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The unit cell of talc

M. AKIZUKI[1] AND J. ZUSSMAN[2]

SUMMARY. Six specimens of talc studied by the electron microscope lattice-imaging and diffraction techniques were found to have the triclinic one-layer (1 Tr) structure. Since no evidence of a monoclinic two-layered structure was found in any specimen it is concluded that the 1 Tr structure is the common one for talc, and it may, moreover, be the only one. Extremely fine polysynthetic twinning and single intrinsic stacking faults were found in talc.

GRUNER (1934) analysed the crystal structure of talc by the powder method, and gave the unit cell as monoclinic with $a = 5{\cdot}26$, $b = 9{\cdot}10$, $c = 18{\cdot}81$ Å, and $\beta = 80°$. Hendricks (1938) obtained a similar result by single-crystal X-ray diffraction methods, and it became accepted that talc has a monoclinic two-layer structure (2M). Stemple and Brindley (1960) studied a talc from Manchuria by 114·6 mm diameter X-ray powder camera and high-angle X-ray diffractometer and reported it as having the 2M structure. However, Ross *et al.* (1968) examined talc single-crystal specimens from two localities (Gouverneur, New York, and Balsam, N. Carolina) and determined their unit cells as triclinic, and Rayner and Brown (1973) re-examined the talc from Maryland previously studied by Hendricks and found that the true unit cell was triclinic (pseudo-monoclinic) with $a = 5{\cdot}293$, $b = 9{\cdot}179$, $c = 9{\cdot}496$ Å and $\alpha = 90{\cdot}57$, $\beta = 98{\cdot}91$, $\gamma = 90{\cdot}03°$, space group $C\bar{1}$. These results cast considerable doubt on the reality of monoclinic talc although it is possible that both triclinic and monoclinic polymorphs exist.

Since the study by Hendricks, it has become well known that talc commonly exhibits very disordered stacking (see, for example, Zvyagin, 1967, who found very disordered talc by observing *hkl* electron diffraction patterns).

The writers studied the polymorphs and the layer stacking in talc by means of lattice images and diffraction patterns obtained using a high resolution and high-voltage electron microscope (JEM 1000) and a normal voltage electron microscope (Philips 301).

[1] Institute of Mineralogy, Petrology and Economic Geology, Tohoku University, Sendai, Japan.

[2] Department of Geology, University of Manchester, Manchester, England.

Specimens and methods. The specimens[3] used for study are:

1. Massive pale-green talc showing distinct foliation (Funato mine, Wakayama Pref., Japan).
2. Whitish fibrous talc transforming topotactically from tremolite (locality as above).
3. Massive pale-green talc with foliation (Nishi-Sonogi Peninsula, Nagasaki Pref., Japan).
4. Massive pale-green talc (Tyrol, Austria).
5. Massive pale-brown talc (Mautia Hill, Tanganyika).
6. Massive deep-green talc (Reading, Vermont, U.S.A.).

Thin sections were made, normal to the foliation for massive talc and normal to the elongation of fibrous talc, that is the *c*-axis of the associated tremolite. (The double chains of tremolite produced during the transformation of talc to tremolite are parallel to the sheet structure of talc (Stemple and Brindley, 1960).) Thin foils were then prepared from these sections by ion-beam etching and coated with carbon for examination in the electron microscope.

A thin foil of muscovite (Ishikawa pegmatite, Fukushima Prefecture, Japan), having a monoclinic two-layer structure, was prepared by the same method, and the electron diffraction pattern and lattice image were observed for comparison with talc.

All photographs shown in this paper were taken by the JEM 1000 kV electron microscope.

Results. Fig. 1A and 1B show the electron diffraction pattern and the lattice image of the muscovite, whose c^*-axis is vertical on the photograph. The diffraction pattern is of the typical monoclinic two-layer structure of muscovite, though some weak forbidden reflections (00*l* with *l* odd) are seen in it. The lattice image is composed of a repetition of strong and weak linear contrast, and is well correlated with the diffraction pattern. Some stacking faults resulting in a local three-layer structure have been observed on some lattice images, though they are not seen on this photograph.

[3] Specimens 4, 5, and 6 were from the Harwood Mineral Collection, Department of Geology, University of Manchester, Nos. M453, M568, and M894 respectively.

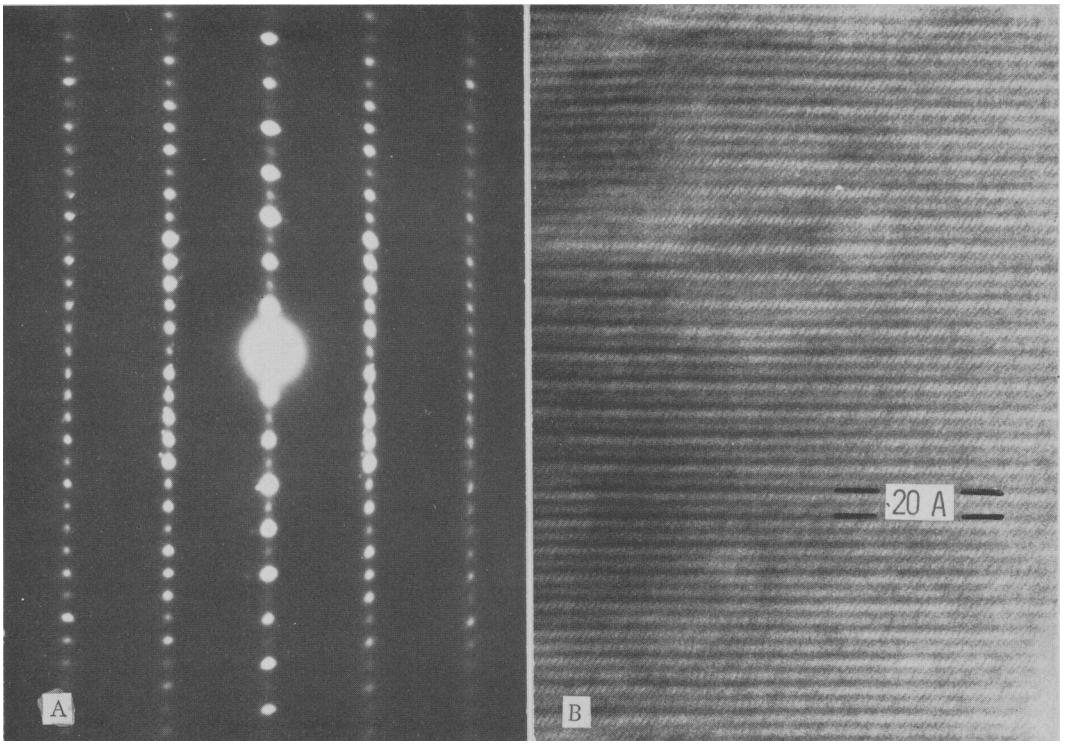


FIG. 1. Electron diffraction pattern and lattice image of muscovite from Ishikawa, Japan. The lattice image consists of alternate weak and strong lines, which correspond to the two-layer structure. The c^*-axes are vertical.

Fig. 2A and 2B show the electron diffraction pattern and the lattice image of massive talc from the Funato mine. The diffraction pattern, which is different from that of muscovite, corresponds to the one-layer triclinic (1 Tr) structure. The approximate lattice parameters obtained from electron diffraction patterns from three crystals of the Funato mine talc including a^*, b^*, and c^* axes are $a = 5{\cdot}23$, $b = 9{\cdot}15$, $c = 9{\cdot}50$ Å, $\alpha = 90{\cdot}5$, $\beta = 99{\cdot}0$, and $\gamma = 90{\cdot}8°$. The space group is assumed to be $C\bar{1}$. The lattice image consists of a single linear pattern whose interval is half that of muscovite, and is well correlated with the diffraction pattern.

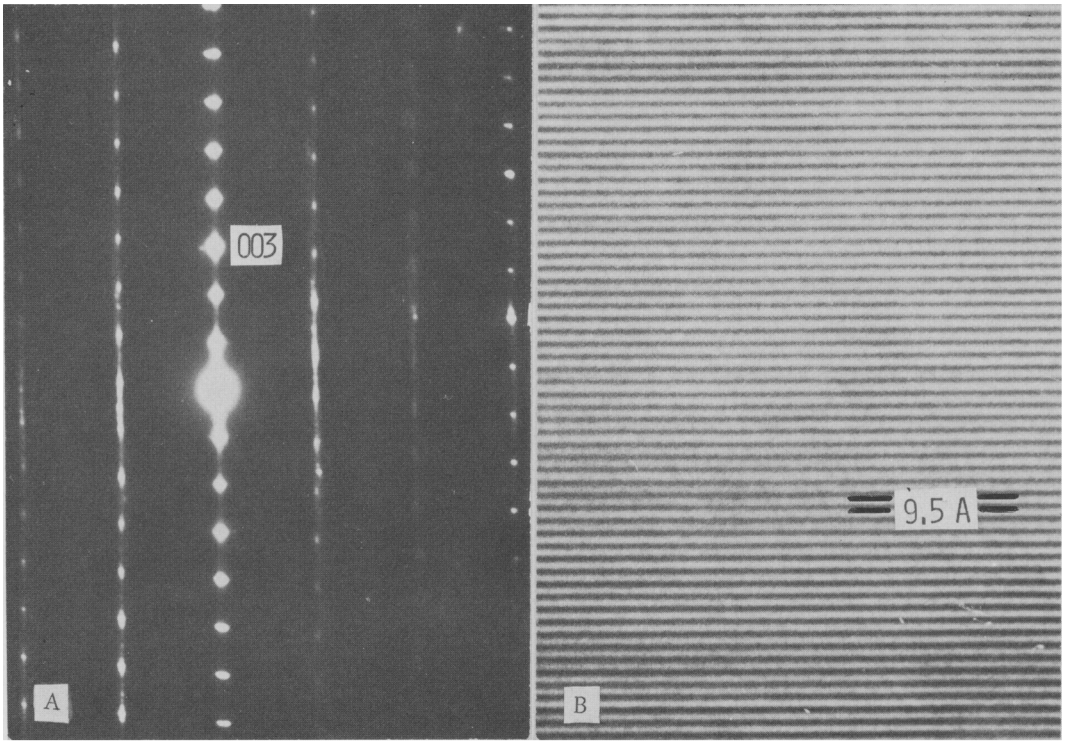
Figs. 3 and 4 show, for the talc from the Funato mine, two-dimensional and one-dimensional lattice images respectively, and they exhibit extremely fine twinning. Since the talc structure is pseudo-hexagonal, successive layers may be rotated by $n \times 60°$. This results in displacement of the c-axis and change of lattice plane orientation across a stacking fault, as shown in fig. 3. The tremolite from the same mine has been examined and shows fine polysynthetic twinning on (100). The associated talc and tremolite were found to be in a topotactic relationship (see Stemple and Brindley, 1960); their boundaries are distinct but are sometimes parallel to the twin plane and sometimes irregular.

Specimens 3, 4, 5, and 6 gave high resolution lattice images and electron diffraction patterns similar to those shown in fig. 2A and 2B, i.e. corresponding to a one-layered structure. Thus the two-layer structure was not found at all in the six specimens examined. All six specimens showed regions of ordered as well as disordered 1 Tr structure.

Discussion. Published work would imply that two polymorphs of talc (2M and 1 Tr) exist. The lattice images and diffraction patterns reported

FIG. 2 (*opposite, top*). Electron diffraction pattern and lattice image of talc from the Funato mine, Japan. The lattice corresponds to a one-layer structure. As the diffraction pattern was taken from a wide area including some stacking disorder, it shows streaks parallel to c^*. The c^*-axes are vertical.

FIG. 3 (*opposite, bottom*). Lattice image of talc from the Funato mine, Japan. The fine twinning is shown by the zigzag line drawn on the photograph. The c^*-axis is vertical.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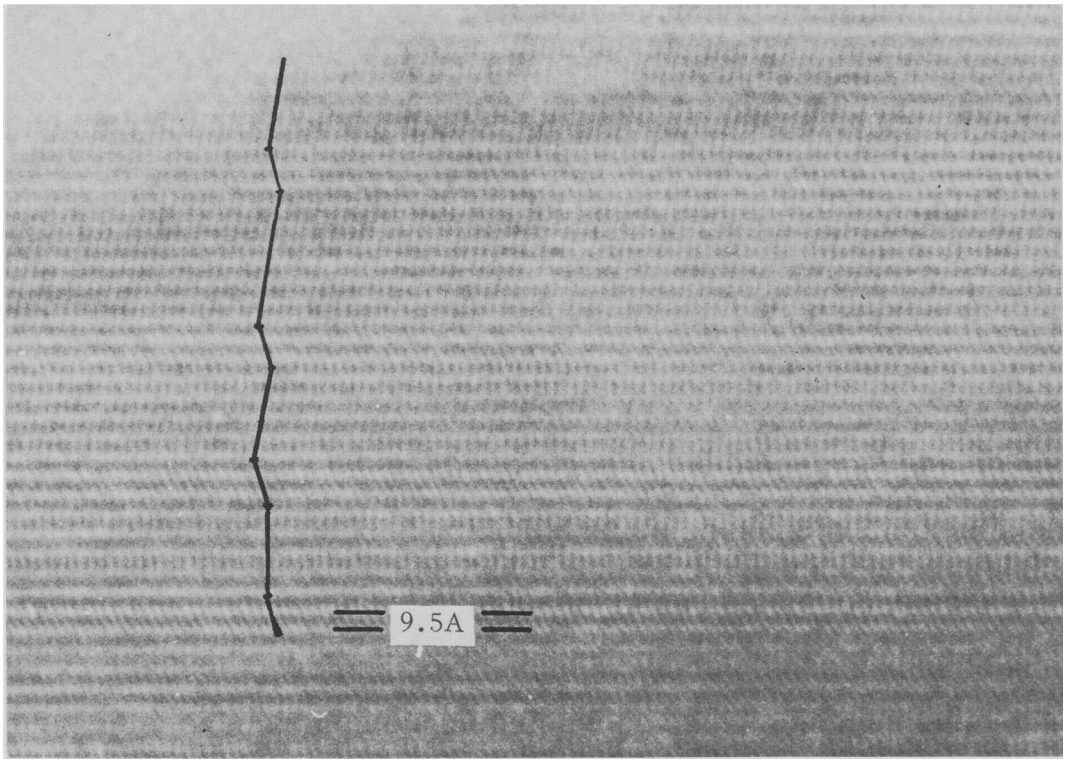
9.5A

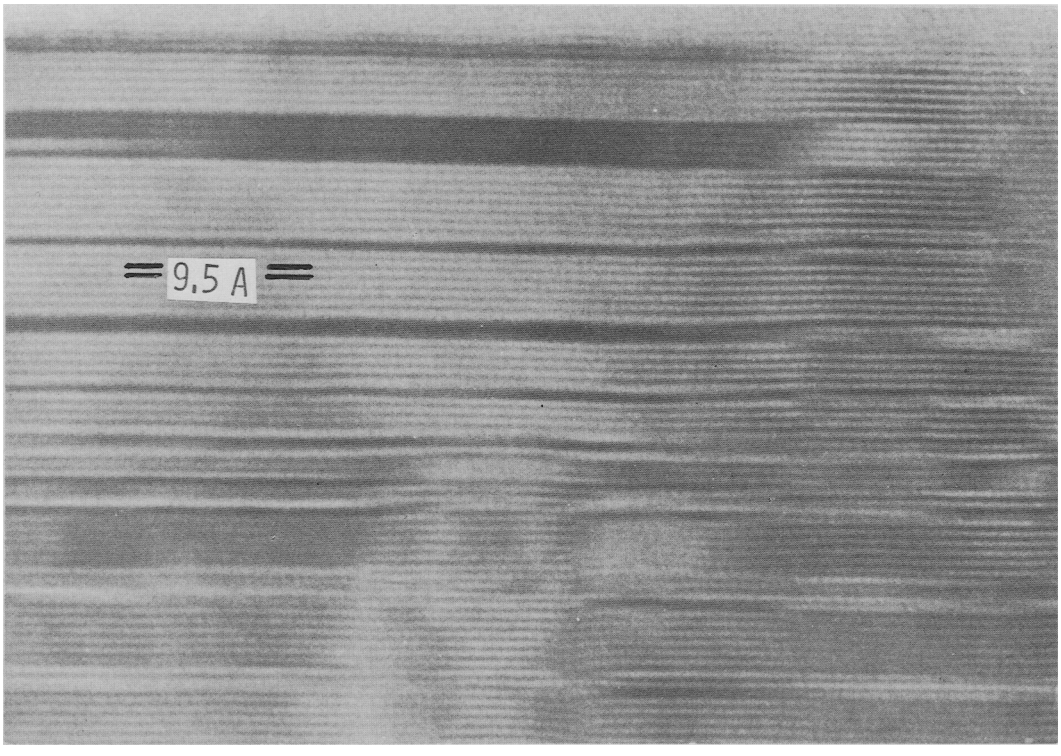

FIG. 4. Lattice image of talc from the Funato mine, Japan. The diffraction contrast changes between the finely twinned crystals. The c^*-axis is vertical.

here are completely different from those of muscovite with a 2M structure. Six specimens of talc from five localities show a one-layered structure without other polymorphs. Thus the present work supports by another method that by Ross *et al.* (1968), which suggested that there is as yet no real evidence for the existence of a 2M talc.

The geometrical differences between the 1 Tr and 2M cells are slight and the extra reflections for the 2M cell very weak so that a distinction would be very difficult by the X-ray powder diffraction method (e.g. Gruner, 1934; Stemple and Brindley, 1960). The presence of disordered stacking would lead to the streaking of reflections and this plus twinning might make the correct interpretation of single-crystal X-ray photographs also difficult (e.g. Hendricks, 1938).

It has been known from X-ray diffraction that the stacking of talc is very disordered. The present study confirms that the structure is disordered on the unit-cell scale.

The separation between fine twin lamellae in tremolite is from several hundred to several thousand Ångstroms and is larger than that of twins or stacking faults in talc. However, even talc transformed topotaxially from tremolite shows extremely fine twinning and stacking faults similar to primary massive talc. Thus the transformation process from tremolite to talc is not simple, and the crystal lattice must develop fine-scale twinning and stacking faults during the transformation.

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