OCCURRENCE OF REGULARLY INTERSTRATIFIED CHLORITE-VERMICULITE AS A WEATHERING PRODUCT OF CHLORITE IN A SOIL[1]

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ABSTRACT

Regularly interstratified chlorite-vermiculite (1:1) is found as a weathering product of chlorite in a Highfield channery silt loam soil profile in Adams County, Pennsylvania. The parent rock is greenstone, a metamorphosed basalt, composed of chlorite, epidote, albite and ilmenite. Greenstone fragments in the soil are found with different degrees of chlorite alteration to chlorite-vermiculite. Most prominant development is in the fine silt separate of the soil. X-ray examination revealed that $d(001) = 28.5$ Å for magnesium saturated, air dry material; $d(001) = 28.5$ Å for magnesium saturated, ethylene glycol solvated material; and $d(001) = 24.3$ Å for potassium saturated, air dry material. Cation exchange capacity is estimated to be 85 me/100 grams. It is suggested that the parent chlorite is a 2-layer polytype with different degrees of bonding of alternate brucite interlayers. When subjected to a leaching environment, the more weakly bonded interlayers are preferentially removed.

INTRODUCTION

Reported occurrence of regular interstratification of chlorite with vermiculite, montmorillonite, or swelling chlorite have indicated an association of this mineral type with carbonate deposits (Bradley and Weaver, 1956; Vivaldi and MacEwan, 1957; Peterson, 1961) or with evaporites (Grim *et al.*, 1960). Lippmann (1956) had initially suggested that the chlorite-swelling chlorite, which he designated as corrensite, found in the red member of the Triassic in Germany was the result of diagenesis after deposition of a pre-existing chlorite structure; since then Lippmann (pers. comm., 1962) stated that the mineral is more probably associated with a saline environment. The mineral has also been found to occur in shales (Bradley and Weaver, 1956), argillaceous siltstone (Earley *et al.*, 1956) and in hydrothermal deposits (Sudo *et al.*, 1954). Bradley and Weaver suggested the origin of the mineral to be from a chlorite lattice in which alternate brucite layers are replaced by water and exchangeable cations. Stephen and MacEwan (1951) reported the formation of a regular 1:1 chlorite-swelling chlorite from the weathering of hornblende in crystalline rocks of the Malvern Hills.

The purpose of this report is to cite the formation of regularly interstratified 1:1 chlorite-vermiculite as a weathering product of chlorite in a soil profile.

Occurrence

The sample was obtained from a Highfield channery[1] silt loam (sample No. S61 Pa. 1–12) located in Hamilton Township, Adams County Pennsylvania. Although the chorite-vermiculite is present in several horizons within the soil profile, the data recorded are from a sample of the B_3 horizon (32–38″ depth).

Mineralogy of the Parent Rock

The Highfield soil was derived from greenstone and a minor amount of sericite schist. The greenstone is pre-Cambrian (Algonkian?) in age and was formed by metamorphism of basalt (Stose, 1932). The greenstone contains chlorite, epidote, albite, ilmenite and leucoxene in order of abundance. Microscopic examination of coarse silt $(50–44\mu)$ sized particles of the chlorite oriented on the (001) plane showed the mineral to be biaxial $(-)$, 2V almost $0°$, birefringence 0, and the mean refractive index $n = 1.59$. According to the data of Winchell (1927) the mineral would be classified as delessite, a chlorite with partial replacement of MgO with FeO and Al_2O_3 and some Al_2O_3 replacing SiO_2.

Numerous fragments of the greenstone occur within the lower horizons of the soil profile. X-ray data of an oriented specimen, prepared by air drying onto a glass slide a water suspension of material scraped from a greenstone fragment, are given in Table 1. This sample contains a predominance of chlorite with a minor quantity of altered chlorite (chlorite-vermiculite). Alteration is indicated by the presence of a small diffraction peak at approximately 29 Å and an abnormally intense 001 chlorite peak. Heat treatment at 425° C. eliminated the 29 Å peak, produced broad peaks centered at 12 Å and 8 Å and decreased the intensity of the 14 Å peak which, thus, in the air-dried specimen, was a combination of 001 chlorite and 002 chlorite-vermiculite. The chlorite d-spacings were unchanged. Further heating to 525° C. caused a major modification of the chlorite peak intensities with a marked increase in the 001, some increase of the 005, and a large decrease in the 002, 003, and 004. In addition the d_{001} decreased to 14.0 Å. This is typical for heated chlorites except that dehydroxylation occurred at a lower temperature (525° C) than is ordinarily expected (around 600° C). After heating to 525° C. the chlorite-vermiculite developed two peaks in the low angle region, 23.9 Å and 21.0 Å. The 23.9 Å peak is the 001 for chlorite-collapsed vermiculite (14 Å + 10 Å). The origin of the 21 Å peak is uncertain but may be the result of a component approaching a regular 1:1 interstrati-

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[1] Term used to describe soils containing fragments of thin, flat sandstone, limestone or schist up to 6 inches along the longer axis.

TABLE 1. X-Ray Data of Chlorite from Greenstone Containing a Minor Amount of Altered Chlorite

Altered Chlorite n	Chlorite n	Air-dried			425° C.			525° C.		
		d/n Å	d Å	I/I₀	d/n Å	d Å	I/I₀	d/n Å	d Å	I/I₀
1		29.0	29.0	2				23.9	23.9	8
								21.0		7
	1	14.2	14.2	28	14.2	14.2	50	14.0	14.0	100
2					12.6	25.2	20	12.1	24.2	26
3					8.0	24.0	14			
	2	7.11	14.22	100	7.11	14.22	100	7.14	14.28	3
	3	4.74	14.22	56	4.74	14.22	80	4.74	14.22	5
	4	3.55	14.20	93	3.55	14.20	100	3.51	14.04	15
	5	2.84	14.20	18	2.84	14.20	30	2.81	14.05	34

fied chlorite-vermiculite but containing an excess of randomly occurring 14 Å layers.

In Table 2 are x-ray data of basal oriented particles from a greenstone sample composed predominantly of altered chlorite. The 001 periodicity of 24 Å in the heated material exemplifies the **1:1** regular interstratification of chlorite and vermiculite. The non-integral d-values, shown par-

TABLE 2. X-Ray Data of an Oriented Sample from Greenstone Containing a Predominance of Altered Chlorite[1]

n	Air-dried			425° C.			525° C.		
	d/n Å	d Å	I/I₀	d/n Å	d Å	I/I₀	d/n Å	d Å	I/I₀
1	29.0	29.0	9	20–22	20–22	10	22.1	22.1	28
2	14.6	29.2	100	13.4		(20)			
2 (heated)				12.4	24.8	100	12.2	24.2	100
3				7.83	23.49	82	8.0	24.0	7
4	7.26	29.04	39	6.42	25.68	13			
5				4.80	24.40	13	5.04	25.2	9
6	4.80	28.40	20						
7				3.40	23.80	70	3.35	23.45	26
8	3.61	28.88	30	2.93	23.44	53	2.90	23.20	33
10	2.89	28.90	14						

[1] Diffraction from a minor amount of chlorite is omitted to avoid confusion.

ticularly in the heat treated samples, are probably caused by the presence of random interlayered chlorite. That is, the material has not been completely altered but contains an excess of chlorite layers. This may also be construed as a difference in degree of heat stability of the interlayer brucite as indicated by a 13.4 Å peak at 425° C which is collapsed to 12 Å on heating to 525° C.

One of the properties of vermiculite is relative ease of collapse of the 14 Å spacing to 10 Å on saturating with potassium ions (Barshad, 1949). When the altered chlorite was potassium saturated, Table 3, the vermiculite component reverted to $d_{001} = 10$ Å producing an 001 periodicity of

TABLE 3. X-RAY DATA OF AN ORIENTED SAMPLE FROM GREENSTONE CONTAINING A PREDOMINANCE OF WEATHERED MATERIAL—SATURATED WITH POTASSIUM AND HEATED

n	Treatment								
	K air-dried			K-105° C			K-250° C.		
	d/n Å	d Å	I/I_0	d/n Å	d Å	I/I_0	d/n Å	d Å	I/I_0
1							23.3	23.3	8
2	13.4	26.8	75	12.6	25.2	60	12.6	25.2	55
3	8.12	24.36	65	8.04	24.12	60	8.04	24.12	65
4							6.24	24.98	8
5	4.88	24.40	35	4.85	24.25	40	4.85	24.25	40
6							4.06	24.36	10
7	3.51	24.57	100	3.48	24.26	100	3.49	24.43	100
8	2.99	23.92	10	3.01	24.08	10	3.04	24.32	6
9				2.70	24.30	10			

24 Å for the material. Heating the air dried sample to 105° C. increased the regularity of the 001 periodicity. At 250° C. 001, 004, and 006 diffraction peaks, which were not previously observed, made their appearance.

A powder pattern of the greenstone gave an 060 spacing of 1.544 Å with $b = 9.26$ Å; thus the chlorite is trioctahedral.

Differential thermal analysis of a sample of partially altered greenstone had endothermic peaks at 100° C., 200°, and 570° C. The two low temperature endotherms are typical for loss of two forms of interlayer water in vermiculite; the endotherm at 570° C. results from the dehydroxylation of brucite interlayers in the chlorite.

MINERALOGY OF THE SOIL (FINE SILT FRACTION)

The best manifestation of the chlorite-vermiculite is found in the fine silt fraction (5-2 μ) of the soil. Table 4 contains x-ray data for basal

oriented samples of magnesium-air dried, magnesium-ethylene glycol solvated, potassium-air dried, and potassium 475° C. (60 hrs) treated fine silt. Figure 1 presents tracings of x-ray patterns of the magnesium and potassium saturated, air-dried, samples. Periodicity of the d_{001} spacings in the magnesium saturated sample is very regular with $d_{001} = 28.5$ Å. The high degree of regularity developed in this chlorite-vermiculite is evidenced by the recording of high order basal diffraction peaks (0012, 0014, 0016, 0020). Assuming the chlorite component to have $d_{001} = 14.2$

TABLE 4. X-Ray Data for Basal Oriented Fine Silt (5-2μ) Separated from the Highfield Channery Silt Loam

n	Treatment											
	Mg-air-dried			Mg-ethylene glycol			K-air-dried			K-475° C (60 hrs)		
	d/n Å	d Å	I/I_0	d/n Å	d Å	I/I_0	d/n Å	d Å	I/I_0	d/n Å	d Å	I/I_0
1	28.5	28.5	21	28.5	28.5	21	13.6		(20)	23.9	23.9	15
2	14.26	28.52	100	14.26	28.52	100	12.28	24.56	81	12.3	24.6	100
3	9.51	28.53	7	9.61	28.83	7	8.12	24.24	76	8.04	24.12	4
				7.31*		(40)	7.28*		(100)			
4	7.14	28.56	46	7.14	28.56	40	6.11	24.44	13	5.64	22.56	2
5	5.68	28.40	3	5.70	28.50	3	4.86	24.30	43			
6	4.74	28.44	26	4.74	28.44	25	4.06	24.36	6	4.13	24.78	2
							3.56*		(75)			
7	4.07	28.49	1	4.08	28.56	2	3.48	24.36	100	3.44	24.08	15
8	3.56	28.48	55	3.56	28.48	56	3.04	24.32	4	3.04	24.32	4
9				3.20	28.80	1	2.71	24.39	4	2.68	24.12	4
10	2.85	28.50	18	2.84	28.40	18						
12	2.38	28.56	3				2.03	24.36	10			
14	2.04	28.56	2									
16	1.79	28.64	1									
17							1.43	24.31	3			
20	1.43	28.60	2									
d Å, Mean		28.52			28.56			24.36			24.06	

* Kaolin mineral.

Å, which appears justified from the data in Table 1, the vermiculite has a $d_{001} = 14.3$ Å at room temperature and humidity. Solvating the magnesium saturated sample with ethylene glycol did not change the $d_{001} =$ spacing. This confirms the vermiculite character of the mineral.

The potassium saturated sample produced a d_{001} spacing of 24.3 Å (chlorite 14.2 Å + vermiculite 10.1 Å) which also has a very regular periodicity. Heat treatment of the potassium sample at 475° C. caused a major modification of relative peak intensities and a prominent development of an 001 peak which did not occur on the air dried sample. The 002 is increased while the 003, 004, 005, 006, and 007 are all reduced in
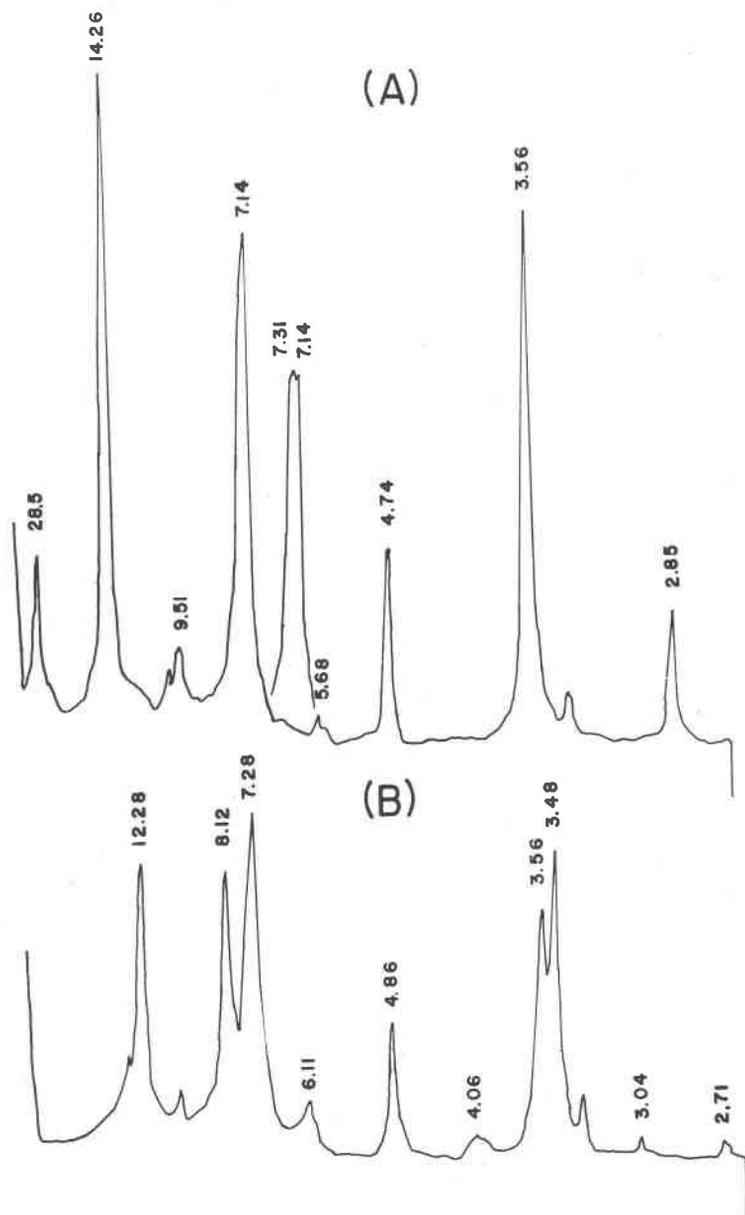
FIG. 1. X-ray diffraction patterns of basal oriented fine silt (5–2μ) from the Highfield soil.

(A) Magnesium saturated air-dried sample—peaks at 7.31 Å and 7.14 Å (offset from main x-ray pattern) illustrates the resolution of the original 7.14 Å peak height after glycolation.

(B) Potassium saturated air-dried sample.

intensity. These changes in peak intensities on heating to 475° C. are the result of the dehydroxylation of the brucite interlayers. That this is the case may be demonstrated from an examination of the data in Table 5. Calculated structure amplitudes were derived by assuming a chlorite-vermiculite $(d_{001} = 24.2$ Å) of general composition $[Mg_{3-x/2}Al_{x/2}(OH)_6]$ $[(Mg_{5-x}Al_xFe_1)(Si_{8-y}Al_y) O_{20} (OH)] K_{0.5}$, and using the chlorite coordinates of Robinson and Brindley (1948), modified to include potassium in alternate interlayers in lieu of brucite. The origin of coordinates was taken at the octahedral brucite interlayer positions. Asymmetrical placement of iron appeared justified since best agreement of calculated and experi-

TABLE 5. CALCULATED AND EXPERIMENTAL STRUCTURE AMPLITUDES AND RELATIVE INTENSITIES FOR POTASSIUM SATURATED FINE SILT, CHLORITE-VERMICULITE COMPONENT

	1	2	3	4	5	6	7
		Relative Intensities air-dried 475° C.			Structure Amplitudes		
001	Lp	I/I_0 (cal)	I/I_0 (exp)	I/I_0 (exp)	F(cal)	6 OH z=0.042	F(exp)
001	31	4	—	15	−10	55	—
002	15.9	54	81	100	−54	48	78
003	10.6	33	76	4	52	38	92
004	8.1	12	13	2	36	25	45
005	6.2	21	43	—	54	12	90
006	5.4	11	6	2	42	− 1	36
007	4.3	100	100	15	142	−12	166
008	3.7	23	4	4	−74	−21	36
009	3.2	15	4	4	−64	−30	39
0010	2.8	0	—		− 4	−32	—
0011	2.5	2	—		−25	−32	—
0012	2.2	23	10		97	−33	72

1. Lorentz-polarization factor

$$\frac{1 + \cos^2 2\theta}{\sin 2\theta}$$

2, 3. Calculated and experimental relative intensities for potassium saturated, air-dried sample.

4. Experimental relative intensities for potassium saturated, 475° C. heated, sample.

5. Calculated structure amplitudes

6. Contribution to calculated structure amplitude of brucite OH layer at z=0.042.

7. Experimental structure amplitudes for potassium saturated, air dry sample. Adjusted so that $\Sigma 1F1$ (exp) = $\Sigma 1F1$ (cal).

mental structure amplitudes was obtained on this basis. Agreement between the calculated and experimental structure amplitudes is sufficiently good to confirm the general correctness of the structure assumed. Nondetection of some basal peaks (001, 0010, 0011) is predictable on the basis of the calculated relative intensities (Table 5, col. 2) and this is substantiated in the experimental data (Table 5, col. 3). The order of the relative peak intensities from most to least intense is similar for the calculated and experimental values. Effect of dehydroxylation of the brucite interlayer on the character of the resultant x-ray pattern is seen by compar-

TABLE 6. BASAL SPACINGS OF THE FINE SILT AFTER SATURATION WITH THE LISTED CATIONS, AIR DRIED, SOLVATED WITH ETHYLENE GLYCOL AND IN TWO CASES GLYCEROL SOLVATED

Interlayer cation	Fine silt air-dried d_{001} Å	Minus 14.2 Å	Vermiculite[1] air-dried d_{001} Å	Fine silt	
				glycol d_{001} Å	glycerol d_{001} Å
Li^+	26.5	12.3	12.6	30.2	
Na^+	26.8	12.6	12.6	27.2	
K^+	24.4	10.2	10.4	24.4	
Mg^{2+}	28.5	14.3	14.3	28.6	28.7
Ca^{2+}	29.2	15.0	15.1	30.6	28.8
Sr^{2+}	29.1	14.9		30.4	
Ba^{2+}	26.5	12.3	12.6	30.6	

[1] Data from Barshad (1950).

ing column 5 with 6, Table 5. When oxygen ions are removed (as H_2O) from the brucite by heating it would be predicted that at the 001 and 002 should be significantly increased in relative intensity and the other basal orders either reduced in relative intensity or not affected to any great extent because of the smaller Lorentz-polarization factor at higher angles and/or a lesser contribution of the brucite OH layer to the structure amplitude. This is verified by the experimental data (Table 5, column 4). The fairly low heat stability, not greater than 475° C. and possibly less, of the chlorite brucite interlayer may be indicative of slight hydration of these layers, due to incipient weathering. Hydroxyl ions could combine with protons from the soil solution to form water molecules $(OH^- + H^+ \rightarrow H_2O)$. To maintain electrical neutrality within the lattice an equivalent amount of magnesium would become exchangeable or soluble (Vivaldi and MacEwan, 1960).

The influence of cations, in addition to potassium and magnesium, and of solvating molecule on the d_{001} spacing of the fine silt is indicated in

Table 6. Lithium, sodium and barium treated samples (d_{001} 26.5 Å) have a single layer of water molecules in the interlayer region of the vermiculite component. With calcium and strontium two layers of water molecules occupy the interlayer region.

Subtracting 14.2 Å (d_{001} for the chlorite component) from the d_{001} spacing for the air-dried specimens, Table 6, column 3, gives values very similar to a vermiculite investigated by Barshad (1950), Table 6, column 4. Solvation with ethylene glycol caused expansion of the vermiculite with all the cations listed except potassium and magnesium, Table 6, column 5. The lithium-, calcium-, strontium- and barium-saturated samples apparently have two layers and the sodium sample one layer of glycol molecules in the interlayer space. Glycerol solvation of a magnesium treated sample caused essentially no change in the d_{001} spacing whereas a calcium treated sample contracted slightly when compared to the air-dried value, Table 6, column 6. Figure 2 presents tracings of x-ray diffraction patterns of the variously solvated calcium sample. This interaction of the vermiculite component of the fine silt with the saturating cation and solvent molecule is analogous to vermiculites described by Walker (1958).

Saturation of the fine silt with cobalt and zinc ions and solvation with water gave the x-ray diffraction patterns shown in Fig. 3. Solvation with ethylene glycol caused no change in the basal spacing. The cobalt and zinc ions are apparently hydrolyzed to some type of hydroxy complex that is partially filling the interlayer region of the vermiculite component. X-ray scattering by these cancels the odd order reflections of the vermiculite-chlorite mineral giving an x-ray pattern similar to what would be expected for a chlorite. That is, the radiation scattered by the zinc or cobalt complexes are equal in amplitude and 180° out of phase with the scattered radiation from the "brucite" interlayers in the chlorite component.

In addition to the chlorite-vermiculite the fine silt also contains a kaolin mineral, and a minor amount of muscovite-type mica. This is seen in Fig. 1 and Table 4, although the mica data are not recorded in Table 4. The kaolin mineral diffraction is superimposed on the 004 ($d = 7.18$ Å) and 008 ($d = 3.56$ Å) peaks of the magnesium saturated chlorite-vermiculite. Direct super position occurs at $d = 3.56$ Å but at $d = 7.18$ Å the kaolin diffraction causes a broadening and tailing to lower angles. When potassium saturated, the diffraction peaks of the kaolin mineral are clearly resolved at $d_{001} = 7.28$ Å and $d_{002} = 3.56$ Å, Table 4 and Fig. 1. The non-integral character of the diffraction peaks indicates the presence of some hydrated layers within the kaolin lattice. Further evidence of this is obtained from the glycolated sample. The 004 peak
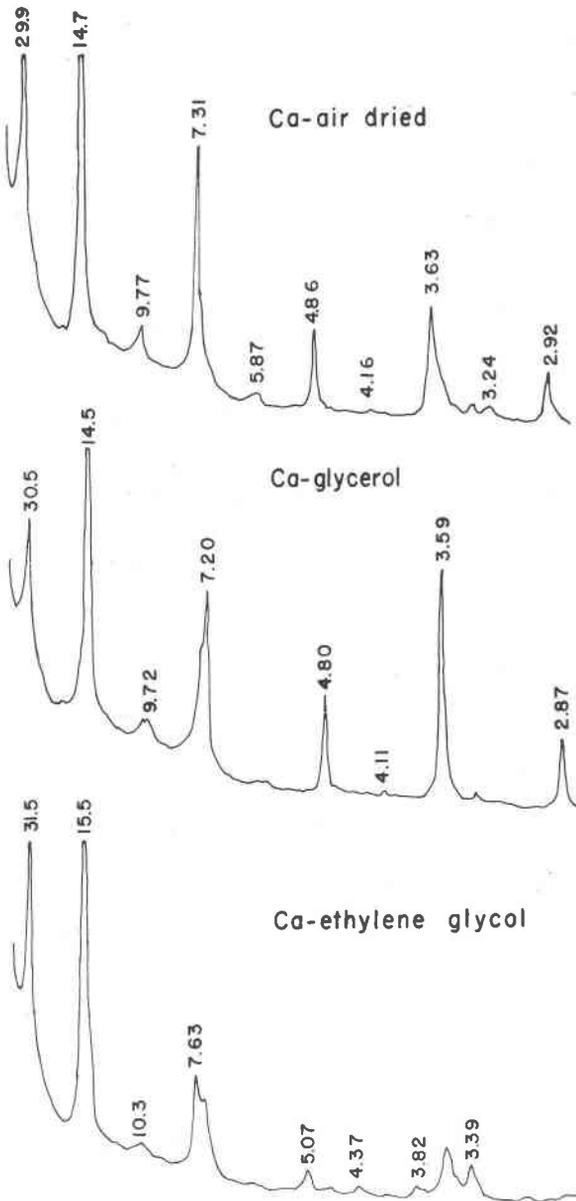
Fig. 2. X-ray diffraction patterns of basal oriented fine silt from the Highfield soil after calcium saturation, air-dried, ethylene glycol solvated, and glycerol solvated.

on the magnesium saturated sample is resolved into two peaks with a concomitant reduction in relative peak height (Fig. 1). Replacement of water by ethylene glycol molecules caused slight increase in the c-parameter of the kaolin mineral. Glycolation of the potassium saturated
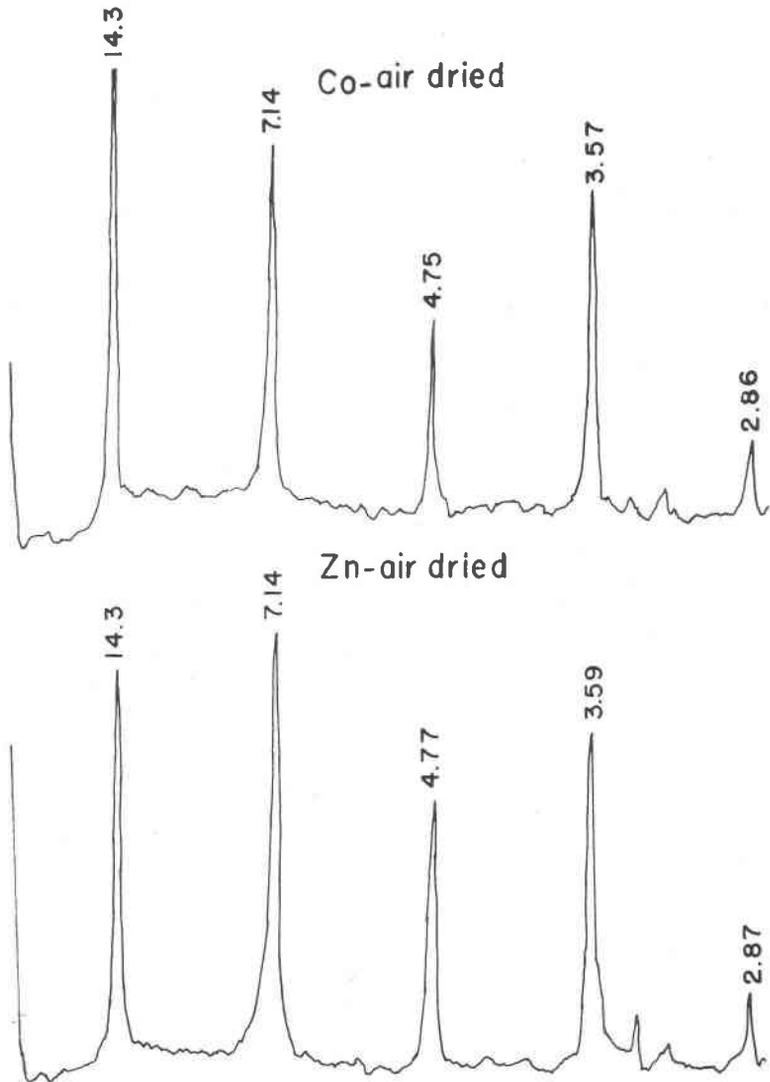

FIG. 3. *X*-ray diffraction patterns of basal oriented fine silt from the Highfield soil after cobalt and zinc saturation and air-dried.

sample produced broadening of the kaolin 001 toward lower angles and the 002 to higher angles.

This mineral may be metahalloysite with some residual hydrated layers that can absorb ethylene glycol (Brindley, 1961), although no two dimensional hk diffraction band was observed on the x-ray patterns.

An electron micrograph, Fig. 4, of the fine silt from the Highfield soil
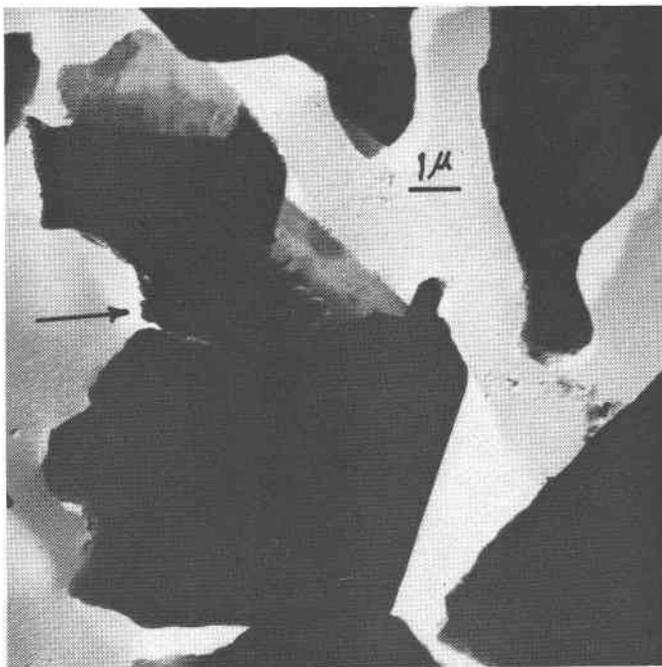
Fig. 4. Electron micrograph of the fine silt from the Highfield soil. Platy particles are chlorite-vermiculite, the arrow points to a particle of the kaolin mineral.

shows the platy character of the chlorite-vermiculite mineral. A particle of the kaolin mineral occurring in this soil is indicated by the arrow. The variable density of the picture gives the appearance of an aggregation of fibrous or lath-like particles. Although the mineral looks somewhat similar to micrographs of some halloysite type minerals its appearance is too indefinite to identify it specifically as metahalloysite.

In Fig. 5 are infrared absorption patterns of greenstone, fine silt from the Highfield soil and a sample of kaolinite prepared from pressed KBr discs. The greenstone pattern is typical of 14 Å chlorite absorption patterns of Stubican and Roy (1961) with the main Si-O band centered at

approximately 1000 cm⁻₁. Presence of the chlorite Si-O band is also seen in the fine silt sample. Absorption at 910 cm⁻¹ (Al—OH, Stubican and Roy, 1961) and 1110 cm⁻¹ in the fine silt correlate with kaolinite bands signifying the occurrence of a kaolin mineral in the fine silt as shown by the x-ray data.
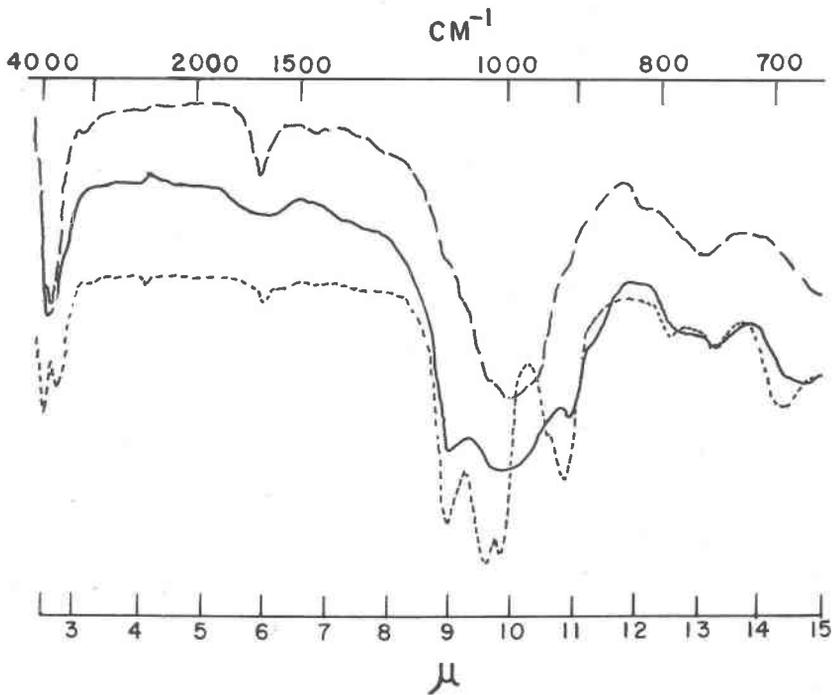
CM^{-1}

FIG. 5. Infrared adsorption patterns of greenstone (————), fine silt (—), and kaolinite (------).

CHEMICAL PROPERTIES

Differentiation of the chlorite-vermiculite from the metahalloysite was also accomplished by hydrochloric acid treatment. Repeated digestion of a silt sample with HCl in a hot water bath left an insoluble residue of metahalloysite and small amounts of mica and albite as detected by x-ray diffraction.

Chemical analyses of the hydrochloric acid extract indicated that very substantial amounts of iron and aluminum were in solution after dissolution of the chlorite-vermiculite. Along with the optical data previously given this verifies the presence of iron in this mineral.

Cation exchange capacity of the fine silt was determined to be 57 milliequivalents per 100 grams. On the basis of x-ray diffraction and HCl dissolution the fine silt was estimated to be composed of 65 per cent chlorite-vermiculite, 25–30 per cent metahalloysite, and 5–10 per cent mica and albite. If 2 me/100 grams of CEC are assigned to the metahalloysite and other minerals, which is reasonable for 30 per cent metahalloysite, the remaining 55 me/100 grams would represent the CEC of the chlorite-vermiculite component. Recalculating on a basis of 100 per cent chlorite-vermiculite gives a value of 85 me/100 grams. Assuming chlorite to have a CEC of 30 me/100 grams (Grim, 1953), the vermiculite component of the 1:1 chlorite-vermiculite has as CEC of 140 me/100 grams, a value characteristic for vermiculite.

Formation of the Chlorite-Vermiculite

Origin of the 1:1 regularly interstratified chlorite-vermiculite from a pre-existing chlorite in the leaching environment of the Highfield soil is evidenced by the presence of greenstone fragments with various degrees of alteration of chlorite to chlorite-vermiculite in the soil profile. That the process involved is a removal of alternate brucite interlayers from a chlorite lattice is demonstrated by considering the influence of the brucite interlayers on the x-ray diffraction properties of a chlorite. The appropriate data are listed in Table 7. The assumptions made in the calculations are the same as previously discussed except that the chlorite-vermiculite has a $d_{001} = 28.5$ (Mg-saturated) and the $K_{0.5}$ is replaced by $Mg_{0.25} \cdot 6H_2O$. Best agreement of calculated and experimental structure amplitudes was again obtained by replacing $\frac{1}{6}$ of the magnesium ions by iron in the "talc" layer of the chlorite. The only change assumed on weathering of the chlorite is a reduction in the amount of magnesium ions from six to $\frac{1}{2}$ in alternate brucite interlayers and the replacement of OH by H_2O. For the 2-layer unweathered chlorite no odd order basal peaks are possible since the waves scattered from equivalent atomic layers on opposite sides of the octahedral talc layers are of equal amplitude and of opposite phase. This is illustrated by the contribution to the chlorite structure amplitudes of magnesium in alternate interlayers, Table 7, columns 3 and 4. When scattering matter (magnesium) is removed (by weathering) from alternate brucite interlayers—magnesium at $z = 0.5$ changes from 3 to $\frac{1}{4}$, Table 7, columns 4 and 5—the odd order diffraction peaks become evident. In fact, the intensities of the odd orders are essentially a function of the difference in the amounts in scattering matter in alternate brucite interlayers as modified by the Lorentz-polarization factor. Inspection of the calculated and experimental relative intensities, Table 7, columns 8 and 9, shows that the odd order reflections are reduced in intensity with

increasing angle in proportion to the reduction in the Lorentz-polarization factor. No odd order reflections greater than 001=009 were observed. The effect on even order reflections is to increase very significantly the 002 and decrease the others except for 0010 which should in-

TABLE 7. CALCULATED AND EXPERIMENTAL STRUCTURE AMPLITUDES AND RELATIVE INTENSITIES FOR MAGNESIUM SATURATED FINE SILT, CHLORITE-VERMICULITE COMPONENT

001	1	2	3	4	5	6	7	8	9
	Lp	F(cal)	3 Mg $z=0$	3 Mg $z=0.5$	$\frac{1}{4}$ Mg $z=0.5$	F(cal)	F(exp)	I/I$_0$ (cal)	I/I$_0$ (exp)
001	38.4	0	30	−30	−2	28	32	24	21
002	18.1	−55	30	30	2	−83	99	100	100
003	12.2	0	30	−30	−2	28	33	8	7
004	9.2	94	29	29	2	73	90	39	40[1]
005	7.2	0	29	−29	−2	27	29	4	3
006	5.9	95	29	29	2	74	89	26	26
007	5.0	0	28	−28	−2	26	21	3	1
008	4.3	158	28	28	2	138	129	66	40[1]
009	3.8	0	28	−28	−2	26	23	2	1
0010	3.3	−117	26	26	2	−141	99	53	18

1. Lorentz-polarization factor

$$\frac{1 + \cos^2 2\theta}{\sin 2\theta}$$

2. Calculated structure amplitudes assuming a 2-layer chlorite; origin taken at Mg layer in interlayer brucite.
3. Contribution to structure amplitudes for Mg in brucite interlayer at $z=0$.
4. Contribution to structure amplitudes for Mg in brucite interlayer at $z=0.5$.
5. Contribution to structure amplitude for Mg in vermiculite interlayer at $z=0.5$.
6, 7. Calculated and experimental structure amplitudes for 1:1 chlorite-vermiculite F(exp) adjusted so that 1F1(cal=1F1(exp)).
8, 9. Calculated and experimental relative intensities for 1:1 chlorite-vermiculite.
[1] Corrected for kaolin mineral contribution.

crease. With the exception for the 0010 these were the changes observed.

It should be noted that the odd order diffraction intensities would be very sensitive to the presence of any significant amounts of iron in the brucite interlayers ($z=0$). That the calculated and experimental relative intensities are in good agreement corroborates the asymmetrical placement of iron in the talc layers only.

Relatively high amounts of exchangeable magnesium ions in the subsoil of this Highfield soil is also a good indication of the weathering of

chlorite since no other source of magnesium is available in this soil. Of two Highfield soils sampled in Adams County the one containing green-stone had an average exchangeable magnesium content in the subsoil of 2.7 me/100 grams. In the other profile, which contained no greenstone, the subsoil exchangeable magnesium averaged 0.7 me/100 grams; a difference of approximately 400 per cent.[1]

Consideration of a mechanism or mechanisms controlling the forma-tion of a 1:1 regularly interstratified chlorite-vermiculite from chlorite can only be speculative since no direct evidence is available. It has been suggested by F. Lippmann (pers. comm. 1962) that the parent chlorite may be a 2-layer polytype. This would provide a structural control for the alteration process. Brown and Bailey (1962) described the different one-layer chlorite polytypes that are theoretically possible. Differences in stability among the polytypes were explained on the basis of dissimilar bond strength between the brucite and talc layers resulting from different degrees of cation-cation repulsion and OH-O bond lengths. Superposi-tion of two unique one-layer polytypes would result in a 2-layer polytype with different degrees of bonding of alternate brucite interlayers. Ex-posed to a weathering environment the more weakly bonded brucite would be preferentially removed, being replaced by exchangeable cations and water, forming a regular 1:1 interstratified chlorite-vermiculite.

NOMENCLATURE

Vivaldi and MacEwan (1960) presented a thorough discussion of the relationships and characteristics of minerals resulting from interstrati-fication of chlorite with swelling chlorite, montmorillonite, vermiculite and labile chlorite. Conforming to the definitions suggested by these authors, the mineral reported in this work is not corrensite (1:1 regular chlorite-swelling chlorite) but can be most simply designated as 1:1 regularly interstratified chlorite-vermiculite.

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