A LATH SHAPED NON-EXPANDED DIOCTAHEDRAL 2:1 CLAY MINERAL

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Abstract

A lath-shaped clay mineral has been found in the Oswego graywacke near State College, Pennsylvania. Electron micrographs, x-ray and differential thermal analysis patterns and chemical analysis indicate that the clay is a non-expanded dioctahedral 2:1 mineral with less iron and magnesium than the average illite. The clay is found both in the graywacke itself and in one to six inch beds of clay occurring within the formation.

Introduction

A clay mineral of the non-expanded dioctahedral 2:1 type (illite) showing a different morphology from that of previously studied representatives of this group has been found in samples of the Oswego formation of Upper Ordovician Age in the vicinity of State College, Pennsylvania. Because of the unusually good crystallographic development of the minute lath-shaped particles, a mineralogical study has been made of the clays associated with the Oswego and overlying Juniata formations to learn more of the nature and distribution of this clay mineral.

The Oswego formation is a graywacke consisting of approximately 800 feet of thick-bedded greenish-gray sandstone, siltstone and shale. It also contains numerous beds, one to six inches thick, which are 95 per cent clay. The Juniata graywacke is similar in composition but is largely red in color.

The following samples were collected at State College:

Sample	*Feet Below Juniata Shale*	*Description*
OS-1	200	Gray, six inch clay bed
-2	212	Gray, one inch clay bed
-3	227	Gray, one inch clay bed
-4	280	Gray, two inch clay bed
-5	296	Gray, two inch clay bed and clay gulls
-6	304	Gray, six inch clay bed
-7	370	Tan, moderately weathered shale
-8	203	Gray, highly weathered, fine grained graywacke
-9	300	Gray, highly weathered, medium grained graywacke
-10	300	Gray, fresh, medium grained graywacke

Several samples of the Juniata red shale (Ju-1, 2, 3) were collected about 100 feet above the Oswego contact.

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Additional samples of the Oswego clay beds were collected near Williamsport, 60 miles northeast of State College. Here it was noticed that the parallel breaks (commonly called bedding) in the coarse sandstone contain thin, one sixteenth to one quarter inch layers of clay similar to that in the larger beds.

MINERALOGY

Tuttle (1940), in his study of the Oswego and Juniata graywackes, showed that the average composition of the Oswego is 40 per cent rock fragments (slates, phyllites, argillites, schists, etc.), 50 per cent quartz grains, 10 per cent clay, and from less than one to fifteen per cent feldspar (albite, andesine, microcline). The Juniata is similar except for the presence of considerable iron oxide.

He found that the non-opaque heavy minerals are predominantly zircon and tourmaline which vary in shape from round to angular with apatite and chlorite being fairly abundant. Leucoxene, anatase, and iron oxides are the most common opaque heavy minerals.

In the present study it was found that the coarser grains which comprise approximately five per cent of the clay beds are similar to the grains in the sandstone. The heavy minerals from the shale and the clay beds are identical to those in the sandstone. The opaque minerals pyrite, leucoxene, and anatase, comprise about 90 per cent of the total heavy mineral concentrate. The non-opaques are largely sub-round zircon and tourmaline grains. (The zircon-tourmaline ratio varies from 1:3 in the clay beds and shale to 6:1 in the sandstone.)

ELECTRON MICROSCOPE DATA

The shape of the particles is the most interesting feature of the clay. To serve as a basis of comparison Fig. 1 is an electron micrograph of Fithian illite and Fig. 2 shows the non-expanded dioctahedral 2:1 clay mineral found in the Juniata formation. The morphology of the latter is typical of many illites, of brammallite, and of mixed-layer clays.

Figure 3 illustrates the appearance of clay particles in the less than one micron fraction of sample OS-8 from a sandstone member of the Oswego formation. Approximately half of the particles are sub-equant flakes while the remainder are thin, well-developed laths which range from 0.2 to 6 microns in length. The shadows cast by the metal shadowing technique show that some of the thinner laths are 40 to 60 Å thick indicating a stacking of 4 to 6 layers of 10 Å thickness.

Individual laths are the most common, but quite frequently they occur together in a parallel arrangement as equant or rectangular flakes (Figs.

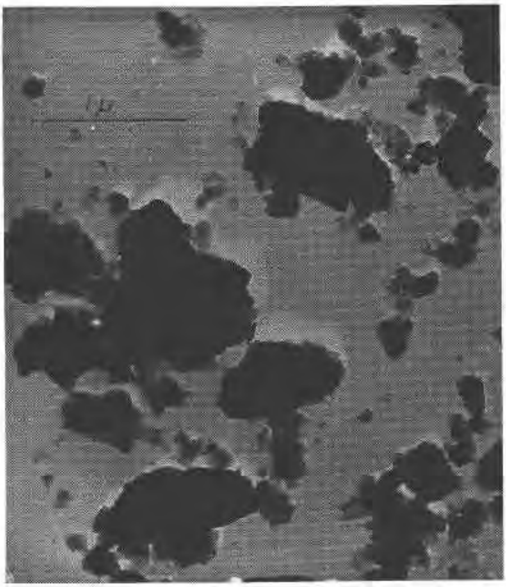

Fig. 1. Electron micrograph of the $<1\mu$ fraction of Fithian illite showing irregular small flakes. Mag. 27,600.

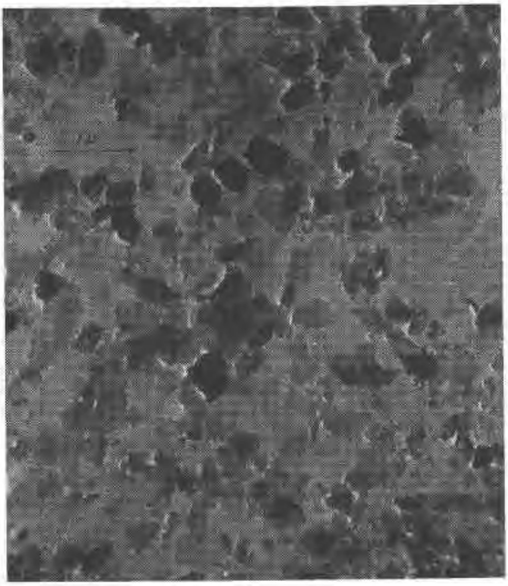

Fig. 2. Electron micrograph of the $<1\mu$ fraction of Juniata shale showing thin, sub-equant flakes with sharp boundaries typical of many illites. Mag. 13,500

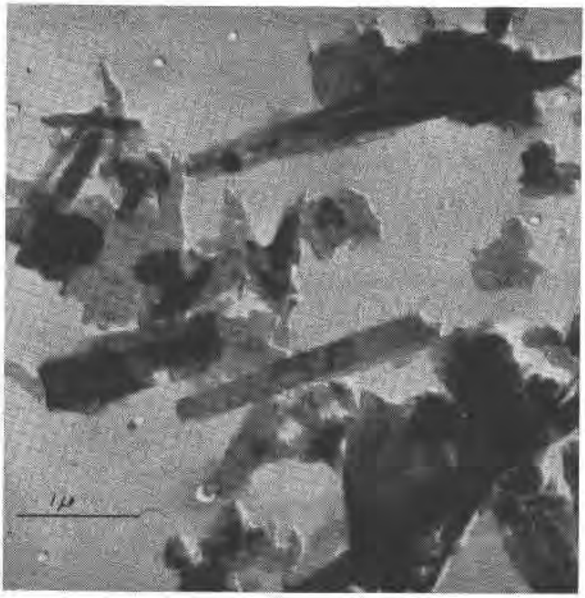

Fig. 3. Electron micrograph of the $<1\mu$ fraction of a sandstone member of the Oswego graywacke (OS-8) showing both sub-equant and lath shaped flakes. Mag. 21,400.

FIG. 4. Electron micrograph of sample OS-8 showing the step-like surface found on many large laths. Mag. 43,200.

4 and 5). From the evidence now available it is uncertain whether the laths result from cleavage of the flakes or by an oriented agglomeration of lath-shaped units. Figure 4 contains a flake which has a step-like surface. Figure 5 has several wide lath-shaped flakes with smooth surfaces which give no hint of being composed of parallel laths; however, the indentations on the ends of the flakes show that the larger laths consist of smaller laths in parallel orientation. It is possible that many of the smooth surfaced, sub-equant flakes are composed of, or would break into laths.

The smooth, sharp edge of the end of the lath seen in Fig. 4 was observed on a number of particles. The well-defined angles between sides and ends suggest that the laths often terminate in crystal faces.

The samples from the clay beds (OS-1 to -6) are composed largely of thin, angular, sub-equant flakes (Fig. 6). However, lath-shaped particles are frequently found. Figure 6 shows an aggregate of laths lying on a group of sub-equant flakes. The laths are similar in size and shape to those found in the clay fraction of the sandstone.

The electron micrographs of clay from the shale (OS-7) show that it consists largely of thin flakes many of which are sub-equant while others are elongated and have a lath-like shape. The laths are wider than those previously described and have a length-to-width ratio of about 4:1. In addition, the pictures show numerous well-developed halloysite tubes.

The clay from the Juniata shale samples consists entirely of thin, angular, sub-equant flakes.

X-RAY DATA

Powder photographs of the less than one micron fractions of both Oswego and Juniata samples indicate that all the clays are of the non-expanded dioctahedral 2:1 (illite) variety. Table 1 contains a list of the *d* values for a sample from a clay bed (OS-1) and for a sample of the less than one micron fraction of the sandstone (OS-8). These values compare quite well with those given by Grim, Bray, and Bradley (1937) for the Calhoun illite.

However, the Oswego and Juniata clays contain several lines (3.04, 1.94, 1.42, and 1.26 Å) which were not given by the Calhoun illite but do occur in muscovite patterns. Several of these values were reported in patterns of the Ballater illite (McKenzie, Walker, and Hart—1949) and Ordovician K-bentonite (Weaver—1952). The Juniata samples contain a small amount of chlorite.

The pattern of the sample containing few laths (OS-1) has two very weak lines, 3.19 and 2.98 Å, which do not occur in the patterns of the lath-shaped clay (OS-8).

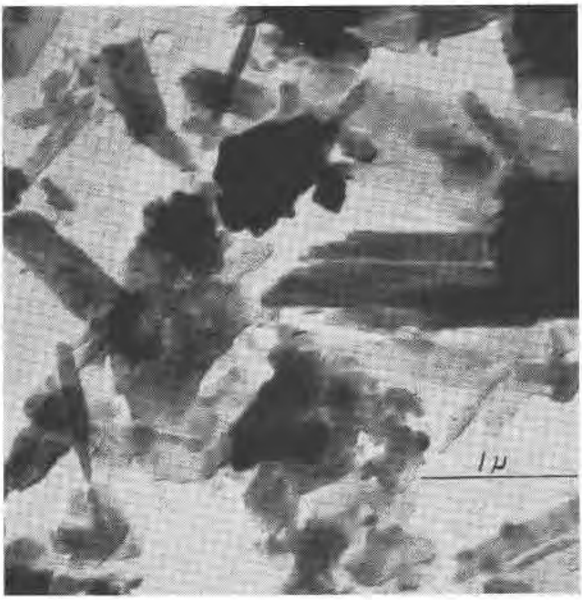

FIG. 5. Electron micrograph of sample OS-8 showing several wide lath-shaped flakes with smooth surfaces but with indentations on the end indicating that the larger laths are composed of, or may split into smaller ones. Mag. 27,200.

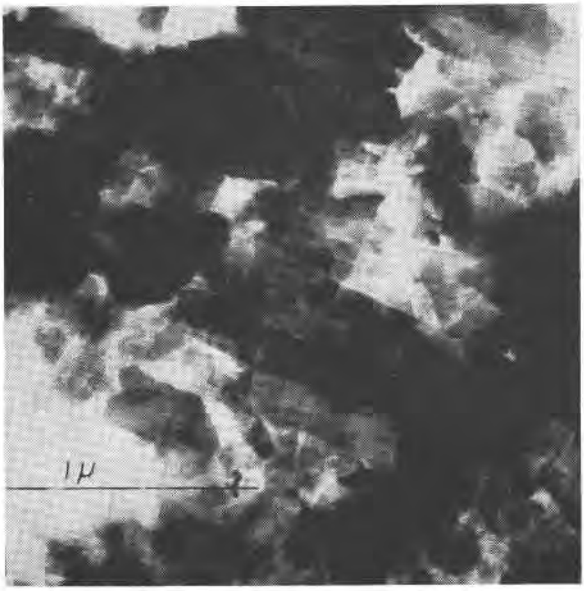

FIG. 6. Electron micrograph of the $<1\mu$ fraction of an Oswego clay bed (OS-4) showing sub-equant flakes overlain by a large aggregate of parallel laths. Mag. 43,200.

X-ray patterns of the lath-shaped material treated with ethylene glycol and with $CaCl_2$ show no indications of any expanded layers. *X*-ray spectrometer patterns of oriented slides of the lath-shaped clay show the same 001 periodicity and intensity as do the sub-equant flakes, indicating that the "*c*" axis is perpendicular or nearly perpendicular to the plane of the laths. The patterns of the oriented material also contain a broad, very weak peak at 7.2 Å possibly caused by a small amount of kaolinite.

TABLE 1

Indices	Calhoun Illite		OS-1		OS-8	
	d	*I*	*d*	*I*	*d*	*I*
002	9.98 Å	S	10.0 Å	S	10.0 Å	S
004	4.97	W	4.9	W	5.0	W
110	4.47	S	4.46	SS	4.45	S
022	4.11	WW	4.10	WW	4.10	WW
023	3.7	WW	3.65	W	3.66	W
$11\bar{4}$	3.4	WW	3.50	W	3.46	WW
006	3.31	M	3.32	M	3.32	M
114	3.2	WW	3.19	WW	—	
$11\bar{5}$	—		3.04	WW	3.05	W
025	2.98	W	2.98	WW	—	
115	2.84	WW	2.83	WW	2.82	WW
$20\bar{2}$	2.56	S	2.56	SS	2.56	SS
$13\bar{3}$	2.44	W	2.44	WW	2.44	WW
133	2.38	M	2.37	M	2.37	M
$22\bar{1}$	2.24	M	2.24	M	2.24	M
$22\bar{3}$	2.18	W	2.19	W	2.19	W
043	2.11	W	2.13	W	2.13	W
0010	1.98	M	1.98	S	1.98	S
206	—		1.94	WW	1.94	WW
$13\overline{10}$	1.65	W	1.65	W	1.65	M
312	1.64	M	—		—	
060	1.50	S	1.49	S	1.49	S
0014	—		1.42	WW	1.42	WW
335	1.34	WW	1.34	WW	1.34	WW
			1.33	W	1.33	W
400	1.29	M	1.29	WW	1.29	M
402	—		1.26	WW	1.26	WW
0016	1.24	W	1.24	WW	1.24	W

SS = very strong.
S = strong.
M = moderate.
W = weak.
WW = very weak.

CHEMICAL DATA

A chemical analysis of the less than one micron fraction of the sandstone sample is given in Table 2. *X*-ray data indicate that a small amount, less than five per cent, of kaolinite and two or three per cent of quartz are present. As the aggregate composition of these impurities would be approximately equal to that of a 2:1 dioctahedral clay the analysis was not recomputed.

TABLE 2

	Oswego (OS-8) Lath-shaped Clay	Average of Five Illites
SiO_2	49.67	48.95
Al_2O_3	27.31	25.03
Fe_2O_3	2.96	7.29
FeO	—	1.61
TiO_2	0.23	0.51
MgO	1.09	3.10
CaO	0.29	0.29
Na_2O	0.10	0.15
K_2O	7.26	6.03
MnO	0.06	—
H_2O	10.50	9.26
	99.47	100.22

Oswego: Analyzed by G. Kunze, Department of Agronomy, The Pennsylvania State College.

Illite: Average of five analyses, Grim *et al.* (1937).

The only significant difference between the Oswego sample and the average of the five illites is in the amount of iron and magnesium present; the five illites contain approximately three times as much of both as does the Oswego material.

Neglecting the TiO_2 and MnO the structural formula as computed by the method of Ross and Hendricks (1945) is:

$$K_{.65}\frac{Ca}{2}_{.04}Na_{.01}$$

$$[Al_{1.71}Fe'''_{.16}Mg_{.11}]\quad[Al_{.53}Si_{3.47}]\quad O_{10}[OH]_2.$$

As compared to other illites, the amount of replacement of Si by Al in the tetrahedral layer (13%) is similar, whereas that of Al by Fe and Mg in the octahedral layer (13%) is much less.

DIFFERENTIAL THERMAL DATA

Differential thermal analysis curves of the less than one micron fraction of a number of samples are shown in Fig. 7. All curves show a weak peak near 110° caused by the hygroscopic moisture. Curves 1 and 2, from the Oswego clay beds have a broad hydroxyl-endothermal peak with an apex at 625° C. Curve 4 of the clay from the Juniata shale is quite similar. Curve 3 of the Oswego clay from Williamsport has a broad peak similar to the others but in addition has a small dip at 575° C. possibly caused by a small amount of kaolinite. Curve 5 is typical of the Oswego shale. This curve shows the broad hydroxyl-endothermal peak of the illite but in addition has a sizable peak at 580° C., extending below the broad peak, which is probably caused by the halloysite that was noted in the electron micrographs. Curve 6 was obtained from the lath-shaped clay from a sandstone sample (OS-8). The curve has the same type of broad hydroxylendothermal peak as the others but has apices at both 550° C. and 600° C., one of which may be caused by a small amount of kaolinite. The exothermal peak at 475° C. may be caused by pyrite or organic material.

The hydroxyl-endothermal peak in these clays is higher than those found in most illites. This is possibly due to the small amount of Fe present.

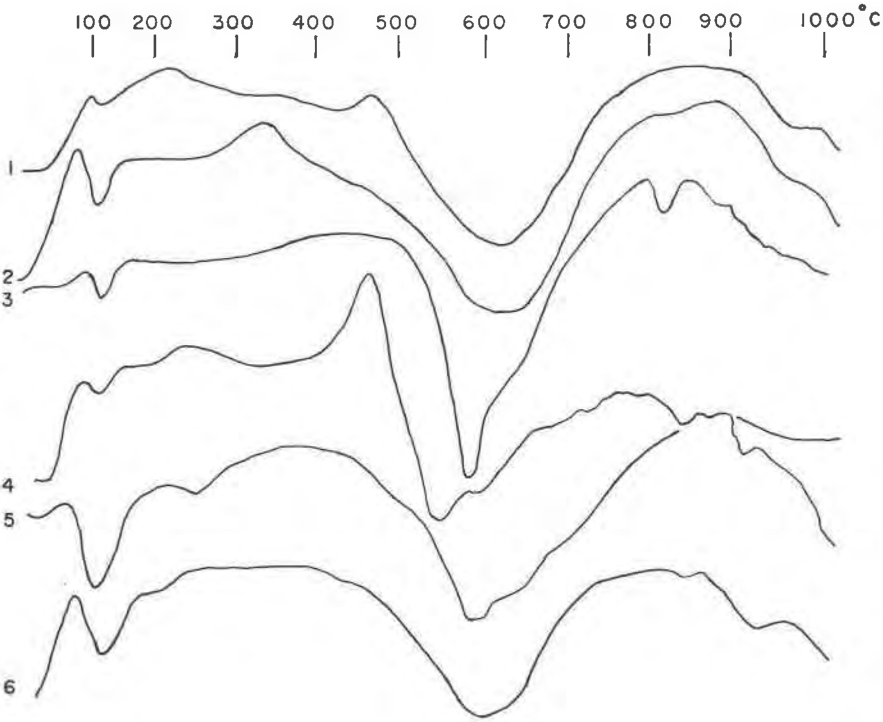

Fig. 7. Differential Thermal Curves: (1) Oswego clay bed, OS-1; (2) Oswego clay bed, OS-4; (3) Oswego shale; (4) Oswego graywacke, OS-8; (5) Oswego clay bed from Williamsport, Pa.; (6) Juniata shale.

ORIGIN OF LATHS

In the 2:1 clay minerals predominant growth along one axis is usually considered to be caused by a directional strain in the mineral lattice due to the inequality in size between the octahedral layer and the two tetrahedral layers. Whereas a similar misfit in the 1:1 lattice causes curved plates and in many cases tubes, here the misfit layer is sandwiched on both sides by layers which prevent curling of the sheets but do not relieve the strain. The inequality in size is usually caused by the presence of ions larger than Al, usually Mg and Fe‴, i.e. hectorite and nontronite, (Ross and Hendricks—1945). However, in the Oswego material Fe‴ and Mg are both present in amounts considerably less than is generally found in other non-expanded dioctahedral 2:1 clays.

The sharp angles found on many of the laths plus the small amount of isomorphous replacement in the octrahedral layer suggest that this may be a more highly crystallized form of a non-expanded dioctahedral 2:1 mineral and have less strain than clay particles of a similar type described in the past.

ORIGIN OF CLAY

The examination of the heavy and light minerals in the clay beds revealed no trace of the volcanic minerals which are common in many Ordovician clay beds. The heavy minerals are similar to those of the coarser fractions of the Oswego and Juniata graywackes. It is concluded, therefore, that the clay had the same source area as the coarser material and is detrital in origin.

The concentration of the clay into relatively pure layers one to six inches thick is possibly caused by a winnowing of the clay from the coarser sand by wave action. Ocean currents would carry the clay away in suspension until calmer water was reached and it would then be deposited for varying lengths of time until the current became strong enough to include silt and sand grains in its load. The thin clay layers between the bedding planes were probably deposited by a similar process during a much shorter period of time.

The lath-shaped clay, which was not found in the Juniata, is most abundant in the Oswego sandstone samples. As it is also present, but in lesser amounts, in the relatively pure clay beds it is possible that this clay is detrital; however, within the sandstone samples it appears to be more abundant in the more highly weathered samples suggesting that it may be secondary, possibly from the weathering of the feldspar.

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