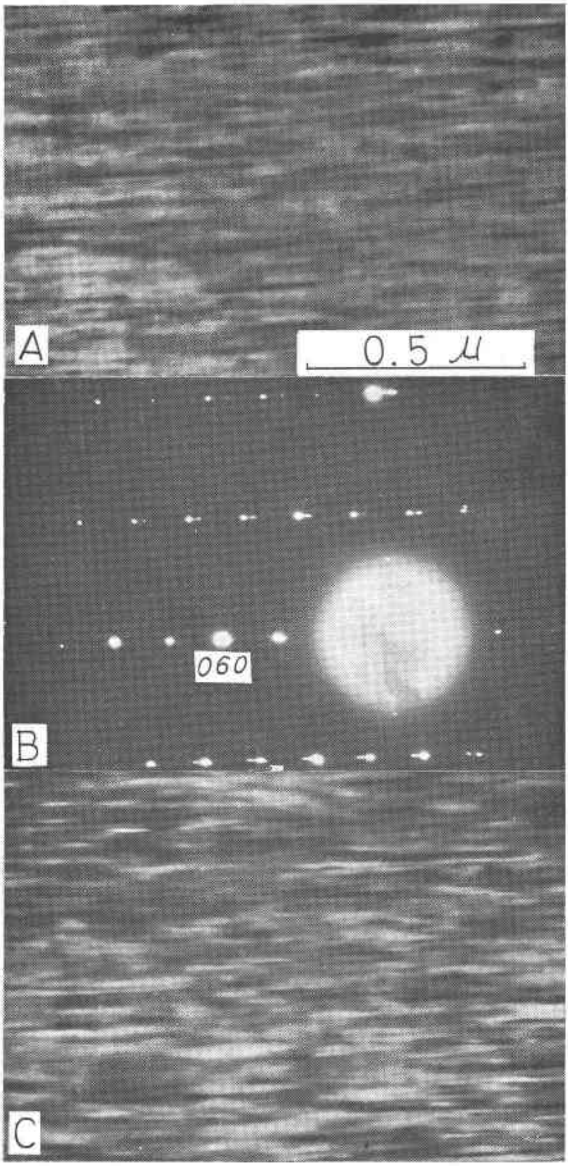

FIG. 3. Electron micrographs and electron diffraction pattern of microcline from Otome mine. A: bright-field image, C: dark-field image by (060) diffraction spot.

ing optical microscope, they do not form cross-hatching. Both twins protruded slightly from the contact region and their diffraction spots were accompanied by diffuse streaks resulting in a "z" shape, similar to those described by Laves (1950).

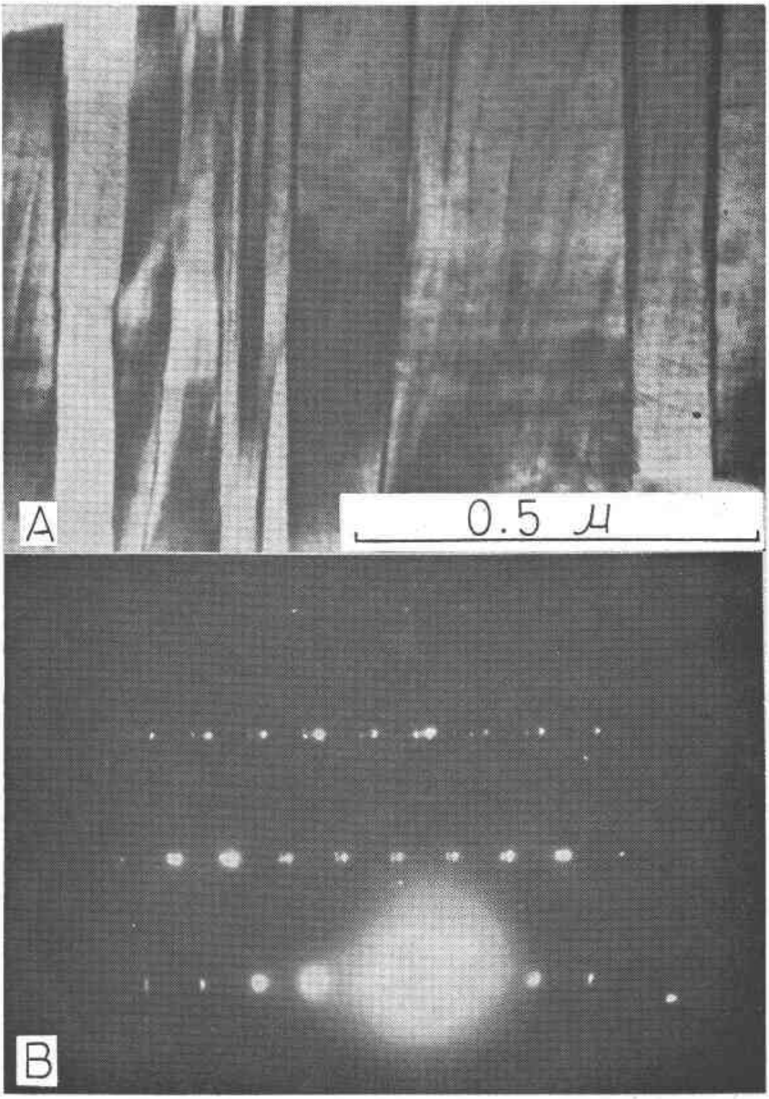

FIG. 4. Electron micrograph and electron diffraction pattern of the rim part in microcline from Tanokami-yama.

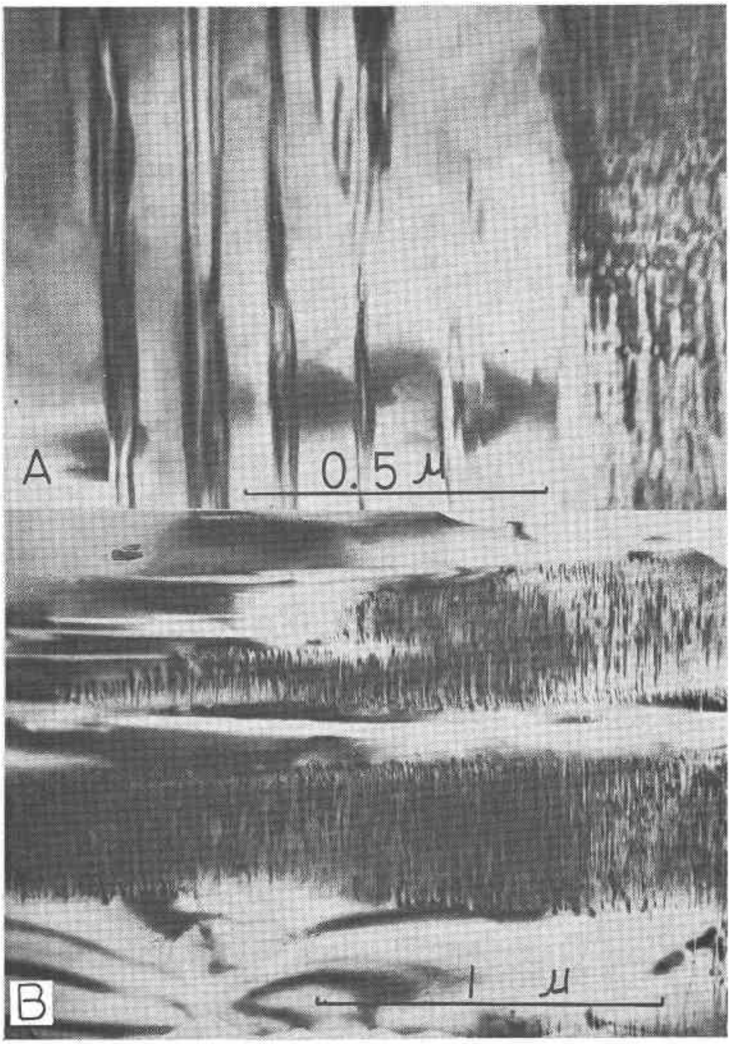

Fig. 5. Electron micrographs of microcline from Amelia (A) and Spruce Pine (B).

Discussion

The formation from monoclinic feldspar of albite and pericline twinnings accompanied by diffuse diffraction streaks resulting in a "z" shape was suggested by Laves in 1950. Although the diffraction patterns of microcline observed in this study do not always show diffuse streaks with a "z" shape and the streaks observed are found only at the contact regions of both twinnings, the extremely fine twinnings are

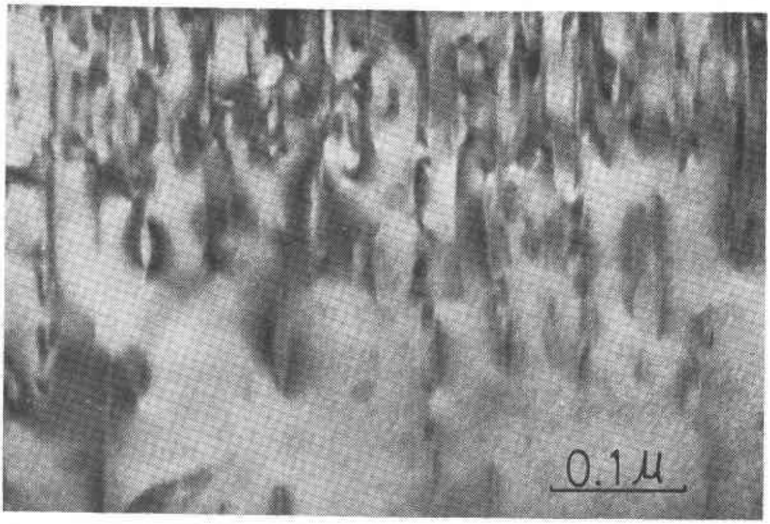

Fig. 6. Electron micrograph of microcline from Amelia.

considered to be formed from monoclinic feldspar. McConnel (1965) described a monoclinic adularia with strong streaks that contain Bragg maxima on X-ray and electron diffraction photographs. The electron micrograph showed cross-hatching similar to that in Figure 2 of this study. McConnel also suggested that the structure of adularia in its transitional state is a homogeneously disordered monoclinic lattice rather than a complex inversion twinning. As the order of silicon and aluminum increases, triclinic characteristics increase, and the transitional state finally changes to real inversion twinning. Although cross-hatching without diffraction patterns of pericline twins was seen, the patterns consisting of both albite and pericline twins were not observed under the electron microscope. It may be conjectured that even if triclinic nature increases, the disordered lamellae intersecting the albite twin domains will not change to pericline twinning. At the early stage of transition from monoclinic feldspar, fine cross-hatching without a twinned diffraction pattern, similar to the texture in orthoclase and monoclinic adularia, will be formed. As triclinic characteristics increase, one direction of the cross lamellae will develop into albite or pericline twins and the other will remain in its original state. Due to weak recrystallization properties, fine albite and pericline twin lamellae will show further development whereas the other lamellae will disappear, and thus many blocks of polysynthetic albite or pericline twins are formed (Fig. 7A).

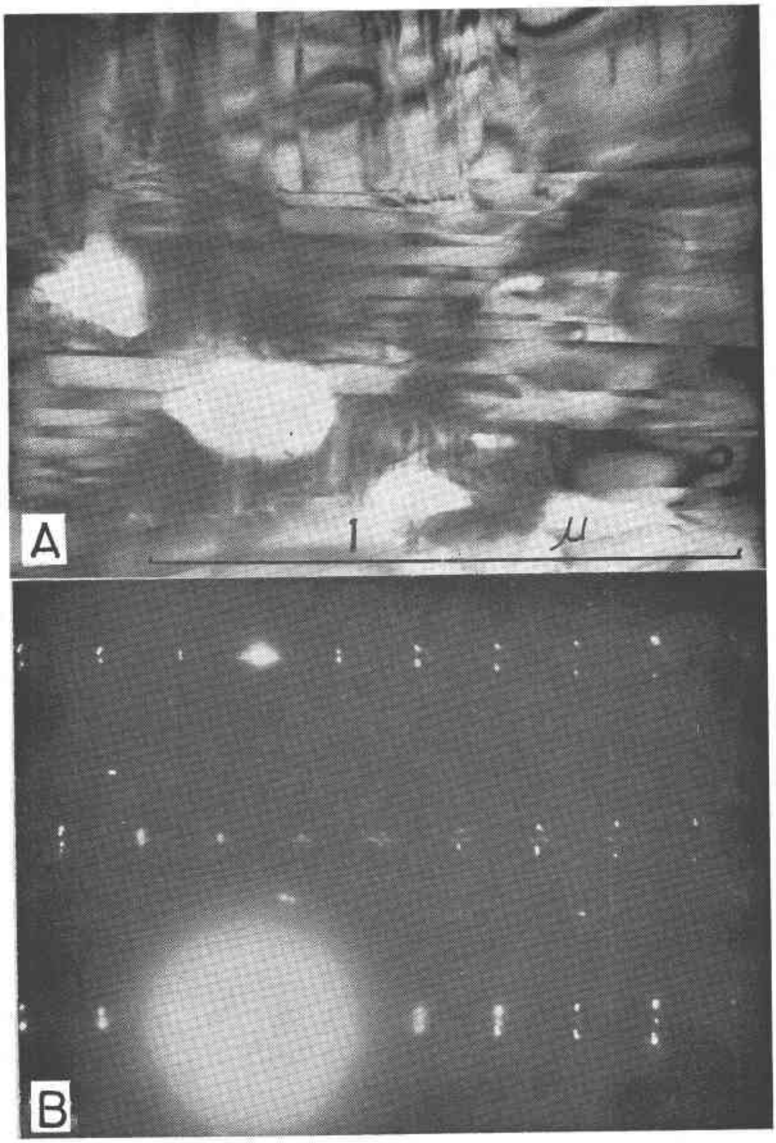

FIG. 7. Electron micrograph and electron diffraction pattern of microcline from Amelia.

In terms of a simple transition it is difficult to account for the genesis of a homogeneous region in the Amelia and Spruce Pine specimens. Nor can the replacement theory reasonably explain the extremely fine albite twinning in the homogeneous region. Aluminum and silicon ions in the framework of potassium feldspar may become mobile under hydrothermal conditions (Goldsmith and Laves, 1954), with a consequent recrystallization (Laves, 1955). In the case of the Amelia and Spruce Pine microcline specimens, there are two possibilities: 1) some regions of monoclinic K-feldspar recrystallized to form a single microcline crystal and other regions transited to microcline with finely twinned domains, or 2) after completion of the microcline structure with the fine domains, a continuation of recrystallization will result in untwinned microcline. Recrystallization may occur in selected areas such as cracks, these places gradually becoming untwinned homogeneous regions resulting in the decreased length of the twin domains adjoining the untwinned region and a final disappearance. If expansion of the recrystallizing regions is disturbed at the pericline twin or at other places of structural discontinuation, band structures of albite twins with perpendicular sharp boundaries will be formed.

The rim part of the microcline from Tanokami-yama consisted of wider albite twinning with fine lamellae similar to that of orthoclase; the occurrence of such fine lamellae following formation of the homogeneous region is thought to be due to the increase in triclinic nature.

Acknowledgement

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