

The Crystal Structure of the Chlorite Minerals.

By

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(With 3 figures.)

Introduction.

The study of the chlorite minerals was undertaken to establish the structures of some definitely known varieties and if possible to develop a means for determining what minerals are members of this group.

The basis for the investigation was the structure suggested by Pauling¹). He states that the mineral is in the monoclinic base centered space group C_{2h}^3 with a unit cell of $a_0 = 5.2 - 5.3 \text{ \AA}$, $b_0 = 9.2 - 9.3 \text{ \AA}$, $c_0 = 14.3 - 14.4 \text{ \AA}$ and $\beta = 96^\circ 50'$. This space group and also C_{2h}^6 have been thoroughly investigated by the writer for the suggested arrangement of mica and brucite sheets. Some other possibilities for the same space groups have been examined.

The writer wishes to acknowledge his indebtedness to Dr. J. W. Gruner for his interest and valuable advice throughout the investigation which was conducted in his laboratory at the University of Minnesota. He wishes also to express his thanks to Dr. W. F. Foshag of the National Museum at Washington for the fine specimens furnished and to Dr. C. S. Ross of the United States Geological Survey for another specimen of chlorite.

Several X-ray diagrams were made with a Müller electron tube with a *Cu* target. Good pictures were obtained in about three hours at 25 kV. and 32 mA. for those varieties of chlorite which contain a small amount of iron. All the other X-ray diagrams were made with a modified Ksanda-type gas tube. Both *Cu* and *Fe* targets were used. For minerals having a high percentage of iron an exposure of 40—50 hours was necessary at about 30 kV. and 7 mA. using an iron target. A circular camera with a radius of 57.3 mm. was used.

The powder method was used for all diagrams. Three methods of mounting the sample were employed, namely, silk thread, glass tube and

1) Linus Pauling, The Structure of the Chlorites. Proc. Nat. Acad. Sci. **16**, 578. 1930.

plate. The diagrams produced from the powdered sample mounted on a thread with collodion were the most satisfactory. The sharp basal reflections were found to be readily distinguishable due to the preferred orientation of the basal plates around the thread. The diagrams obtained by using a sample mounted in a glass tube are thought to give more correct values for the intensities of the reflections but have less sharp borders. When the powder was made into plates about 0.8 mm. wide and about 0.5 mm. thick different intensities of reflections were produced by different orientations of the plate.

Minerals used.

In Table I the chemical analyses of the seven varieties of chlorites X-rayed are given. The analyst was E. V. Shannon except for number III for which no analysis was supplied. The analysis given for number III is that of a chlorite from the same locality¹⁾ and probably is very similar to that of the specimen.

Other information is as follows:

I. Leuchtenbergite, Philipsburg, Mont. Shannon²⁾. "Colorless to pale tale green; biaxial positive (+); $2V = 6^\circ - 14^\circ$, the variation being in part due to slight bending in splitting off plates for examination. Refractive indices $\alpha = \beta = 1.572 \pm .003$, $\gamma = 1.575$. Birefringence = .003. Occurs in metamorphosed limestone. The marble grades into a greenish layer of fibrous material to which the leuchtenbergite crystals are attached."

II. Sheridanite, Miles City, Mont. Shannon³⁾. " $\alpha = 1.580$, $\beta = 1.584$, $\gamma = 1.589$. Sign positive (+). $2E = 35^\circ$." (Compact soapstone-like translucent mineral with silky luster. Color yellowish-green. McM)

III. Chlorite, Brinton Quarry, West Chester, Pa. Not analyzed. (Micaceous structure; bluish green in color. McM)

IV. Chlorite, Burra Burra, Ducktown, Tenn. The analysis made by E. V. Shannon not published; supplied by W. F. Foshag. (The powdered mineral dirty white in color. McM)

V. Prochlorite, Long Hill, Trumbull, Conn. Shannon⁴⁾. "Color greenish black; optically biaxial with the axial angle, $2V$, approaching zero; optically positive (+); acute bisectrix perpendicular to the perfect cleavage. Under the microscope it is seen to be made up of plates of hexagonal outline, transparent and of a deep green color. The pleochroism is distinct, α = bright brownish grass green, β = bright brownish grass green, γ = pale greenish brown. Refractive indices $\alpha = 1.621 \pm .003$, $\beta = 1.618 \pm .003$, $\gamma = 1.618 \pm .003$, $\alpha - \gamma = .005 \pm .003$. Oc-

1) M. J. OrceI, Recherches sur la Composition chimique des Chlorites. Bull. de a Société française de Minéralogie 50, 407. 1927.

2) E. V. Shannon, Am. Mineral. 8, 8-10. 1923.

3) E. V. Shannon, Wash. Acad. Sci. 12, 241. 1922.

4) E. V. Shannon, Proc. U. S. Nat. Mus. 58, 473. 1920.

Table I.

Analyses of seven chlorites used. The sizes of the unit cells and the theoretical specific gravities of these seven chlorites as determined by the writer.

	I	II	III	IV	V	VI	VII ¹⁾
Insoluble						4.28	
<i>SiO</i> ₂	31.44	27.78	29.87	26.68	23.69	21.28	20.95
<i>TiO</i> ₂				tr.		tr.	
<i>Al</i> ₂ <i>O</i> ₃	17.62	24.30	14.48	25.20	21.26	22.40	35.21
<i>Fe</i> ₂ <i>O</i> ₃		1.43	5.52				
<i>FeO</i>	tr.	0.35	1.93	8.70	26.52	33.20	8.28
<i>Cr</i> ₂ <i>O</i> ₃			1.56				
<i>CaO</i>	tr.	tr.		0.28	3.32	1.12	0.58
<i>MnO</i>	tr.				0.43		tr.
<i>MgO</i>	37.64	32.71	33.06	26.96	17.60	6.52	22.88
<i>NiO</i>			0.17				
<i>H</i> ₂ <i>O</i> —		0.06					0.23
<i>H</i> ₂ <i>O</i> +	13.19	13.01	13.60	11.70	7.63	6.09	13.02
<i>S</i>						0.56	
<i>B</i> ₂ <i>O</i> ₃						tr.	
Total	99.89	99.64	100.19	99.52	100.45	99.45	101.15
<i>a</i> ₀	5.304	5.315	5.333	5.318	5.346	5.352	5.298
<i>b</i> ₀	9.187	9.207	9.237	9.211	9.260	9.270	9.177
<i>c</i> ₀	28.494	28.476	28.582	28.420	28.362	28.306	<i>d</i> ₀₀₁ =
β	97° 8' 40''	97° 8' 40''	97° 8' 40''	97° 8' 40''	97° 8' 40''	97° 8' 40''	27.900
Theoretical Spec.							
Grav.	2.681	2.688 ²⁾	2.757	2.797 ²⁾	3.140	3.300	2.794 ²⁾

- I Leuchtenbergite, Philipsburg, Mont.
 II Sheridanite, Miles City, Mont.
 III Chlorite, Brinton Quarry, West Chester, Pa.
 IV Chlorite, Burra Burra, Ducktown, Tenn. Unpublished analysis.
 V Prochlorite, Long Hill, Trumbull, Conn.
 VI Chlorite, Bolivia. Unpublished analysis.
 VII Amesite, Chester, Mass.

curs as small tabular crystals in a limestone bed which has been metamorphosed to marble. Where free the chlorite exhibits the vermiform prismatic crystals."

VI. Chlorite, Bolivia. The analysis made by E. V. Shannon not published; supplied by W. F. Foshag. (The powdered mineral has a leek-green color. McM)

1) The structure of amesite was not completely worked out.

2) The specific gravities determined in the laboratory are as follows: II, 2.678; IV, 2.774; VII, 2.772. Correct values for the other specimens could not be obtained because of the fineness of the sample or the occlusion of gases between the layers.

VII. Amesite, Chester, Mass. Shannon¹). "Pale bluish-green color. Colorless under the microscope. Biaxial with axial angle $2V$ very small; acute bisectrix normal to the perfect cleavage; optically positive (+). Refractive indices $a = 1.597 \pm .003$, $\beta = 1.597 \pm .003$, $\gamma = 1.612 \pm .003$, $a - \gamma = .015 \pm .003$. Occurs with diaspore, some magnetite and rutile. Tabular hexagonal crystals with dull prismatic faces. Extreme diameter 1 cm. Thickness 3—5 mm."

X-ray data and their interpretation.

The powder diagrams and observed intensities are given in Table II.

Table II.

Powder diagrams of chlorite minerals. Samples mounted on thread. Radius of camera 57.3 mm. CuK_{α} 1.537 FeK_{α} 1.932

No.	β lines	I FeK_{α}		II CuK_{α}		III FeK_{α}		IV FeK_{α}		V FeK_{α}		VI FeK_{α}		VII FeK_{α}	
		d	I	d	I	d	I	d	I	d	I	d	I	d	I
1		13.138	6	13.678	7	13.848	10	13.678	8	13.621	4	13.791	7		
2		6.970	9	7.040	8	7.014	8	6.941	10	6.898	8	6.927	10	6.927	8
3	β			5.250	2			5.179	1	5.124	1	5.155	$\frac{1}{2}$		
4		4.678	9	4.680	9	4.685	8	4.646	9	4.646	6	4.627	6	4.529	1
5	β	3.893	2	3.922	2	3.907	3	3.871	1	3.858	2	3.854	3	3.832	3
6		3.515	10	3.509	10	3.533	8	3.505	10	3.480	10	3.490	10	3.469	10
7	β			3.129	1	3.109	$\frac{1}{2}$	3.085	$\frac{1}{2}$			3.047	$\frac{1}{2}$		
8		2.824	5	2.828	7	2.831	6	2.815	6	2.797	5	2.791	5	2.733	1
9	β			2.712	$\frac{1}{2}$			2.681	$\frac{1}{2}$						
10		broad	8	2.578	7	2.648	5	broad	6	broad	6	2.599	5	2.605	2
11		2.523		2.542	5	2.546	6	2.539	6	2.546	6	2.551	5		
12		2.431	5	2.430	6	broad	6	2.426	4	2.442	4	2.446	3	2.467	6
13		2.369	1	2.370	3	2.400	6	2.374	1	2.373	4	2.380	2	2.315	3
14		2.251	3	2.247	4	2.243	$\frac{1}{2}$	2.248	2	2.259	3	2.256	2		
15	β	2.171	1	2.215	$\frac{1}{2}$			2.196	1	2.206	1	2.202	$\frac{1}{2}$	2.112	3
16	β			2.064	1			2.057	$\frac{1}{2}$	2.061	1	2.067	$\frac{1}{2}$		
17				2.021	7	2.017	4								
18		1.998	8	1.998	6			1.993	9	1.996	8	1.999	8	1.995	1
19		1.880	3	1.881	4			1.869	3	1.873	4	1.876	3	1.920	7
20		1.818	3	1.825	4			1.813	3	1.814	3	1.817	3		
21	β	1.728	2	1.731	3	1.743	$\frac{1}{2}$							1.748	4
22		1.688	2	1.706	3	1.698	1	1.686	2	1.700	2	1.703	2	1.685	1
23		1.655	2	1.659	2	1.668	1	1.651	2	1.653	2	1.653	2		
24		1.563	7	1.562	10	broad	9	1.560	7	1.558	7	1.560	7	1.596	3
25		1.531	9	1.534	10	1.537	9	1.535	8	1.539	7	1.543	7	1.529	5
26		1.499	3	1.502	2	1.505	2	1.498	3	1.505	4	1.509	4	1.494	1
27		1.455	2	1.460	2	1.467	$\frac{1}{2}$	1.460	1	1.464	$\frac{1}{2}$	1.465	$\frac{1}{2}$	1.456	4
28		1.420	1	1.417	3	1.419	1	1.412	3	1.407	4	1.407	3	1.398	4

1) E. V. Shannon, Proc. U. S. Nat. Mus. 58, 371. 1920.

Table II (continuation).

No.	β lines	I FeK_{α}		II CuK_{α}		III FeK_{α}		IV FeK_{α}		V FeK_{α}		VI FeK_{α}		VII FeK_{α}	
		<i>d</i>	I	<i>d</i>	I	<i>d</i>	I	<i>d</i>	I	<i>d</i>	I	<i>d</i>	I	<i>d</i>	I
29		1.394	8	1.390	10			1.384	9	1.384	8	1.386	8		
30				1.350	2			1.341	$\frac{1}{2}$						
31		1.315	3	1.319	4	1.320	2	1.314	3	1.324	2	1.326	1	1.339	4
32		1.287	3	1.283	4	1.296	2			1.295	2	1.296	1	1.301	3
33				1.251	$\frac{1}{2}$										
34				1.218	7										
35				1.191	$\frac{1}{2}$										
36				1.181	3										
37				1.131	4										
38				1.094	4										
39				1.040	5										
40				1.030	5										
41				1.013	3										
42				1.001	3										
43				.987	4										

I Leuchtenbergite, Philipsburg, Mont.

II Sheridanite, Miles City, Mont.

III Chlorite, Brinton Quarry, West Chester, Pa.

IV Chlorite, Burra Burra, Ducktown, Tenn.

V Prochlorite, Long Hill, Trumbull, Conn.

VI Chlorite, Bolivia.

VII Amesite, Chester, Mass.

The structure suggested by Pauling¹⁾ is made up of alternating mica and brucite sheets as shown in Fig. 4. This proportion of the mica to brucite sheets is in agreement with the chemical formula. Three other possibilities (Fig. 2—4), two of which include kaolinite sheets, described by Pauling²⁾ and Gruner³⁾ would also agree with the composition and would have heights along the *c* axis of about 14 Å or about 28 Å depending on the space group chosen.

These four arrangements were tested by computing the intensities of basal plane reflections. Only the first arrangement agreed with the powder diagrams, so the others were discarded.

A structure proposed by Mauguin⁴⁾ was also tested for the low orders of the basal reflections. The calculated intensities were found to be quite

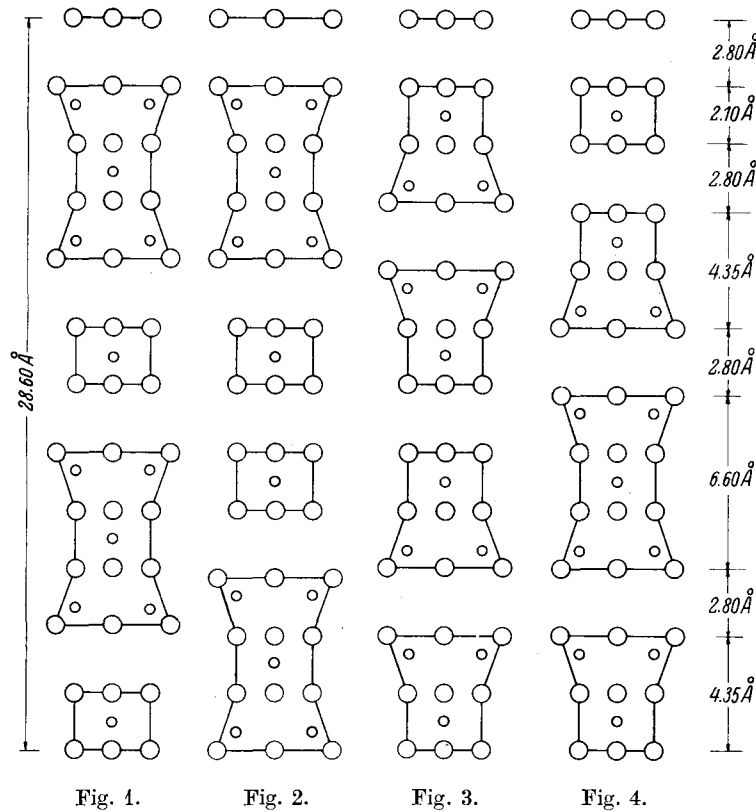
1) Op. cit. 2) Op. cit.

3) J. W. Gruner, The Crystal Structure of Kaolinite. *Z. Krist.* **83**, 84. 1932.

4) Ch. Mauguin, La Maille, crystalline des Chlorites. *Bull. de la Société française de Minéralogie* **53**, 297—299. 1930.

different from the observed intensities. Therefore, the structure was discarded as unlikely.

The arrangement of Fig. 1 was inspected for possible shifts and rotation in the basal plane of one sheet relative to the other for space groups C_{2h}^6 and C_{2h}^3 . For each of these space groups eight possible



Figs. 1—4. Possible stackings of mica, brucite and kaolinite sheets which would agree with the composition of the chlorites and have heights along the c axis of about 14 Å or about 28 Å.

arrangements were found and investigated. If the angle of inclination of the c axis is taken as $96^{\circ}50'$ as stated by Pauling¹⁾ the shift of one mica unit with respect to the next mica unit above or below is 120° or $\frac{1}{3}a_0$.

1) Op. cit.

Table III.

Coordinates of atomic positions of chlorite for space group C_{2h}^6 . Four equivalent positions for each atom listed.

	<i>x</i>	<i>y</i>	<i>z</i>		<i>x</i>	<i>y</i>	<i>z</i>
<i>Mg, Al</i> ₁	0	0	0	<i>O</i> ₃	- 2	30	41
<i>Mg, Al</i> ₂	0	120	0	<i>O</i> ₄	- 2	- 150	41
<i>Mg, Al</i> ₃	0	- 120	0	<i>O</i> ₅	- 92	- 60	41
<i>Mg, Al</i> ₄	0	60	90	<i>OH</i> ₂	51	0	76
<i>Mg, Al</i> ₅	0	- 60	90	<i>OH</i> ₃	51	120	76
<i>Mg, Al</i> ₆	0	180	90	<i>OH</i> ₄	51	- 120	76
				<i>OH</i> ₅	- 51	0	103
<i>Si, Al</i> ₁	- 97	0	34	<i>OH</i> ₆	- 51	120	103
<i>Si, Al</i> ₂	- 97	- 120	34	<i>OH</i> ₇	- 51	- 120	103
<i>Si, Al</i> ₃	97	0	146	<i>O</i> ₆	2	30	138
<i>Si, Al</i> ₄	97	- 120	146	<i>O</i> ₇	2	- 150	138
				<i>O</i> ₈	92	- 60	138
<i>OH</i> ₁	- 111	120	14	<i>OH</i> ₈	111	120	166
<i>O</i> ₁	- 111	- 120	14	<i>O</i> ₉	111	- 120	166
<i>O</i> ₂	- 111	0	14	<i>O</i> ₁₀	111	0	166

In the case of C_{2h}^3 all eight arrangements have the planes of symmetry of individual sheets of both mica and brucite units in the plane of the *a* and *c* axes (conventional crystallographic orientation). Four possibilities are produced by inclining the *c* axis in either of two directions and by changing the position of the brucite sheets with respect to the (*Mg, Al*)₃(*O, OH*)₆ portions of the mica sheets as shown in *A, A', B* and *B'* of Fig. 6. Twice the number of possibilities is produced by shifts of the brucite sheets with respect to the mica sheets parallel the *a* axis. Two shifts differing by 180° (= ½ *a*₀) are possible. In one of these the *c* axis passes through one of the *Mg, Al* positions of the brucite sheet; in the other it passes symmetrically between two *Mg, Al* positions of this sheet.

The arrangement of mica and brucite sheets for C_{2h}^3 which was found to give the only satisfactory results was position *B* of Fig. 6. The shift parallel the *a* axis is such that the *c* axis passes through one of the *Mg, Al* positions of the brucite sheets and symmetrically between two *Mg, Al* positions of the mica sheets. The calculated intensities for this position are presented in Table IV.

Table IV.

Theoretical and observed intensities for space groups C_{2h}^6 and C_{2h}^3 of Sheridanite. Theoretical intensities calculated for four molecules approximating the formula $Al_2Mg_5Si_3O_{10}(OH)_8$ and reduced by dividing by 4000. β lines of Table II omitted.

Indices	C_{2h}^6		Observed Intensities		C_{2h}^3		No. of line in Table II		
	d	Theoretical Intensities	Glass Tube	Silk Thread	Theoretical Intensities	Indices			
002	14.120	7	3	7	7	001	1		
004	7.060	26	4	8	26	002	2		
006	4.707	52	7	9	52	003	4		
020	4.600	5						22	020
11 $\bar{1}$	4.592	17							
110	4.572	0			0	110			
021	4.540	8							
112	4.494	11			43	11 $\bar{1}$			
111	4.438	23							
022	4.374	1			3	021			
113	4.299	6							
112	4.218	9			36	111			
023	4.133	25							
114	4.042	1			3	112			
113	3.948	3							
024	3.854	7			28	022			
115	3.757	28							
114	3.662	3			11	112			
025	3.567	0							
008	3.530	73	7	10	73	004	6		
116	3.472	5			21	113			
115	3.380	25							
026	3.290	5			20	023			
117	3.201	0							
116	3.116	3			13	113			
027	3.033	3							
118	2.952	5			20	114			
117	2.875	1							
0010	2.824	55	6	7	55	005	8		
028	2.801	2			10	024			
118	2.659	5			18	114			
130	2.650	2			2	130			
202	2.650	1			1	201			
132	2.635	3			3	131			
200	2.634	1			1	200			
132	2.576	45	8	7	45	131	10		
204	2.575	23						23	202

Table IV (continuation).

In- dices	C_{2h}^6		Observed Intensities		C_{2h}^3		No. of line in Table II
	d	Theoretical Intensities	Glass Tube	Silk Thread	Theoretical Intensities	In- dices	
134	2.534	166	6	5	166	132	11
202	2.533	83			83	201	
134	2.432	253	6	6	253	132	12
206	2.431	127			127	205	
136	2.374	68	2	3	68	135	13
204	2.373	34			34	202	
0012	2.353	16	4	4	16	006	14
136	2.250	95			95	133	
208	2.249	48			48	204	
138	2.186	29			29	134	
206	2.186	14			14	203	
138	2.058	22			22	134	
2010	2.058	11			11	205	
0014	2.017	13			13	007	
1310	1.996	265	7	7	265	135	17
208	1.995	132			132	204	
1310	1.875	77	1	4	77	135	19
2012	1.875	38			38	206	
1312	1.817	56	1	4	56	136	20
2010	1.817	28			28	205	
0016	1.765	4			4	008	
1312	1.707	13	2	3	13	136	22
2014	1.707	7			7	207	
1314	1.656	62	2	2	62	137	23
2012	1.656	31			31	206	
0018	1.569	5			5	009	
1314	1.559	326	4	10	326	137	24
2016	1.558	163			163	208	
060	1.533	228	10	10	228	060	25
332	1.533	457			457	331	
062	1.524	3			3	061	
330	1.524	3			3	330	
334	1.524	3			3	332	
1316	1.513	14			14	138	
2014	1.513	7			7	207	
064	1.498	99	3	2	99	062	26
332	1.498	99			99	331	
336	1.498	99			99	335	
066	1.458	22			22	063	
334	1.458	22	3	2	22	332	27
338	1.458	24			24	334	

Table IV (continuation).

In- dices	C_{2h}^6		Observed Intensities		C_{2h}^3		No. of line in Table II		
	d	Theoretical Intensities	Glass Tube	Silk Thread	Theoretical Intensities	In- dices			
1316	1.428	18			18	438			
2018	1.428	9			9	209			
0020	1.442	63	$\frac{1}{2}$	3	63	0010	28		
068	1.406	13			13	064			
336	1.406	15			15	333			
3310	1.406	13			13	335			
1318	1.389	271	6	40	271	139	29		
2046	1.389	135						135	208
0640	1.347	19	$\frac{1}{2}$	2	19	065	30		
338	1.347	18						18	334
3312	1.347	17						17	336
400	1.327	81	3	4	81	400	34		
402	1.327	1						1	401
1318	1.314	6						6	139
2020	1.314	3						3	2010

In the case of C_{2h}^6 the planes of symmetry of the individual mica sheets make angles of 60° and -60° alternately with the axial plane of a and c (see Fig. 5 of Gruner's article on kaolinite¹). One of the three planes of symmetry of the brucite sheets is in the plane of the a and c axes. The eight possible positions are produced in the same manner as in the case of C_{2h}^3 and again position B of Fig. 6 is the preferred one. This is represented in greater detail in Fig. 5. The calculated intensities for this position are presented in Table IV.

In the calculation of the theoretical intensities of Table IV the formula $I \propto j(F')^2 \propto j(A^2 + B^2)$ given by Wyckoff² was used. F values were taken from Pauling's and Sherman's table of scattering factors for ions³). Since both Mg and Al ions are in the $(Mg, Al)_3(O, OH)_6$ layers and both Si and Al ions are in the Si_4O_{10} layers F values were interpolated for approximately the relative number of Mg to Al and Si to Al ions. The proportion of 3:1 was taken for the $Mg:Al$ and 2:1 for the $Si:Al$ for the variety Sheridanite. $j = 1$ for $00l$, $h00$, $0k0$, $h0l$, $h0\bar{l}$

1) Op. cit., p. 86.

2) R. W. G. Wyckoff, The Structure of Crystals. New York. 2nd edition, p. 95, 1931.

3) L. Pauling and J. Sherman, Z. Krist. 81, 27. 1932.

and $j = 2$ for all other planes. No allowance was made for the glancing angle.

In calculating the reflections of the various planes and the d_{hkl}

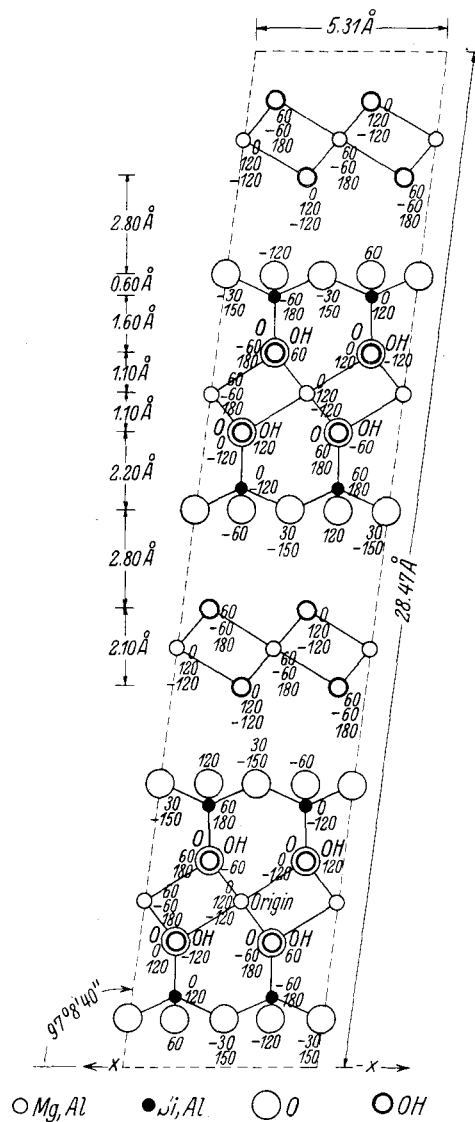


Fig. 5. Unit cell of chlorite. The plane of the paper is the principal glide plane of symmetry of C_{2h}^6 and contains the origin. y coordinates are given in degrees.

for them it was noticed that pairs of $13l$ and $20l$ planes having strong theoretical reflections occurred very close to each other. There seemed to be only one reflection recorded for each pair in the film. To account for this apparent difference the angle β was changed slightly from $96^\circ 50'$ to $97^\circ 8' 40''$ to bring two reflections into coincidence. This change also brought into coincidence reflections from the $33l$ and $06l$ planes. The basal plane reflections, having been recognized early in the investigation, the only theoretical reflections left unaccounted for were the $11l$ planes. Some of these with d greater than 2.65 \AA are relatively strong. Most of the films show a considerable darkening in this region with no lines visible to the eye other than those from the basal planes. These $11l$ reflections are generally absent in all powder diagrams of micas, kaolinites, talcs and pyrophyllites. It was thought that for some reason the reflections of the $11l$ planes might be diffused. A microphotometer was employed in an effort to detect the presence of any of these reflections in the films. The

results obtained although not conclusive seem to indicate that there is a corresponding darkening of the film particularly between $d = 3.56$ and $d = 4.59 \text{ \AA}$ which is the region of the strongest $11l$ reflections.

It will be noticed in the table that the corresponding theoretical reflections for the $11l$ and $02l$ planes are stronger in C_{2h}^3 than in C_{2h}^6 . This is especially conspicuous for $d = 4.494$ and $d = 4.218 \text{ \AA}$. This seems to point to C_{2h}^6 as the more probable structure.

The effect of the large amount of *Fe* present in the prochlorite from Trumbull and the chlorite from Bolivia on the basal reflections is shown

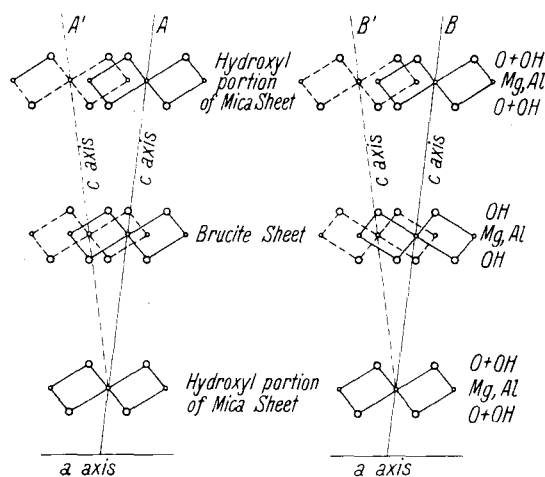


Fig. 6. Possible positions of C_{2h}^3 and C_{2h}^6 produced by inclining the c axis in either of two ways and by changing the position of the brucite sheets relative to the hydroxyl portion of the mica sheets.

in Table II. Lines 2 and 6 increase in intensity relatively to lines 4, 4 and 8. The calculated intensities, taking into account the high percentage of iron, agree with the observed intensities for these lines.

The basis for the determination of the size of the unit cell in each case was the basal reflections¹⁾ and the strong easily recognized one of the plane 060. Assuming the hexagons to be undistorted a_0 is then calculated from b_0 .

Table I furnishes some data on isomorphous replacement and the effect of this replacement on the size of the unit cell. For purposes of comparison chlorite number III, for which the analysis given may be

1) Basal reflections from planes with n equal or greater than 5 were used on account of the great error for those with low indices.

incorrect, and chlorite number VII, of which the structure was not completely worked out, are omitted. The analyses arranged in order of increasing iron content are found to show regular decreases in SiO_2 , MgO and H_2O . Taken in the same order the dimensions of a_0 and b_0 increase while c_0 decreases. It is thought that the replacement of Mg ions by the somewhat larger Fe'' ions expands the structure. a_0 and b_0 increase in agreement with this replacement but c_0 decreases. It is suggested that the OH content has a greater effect in determining the size of the unit cell in this direction.

The theoretical specific gravities were calculated from the chemical analyses given and the calculated sizes of the unit cells. CaO was disregarded as it was thought that owing to the relatively large size of the Ca ion it probably occurred as an impurity.

Summary.

The structure of six varieties of chlorites of varying composition has been worked out and found to be the same. The space group is C_{2h}^6 with C_{2h}^3 as a possible structure. The units of the structure are alternating brucite and mica sheets as predicted by Pauling. The unit cell contains four molecules approximating the formula $Al_2Mg_5Si_3O_{10}(OH)_8$. The sizes of the unit cells for the six chlorites, whose structures were completely worked out, vary between the limits $a_0 = 5.304 - 5.352 \text{ \AA}$, $b_0 = 9.187 - 9.270 \text{ \AA}$, $c_0 = 28.306 - 28.582 \text{ \AA}$. The shift of one mica unit with respect to the next mica unit above or below is 120° or $1/3 a_0$. The angle β of $97^\circ 8' 40''$ is very close to Pauling's angle of $96^\circ 50'$. The face $30\bar{2}$ corresponds to Tschermak's 100 face, which gives the often quoted angle for β of $89^\circ 40'$. The specimen of amesite, although producing some reflections which correspond to reflections obtained in the films of the other six chlorites, does not on the whole appear to have the same structure. Isomorphous replacement of Mg by Fe'' is thought to account for most of the variation in the size of the unit cell. In the variation of the length of c_0 the OH content is believed to control the size more than the ratio of Fe to Mg .

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