Some Serpentine Minerals Occurring in Yamaguchi Prefecture, Japan

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with 4 Tables, 6 Text-figures, and 4 Plates

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ABSTRACT: Most part of serpentinite intercalated narrowly in the Sangun metamorphics distributing in the eastern area of Yamaguchi Prefecture is composed mainly of antigorite, chrysotile and lizardite with a small amount of carbonates, magnetite and so on. Of all, the serpentine minerals displaying the peculiarity in occurrence and texture have been studied in relation to their geneses and formation stage.

CONTENTS

I. Introduction
II. Outline of geology
III. Occurrence of the serpentine minerals
IV. Descriptive mineralogy
V. Consideration
References

I. INTRODUCTION

As has widely been known, some species of the serpentine minerals with tubulous, fibrous, rectangular or platy modifications caused from the respective characteristics of crystal structure are discriminated one from another. According to the electron-microscopical investigation carried out by ZUSSMAN, BRINDLEY and COMER (1957), their morphologies are disposed in Table 1. As the results obtained from the electron-microscopical observation for the specimen with splitting of the diffraction spots related to (0*k*0)

TABLE 1. MORPHOLOGICAL CLASSIFICATION OF SERPENTINE MINERALS

Means of observation	Chrysotile {clino-, ortho-, para-}	Lizardite	6-layer serpentine	Antigorite
Megascopically	fibrous, massive	massive, platy	massive, platy, fibrous	massive, platy fibrous
Electron-microscopically	tubulous, lath-shaped	platy	lath-shaped, platy	lath-shaped, platy

plane, YADA (1971) reported that the lattice fringes corresponding to (020) plane represent a sort of chrysotile oblique to the fiber axis in some degrees. On the basis of such an assumption that the polymorphs may be derived from discord in each periodicity of the octahedral and tetrahedral layers, the synthetic experiments of replacing a part of Mg ions with Al or Ni ions and a part of Si ions with Al or Ge ions were put into operation under the hydrothermal conditions in pursuit of the factors concerned with the polymorphs of serpentine (cf. ROY and ROY, 1954 and GILLERY, 1959), resulting in formation of the modifications other than antigorite and para-chrysotile. HESS, SMITH and DENGO (1952) pointed out the relation of formation of antigorite to metamorphism in their description of the mineral occurring in Caracas, Venezuela. KUNZE (1958) defined the ideal formula of antigorite to be $Mg_{5.626}$ $Si_4O_{10}(OH)_{7.294}$. PAGE (1968) indicated its characteristics with scarcity of MgO and H_2O as well as with abundance of SiO_2 in comparison with other modifications. IISHI and SAITO (1973) succeeded in an attempt of its synthesis through regulating the ratio MgO : SiO_2 and H_2O content under the hydrothermal condition.

On the other hand, the ultrabasic rocks are found exposed in various scale in the inner zone of the southwestern Japan with a trend controlled roughly by those of the country rocks. In contrast to that the latters composed of the non-metamorphic and metamorphic rocks have been detailedly investigated by some authors (cf. KOJIMA, 1947; NISHIMURA and NUREKI, 1966; HASHIMOTO, 1968; NISHIMURA, 1971a and b and so on), the formers have been not so much mineralogically researched excepting the cases including the chromite deposits in Hirose, Wakamatsu and Hinokami mines locating within the bordered zone of Hiroshima, Okayama and Tottori Prefectures. Considering these circumstances, the present work has been concerned specifically with the serpentine minerals in the serpentinite intercalated among the Sangun metamorphics distributing in the eastern area of Yamaguchi Prefecture.

II. OUTLINE OF GEOLOGY

The area is mostly composed of the Paleozoic formations and the late-Mesozoic rhyolite. According to the researches carried out by NISHIMURA and NUREKI (1966) and NISHIMURA (1971a and b), the Paleozoic metamorphics developing in this area are divided into the low-grade metamorphics named the Nishiki Group and the Sangun metamorphics called the Tsuno Group. The former is mainly composed of alternation of the arenaceous and argillaceous rocks associated with the acidic tuffs including chert, schalstein, limestone and sandy conglomerate in parts, while the latter is predominantly composed of the basic schist and arenaceous and argillaceous schist together with serpentinite, siliceus schist and calcareous schist. In addition, these metamorphic formations have been divided into two zones by NISHIMURA and NUREKI (1966) on the basis of presence or absence of pumpellyite. Geological map concerning the area in question is given in Fig. 1.

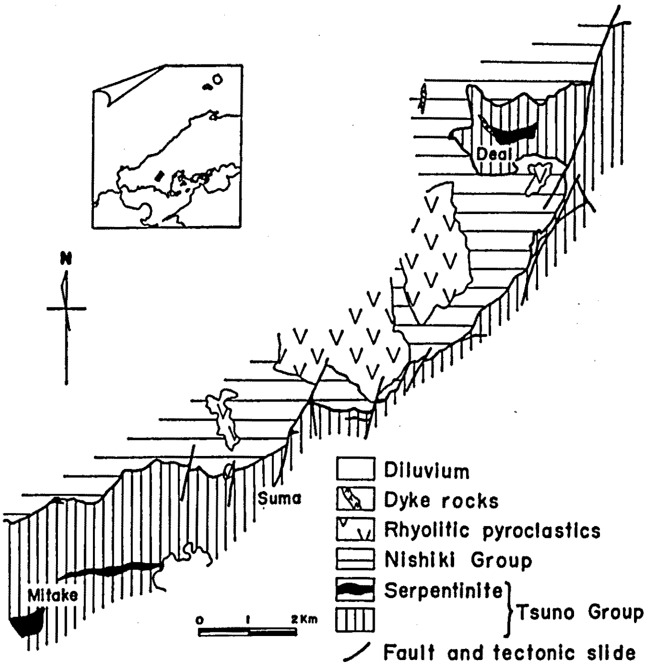


FIG. 1. Geological map of Nishiki-chō area. (after Y. NISHIMURA, 1971, but partially modified by the present author).

III. OCCURRENCE OF THE SERPENTINE MINERALS

The masses of serpentinite under consideration are found conformably with the surrounding Paleozoics and as the lenses with the width of 1~2 km in the Tsuno Group, of which those developing in the vicinity of Deai and Mitake contain merely a few amount of diopside as the relics and are too altered to be discerned.

A. Serpentinite in the surrounding of Deai

The mass concerned, about 1 km in width from east to west, is conformable with the basic schist and comes into contact with the dyke of quartz porphyry at the western end, bearing the anticlinal axis with the trend of WSW–ENE in the central part. As is observed in Plate 2–1, the mass is furthermore characterized with occurrence of the lenticular or nodular serpentinite, some or scores of cm in scale, enclosed in that with the fractured and schistose texture, of which the former is deep green to black in color, compact and hard in property but the latter is yellowish green to deep green in color and rich in the minute-scaled fracture. Observation under the microscope indicates that the serpentinite occurring as the mass or block is, as are recognizable in Plates 3–1 and 2, constructed of the lath-like texture of 100~1000 μ in size or of the aggregate of the fibrous texture of less than 60 μ in size, as is conspicuous in Plate 3–3, and associated with magnetite and a few amount of chromite at the scattered state or as the veins, while that found in the fractured zone without any amount of magnetite displays the irregularly waxy or the feather-like texture, as is confirmed in Plates 3–1 and 4. Two kinds of serpentinite are not distinctly demarcated with each other.

Besides, serpentine occurring as the veins of some cm in width looks like asbestos, white in color and silky in luster, and like the green-colored and waxy materials. Magnetite is not found associated in the former case but as is observed in Plate 3–5, contained along the definite direction in the latter case.

Along the fractures cutting across all of the serpentinites carbonate minerals such as calcite, dolomite and magnesite are observable.

B. Serpentinite in the neighborhood of Mitake

The mass in question, about 2 km in width from east to west, reveals the distribution conformable with the border between the argillaceous schist and the basic one and often the remarkable slide-planes but not so much fractures as is in the case of Deai, being compact and hard in property. As are confirmable in Plates 2–2 and 3–6, the fibrous serpentinite occurring as the vein of 10 cm in width is found at the western end of the former.

The brown-colored facies, extremely hard in property and some meters in width, is recognized predominant along the contact with the Tsuno Group but considered transitive to the latter, traversing the fine-grained quartz with undulatory extinction and the tiny-sized magnesite and dolomite, and magnetite and chromite in minor amount. Along the other contact zone, the schistose and greenish white-colored actinolites embracing the minute flakes of serpentine are found within the width of 1∼2 m.

In order to scrutinize the polymorphs of serpentine minerals occurring in various manners the ordinary procedures of X-ray and electron diffraction have been put into operation and identification through these methods has been based respectively on those shown by Whittaker and Zussman (1956) and by Zussman *et al.* (1957). The results of X-ray powder diffraction and the electron microscopic observation obtained for the representative specimens are presented in Fig. 2 and Plate 5 respectively. From difference appearing in the patterns antigorite and chrysotile are easily discriminated from each other whereas the polymorphs of chrysotile and lizardite are hardly discernible only by means of X-ray diffraction. The mutual relation of the polymorphs from different modes of occurrence is given in Table 2, wherein presence of antigorite, clino- and ortho-chrysotile and lizardite is confirmable but that of para- and 6-layer serpentine is not recognized. It seems significant that the latter two are quite rarely found and that generally antigorite is preponderant in the massive body and chrysotile in the fractured zone. The serpentinites developing as the veins in the mass of Deai are composed of clino- and ortho-chrysotiles and those distributing at Mitake merely of antigorite (numbered MT21–3). Since most of antigorite and the serpentine minerals derived from hydrothermal solution have previously been considered respectively the products resulted from serpentinization and chrysotiles, that possibility of production of the former has been confirmed by the present author is very important with respect to its natural genesis. As was alluded to already by Tomisaka and Kato (1963), noticeable is that the amount of antigorite is in proportion to deepness of its green color and that of chrysotile to the yellowish tint.

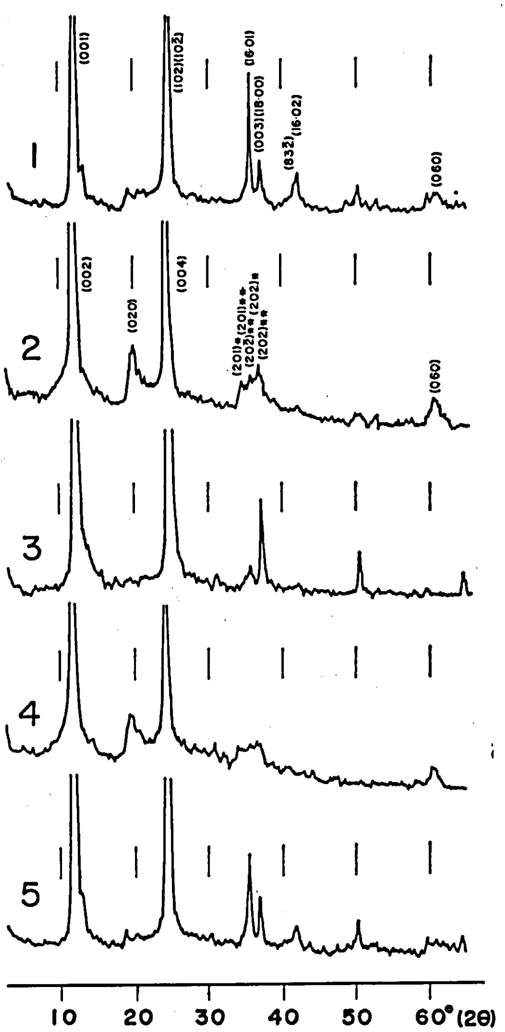


FIG. 2. X-ray powder diagrams of the serpentine minerals from various modes of occurrence.

1: Massive block (Specimen No. DA3–2).
2: Fractured zone (Specimen No. DA8–1).
3: Vein (Specimen No. MT21–3).
4: Vein (Specimen No. DA3–1).
5: Slickenside (Specimen No. MT14–1).

*: Reflection of ortho-chrysotile.
**: Reflection of clino-chrysotile.

TABLE 2. MODIFICATIONS OF THE SERPENTINE MINERALS IN VARIOUS MODES OF OCCURRENCE

Mode of occurrence	Specimen No.		Color	Modification of serpentine minerals*				other minerals**
				A	C	O	L	
massive block	DA	2–3	black	+ + +	+	+		mt, ms
		3–2	yellow-white	+ + +	+ +	+		dol
		4–1	deep green	+ + +	+		+	mt
		5–2	black	+ +	+ +			mt
		6–3	black	+ +	+	+	+	mt
		7–1	green	+ + +				mt
		9–2	pale green	+ + +				
		10–2	green	+ +	+	+		
		11–1	black	+ + +				mt

TABLE 2. (Continued)

Mode of occurrence	Specimen	No.	Color	Modification of serpentine minerals* A	C	O	L	other minerals**
massive block	MT	1–1	pale green	+++	+	+		mt
		2–1	green	+++				
		2–3	black	+++				mt
		3–1	green	+++				
		6–1	green	+++	+			
		8–2	pale green	+++	++			
		11–2	black	+++				mt
		15–1	black	+++				mt
		21–1	dark green	+++				
		22–1	black	+++	++	+		
		25–1	dark green	+++				mt, ms, t
		27–2	black	+++				mt
		28–1	brown-white	+++				
fractured zone	DA	1–3	deep green		+++			mt
		2–1	green		+++	+		
		3–3	green		+++	+		
		5–1	pale green		++	++	+	
		6–2	green		+++		+	
		8–1	green-yellow		+++	+		
		10–1	green		+++	+		
		15–1	green-yellow		+++	++		
	MT	2–2	yellow-green	+	+++			
		4–1	green	++	+			
		5–1	dark-green	++	+			mt
		6–3	green	++	++			
		7–1	green-white	+	+++			
		10–1	dark green	++	++			
		11–1	green		+++	+		
		17–1	dark green	+++				
		20–1	green	++	++			
		21–2	dark green	+++	+			
		22–2	deep green	++	++			dio, t
		26–1	deep green	++	+			
		27–1	yellow-green	+	++			
		34–1	dark green	+	++	+		cal, mt
vein	DA	1–1	pale green		+++			
		2–2	pale green		++	++		ms
		3–1	yellow-green		+++	++		
		6–1	yellow-green		+++	+		
	MT	21–3	deep green	+++				
slickenside	MT	3–2	green	+++	+	+		
		6–2	yellow-green		++	+++	+	
		14–1	green	+++	++	+		
		26–2	green	+++				

*: A: antigorite, C: clino-chrysotile, O: ortho-chrysotile, L: lizardite.
+++: dominant, ++: common, +: rare.

**: mt: magnetite, ms: magnesite, dol: dolomite, cal: calcite, t: talc, dio: diopside.

IV. Descriptive Mineralogy

A. Antigorite

Some modifications of the serpentine minerals other than para-chrysotile were synthesized by some investigators (cf. Roy and Roy, 1954; Gillery, 1959; Korytkova *et al.*, 1972; Ishi and Saito, 1973). Most of them were prepared on the basis of such an assumption that their fundamental structure be ascribable to discord in each periodicity of the octahedral and tetrahedral layers in the kaolinite structure, whereas synthesis of antigorite with the long-period lattice in the direction along *a* axis was not successful. According to the data obtained from electron diffraction by Zussman, Brindley and Comer (1957), the periodicity of antigorite along *a* axis was estimated about 33∼110 Å, though not continuously concentrated at 33.7, 35.8, 38.6, 41.2 and 43.0 Å. After Kunze (1961), preparation of antigorite bearing the periodicity of about 250 Å with interval of about 2.6 Å along *a* axis was theoretically introduced through regulation of the Mg: OH ratio in its chemical constituents.

In the case of determining the parameters of the crystal in question from the electron diffraction patterns the errors are probably caused from the calibration method and missetting of the specimen in the apparatus. In the experiment carried out by the present author that for the patterns obtained as the internal standard from thin film prepared through sublimation of Au has been confined in the range of 1% and the mean value of *b* parameter has been estimated 9.25 Å with the standard deviation of 1.5%. The related data are disposed in Table 3. Inspection of the results indicates that any of such a periodicity as was suggested by Zussman *et al.* (1957), Uyeda *et al.* (1957), Kunze (1961) and so on are not recognized, presence of the lattice with the periodicity of 37.6∼49.9 Å is discernible and the smaller the grain size of the crystal is, the shorter is its period and vice versa.

Table 3. *a* Parameters for Antigorite

No.	(Å)	Remarks
DA 7–1	37.6	fine-grained, very hard
DA 4–1	38.8	fine-grained, very hard
MT 14–1	44.2	fine-grained
MT 13–1	45.0	fine-grained, fibrous texture
MT 6–1	46.1	fine-grained, hard
DA 6–3	46.3	coarse-grained
MT 21–3	46.9	coarse-grained, fibrous vein, without any traces of magnetite
MT 2–1	47.3	mixture of coarse- and fine-grained
MT 28–1	47.9	mixture of coarse- and fine-grained
DA 2–3	48.3	coarse-grained
MT 15–1	49.1	aggrerate of needle crystals
MT 22–1	49.9	mixture of coarse- and fine-grained

B. Chrysotile

Chrysotile with elongation along *a* or *b* axis is morphologically distinguishable from the other serpentine minerals and found occurring in various modes: for instance, some are of the empty tube, of the rod-like one, as is clear in Plate 4–3, of the fibrous pipe filled in part with the solid matters, as in apparent in Plate 4–4, and of the short and thick lath-like one with the diameter of about 1700 Å, as is observable in Plate 4–5. As is conspicuous in Plate 4–6, the interior of these tubes or pipes is structurally obscure but considered to be of the fibrous texture as the result of scrutiny of the single crystal through electron diffraction, suggesting a sort of unit cell containing two layers with the odd value for l in $(20l)$ reflection and with some of $(13l)$ reflection found near (130). In consequence, this kind of chrysotile is, as was pointed out already by JAGODZINSKI and KUNZE (1954) and YADA (1971) considered to include the disorder caused by the stacking between the respective layers due to the step-wise growth. This fact was also confirmed by NAUMANN and DRESHER (1966) in the experiment concerning the nitrogen adsorption for the natural chrysotile. Tilting of the fringes, corresponding to (020) plane, from the fiber axis with 10° (2°~3° on an average) in angle was reported by YADA (1971) on the basis of the data obtained electron-microscopically for the specimens collected from various localities and those synthesized. The fiber structures revealing the spots for (020) and the splitted ones for (110) and (130) related to the former are, as is shown in Plate 4–7, ascertainable merely in clino-chrysotile.

Distribution of the outermost diameters, in maximum value, of chrysotile crystals collected from different modes of occurrence is plotted in Fig. 3. In spite of 260 Å given for its diameter theoretically by WHITTAKER (1957) it is common that the larger values are observable: e. g. about 1600 Å for the specimens occurring in the slickenside (MT6–2). The distributions of the outer diameter for chrysotiles occurring in the fractured zone (DA3–3) and in the asbestos-like veins (DA3–1) reveal a sharp mode concentrating near 500 Å, while those in the slickenside (MT6–2) and in the waxy vein (DA6–1) represent the wide variation. This may imply either the mechanism of their genesis or

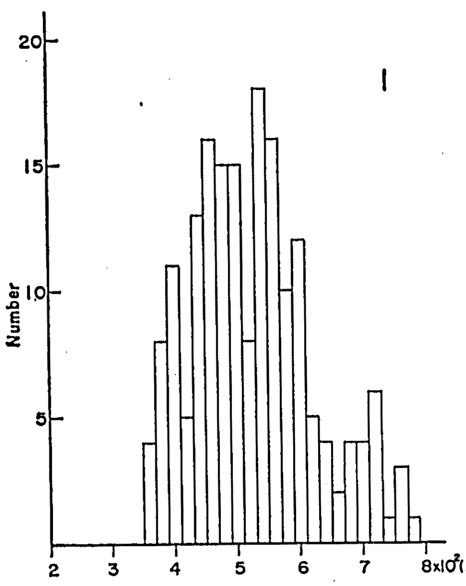


FIG. 3-1.

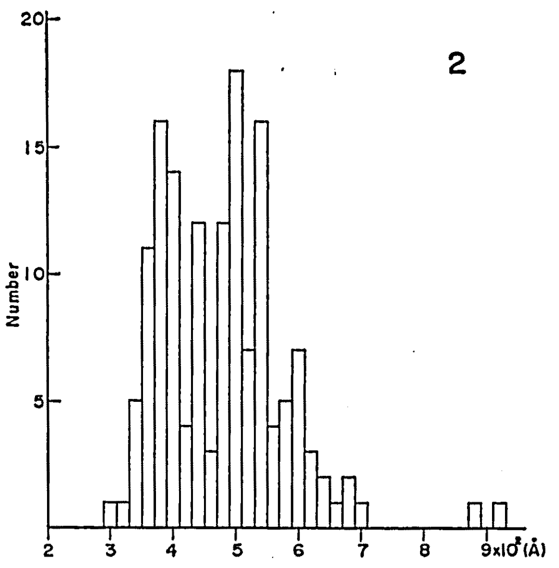


FIG. 3-2.

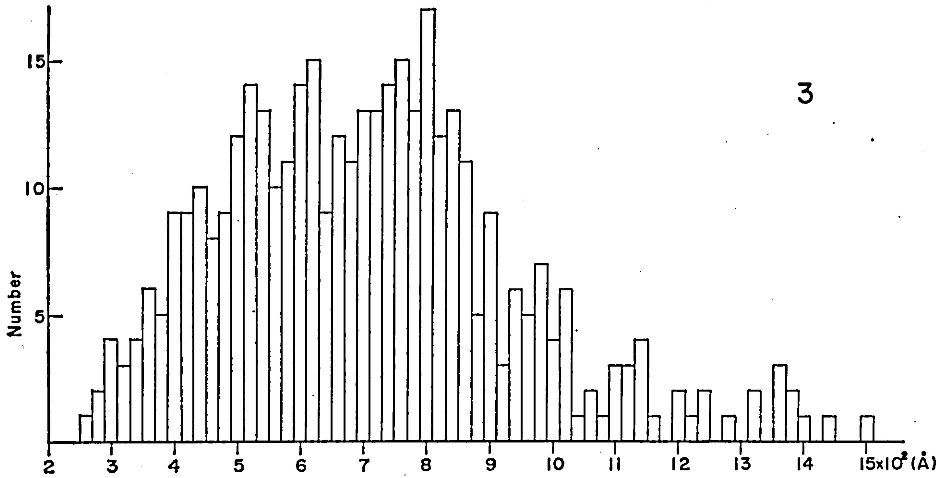


FIG. 3-3.

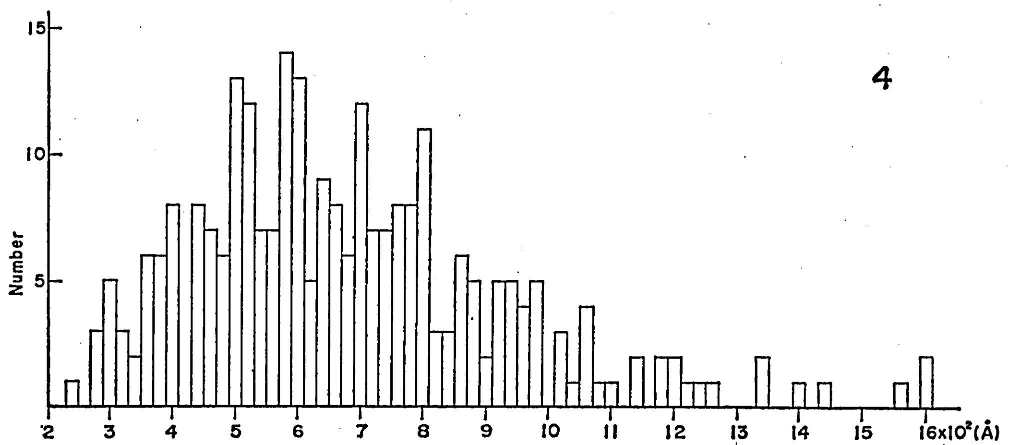


FIG. 3-4.

FIG. 3. Frequency distribution of the outermost diameter of chrysotile from various modes of occurrence.

1: Outermost diameter of chrysotile in the fractured zone (Specimen No. DA3-3).
2: That in the asbestos-like vein (Specimen No. DA3-1).
3: That in the waxy vein (Specimen No. DA6-1).
4: That collected from the slickenside (Specimen No. MT6-2).

difference in the conditions for their formation. According to the private communication from IISHI (1972), the specimens with various thickness have been prepared from the starting materials with the same composition through regulation of pH values in the media as the result of hydrothermal synthesis. In contrast to remarkable variation of the outer diameter, the values for the inner one are, in no relation to the former, kept almost constant in the range of about 30~60 Å.

DTA data for antigorite collected from the massive and vein-type serpentinite together with chrysotile in the fractured zone and the waxy vein are indicated in Fig. 4. The patterns of two specimens the former are nearly similar to each other and the large-scaled endotherms signifying the complicated reactions pointed out by SAITO *et al.* (1972) are discernible at 600~800°C, while the maximum endotherms of chrysotile are observed at 650°C in the case of DA8–1 and 660°C in the case of DA6–1. The exotherms concerned with transformation to olivine and pyroxene after dehydration of the structural water are however recognizable almost similarly at 820~830°C for antigorite and chrysotile.

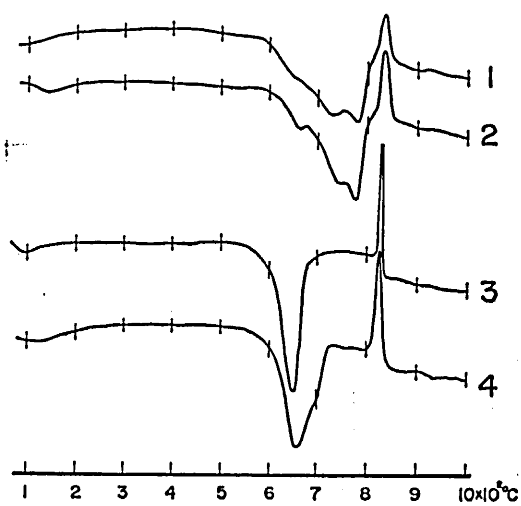
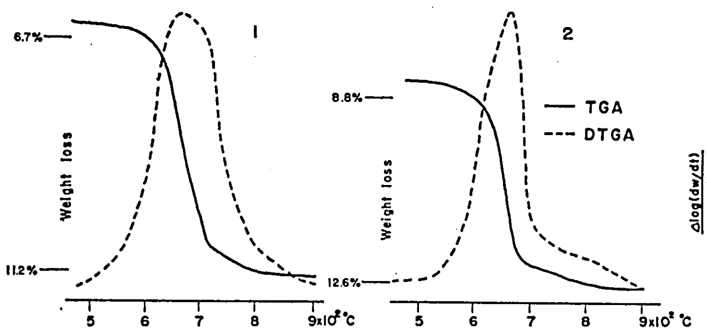


FIG. 4. DTA data for antigorite and chrysotile.
1: Fibrous antigorite occurring as the vein (Specimen No. MT21–3).
2: Fine-grained massive antigorite (Specimen No. DA7–1).
3: Chrysotile in the fractured zone (Specimen No. DA8–1).
4: Chrysotile in the waxy vein (Specimen No. DA6–1).

The ratio of width of the endothermal peak to its height in the case of chrysotile sampled in the waxy vein (DA6–1) is larger than that in the case of the specimen collected in the fractured zone. This is, as was enlightened by CARTHEW (1955) in the experiment concerning kaolinite, probably ascribable to the grain size and crystallinity of the specimens. The results obtained from TGA and DTGA are illustrated in Fig. 5 and the kinetics of dehydration in Fig. 6. The values for activation energy of the specimens collected from each part at dehydrated state which have been estimated according to the method given by FREEMAN and CARROLL (1958) are given in Table 4. Those for chrysotile in the waxy vein and in the fractured zone are evaluated respectively 32.3 Kcal/mol. and 30.2 Kcal/mol., whereas that proposed by SHIMODA (1967) is 36.9 Kcal/mol..



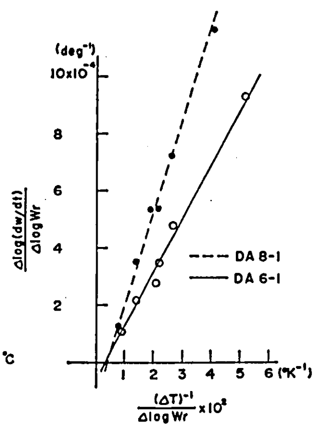


Fig. 5. TGA and DTGA data for chrysotile.

1: Lath-shaped chrysotile in the waxy vein (Specimen No. DA6-1).

2: Tubular-shaped chrysotile in the fractured zone (Specimen No. DA8-1).

Fig. 6. Kinetics of dehydration.

$W_r = w_c - w$.

w_c: Weight loss at completion of reaction.

w : Total weight loss up to time t.

Table 4. Kinetic Data for the Dehydration of Chrysotile

Specimen		T	n	E
fractured zone	(DA 8-1)	650°C	0.4	30.2
waxy vein	(DA 6-1)	660°C	0.3	32.3
Sanbagawa		630°C	0.4	36.9*

T : temperature on the DTA curve.

n : order of reaction.

E : activation energy (Kcal/mole).

* : cited from the data of Shimoda (1967).

C. Magnetite and Chromite

The former with the cell constant of 8.392 Å in the mean value is found scattered as the veinlets and the dusty grains comprised in the mass or the waxy vein of serpentinite often solitarily or in association with the latter. As is discerned in Plate 4–2, the hypidiomorphic crystals of the latter are embraced within those of the former. Inspection under the microscope reveals the former with the fluidal texture of the serpentinite, that assumed to have been separated from the originally same individual, that filled with antigorite running along its cracks and its occurrence in the sedimentary rocks around the serpentinite frequently in association with hematite. In the study of chromites from Rodiani in Greece, Augustithis (1960) stated that the reaction rims formed along their margin are considered the alteration product derived from the later serpentinization. As the result obtained through EPMA concerning the minerals same as those mentioned above Panagos and Ottemann (1966) set forth that their cores are more abundant in Al and Mg but less in Cr and Fe in comparison with the marginal parts.

V. CONSIDERATION

The serpentine minerals composing the serpentinite cropped out as the small-scaled lenses intercalated in the Tsuno Group of the Sangun metamorphics distributing in the inner zone of the southwestern Japan are constituted mainly of antigorite, clino- and ortho-chrysotile and a few amount of lizardite. Of all, antigorite displays various modes of occurrence in the massive serpentinite and is also found as the fibrous veins without any traces of magnetite. As for its genesis HESS *et al.* (1952) alluded to necessity of the sheared field and of competent condition of temperature, although the facts mentioned above are considered to suggest that shearing is not always requisite for its formation. On the other hand, chrysotile is the main constituent of the serpentinite with the well-developed fractures, whereas the border between the massive part abundant in antigorite and the fractures including chrysotile is generally obscure and under the microscope the latter is found impregnated in the former or the assemblage of antigorite plus magnetite is, as a sort of the remainder from hybridization, enclosed in the fractured zone. It is difficult to deduce the compositions and structures of the original rocks from the serpentinite suffered from severe serpentinization but the opinion declared by HESS *et al.* (1952) in connection with ascription of chrysotile to olivine and that of antigorite to enstatite is not easily acceptable, since different kinds of serpentinization taken place under various conditions are rather to be taken into account and it seems possible to infer the prior production of antigorite and magnetite from certain species of the primary minerals in the regional serpentinization and the subsequent formation of chrysotile in the local and incomplete serpentinization at the later stage. Any evidences for replacement of antigorite with chrysotile have however been found nowhere in the area under consideration. MIYASHIRO (1966) proposed such a dualistic theory that the minerals constituting the ultrabasic rocks recognized in many of the regionally metamorphosed terrains are not of primary origin and the emplacement of the ultrabasic rocks is considered mostly earlier than the regional metamorphism. Moreover, PAGE (1967) brought out that the antigoritic serpentinites generally occur in the metamorphic rocks with the grade of metamorphism higher than that of the green schist facies, while the lizardite-chrysotile serpentinites are found in the rocks with low grade of metamorphism. According to the study of WENNER and TAYLOR (1971) on the basis of the ratio of oxygen isotopes, the formation temperature of antigorite is estimated 220°C～460°C and that of chrysotile 85°C～185°C, while it has become clear from the unpublished data obtained by the present author that the physical, chemical and thermal properties of these minerlas are different from each other. In relation to these facts, it seems possible to deduce that antigorite included in the serpentinite intercalated conformably within the Tsuno Group corresponding to the intermediate metamorphic facies between the glaucophane schist and green schist might have been produced at the main stage of the Sangun metamorphism.

Fine-grained assemblages of magnesite and dolomite found in the contact zone between the crystalline schist and Mitake serpentinite are considered to have not been produced as the vein formed at the latest stage but derived through the main process of serpentinization. Assuming that the primary minerals present before the process were simply the members of olivine, possibility of serpentinization simplified by ONUKI (1963) as the chemical reaction:

$$\underset{\text{olivine}}{2Mg_{1.8}Fe_{0.2}SiO_4} + \underset{\text{water}}{2H_2O} \doteqdot \underset{\text{serpentine}}{H_4Mg_{2.85}Fe_{0.15}Si_2O_9} + \underset{\text{magnetite}}{0.08Fe_3O_4} + \underset{\text{removed in solution}}{0.75MgO}$$

may be proved, because paragenesis of antigorite with magnetite in the serpentinite and formation of the carbonates derived probably from excess of MgO along the margin of the serpentinite mass are observed in many cases. Increase of 30% in volume, caused by application of the equation mentioned above, has however been proved nowhere in field.

On the other hand, it has become evident that periodicity in the direction of *a* axis of antigorite is estimated 37.6～49.9 Å by means of the electron diffraction and proportional to the grain size, although the relation in question is crystallochemically or mineralogically still not justifiable. As for abundance in the nature, it seems common that as was already pointed out by WHITTAKER and ZUSSMAN (1956), clino-chrysotile are more predominant than ortho-chrysotile and happen to occur solitarily.

The outermost diameter of chrysotile collected in the terrain surveyed is generally larger than those shown so far by many investigators: e.g. 340 Å by KALOUSEK and MUTTART (1957), 240 Å by WHITTAKER (1958), 300～400 Å by YANG (1961), 275±26 Å and 375±76 Å by NAUMANN and DRESHER (1966), 220～270 Å by YADA (1971) and about 2000 Å for the splintery clino-chrysotile by ZUSSMAN *et al.* (1957) are the representatives given previously. It may be that the diameters of the tubular chrysotiles are related closely to the conditions of crystallization controlled by the properties of solution on one hand and as were dealt with theoretically by JAGODZINSKI and KUNZE (1954) concerning the models and proved actually by YADA (1971), to the rolling manners of the layers constructing the tubes on the other.

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EXPLANATION OF PLATE II

1. Occurrence of serpentine as the mass or block and as the fractured zone around the former (at Deai).
2. Fibrous vein of antigorite, about 10 cm in width (at Mitake).

EXPLANATION OF PLATE III

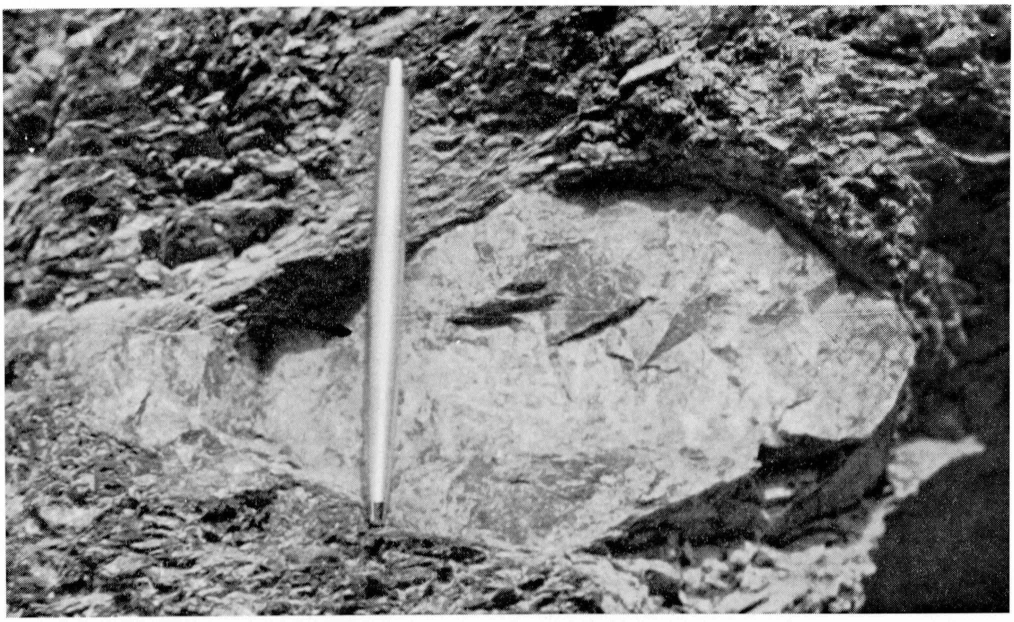
1. Antigorite and magnetite in the mass of serpentinite and chrysotile in the fractured zone (Specimen No. DA3). With crossed nicols. a: antigorite, c: chrysotile.
2. The same section as above. With parallel nicols. m: magnetite.
3. Fine-grained, fibrous antigorite (Specimen No. DA7). With crossed nicols.
4. Magnetite concentrated in the contact zone between the massive serpentinite and the fractured zone around the former (Specimen No. DA5). With crossed nicols. a: antigorite, m: magnetite, c: chrysotile.
5. Chrysotile occurring as the waxy vein in association with magnetite arranged along the fiber axis of the former (Specimen No. DA6). With crossed nicols. a: antigorite, m: magnetite, c: chrysotile.
6. Antigorite produced as the vein of fibrous texture (Specimen No. MT21). With crossed nicols. v.a: vein of antigorite.

EXPLANATION OF PLATE IV

1. Carbonate rock observed between the Mitake serpentinite and Tsuno Group (Specimen No. MT12). With crossed nicols. f.c: fine-grained carbonate minerals (dolomite and magnesite), q: quartz, m: magnetite, v.c: vein of carbonate minerals, v.q: vein of quartz.
2. Magnetite embracing the hypidiomorphic crystal of chromite (Specimen No. MT8). With parallel nicols. Cr: chromite, m: magnetite.
3. Rod-like chrysotile (Specimen No. DA2–1)
4. Chrysotile filled partly with the amorphous substances in the center of the fiber (Specimen No. DA8–1).
5. Chrysotile occurring as the laths and the tubes (Specimen No. DA6–1).
6. Electron diffraction pattern of the lath-like chrysotile (Specimen No. DA6–1).
7. Electron diffraction pattern of clino-chrysotile with splitting of (020) and (130) spots (Specimen No. DA8–1).

EXPLANATION OF PLATE V

1a. The flakes of antigorite in the massive serpentinite (Specimen No. DA7–1).
1b. Electron diffraction pattern of its single crystal.
2a. The tubes of chrysotile in the fractured zone (Specimen No. DA2–1).
2b. Electron diffraction pattern of clino-chrysotile with the splitted spots related to *k*.
3a. Those of chrysotile in the silky vein (Specimen No. DA3–1).
3b. Electron diffraction pattern of ortho-chrysotile in the same sample.
4a. Lizardite and the lath-shaped or tubular chrysotile (Specimen No. MT6–2).
4b. Electron diffraction pattern of the single crystal of lizardite.



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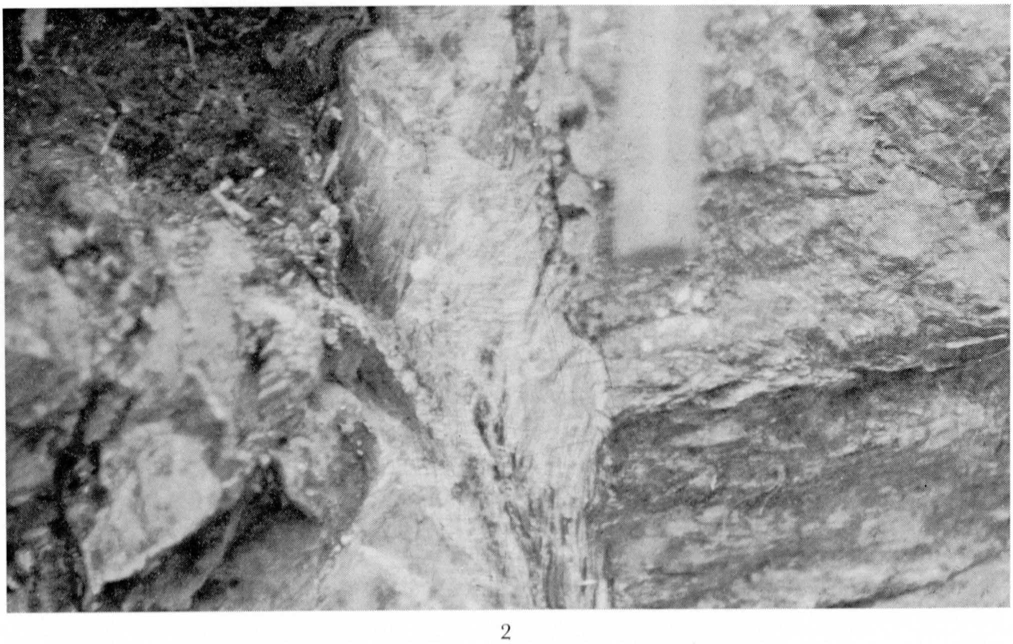

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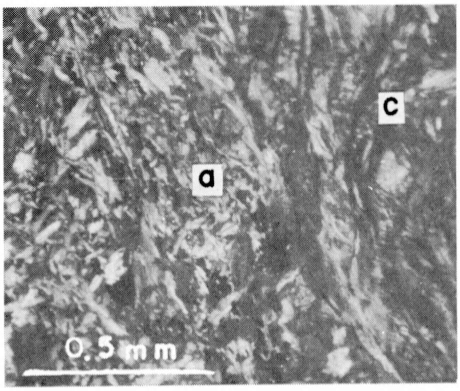

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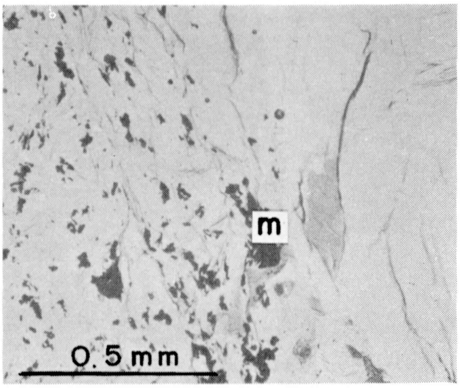

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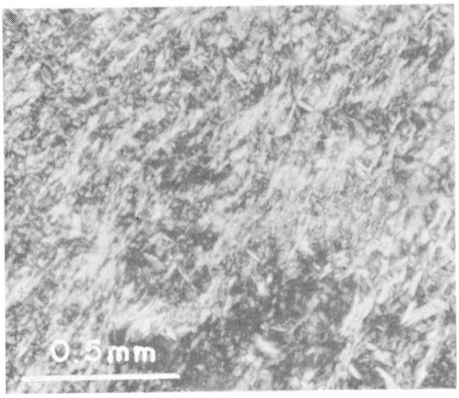

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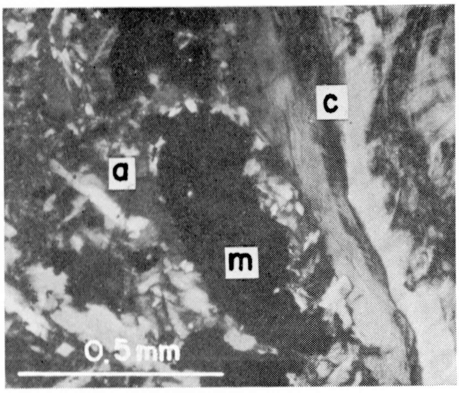

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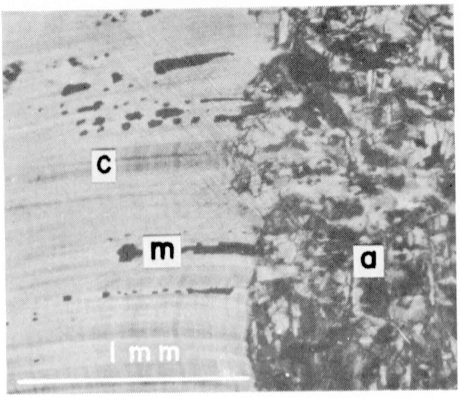

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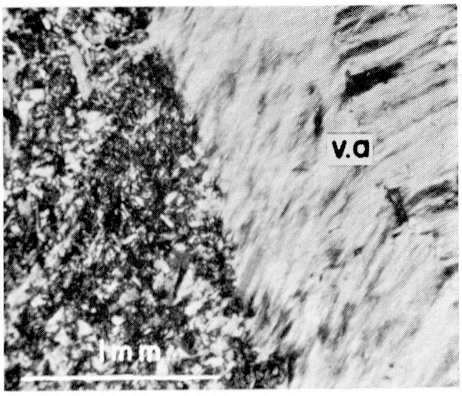

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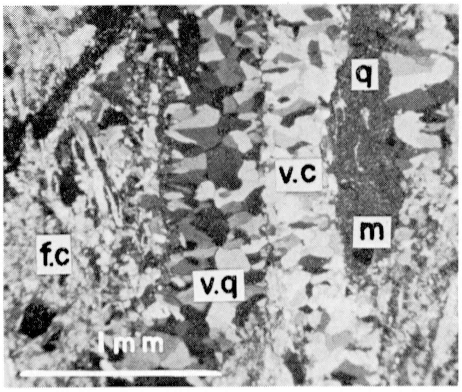

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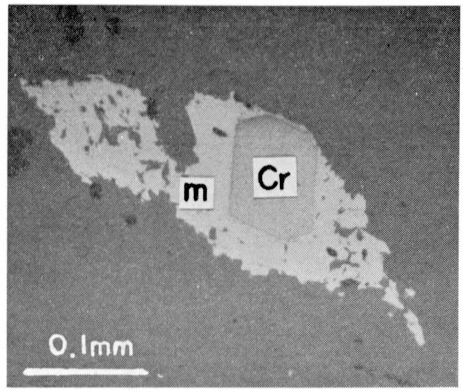

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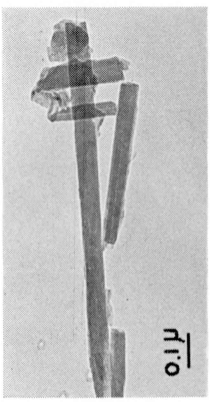

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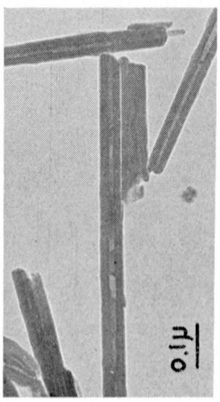

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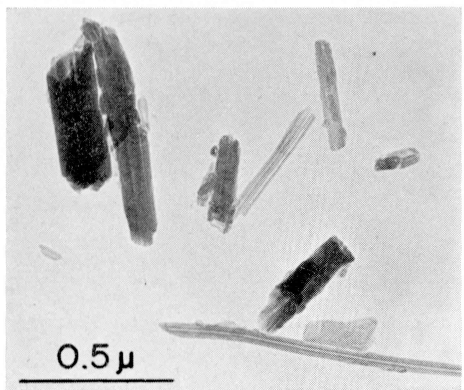

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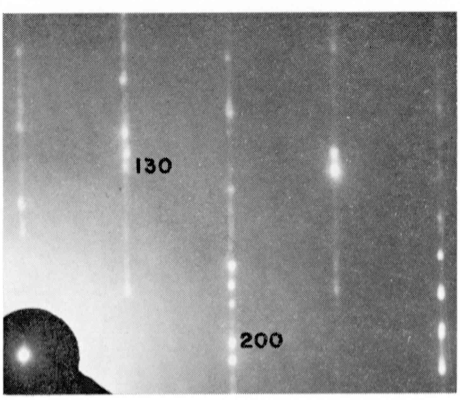

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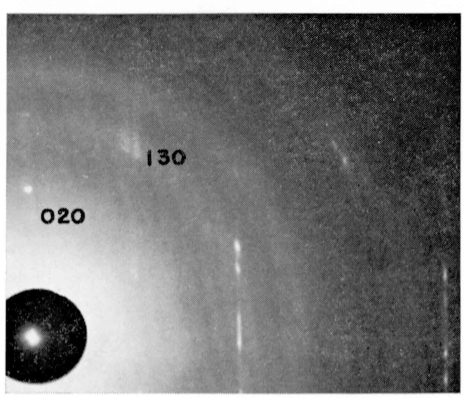

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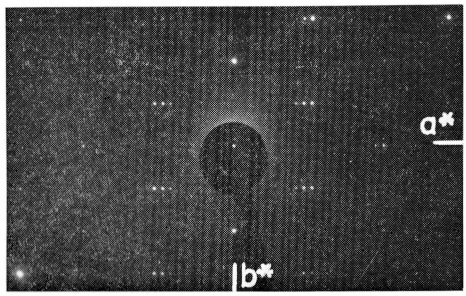

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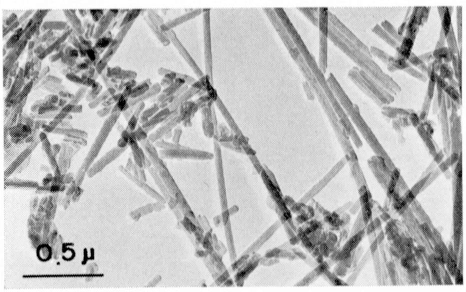

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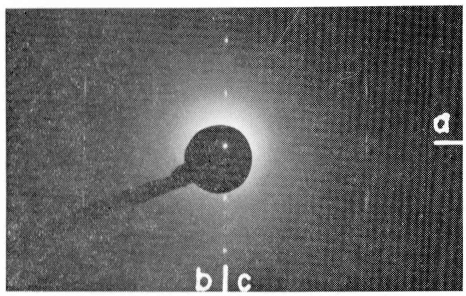

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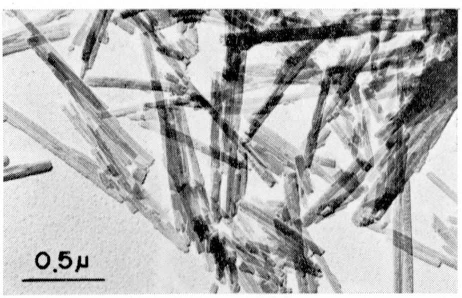

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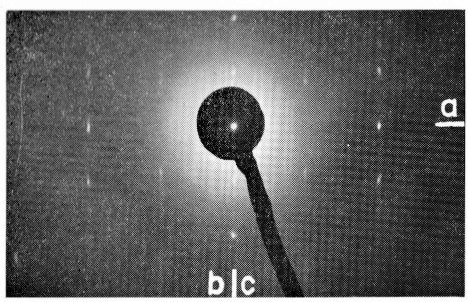

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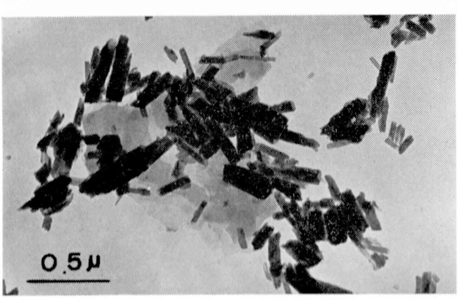

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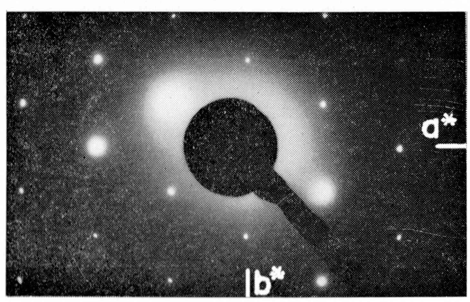

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