Growth twinning in phacolite

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Abstract

Phacolite from Mitaki, Sendai City, Japan, has a core of penetration-twinned chabazite. The crystal has a convex (0001) face on which many twin individuals are produced by a two-dimensional nucleation mechanism, resulting in complicated twinning during growth. Both the r and the $\underline{r}$ $(10\bar{1}1)$ faces repeat finely during growth because of twinning, resulting in $\{11\bar{2}3\}$ sectors with polysynthetic twinning. Finally, single structures nucleate on the crystal edges $[21\bar{1}]$ and develop along the $(11\bar{2}3)$ face, penetrating each other near the centre of the face.

KEYWORDS: phacolite, chabazite, zeolites, growth twinning, Mitaki, Japan

Introduction

CHABAZITE is a common zeolite with a simple rhombohedral form. However, the varieties herschelite and phacolite show various crystal forms (Gottardi and Galli, 1985). Phacolite, a colourless variety, shows complicated twinning of a hexagonal form: the (0001) section has six sectors, while, in addition, each sector is divided into two parts with extinction inclined in each symmetrically at angles of 6° to 7° to the *b*-axis between them (Klein in Dana, 1892, p. 590). Lasaulx (1881) described the texture of herschelite.

Chabazite with rhombohedral form shows complicated sectors between crossed polars as well. Mazzi and Galli (1983) found that the symmetry of four chabazites studied deviates significantly from trigonal symmetry, leading to space group $P\bar{1}$, and that these deviations are due to Al/Si ordering. The internal textures, such as sectorial twinning, are attributed to various Al/Si orderings, which are produced on the vicinal faces of the crystal surface during growth (Akizuki, 1981).

Experimental details

Phacolite crystals, which are distributed widely in Mitaki, Sendai City, Japan, were studied under a reflection interference contrast microscope and between crossed polars. The crystals, which are about 3 mm in diameter, occur in the network-like cavities cutting through a massive tuff. Table 1 shows the chemical analysis of a phacolite crystal and microprobe analysis indicates weak chemical zoning with respect to the Ca/K ratio.

Fig. 1A and B shows typical forms of penetration-twinned chabazite and phacolite. The (0001) face of the phacolite crystal is convex, not flat (see also Gottardi and Galli, Fig. 4.2E, 1985). Fig. 2 shows the surface microtopograph of the $(11\bar{2}3)$ face. Two kinds of domain nucleate on the crystal edges [211], and are interpenetrant near the centre of $(11\bar{2}3)$ faces. Each domain has striations parallel to the edge of the surface. A $(11\bar{2}3)$ thin section, just below the surface, was studied between crossed polars: two kinds of domain corresponding to the surface features, which are reflection twins with respect to the $(1\bar{1}00)$ face, were observed. The twinning was detected with a precession camera and the optical orientation and 2V value determined by a universal stage. The optical properties of the right domain (Fig. 2) are shown in Fig. 3A, suggesting a triclinic symmetry. The $(11\bar{2}3)$ section which is deeper than 0.1 mm below the crystal surface $(11\bar{2}3)$ represents polysynthetic twinning parallel to the $(1\bar{1}00)$ plane. The optical properties vary from place to place and a random example is shown in Fig. 3B.

Figs. 4A and B represent internal texture in the section whose orientation is shown by the dashed line in Fig. 1B. This is a near-centre section of the crystal. The core consists of a penetration twin of chabazite with rhombohedral form. Band (a–b), whose thickness correlates with the diameter of the core along the *c*-axis, consists of a single twin. Crystals with fine twinning grow on both sides of the band. Two sectors (t_1 and t_2) consist of fine irregular twinnings and sector (t_3) has horizontal fine twinning. Sector boundaries consist of vertical striations which are shown by arrows in Fig. 4A.

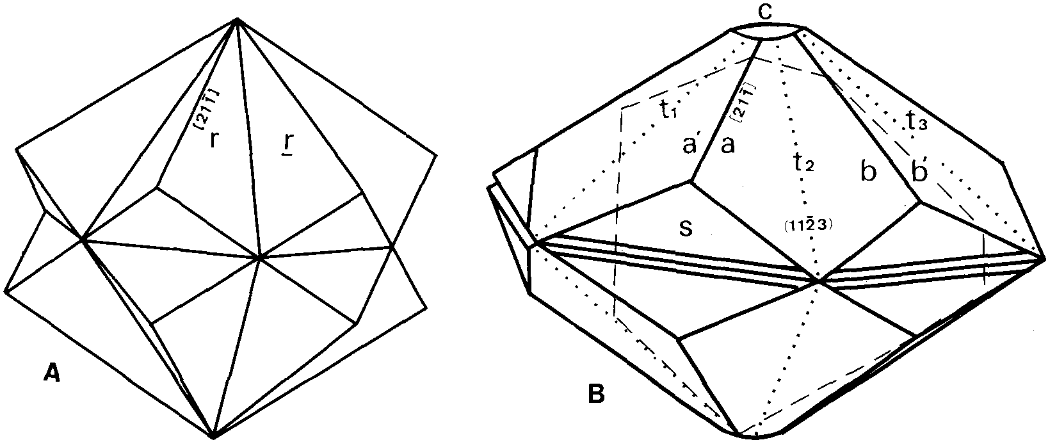

FIG. 1A and B. (A) Ideal crystal forms of penetration-twinned chabazite and (B) phacolite. s(02$\bar{2}$1), t(11$\bar{2}$3), c(0001), r(10$\bar{1}$1). The individuals a (a') and b (b'), which are interpenetrant near the dotted line, are in a twin relation with respect to the framework. The individuals a and a', and b and b' are in a twin relation with respect to the Al/Si ordering.

Growth zoning, which is due to different chemical composition and Al/Si ordering, is observed in Fig. 4B.

Fig. 5 shows a schematic sketch of the irregular twinning in Fig. 4A which was observed on the universal stage. The twin individuals are rod-like and elongated in the direction of the *a*-axis. The length of the rod correlates to the thickness of the thin section. The twinning has the appearance of irregular streaks in sectors t_1 and t_2 (Fig. 4A), because of the inclination and overlapping of the fine rods. The orientation of the twin streaks, when observed under a microscope, varies with the rotation of the section. Twinning in sector t_3 is horizontal regardless of the rotation of the section, because the rods are parallel to the rotation axis. The fine twinning was also observed in X-ray analysis (Narita, 1968).

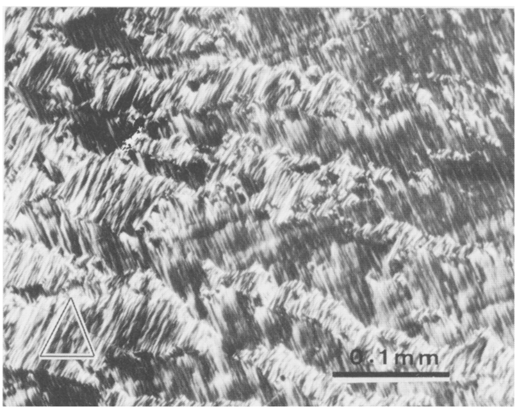

FIG. 2. Reflection interference contrast photomicrograph of the growth pattern on the centre portion of a (11$\bar{2}$3) face of phacolite. The triangular pyramidal face (11$\bar{2}$3) by which the crystal orientation can be recognized is drawn on the surface.

Discussion

The specimens used for the study show a similar texture under the optical microscope. The crystals, without exception, have cores with penetration twins of rhombohedral chabazite. If an event such as a sudden change of growth rate does not occur during growth, the *AABBCC* structural sequence in the core will develop continuously in the direction parallel to the layer structure, otherwise lattice defects will be produced in the crystal. Thus, morphological twinning is observed in the crystal (Fig. 4A and B).

Table 1. Chemical analysis of phacolite

	wt.%	unit cell contents	
SiO_2	45.82	Si	23.36
Al_2O_3	21.15	Al	12.70
Fe_2O_3	0.33	Fe	0.12
CaO	10.02	Ca	5.47
Na_2O	0.50	Na	0.50
K_2O	0.96	K	0.62
$H_2O(+)$	14.43	H_2O	36.66
$H_2O(-)$	7.11	O	72
Total	100.32		

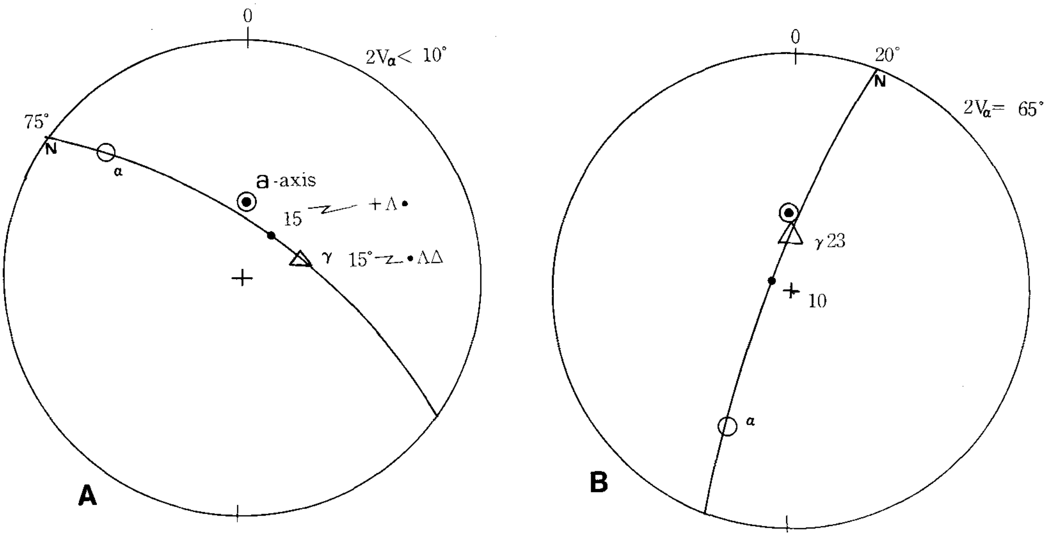

FIG. 3A and B. The stereographic projections of optical properties of the areas (A) near the surface and (B) deeper than 0.1 mm below the surface. The crystallographic axis (*a*), principal vibration axes (α and γ) are plotted in each case and can be identified from the labelling. The symbol + shows the direction normal to the (11$\bar{2}$3) growth surface, and the symbol • shows the direction normal to the N-direction on the optic-axial plane. The numbers are the angles between the two directions indicated by the symbols.

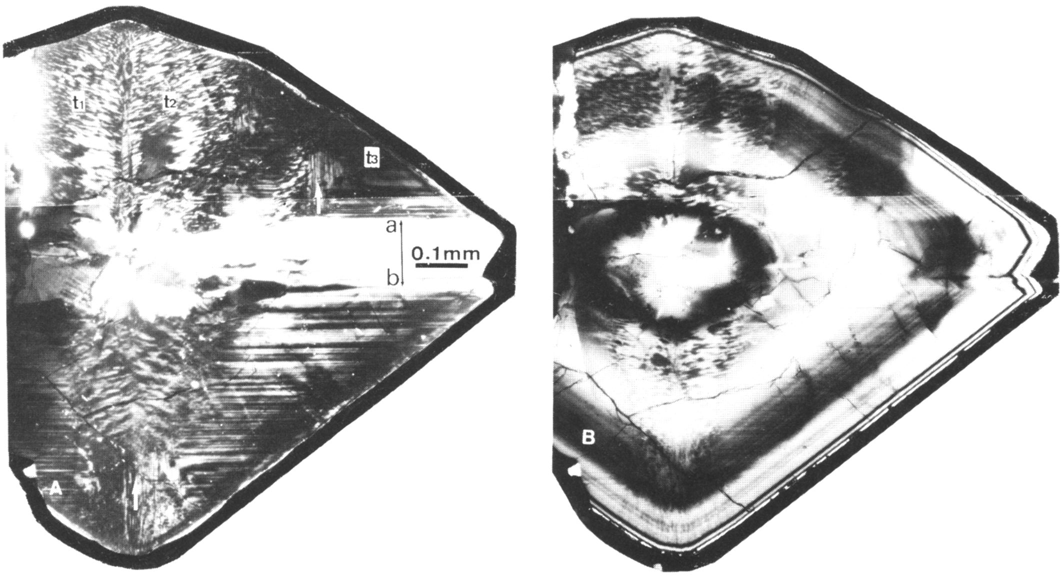

FIG. 4A and B. Cross-polarized photomicrographs of phacolite, showing the internal texture. Polarizing plane is vertical in Fig. 4A and is rotated 35° clockwise from vertical in Fig. 4B. Orientation of the section is shown by the dashed line in Fig. 1B. Sectors (t_1, t_2 and t_3) shown in Fig. 4A correspond to those of Fig. 1B, respectively.

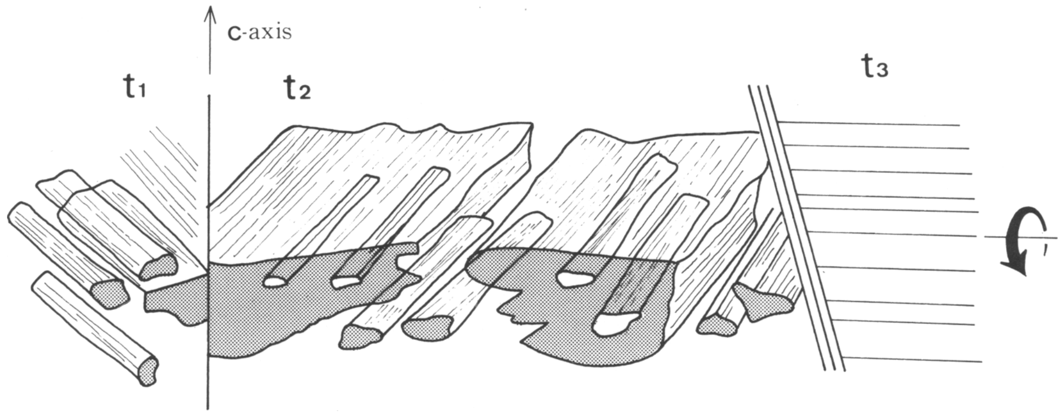

FIG. 5. A schematic sketch of the twinning in Fig. 4A and B which was observed on the universal stage. The *c*-axis is rotated from the vertical to the direction shown by the arrow. The sectors (t_1, t_2 and t_3) correspond to those in Fig. 4A.

Fine twin individuals will be produced on the (0001) face by a two-dimensional nucleation. Because of the polysynthetic twinnings, both the r and r̲ (10$\bar{1}$1) faces repeat finely during growth, resulting in the t (11$\bar{2}$3) face. The twin individuals develop in the direction of the *a*-axis during growth, resulting in rod-like individuals. If the (0001) face does not develop on the crystal, the (11$\bar{2}$3) face will not be produced in the crystal either, resulting in penetration-twinned chabazite with a re-entrant angle (Fig. 1A).

The growth condition changed abruptly in the final stages of growth, and nucleation occurred on the crystal edge [211] between the two pyramidal faces, that is, a thin layer near the surface was produced by an edge nucleation crystal growth mechanism. The framework structure will be single along the edge, because the edge is parallel to the edge of the chabazite with the rhombohedral form. Therefore, the single structure develops along the (11$\bar{2}$3) face, and the crystals are interpenetrant near the centre of the face, resulting in twinning (Fig. 2).

Twinning cannot be observed in a trigonal chabazite between crossed polars, because of uniaxial and parallel optical orientations. The phacolite crystals studied, however, shows various twins between crossed polars, suggesting lower symmetry, that is, the structure is in fact triclinic.

The frameworks are in a twin relation between the individuals a(a′) and b(b′) in Fig. 1B. Although the fundamental frameworks of sectors a and a′, and sectors b and b′ are in the same orientation, respectively, they are in a twin relation with respect to the Al/Si ordering (Akizuki, 1981). Thus, twelvefold twinning is produced on the rim of the crystal. Though the internal portion consists of polysynthetic twins, the twin relations are the same as those on the rim.

Zeolites are metastable minerals, and therefore, various degrees of Al/Si ordering are produced on the surface during growth, resulting in low symmetry (Akizuki, 1985). Chabazite crystals range from single rhombohedral crystals to phacolite with complicated twinning, suggesting that the habit of chabazite is very sensitive to variations in growth environments. Walker (1951) observed systematic variation of the habit in the Garron Plateau area, County Antrim, Ireland. The present locality, however, produced only chabazite in the phacolite form.

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