MINERALOGICAL JOURNAL, VOL. 9, NO. 4, PP. 231-235, OCT. 1978

Short Communications

The first finding of monoclinic tridymite in terrestrial volcanic rocks. KAZUHIDE KAWAI*, TAKEO MATSUMOTO**, KUNIAKI KIHARA**, and KIN-ICHI SAKURAI,*** ****Department of Earth Sciences, Faculty of Science, Kanazawa University, Kanazawa 920, and ***National Science Museum, Hyakunincho, Shinjuku-ku, Tokyo 160.*

ABSTRACT

Monoclinic tridymite was found in volcanic rocks from three localities; Yugawara, Harius and Mt. Myoho in Japan. The unit cell parameters of the Yugawara tridymite are $a=25.89$, $b=5.00$, $c=18.59$ Å and $\beta=117.7°$, and space group is Aa or $A2/a$. This monoclinic tridymite was transformed to the form with $n=10$ by rapid cooling from high temperature.

Introduction

Since the X-ray single crystal study for room temperature tridymite by Buerger and Lukesh (1942), several modifications of tridymite have been reported. To date, the crystal structures of a hexagonal form (Gibbs, 1927), a monoclinic form (Dollase and Baur, 1976; Kato and Nukui, 1976), two different orthorhombic forms (Dollase, 1967; Kihara, 1977) and a triclinic form (Konnert and Appleman, 1978) have been studied by X-ray single crystal methods. The crystal structures of other types have not been determined.

For the apparent periodicity along c of the ideal hexagonal modification, tridymites may be conveniently expressed as $n\times c$ type, where the values of $n=1$, 1.5, 2, 5, 6 and 10 are known (Hoffmann and Laves, 1964). Monoclinic tridymite, which corresponds to $n=6$, has been known to occur in meteorites (Dollase and Buerger, 1966), lunar rocks

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(Dollase *et al.*, 1971; Appleman *et al.*, 1971), fired silica brick (Dollase and Buerger, 1966; Kihara, 1977) and some synthesized materials (Hoffmann, 1967; Kato and Nukui, 1967), but not in terrestrial rocks (Appleman *et al.*, 1971).

In this paper, we report the first finding of the monoclinic tridymite in terrestrial rocks, on the basis of some crystallographic studies including heating experiments on this form from Yugawara dacite.

Samples and experiments

The specimens examined here were found at Yugawara in Kanagawa Prefecture, Harius in Hokkaido and Mt. Myoho in Tochigi Prefecture. The Yugawara tridymite occurs on or near the surface of cracks and cavities in dacite. A monoclinic tridymite from this locality is transparent and has a wedge-like block shape. Another tridymite exhibiting a platy habit was also found in the same dacite; this belongs to the type with $n=10$, which was also found in Mt. Ishigami, Kumamoto Prefecture (Tagai and Sadanaga, 1972; Haga, 1974) and other localities. The observations on tridymites occurring at the present three localities and in Mt. Ishigami suggest that monoclinic tridymite crystallizes with a blocky form and the $n=10$ type crystallizes with a platy form.

Monoclinic tridymites from the three localities are inevitably twinned. Optically homogeneous crystals were chosen for the following experiments. Weissenberg and precession photographs were taken around the c-axis of the hexagonal subcell, c_h. One of the oscillation photographs is shown in Fig. 1a. The apparent periodicity along the rotation axis is six times as long as that of the hexagonal subcell. The precession photographs were taken every 30° around the c_h axis. As shown in Fig. 2, every 60° photographs apparently showed the same 0-layer pattern. X-ray photographs show prominently the pattern of the hexagonal subcell ($a=5$ and $c=8.2$ Å). In addition to the

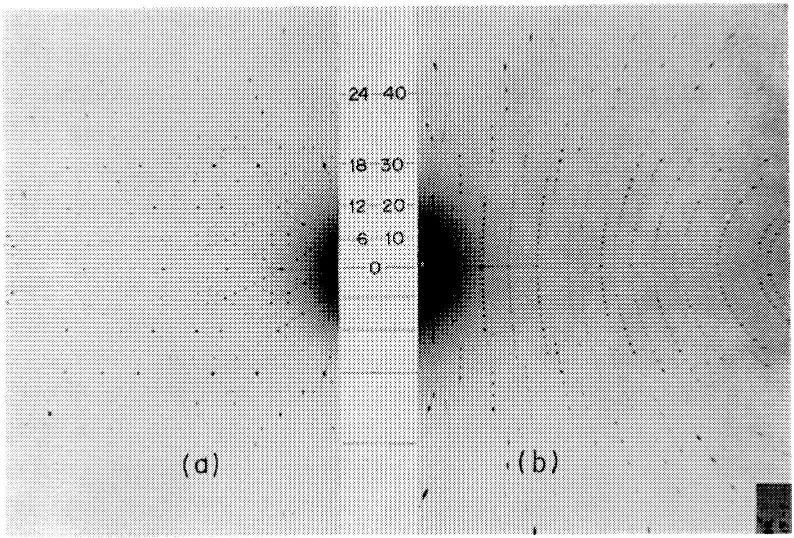

Fig. 1. Oscillation photographs of tridymite from Yugawara volcanic rocks taken along c_h, (a) before heating ($n=6$), (b) after heating ($n=10$).

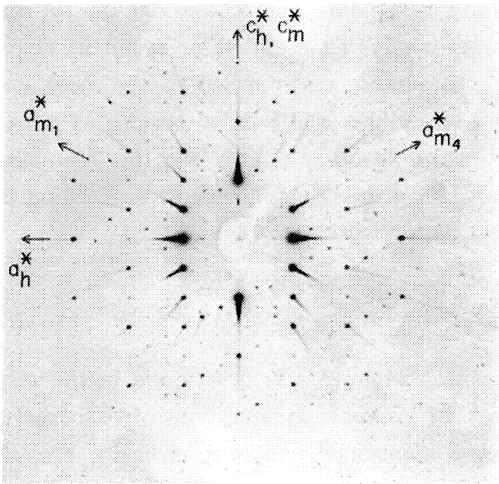

Fig. 2. A precession photograph (*h0l*) of the monoclinic tridymite (twinned) before heating. Subscripts, h and m denote the hexagonal subcell and the monoclinic cell respectively. Numbers, 1 and 4, mean the two individuals among six twinned individuals. This photograph is compatible with that of *H0L* in Fig. 1 by Tagai *et al.* (1978).

strong subcell reflections, weaker but clearly defined superstructure reflections were observed. It has been known that monoclinic tridymite is multiply twinned, and the orientations of six individuals are coincided by every 60° rotation around c_h ($=[103]_m$) (Hoffmann, 1967). This is expressed as $6^6/m$ $(2_I/m_I\ 2_{II}/m_{II}\ 2_{III}/m_{III})$ $(2'_I/m'_I\ 2'_{II}/m'_{II}\ 2'_{III}/m'_{III})$ (Tagai *et al.*, 1977) by color symmetry symbolism (Curien and Donnay, 1959). By taking account of this relation, the complicated diffraction pattern is interpreted to be a result of twinning of monoclinic tridymite in the six possible orientations. The cell constants* and the space group are as follows:

$a=25.89(10)$, $b=5.00(2)$, $c=18.59(8)$ Å and $\beta=117.7(8)°$, Aa or $A2/a$.

This twinned tridymite was transformed to the $n=10$ type by the procedure described below. The specimens were heated at about 1000°C for a few minutes in air and cooled by dropping them into liquid nitrogen. Fig. 1b shows the diffraction pattern recorded at the room temperature after cooling. Moreover, the specimens heated at about 1200°C for a few hours and cooled so as to reach the room temperature in two days gave the same result as above. The $n=10$ type tridymites, both those transformed in the way described above from monoclinic tridymite and natural specimens from Mt. Ishigami, were not transformed to other phases by the following procedures: heating at about 1200 and 900°C followed by succeeding cooling through one day and ten days respectively.

Discussion

The monoclinic tridymite was first found in the terrestrial rocks. It is interesting to compare this tridymite with usual terrestrial tridymite. The $n=6$ monoclinic tridymite is easily transformed to the usual $n=10$ type by rapid cooling, which occurs naturally in Yugawara,

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* This setting is transformed from Hoffmann's setting by the matrix, $(001/0\bar{1}0/100)$.

Mt. Ishigami and other localities. The monoclinic tridymite (n=6) found in this study might be cooled more slowly than the n=10 tridymite on its formation in rocks. So far as we examined, the two types of tridymite (n=6 and n=10) might be the typical ones at the room temperature.

The authors are indebted to Dr. H. Takeda for providing the copies of the precession photographs on the Steinbach tridymite. They also thank Mr. K. Nakamura for preparing the figures.

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Received January 25, 1978.