

MUSCOVITE WEATHERING IN A SOIL DEVELOPED IN THE VIRGINIA PIEDMONT

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ABSTRACT

A study was made of the weathering of muscovite-type mica to dioctahedral vermiculite in soils formed from Wissahickon schist in the Piedmont of Virginia. The trend of weathering as a function of depth was most apparent in the soil fractions from 20 to 0.2 microns. X-ray diffraction and chemical analyses indicate loss of potassium and expansion of the muscovite to form vermiculite as weathering proceeded. The amount of interstratified illite-vermiculite relative to vermiculite varied greatly between three soils and was characteristic for each. The widespread occurrence of dioctahedral vermiculite in highly weathered and acid soils suggests the formation of this mineral from commonly occurring muscovite-type micas.

INTRODUCTION

The occurrence of the dioctahedral analogue of vermiculite in soils in the Shenandoah Valley, Virginia (Hathaway, 1955), in the Piedmont of Virginia (Rich, 1954; Rich and Obenshain, 1955), and in England (Brown, 1953) has been reported. Preliminary work by the author indicates that this is the most abundant clay mineral in the surface soils of the Coastal Plain of Virginia and occurs in many of the soils of the state.

The abundance of the dioctahedral vermiculite in certain soils of the Piedmont of Virginia developed from micaceous rocks suggests that this mineral may have resulted from the weathering of dioctahedral or muscovite-type micas as has been proposed by Hathaway (1955) and Rich and Obenshain (1955). The purpose of this paper is to present data that support this hypothesis.

The distribution of the vermiculite relative to mica in three soil profiles is reported. The distribution, according to particle size and soil depth, is indicated by x-ray diffraction and total potassium analyses. It is assumed that as the particle size decreases and as the surface of the soil is approached there is a tendency for intensified weathering of the mica.

EXPERIMENTAL METHODS

Sampling

Tatum silt loam was sampled according to its genetic horizons in Orange, Fluvanna, and Fauquier counties, Virginia. This is a Red-Yellow Podzolic soil

developed from a muscovite schist in the Wissahickon formation. The rock is sometimes designated as a sericite schist but the less specific name is used here. Tatum silt loam has a red subsoil, whereas Nason silt loam, which is developed from the same parent material, has a reddish-yellow subsoil. A description of some of the chemical, physical, and clay mineral properties of these soils has been given by Rich and Obenshain (1955). The clay minerals in the Nason and Tatum soils are similar except that the Tatum soil contains somewhat more illite.

The x-ray patterns of four representative horizons for three Tatum soils are given in this paper. These are the A_2 , B_1 , B_2 , and the deepest C horizon sampled.

Separation of the Size Fractions

Organic matter was destroyed with hydrogen peroxide and the clay dispersed at pH 10 in a sodium carbonate solution according to the method of Jackson (1949). Separation of the various fractions was effected by decanting and centrifuging. Because there may be some question as to the destructive action of these chemical treatments on the soil, the separation of one sample was repeated using only distilled water. The x-ray patterns of the separates showed no indication of destruction by the chemical treatments.

X-ray Diffraction Analysis

Parallel-oriented specimens were prepared by sedimenting a water suspension containing 50 mg of the sample on a glass slide and drying at room temperature. The samples were normally magnesium saturated but for diagnostic purposes some samples were potassium saturated. A General Electric XRD-3 x-ray diffraction instrument was used. Copper $K\alpha$ (35kv and 23 ma) or cobalt $K\alpha$ (40kv and 15 ma) radiation was used in conjunction with a 0.2° detector slit, MR soller slit, and a 1° beam slit. Scanning rate was $2^\circ 2\theta$ per minute.

Measurement of 060 reflections.—To emphasize diffraction from the (060) planes an orientation technique was devised for use with the proportional counter type diffraction recording instrument. The material to be examined was sedimented on a 0.0003 inch thick aluminum foil previously fastened to an aluminum frame with Scotch tape. The parallel-oriented sample was mounted in the normal fashion except the slide holder was turned 90° from the usual position so that x-rays were transmitted through the sample. The assembly is not adversely altered by heat treatment to 550°C .

Potassium Analysis

Total potassium was determined by flame photometer following the method of Corey and Jackson (1953).

RESULTS AND DISCUSSION

General Results

The present study indicates that muscovite-type micas weather to form dioctahedral vermiculite and that this is accomplished by expansion of the mica structure and loss of potassium. Some studies, such as those of Sand (1956), have indicated that muscovite weathers to kaolinite. The changes in crystal structure necessary to form dioctahedral vermiculite are not so great as those necessary to form kaolinite. That vermiculite is an intermediate phase in the formation of kaolinite is not shown by this study. Kaolinite appears as a weathering product in the saprolitic rock where vermiculite has not formed to an appreciable extent and as the more highly weathered surface soil is approached the proportion of vermiculite relative to kaolinite increases. The relative deficiency of kaolinite in the solum may reflect a lack of feldspars (a source of kaolinite in the saprolitic rock), whereas there is an abundance of mica—a source of vermiculite—throughout the soil. This confounds deductions, based on the proportions of kaolinite and vermiculite in the various soil horizons, concerning the relative weathering resistance or weathering sequences.

Kaolinite is abundant in the weathered schist, possibly having formed as an alteration product of the feldspars. The mica appears to be one of the least weathered of the silicate minerals presumed to have been present in the original rock. In the sand ($> 50\mu$) fraction of the soil, quartz is more abundant but mica is more abundant in the finer fractions. The highly weathered nature of the soil is indicated by its low pH and deficiency in exchangeable bases such as calcium and magnesium.

Figure 1 shows x-ray diffraction patterns of the weathered saprolitic rock sampled at a depth of 50 to 60 inches in Tatum silt loam in Orange County. The abundance of mica and the presence of kaolinite are indicated. The peak that disappears on heating probably represents a random interstratification of mica and vermiculite. This may be one of the first alteration products of muscovite at this location.

Identification of the Mica

Because of the high proportion of very fine material in the soils and underlying saprolitic rock, the identification of the mica is based primarily on x-ray diffraction, including the position of the 060 reflection, and chemical analysis. For dioctahedral minerals the value of the 060 reflection is near 1.50A whereas for trioctahedral minerals it is near 1.53A (Grim, 1953, p. 93).

Because kaolinite has a reflection at 1.49A, there may be some interference with the determination of 060 for muscovite at 1.50A. This may be overcome by heat treatment of the sample at 550°C, which destroys kaolinite but has little effect on muscovite. The sample orientation technique employed also emphasizes the $h00$ and $0k0$ reflections more than those from other planes and

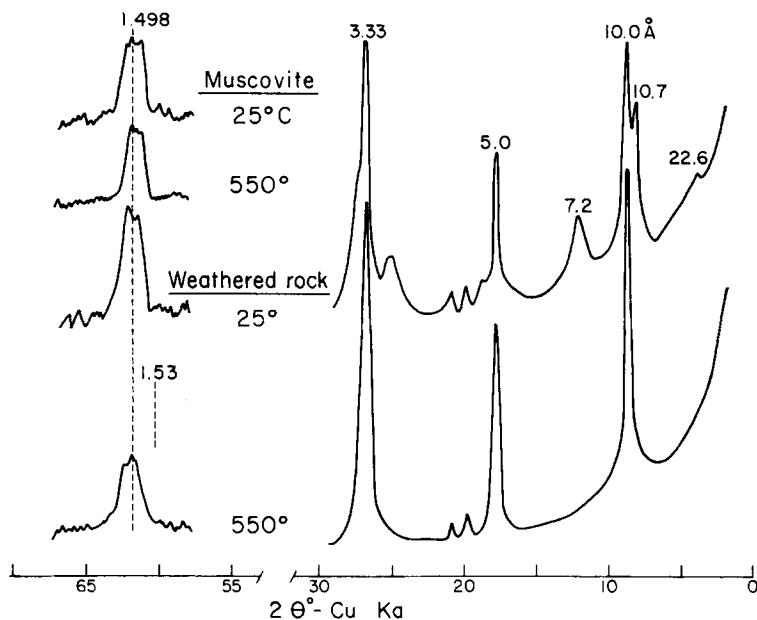


FIGURE 1.—Tracings of x-ray diffraction patterns for reference muscovite and weathered schist from 50- to 60-inch depth in Tatum soil, Orange County, Virginia. The 060 reflections were obtained by transmission technique.

thus reduces interference by other minerals that have reflections in the 1.48 to 1.54Å region.

Well-defined peaks for the 060 reflection at 1.50Å, similar to that given by the 5 to 2 μ reference muscovite (Ontario, Canada), were obtained for the samples of weathered schist (Fig. 1) and soil clay (Fig. 3). These results indicate that the mica and vermiculite in the parent rock, as well as in the soil fractions, are dioctahedral. No peaks were obtained near 1.53Å that could be attributed to trioctahedral minerals. Similar results were obtained for the other two Tatum soils.

Other factors which indicate the type of mica are: (1) moderately strong 002 relative to 001 reflections; (2) high resistance to acid weathering; and (3) light color after removal of free iron oxides.

Characteristics of the Clay Fraction

One of the characteristics of normal or trioctahedral vermiculite is that, on potassium saturation of the clay, the 14Å spacing is replaced by one at 10Å (Barshad, 1948). The dioctahedral analogue is variable in this respect possibly because of a variable amount of difficulty replaced material, particularly aluminum, in the interlayer position (Rich and Obenshain, 1955). The soil from Orange County contained vermiculite that is easily collapsed by potas-

sium saturation, whereas this mineral from the other two counties was affected little by K saturation but collapses on heat treatment at 500°C. Glycerol or ethylene glycol solvation did not expand the mineral beyond 14.7Å.

Figures 2 and 3 show the effect of several heat treatments and K saturation on the x-ray diffraction patterns of the samples containing vermiculite that is easily collapsed. The randomly interstratified illite-vermiculite 001/001 reflection shifts toward higher angles on heat treatment or potassium saturation, indicating collapse of the vermiculite component. The 25 to 26Å peak may be due to regular interstratification of alternate vermiculite and illite layers or to a random illite-vermiculite mixture containing 50 percent of each component. Heating or K saturation also collapses this component. These patterns show that the 7Å diffraction intensity is largely due to the 001 reflection of kaolinite rather than to the 002 reflection of vermiculite. The kaolinite was destroyed by the 500°C heat treatment.

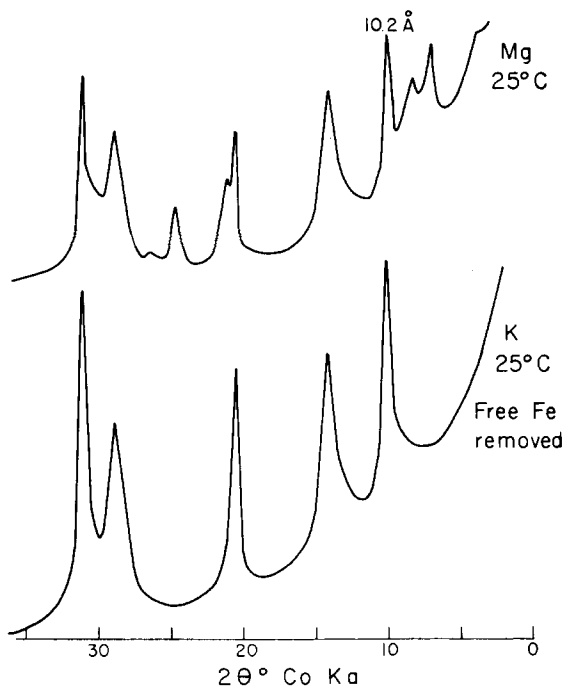


FIGURE 2. — Smoothed tracings of x-ray diffraction patterns of 2 to 0.2 μ fraction from 38- to 50-inch depth of Tatum silt loam, Orange County, showing effect of potassium saturation.

Weathering Sequences

Weathering sequences of mica are indicated for three soils in Figures 4, 5, and 6. The sequences are similar between soils in that, in each, vermiculite—

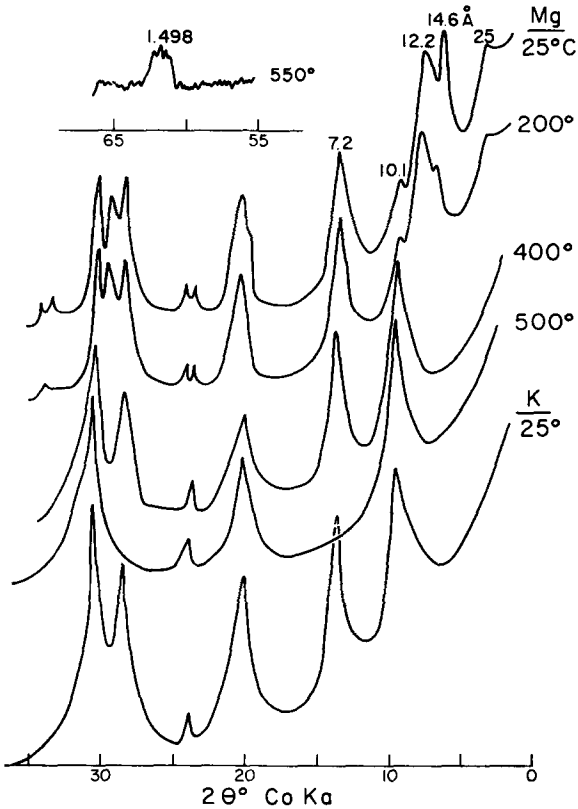


FIGURE 3.—Effect of heat treatment and potassium saturation on the 2 to 0.2μ fraction from the 0- to 2-inch depth of Tatum silt loam, Orange County, as indicated by smoothed x-ray diffraction patterns. Tracing of 060 reflection after heat treatment.

the 14.7A component (either as vermiculite or in the random mixture)—increases with weathering whereas the mica or illite component decreases. As would be expected, there is a greater change with decrease in particle size than with decrease in soil depth. Patterns for the 0.2 to $.08\mu$ fraction in the other two soils are similar to those shown. The shoulder on the high angle side of the 14.7A component indicates the presence of random interstratification of illite with a high proportion of vermiculite. The potassium analyses of this fraction also bear out this conclusion.

The amount of interstratified illite-vermiculite, as indicated by the size of the peak between 10.0 and 14.7A, varies greatly between soils. This property appears to be characteristic of the soil and the underlying saprolitic rock, suggesting differences in weathering or in the mica component. Some of the mica layers may have contained more easily displaced cations, such as sodium, that partially substituted for potassium. The loss of these cations by weathering

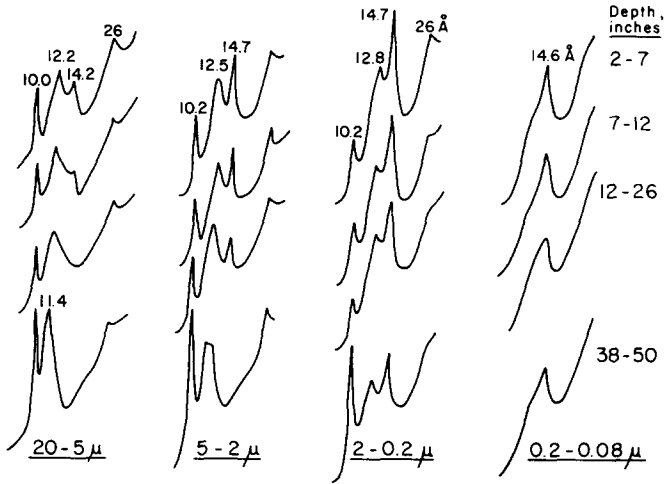


FIGURE 4.—Weathering sequence of muscovite-type mica in Tatum silt loam, Orange County, Virginia, as indicated by smoothed x-ray diffraction patterns of low-angle reflections.

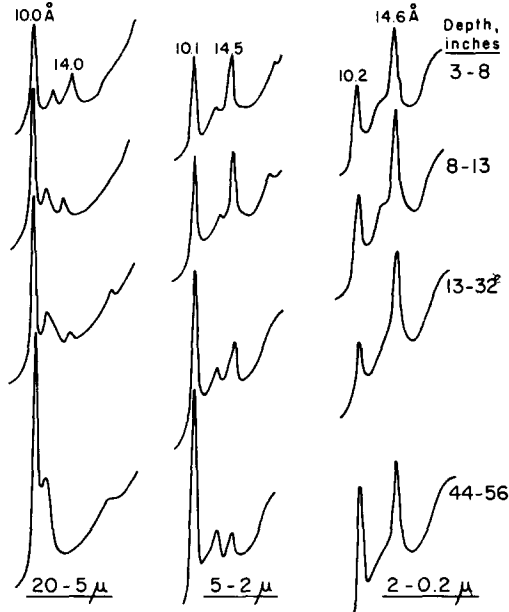


FIGURE 5.—Weathering sequence of muscovite-type mica in Tatum silt loam, Fluvanna County, Virginia, as indicated by smoothed x-ray diffraction patterns of low-angle reflections.

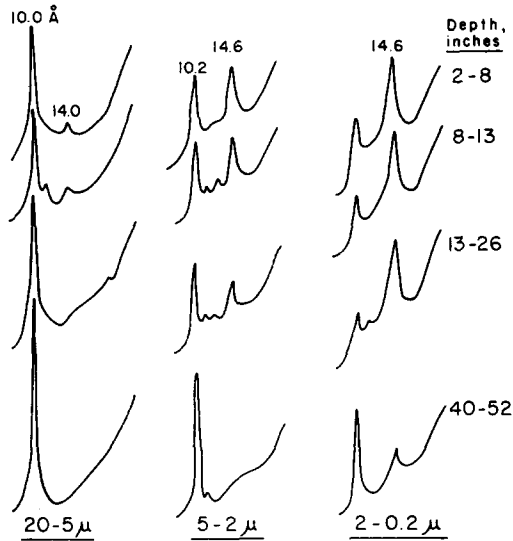


FIGURE 6.—Weathering sequence of muscovite-type mica in Tatum silt loam, Fauquier County, Virginia, as indicated by smoothed x-ray diffraction patterns of low-angle reflections.

and the substitution of H_3O^+ or Al^{3+} ions, differentially by layers according to the degree of initial isomorphous substitution of potassium in the mica prior to weathering, may have led to differential expansion and the random interstratification.

Decrease in layer charge.—The vermiculite formed in these soils apparently has a layer charge considerably less than that of muscovite, assuming all the potassium is replaced by exchangeable cations. In the alteration of biotite to trioctahedral vermiculite the loss of layer charge has been attributed to the oxidation of Fe^{2+} to Fe^{3+} . In muscovite some other mechanism is needed to explain the decrease in charge from the theoretical 250 meq/100 g to the low value of 50 to 65 meq/100 g (Rich and Obenshain, 1955, p. 337) for the dioctahedral vermiculite. There are at least three possible explanations for the low charge of the vermiculite: (1) incomplete loss of potassium (borne out by chemical analysis), (2) neutralization of the charge by aluminum ions which later become nonexchangeable, and (3) formation of hydroxyl tetrahedra (McConnell, 1950) by the entrance of hydrogen ions and loss of potassium ions. All three of these mechanisms may be operating at the same time.

Interpretation of the Potassium Analyses

Total chemical analyses of soils are generally difficult to interpret mineralogically because of the many possible allotments of the elements. In these soils the potassium content can be attributed largely to the mica or illite component. The feldspar content is low because of the extensive weathering that

has occurred. But variations in the content of minerals other than mica (or illite) and vermiculite somewhat confound the interpretation. In these soils, quartz (a major component) decreases with soil depth and particle size. Thus, the data are interpreted generally as regards loss of potassium by weathering. The potassium contents (Table 1) show the same trends of mica or illite content relative to changes with depth and particle size as are indicated by the x-ray diffraction patterns.

TABLE 1.—PERCENTAGE OF POTASSIUM IN WHOLE SOIL AND FRACTIONS; CLAY CONTENT AND pH OF TATUM SILT LOAM, ORANGE COUNTY, VIRGINIA

Horizon	Depth Inches	Whole Soil	Percentage K					Clay ($<2\mu$), Percent	pH	
			>50 μ	50-20 μ	20-5 μ	5-2 μ	2-0.2 μ			0.2-.08 μ
<i>A</i> ₁	0-2	1.12	0.19	0.34	1.88	2.38	2.02	0.99	11.7	4.26
<i>A</i> ₂	2-7	1.38	0.24	0.40	1.73	2.37	2.19	1.35	14.1	4.61
<i>B</i> ₁	7-12	1.42	0.26	0.85	2.07	2.46	2.21	1.43	26.1	4.74
<i>B</i> ₂	12-26	1.58	0.99	1.32	2.65	2.56	1.95	1.05	46.2	5.31
<i>B</i> ₃	26-38	3.09	4.16	3.70	4.69	4.50	2.63	1.10	35.8	4.97
<i>C</i> ₁	38-50	3.47	3.41	3.39	4.66	4.56	3.09	0.91	19.4	4.94

The decrease in potassium in the fractions coarser than 20μ is attributed to marked increase in quartz in these fractions. The sharp increase in potassium between the *B*₂ and *B*₃ horizons indicated for the Orange County sample is also characteristic of the soils from the other two counties. It probably marks the terminal zone of intensive leaching and eluviation in the soil. By field description and laboratory analysis the *B*₂ is the horizon containing the most clay. This horizon also contains the most exchangeable calcium and magnesium. Below the *B*₂, weathering has been less effective in the absence of extensive leaching. Also, the translocation of clay by eluviation from the upper horizons to the *B*₂ tends to bring in more highly weathered clay than otherwise would be present in the *B*₂. The eluviation process tends to even out clay mineral differences in the upper horizons and partially accounts for the sharp difference between the *B*₂ and the lower horizons.

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