CHLORITOID FROM RAWLINSVILLE, LANCASTER COUNTY, PENNSYLVANIA

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ABSTRACT

Chloritoid occurs in a mica schist near Rawlinsville, Pa. Measurements on the universal stage showed that most chloritoid flakes from this area are monoclinic with $X=b$, but some are triclinic. Polysynthetic twinning on (001), which is also the direction of cleavage, is common. The new twinning axes, [210], [120] and [310], in addition to the known axes, [110] and [130], were measured.

A chloritoid from South Carolina also shows both monoclinic and triclinic symmetry, the monoclinic variety having $Y=b$.

The indices of refraction of chloritoid from Lancaster County are as follows: $\alpha=1.719$, $\beta=1.721$ and $\gamma=1.725$, all ± 0.001. The formula calculated for the Lancaster County material on the basis of a chemical analysis is: $(Fe'', Mn, Mg)_{1.9}(Fe''', Al)_{2.2}(Al_{1.9}Si_{2.1})O_{10.4}(OH)_{3.7}$, in which $Fe'':Mn:Mg=1.37:0.07:0.48$, and $Fe''':Al=0.2:2.0$.

INTRODUCTION

The descriptions of the optical properties of the chloritoids found in the literature are rather controversial. There is considerable doubt whether this mineral shows varying optic orientations when monoclinic and whether or not a triclinic form exists.

The present writer collected a hand specimen of chloritoid schist near Rawlinsville, Lancaster County, Pa., in December 1939. The chloritoid was studied optically and chemically in the Institute of Geology at the University of Helsinki during the following winter. A study of the twinning was undertaken later. Careful measurements of this mineral on the universal stage and of a chloritoid from Chesterfield County, S. C., seem to suggest that the mineral can be either monoclinic with X or $Y=b$, or triclinic.

X-ray study of the recorded triclinic forms would be necessary to prove the true symmetry.

OCCURRENCE

Chloritoid occurs as dark aggregates in a pinkish white schist at a road cut a mile east of Rawlinsville in southern Lancaster County, Pa. (the locality is the same as mentioned on p. 121 in Cloos and Hietanen, 1941). The specimen used for investigation is medium grained and contains abundant chloritoid. The chloritoid flakes range from 2 to 3 mm. in diameter and show the usual radiating arrangement. Chloritoids from the schists in the Appalachian area have been described from Dutchess County, N. Y., by Barth and Balk (1934) and from the Deep River

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region in North Carolina by Stuckey (1926). Milne (1949) recently made a detailed study including x-ray determinations, of a chloritoid from Megantic County, Quebec.

THE CHLORITOID SCHIST

The muscovite-chlorite schist in which the chloritoid occurs as newly crystallized aggregates is fine grained and was strongly deformed prior to the crystallization of the chloritoid. A minute, intense wrinkling of the early muscovite flakes and the fracture cleavage are easily visible under the microscope (Figs. 1 and 2). Some newly crystallized muscovite flakes ranging from ½ to 1 mm. in length grow across the older wrinkled ones. Chlorite also is found in two generations; the older small flakes occur with the early muscovite, whereas the later larger flakes are grouped around the chloritoids.

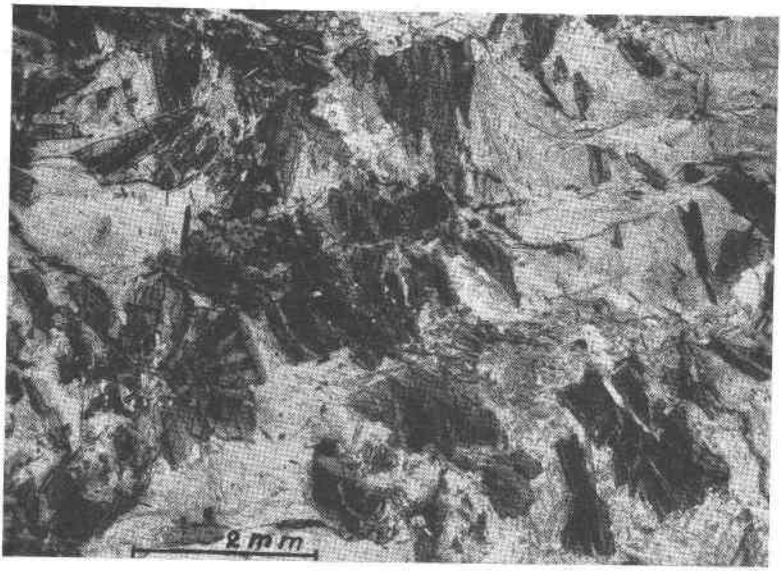

FIG. 1. Chloritoid schist near Rawlinsville, Lancaster County, Pennsylvania. The dark mineral is chloritoid.

Tiny twinned grains and prisms of rutile occur as inclusions throughout the rock. Their orientation indicates them to be early: they follow the wrinkled texture shown by the muscovite, even when they are included in chloritoid. Larger prisms are later: they follow shear planes and irregular surfaces which probably represent healed cracks. As a rule the late muscovite and chlorite are free of the rutile inclusions. Thus the sequence of crystallization was as follows:

First stage: rutile I, muscovite I, chlorite I.
Second stage: chloritoid, muscovite II, chlorite II, rutile II.

The amount of quartz in the schist varies considerably even in the hand specimen. It may range from about 10 to 60 per cent. A few small albite grains occur as an additional constituent. The chemical and mineralogical composition of the chloritoid schist is shown in Table 1. The amounts of K_2O and Na_2O are small and the amount of FeO is large compared with the amounts shown by analyses of surrounding biotite schist and muscovite-chlorite schists (see tables of analyses in Cloos and Hietanen, 1941). The crystallization of chloritoid instead of chlorite is mainly due to this difference in the chemical composition.

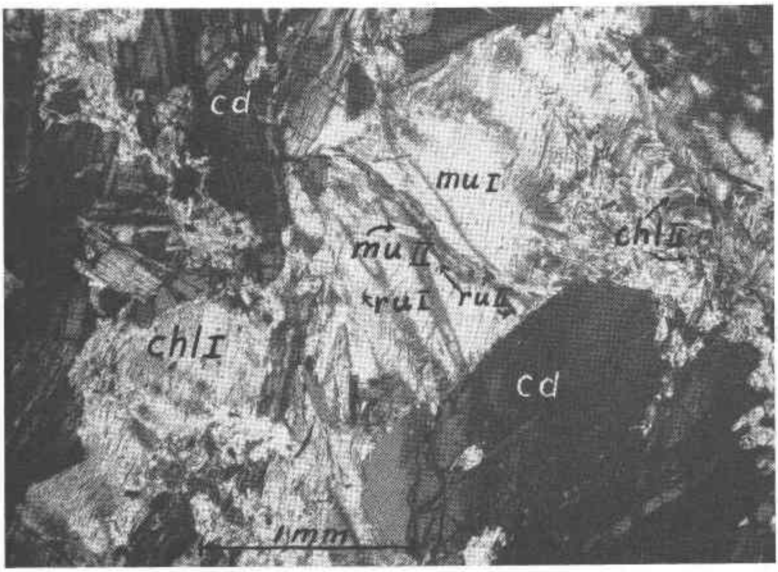

Fig. 2. Twinning in chloritoid (cd) from Lancaster County. Second generation muscovite (mu II), chlorite (chl II), and rutile (ru II) transect the older wrinkled muscovite (mu I) and chlorite (chl I).

Chloritoid is usually considered to be a stress mineral and appeared to be so in other nearby localities in Lancaster County and the Norristown quadrangle, Pa. (Cloos and Hietanen, 1941, pp. 122, 123, 152, and Table 15). At Rawlinsville, however, the largest flakes occur next to the quartz veins and they are clearly crystallized after the shearing movements, which caused the microfolding of the micas. Probably the chloritoid at this locality crystallized also at an earlier stage, as it did in the

TABLE 1. CHEMICAL AND MINERALOGICAL COMPOSITION OF THE MUSCOVITE-CHLORITE-CHLORITOID SCHIST AT RAWLINSVILLE, LANCASTER COUNTY, PA.

Analyzed by Miss Elsa Ståhlberg

SiO_2	70.12	quartz	56
TiO_2	0.67	chloritoid	26
Al_2O_3	15.48	muscovite	11
Fe_2O_3	0.68	chlorite	5
FeO	5.98	albite	1
MnO	0.23	rutile	1
MgO	2.17		
CaO	0.16		100
Na_2O	0.33		
K_2O	0.99		
P_2O_5	0.00		
H_2O+	2.88		
H_2O-	0.32		
	100.01		

surrounding schists (Cloos and Hietanen, 1941, p. 119) and recrystallized later as large flakes under the influence of the watery solutions, which deposited the vein quartz. The occurrence is comparable with the one described by Friedlaender (1930) from Crestlianderstobel, Switzerland, where large recrystallized chloritoid flakes occur in later quartz veins which show only minor traces of strain. Friedlaender, in accord with Riecke (1895), assumes that the chloritoid has a greater solubility under stress. It therefore might go into solution under stress and is redeposited in places of less stress. Some other stress minerals, as for instance kyanite, are found in quartz veins which were deposited toward the end of or after the shearing movements (Hietanen, 1938, pp. 90–91). Therefore, stress does not seem to be essential for the formation of these minerals, but unlike the anti-stress minerals, they are stable also under stress. Chloritoid, like many other minerals which may occur as porphyroblasts, seems to stay mobile until the late stages of recrystallization.

CHLORITOID

General appearance. The chloritoid flakes grow across the old structure, which is somewhat disturbed in the immediate surroundings of the flakes. A part of each flake, commonly a part of the rim, is free of relict rutile inclusions. The flakes show one good cleavage, poor parting, and polysynthetic twinning.

Optical properties. The pleochroism of the chloritoid from Lancaster County is similar to that described in the literature for chloritoids in general (Winchell, 1933): X = green, Y = blue, Z = colorless. Absorption is thus $Y>X>Z$. Z makes an angle of 13° with the pole of (001). The indices of refraction determined in immersion liquids are as follows:

$$\alpha=1.719\pm0.001$$
$$\beta=1.721\pm0.001$$
$$\gamma=1.725\pm0.001$$

The optic angle was measured by universal stage, $2V=56°\pm2°$. These properties are closest to those determined by Milne for the chloritoid from Megantic County except for lower birefringence and somewhat smaller optic angle. The birefringence is $\gamma-\alpha=0.006$, the same as found by Barth and Balk (1934) for the chloritoid from Dutchess County.

Twinning and optic orientation of chloritoid. The composition face of the twinning lamellae is parallel to the basal cleavage. Two sets of twinning lamellae show an inclined extinction. The optic orientation of several flakes showing distinct lamellae were measured and the results are shown in Figs. 3, 4, and 5. Figures 3 and 4 show monoclinic symmetry with $X=b$, but Fig. 5 shows triclinic symmetry.

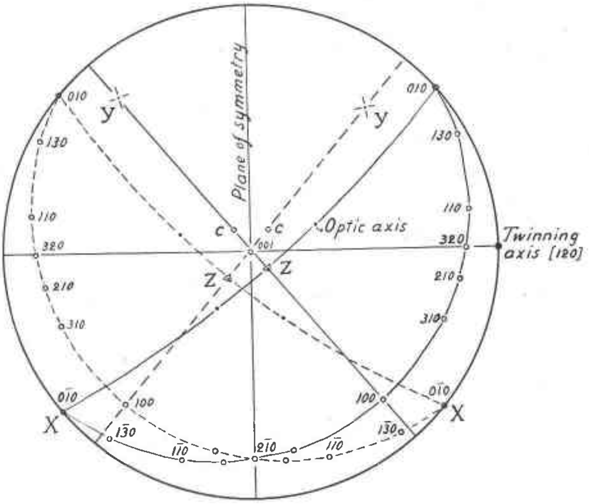

FIG. 3. Optic orientation of the two twinned lamellae in a chloritoid from Lancaster County. The twinning axis is the zone-axis [120]. $X=b$, $c=c$ axis.

If the cell dimensions measured by Milne (1949) are assumed to hold for the monoclinic varieties, the twinning law shown in Fig. 3 is as follows: The composition face is the base (001), the twinning axis is a line of intersection between the base and the face (210), and is the zone-axis [120]. Figure 4 shows a different law; namely that the twinning axis is a

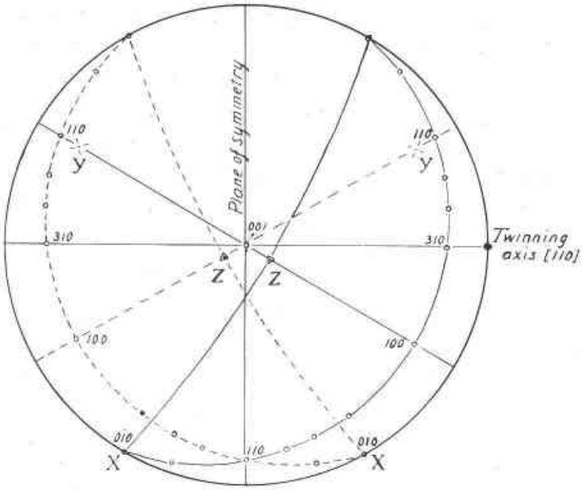

FIG. 4. Orientation of two sets of twinning lamellae in a chloritoid from the same thin section as Fig. 1. Twinning axis is [110]. $X=b$.

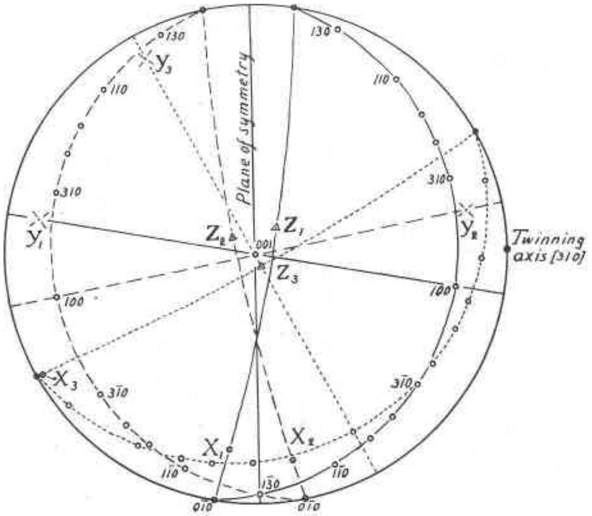

FIG. 5. Orientation of three sets of lamellae in a chloritoid from Lancaster County. Two sets are clearly triclinic and twinned; the third set is very nearly monoclinic.

line of intersection between the base (001) and the face (110), and is the zone-axis [110]. In Fig. 3 the zone-axis [230] in one set of lamellae falls over [230] in the other set of lamellae. In Fig. 4 the two zone-axis [130] in each set of lamellae coincide and lie in the plane of symmetry (Pl. S. in Fig. 4). The twinning axis [210] also was measured.

Figure 5 shows measurements of three sets of lamellae parallel to the cleavage. Two sets are twins and are clearly triclinic, whereas the third set is nearly monoclinic and is intergrown with the others parallel to the base. The twinning axis would probably be the zone-axis [310].

For comparison a number of twinned chloritoid flakes from a chloritoid schist from Chesterfield County, S. C., were measured on the universal stage. The thin section was kindly lent to the author by Miss Jewell Glass, who had determined the optical properties, finding some flakes to be optically negative. In some grains she suspected a triclinic symmetry. Measurements on the universal stage confirmed these properties and it appeared that here also, as in Lancaster County, both monoclinic and triclinic symmetry occur in various sets of lamellae of a twinned crystal. The twinning on a flake with three sets of lamellae is shown in Fig. 6. This twinning is comparable with the one shown in Fig. 4 but the optic orientation is different, Y being parallel to *b*. The twinning axis is [110]. The composition face is (001) as usual.

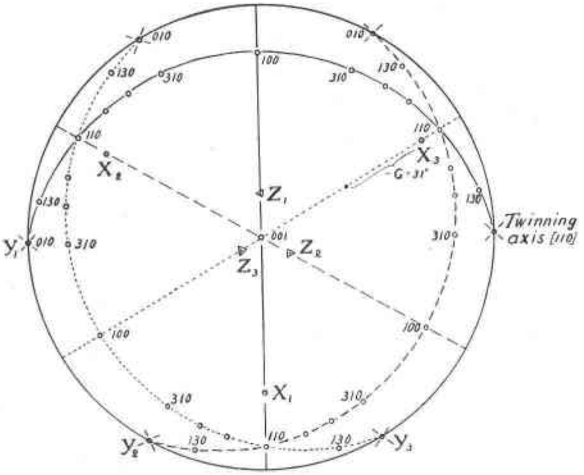

FIG. 6. Orientation of three sets of twinned lamellae in a chloritoid from Chesterfield County, South Carolina. This grain is optically negative, has Y = *b*, and the twinning axis is the zone-axis [110].

These measurements show that the optic orientation and the twinning laws of the chloritoid may vary even in the same thin section. Various orientations have been described in the literature. Barth and Balk (1934) measured 30 chloritoid flakes in a chloritoid schist from Dutchess County, N. Y., and found that all showed Y parallel to the cleavage (001), thus Y = *b*. The angle between the optic planes of the twinned individuals is 60° in their diagram, and the twinning axis is [110].

Simpson (1915) reports a similar orientation $Y=b$ from Yampi Sound, Australia. Shannon (1926) described a chloritoid with $X=b$ from Lemhi County, Idaho. The chloritoid from the Champion mine, Michigan, was first reported by Lane, Keller, and Sharpless (1891) to be triclinic with X near the cleavage plane and Y making an angle of 20° with it. Milne (1949) restudied the mineral, but failed to give a direct comment about the optic orientation. He described in the same paper a chloritoid with $X=b$ from Megantic County, Quebec, and established the optic orientation in this mineral by *x*-rays and universal stage. The twinning axis in the Quebec mineral is, according to Milne, the zone-axis [130]. Thus the pole of (310) face would fall over the pole of (310) of the other individual and the angle between the optic planes would be about 120°.

X-ray study. A powder pattern of the chloritoid from Lancaster County was made by Fred A. Hildebrand. The data (Table 2) compare well with that of the known chloritoids.

Chemical composition. The chloritoid was separated from the schist

TABLE 2. *X*-RAY POWDER DATA OF CHLORITOID FROM RAWLINSVILLE, LANCASTER COUNTY, PENNSYLVANIA

I	*d* (meas.)	*I*	*d* (meas.)
1	8.9	3	2.12
5	4.90	1	2.07
3	4.68	3	2.04
10	4.44	½	1.982
1	3.80	2	1.878
1	3.58	½	1.857
1	3.53	½	1.836
1	3.41	2	1.798
3	3.26	1	1.744
2	3.08	1	1.723
6	2.97	1	1.702
1	2.92	1	1.687
3	2.76	2	1.646
4	2.69	1	1.629
3	2.63	1	1.597
3	2.48	6	1.579
3	2.45	4	1.561
5	2.36	3	1.551
1	2.33	½	1.504
5	2.31	½	1.496
1	2.25	4	1.482
1	2.22	1	1.463
1	2.18	½	1.442
		3	1.403

by means of Clerici solution. The fraction with a specific gravity from 3.517 to 3.522 was used for the chemical analyses. The mineral was clean except for minute rutile inclusions. Therefore the true composition of the chloritoid (Anal. 2, Table 3) was calculated after subtracting TiO_2 and H_2O- from the original analysis (Anal. 1, Table 3). The relative number of atoms contained in a chloritoid molecule was calculated on the basis of the corrected analysis. Using the structural formula suggested by Milne (1949), the composition of the chloritoid from Lancaster County would be as follows: $(Fe'', Mn, Mg)_{1.9}\ (Fe''', Al)_{2.2}\ (Al_{1.9}Si_{2.1})O_{10.4}(OH)_{3.7}$, in which $Fe'':Mn:Mg=1.37:0.07:0.48$ and $Fe''':Al=0.2:2.0$. This is close to the assumed ideal formula: $(Fe'', Mg)_2(Al, Fe''')_2(Al_2Si_2)O_{10}(OH)_4$.

TABLE 3. CHLORITOID FROM RAWLINSVILLE, LANCASTER COUNTY, PENNSYLVANIA
Analyzed by Miss Elsa Ståhlberg

	1	2	Atomic ratios for analysis 2		
SiO_2	24.90	25.12	Si	2.09	4.00
			Al	3.95	
TiO_2	0.63	—			2.24
			Fe'''	0.20	
Al_2O_3	39.93	40.25			
Fe_2O_3	3.20	3.22	Fe''	1.37	
FeO	19.44	19.62	Mn	0.07	1.92
MnO	1.04	1.05	Mg	0.48	
CaO	0.00	0.00	K	0.01	
MgO	3.85	3.89	OH	3.75	
Na_2O	0.00	0.00	O	10.46	
K_2O	0.09	0.09			
H_2O+	6.70	6.76			
H_2O-	0.14	—			
	99.92	100.00			

Comparison of the earlier published chemical analyses of chloritoid shows that there is very little variation in the chemical composition of this mineral in spite of the considerable variation of the optical properties. A slight decrease in the indices of refraction can be observed with increasing amounts of Mg replacing the Fe.''

CONCLUSIONS

Chloritoid may be either triclinic or monoclinic with varying orientation. $X=b$ has been reported from Lemhi County, Idaho (Shannon, 1926); Megantic County, Quebec (Milne, 1949); and Lancaster County, Pa. (this paper). Y = *b* is reported from Dutchess County, N. Y. (Barth and Balk, 1934); from Yampi Sound, Australia (Simpson, 1915); and from Chesterfield County, S. C. (this paper). Both monoclinic and triclinic symmetry occur together at certain localities. In the monoclinic chloritoid where X or Y coincide with *b*, the two other axes have a variable position in the plane of symmetry. The angle between Z and the pole of (001) varies even in the twinned individuals. The smallest measured value for this angle was 4° and the largest 50°, and both occurred on the chloritoid from South Carolina. 2V is highly variable in the same mineral and either Z or X may bisect the acute angle. Polysynthetic twinning is common. The composition face is always (001), and the twinning axis lies parallel to the composition face. Its direction in this face, however, varies.

A more thorough study of chloritoids from various localities will be necessary to establish the relations between the two monoclinic varieties (X = *b* and Y = *b*) and a triclinic form.

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