Proc. NIPR Symp. Antarct. Geosci., 1, 66–72, 1987

MICROSTRUCTURE AND PHASE TRANSITION OF CALCIC ANORTHOCLASE FROM MOUNT EREBUS, ANTARCTICA

Tokuhei TAGAI[1], Hiroshi TAKEDA[1], Osamu TACHIKAWA[1], Katsutada KAMINUMA[2] and P. R. KYLE[3]

[1]*Mineralogical Institute, Faculty of Science, University of Tokyo, 3–1, Hongo 7-chome, Bunkyo-ku, Tokyo 113*
[2]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*
[3]*Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, New Mexico 87801, U.S.A.*

Abstract: Monoclinic-triclinic inversion and exsolution phenomena in calcic anorthoclase were investigated by means of high temperature X-ray diffraction, X-ray microprobe analysis and analytical transmission electron microscope on natural calcic anorthoclase from Mout Erebus, Antarctica.

Mt. Erebus anorthoclase is the most calcic one-phase anorthoclase which was twinned according to the albite- and pericline-laws in the course of monoclinic-triclinic inversion, whose temperature was measured to be 750°C. The occurrence of the one-phase anorthoclase was closely related with the eruption mechanism of Mt. Erebus.

1. Introduction

Almost all natural feldspars can be described in terms of three end components, Or (orthoclase: K-feldspar), Ab (albite: Na-feldspar) and An (anorthite: Ca-feldspar). In this ternary system, solid solution has not been observed in the Or-An series but only between the Or-Ab (alkali feldspar) series and the Ab-An (plagioclase) series. In alkali feldspar and plagioclase, the third components, Ca and K respectively, are usually present in small amounts or entirely lacking. Only a few ternary feldspars are known. The region of anorthoclase is shown in Fig. 1 on the feldspar triangular diagram of SMITH and MACKENZIE (1958). The two-feldspars region was investigated at high pressure by SECK (1971a, b).

In the present work, a calcic anorthoclase from Mout Erebus, Antarctica was studied. This anorthoclase shows very calcic bulk composition and quite complicated microstructure due to the thermal histories experienced.

Mt. Erebus is located in Ross Island, East Antarctica, and the geological details are described by PRIOR (1907), SMITH (1954) and KYLE *et al.* (1982). Anorthoclase crystals from Mt. Erebus were first studied by MOUNTAIN (1925) who compared them with other anorthoclases from Mt. Kenya and Mt. Kilimanjaro. Other studies of Mt. Erebus anorthoclase include MACKENZIE (1952), SMITH and MACKENZIE (1958), CARMICHAEL and MACKENZIE (1964), BOUDETTE and FORD (1966) and KYLE (1976). The bulk chemical composition of the Mt. Erebus anorthoclase is about $Or_{18}Ab_{64}An_{18}$, but details of the crystallographic characteristics are not well described. MACKENZIE

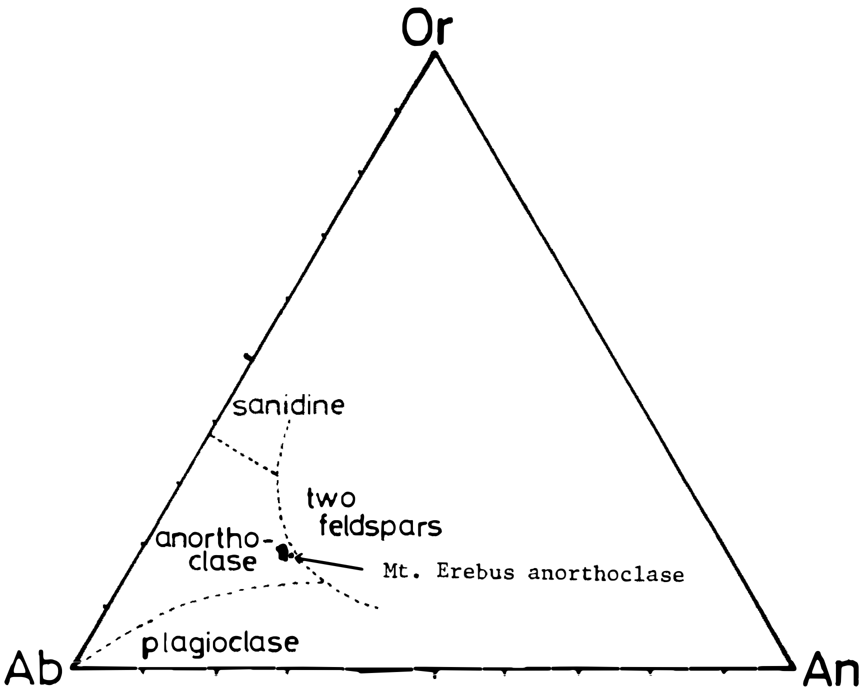

Fig. 1. Part of the ternary system $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$ showing the field of anorthoclase after the definition by SMITH and MACKENZIE (1958). Plot of compositions of the Mt. Erebus anorthoclase on the ternary diagram after the results of XMA.

(1952) carried out high temperature experiments on natural and synthetic Na-rich feldspars using a powder diffractometer attached to the furnace and gave the triclinic-monoclinic inversion temperature of 600°C in the Mt. Erebus anorthoclase. BOUDETTE and FORD (1966) described anorthoclase from the Crary Mountains and Cape Royds, Antarctica.

Additional descriptions of Ca-rich anorthoclases are given by MUIR and TILLEY (1961), CARMICHAEL and MACKENZIE (1964) and PARSONS and BROWN (1983a, b).

In this work, the microstructure and phase transition of the calcic anorthoclase from Mt. Erebus were studied by means of high temperature X-ray diffraction, analytical transmission electron microscopy and X-ray microprobe analysis.

2. Description of Samples

Three anorthoclase crystals erupted from Mt. Erebus at different times were collected. The first from near the crater rim is about 5 cm long lozenge-shape crystal (it is often twinned by the Carlsbad-law). Time of eruption of this sample is unknown and the surface of the crystal is well weathered. The second crystal was erupted in 1982. The maximum size is about 1 cm and some vesicular phonolite glass remains adhered to the surface of the crystal. The third crystal was obtained from the volcanic bomb erupted on 14 December 1983. The bomb was fresh and was collected just after the eruption. The anorthoclase crystal from the bomb is about 3 cm long and is embedded in vesicular glass. The three anorthoclases show no major differences in chemical composition and diffraction characteristics. Therefore, only the third sample was examined because it retained the fresh vesicular glass containing the anorthoclase crystals of μm-cm size without weathering. The Mt. Erebus anorthoclase shows the typical cross-hatched twinning (albite- and pericline-twinning). The microscopical distribution of the twinning was investigated by the polarization microscope. In the large crystals, the cross-hatched twinning becomes indistinct sometimes in the rim of the crystal.

3. Chemical Compositions

The chemical compositions of the anorthoclase crystal and glass from Mt. Erebus were determined by microprobe analysis using a JEOL JCXA-733 at the Ocean Research Institute, University of Tokyo.

According to the results of the chemical analysis, the Mt. Erebus anorthoclase is chemically homogeneous, which was confirmed also in the back-scattered electron images. The averaged chemical composition is $Or_{19}Ab_{63}An_{18}$. The Mt. Erebus glass contained much more Fe, Ti, K and Mg and less Si, Ca and Al than the anorthoclase. The results of the microprobe analysis are summarized in Table 1.

Table 1. The chemical compositions of the Mt. Erebus anorthoclase and glass (wt%) by XMA.

	Anorthoclase	Glass
SiO_2	63.70	56.14
TiO_2	0.14	1.20
Al_2O_3	21.19	19.73
FeO	1.23	6.38
MnO	—	0.27
MgO	—	0.64
CaO	4.40	1.27
Na_2O	7.14	7.59
K_2O	2.87	5.76
Cr_2O_3	0.04	—
V_2O_3	0.01	—
P_2O_5	—	0.24
	99.72	99.22

Chemical formula

Anorthoclase: $(Na_{0.62}K_{0.17}Ca_{0.21}Fe_{0.05})(Si_{2.88}Al_{1.13})O_8$

Glass: $(Na_{0.69}K_{0.34}Ca_{0.06}Fe_{0.25}Mg_{0.04}Mn_{0.01})(Si_{2.62}Al_{1.09}Ti_{0.04})O_8$

Anorthoclase: $Ab_{62}Or_{17}An_{21}$

Glass: $Ab_{63}Or_{31}An_6$

4. High Temperature X-ray Experiments

The triclinic-monoclinic phase transition in the anorthoclase was examined by high temperature X-ray experiments using a precession camera on an X-ray generator with rotating anode (50 kV, 180 mA). Each crystal was enclosed in an evacuated SiO_2 glass capillary and mounted on the camera. A Pt-furnace was attached to the

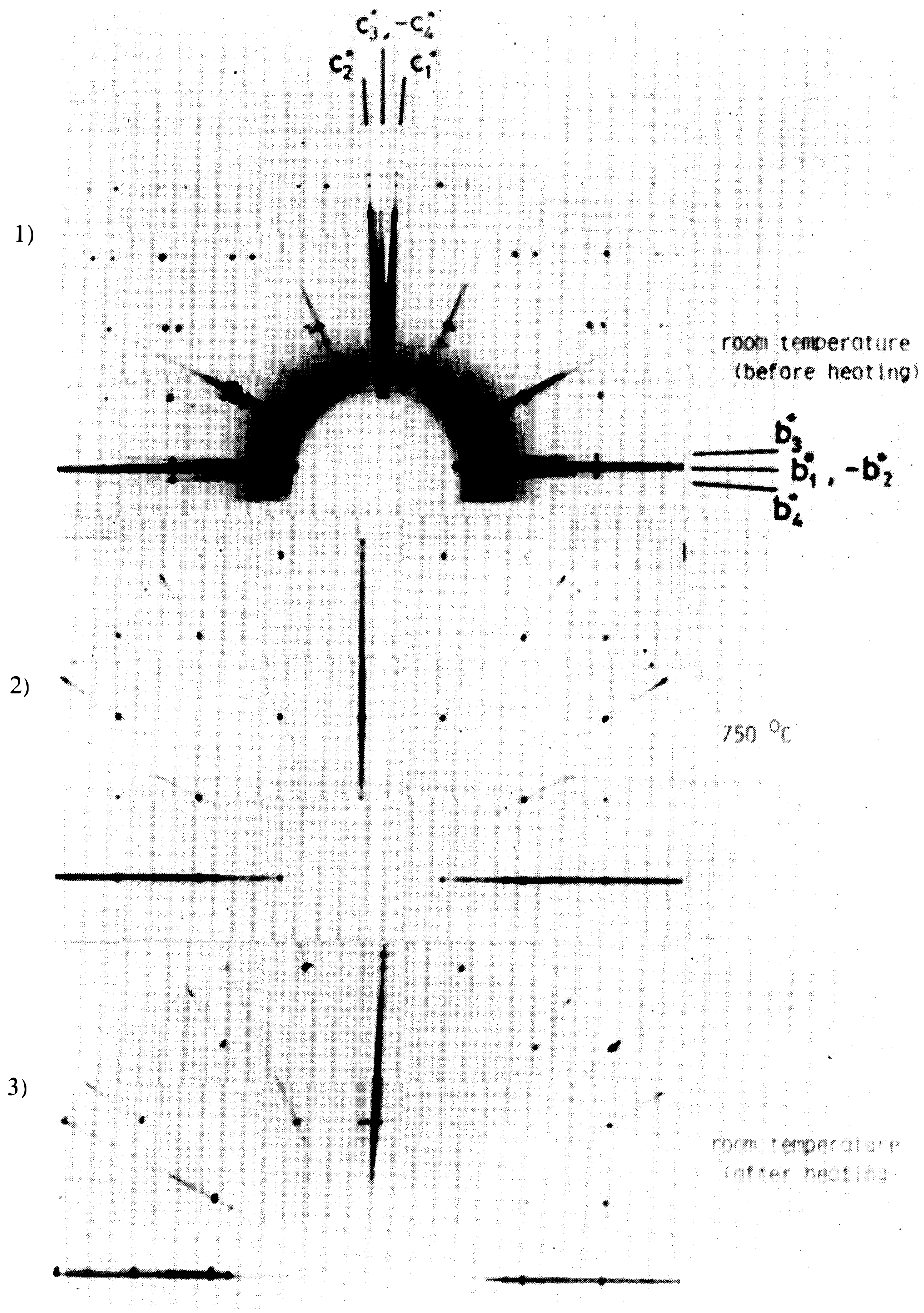

Fig. 2. The X-ray diffraction diagrams of the Mt. Erebus anorthoclase in the heating experiments. 1) is the precession photograph at room temperature before heating, 2) is the one at 750°C and 3) is the one at room temperature after heating. The b_i and c_i* (i=1, 4) indicate the reciprocal axes, which are related by the albite-law (i=1 and 2) and by the pericline-law (i=3 and 4).*

precession camera and the temperature was controlled to be within ±10°C. Diffraction photographs were taken from room temperature to 950°C, at intervals of 50°C with 2 h exposure time.

The Mt. Erebus crystal was triclinic at room temperature and showed albite- and pericline-twinning (M-twinning or cross-hatched twinning) in the diffraction diagram (Fig. 2-1). It is suggested that the anorthoclase first crystallized with monoclinic symmetry above the inversion temperature and the cross-hatched twinning resulted from the monoclinic-triclinic inversion during cooling. With increasing temperature the angle $90°-\alpha^*$, which can be an indicator of the deviation from monoclinic symmetry, became constantly smaller and at 750°C the crystal was metrically monoclinic (Fig. 2-2). When the crystal was cooled to room temperature, it again became triclinic and formed M-twinning, though, the volume ratio of each type of twinning was different (Fig. 2-3).

5. Transmission Electron Microscopic Observations

The anorthoclase was examined using a JEOL 100CX transmission electron microscope (TEM) and a HITACHI H-600 analytical transmission electron microscope (ATEM) equipped with an energy dispersive detector (both were operated at an accelerating voltage of 100 kV). The samples were prepared from petrographic thin sections by Ar-ion bombardment.

The Mt. Erebus anorthoclase showed both microscopic and submicroscopic albite- and pericline-twinning (Fig. 3). The ATEM data showed that the sample is chemically homogeneous also in the submicroscopic scale.

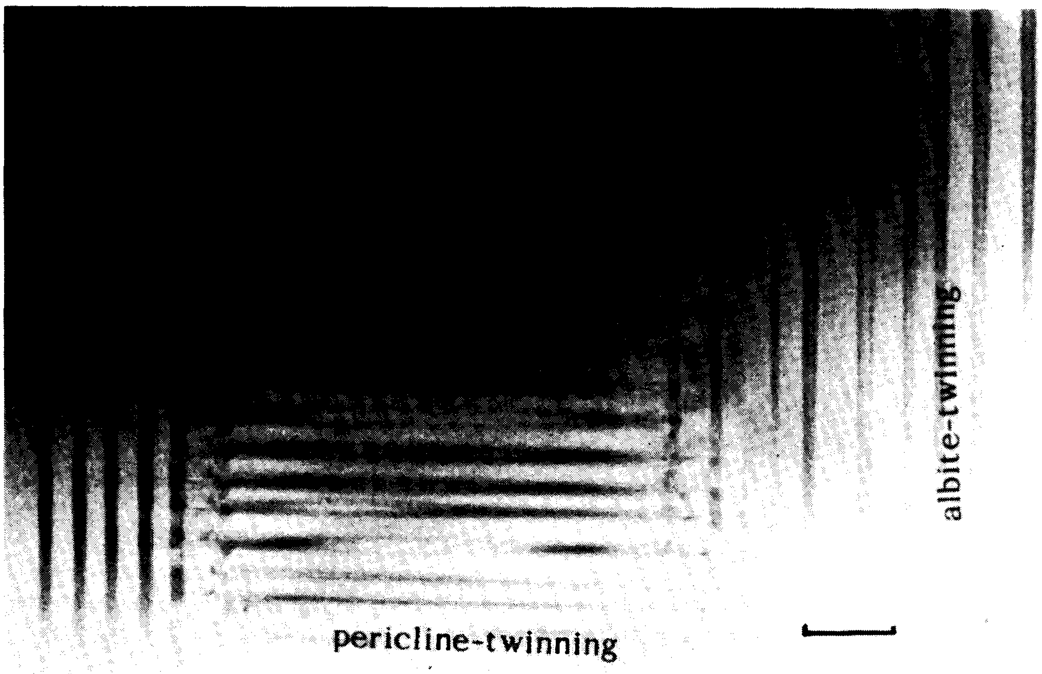

Fig. 3. TEM photographs of the Mt. Erebus anorthoclase. The submicroscopic albite-pericline-twinning is shown. The scale line in the figure indicates 0.1 micron.

6. Discussion

The location of the magma chamber of Mt. Erebus, where the anorthoclase grew, is not well defined. But if the magma chamber is supposed to lie at the depth of 5–6 km under the summit of Mt. Erebus, the pressure may be calculated to be about 1.5 kb, assuming the average density of the crust-constituting rocks is 2.8 g/cm^3. The transition temperature from glass to liquid in the Mt. Erebus glass was measured to be 1050°C by means of the Seger-cone method. Judging from the present situation of the eruption of Mt. Erebus, the glass is believed to have been melted at the eruption time. The anorthoclase of Mt. Erebus may have grown in good equilibrium condition at about 1100–1200°C and about 1.5 kb. At such temperature and pressure, the anorthoclase was in the one-phase region of feldspar and the crystal had the monoclinic symmetry. Then, in the course of eruption, the anorthoclase was cooled rapidly enough not to be exsolved to two feldspars through the unmixing temperature, and only the monoclinic-triclinic transition took place. The transition temperature was expected to be about 750°C from the results of the present high temperature X-ray experiments. According to LAVES (1952) and KROLL *et al.* (1980) this transition can be classified as the displacive transition of analbite-monoalbite. The anorthoclase from Mt. Erebus is the most calcic one which was not unmixed to two feldspars. The magma including anorthoclases, melt and volatile components rase rapidly from the depth to the summit of Mt. Erebus, and at the time of volcanic eruption the anorthoclase and glass with bubbles were ejected accompanied by rapid cooling and rapid release of pressure, which produced one-phase anorthoclase.

The calcic anorthoclase, which was cooled more slowly showed complicated phenomena of the phase transitions and exsolutions (BROWN and WILLAIME, 1974; WILLAIME *et al.*, 1976; TAGAI *et al.*, in preparation). According to these authors, anorthoclase was first crystallized in the single monoclinic phase. When the cooling was very fast, the exsolution would not occur and only the monoclinic-triclinic transformation might have taken place. If the cooling rate was slow, the unmixing between K-rich phase and Na-rich phase would be encountered. After the unmixing took place, the phase transformation from monoclinic to triclinic occurred first in the Na-rich phase. When the cooling rate was much slower, the monoclinic-triclinic transformation could take place in the K-rich phase also.

Acknowledgments

The XMA works were carried out at the Ocean Research Institute, University of Tokyo, in accordance with the cooperative program (Project No. 85149). Melting experiments of the glass samples were carried out in the central laboratory of Mitsubishi Mining and Cement Co., which is gratefully acknowledged.

This work was supported in part by the Grant in Aid for Scientific Research, from the Ministry of Education, Science and Culture, and the research grant from the Okura Foundation.

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(*Received March 2, 1987; Revised manuscript received May 8, 1987*)