

CLAY MINERALOGY AND WEATHERING OF A RED-YELLOW PODZOLIC SOIL FROM QUARTZ MICA SCHIST IN THE ALABAMA PIEDMONT

by

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ABSTRACT

Mineralogical and chemical properties of Madison soil derived from quartz mica schist reflected the degree of weathering. The Madison soil had sandy surface horizons and clayey B horizons. The clay in surface horizons contained more mica than clay in the subsoils; a maximum of about 40 per cent mica in the coarse clay of surface horizons. Intergradient chlorite-vermiculite was present in appreciable quantities in clays of surface horizons. The presence in the whole soil of B2 horizons of about 15 per cent gibbsite and 12 per cent free iron oxides indicated a high degree of weathering. Kaolinite and gibbsite increased with depth and were the major clay minerals in all clay fractions in the lower portion of the profiles. Kaolinite and gibbsite also were important accessory minerals of the coarse and medium silt fractions and increased in percentage with depth. The B3 horizons had much of the morphology of the schist. Results indicated a high weathering intensity in the subsoil and leaching of weathering products.

INTRODUCTION

WEATHERING of mica in soils of the Piedmont Region of the southeastern United States has been a topic of considerable interest in recent years. Previous studies (Rich and Obenshain, 1955; and Rich, 1960) of soils formed from a muscovite schist in the Virginia Piedmont showed that major clay minerals were kaolinite, vermiculite, and inter-stratified mica-vermiculite. High amounts of gibbsite also have been found in some Piedmont soils derived from similar parent material (Alexander *et al.*, 1941). Cook and Rich (1963) used an artificial weathering approach to follow the sequence of mica alterations.

Objectives of these investigations of Madison soil were to determine clay minerals formed during soil development from mica schist and to determine the distribution of constituents in soil profiles.

Topography in the sample area is generally hilly with more gentle slopes occurring on major interstream divides. Mean annual precipitation is about 50 in. and is distributed fairly evenly throughout the year. Mean

temperatures for January and July are about 48 and 80°F, respectively.

MATERIALS AND METHODS

Soil Studied

Madison sandy loam is a Red-Yellow Podzolic soil in the present system of soil classification and is classified 8.230, currently called a Typic Normudult, in the classification system proposed by the Soil Survey Staff (1960, p.227). Madison is among the most important agricultural soils of the Piedmont region in Alabama. The Madison series extends north-easterly from Alabama into the Piedmont area of Virginia. It occurs on gently sloping to steep topography with a high percentage of the gentle slopes being in crops. Madison soils constitute more than half of the cultivated in Randolph County, Alabama, where the samples reported were taken.

The profiles sampled occurred at elevations of 900 to 1000 ft. All sites were virgin and the vegetation was a mixture of hardwood and pine trees.

The following description represents the Madison profiles studied. The soil had a dark yellowish-brown, sandy loam A horizon about 7 in. thick. The horizon that was transitional between A horizon and B2 horizon was a yellowish-red clay loam. The red clay or sandy clay B2 horizon was about 20 in. thick. The B horizon that was transitional to the rock was mixed red, yellowish-red, and reddish-brown sandy clay loam; it contained many fragments of partially weathered mica schist. The total soil profile was about 36 in. thick and it contained many fine mica flakes throughout.

Procedures

Six sites were selected for study of the Madison series. A pit was dug at each site and bulk samples were collected from each horizon after describing the profile. The samples were air dried in the laboratory and crushed gently with mortar and pestle to pass a 2 mm sieve in preparation for subsequent chemical, physical, and mineralogical analyses. The material coarser than 2 mm, primarily rock fragments in B3 horizons, was not studied.

The soil was dispersed and particle size distribution was determined according to the methods described by Jackson (1956, pp.31-164). Percentages of the various fractions were computed on the basis of the oven dry weight of the material remaining after removal of organic matter and free ion oxides.

Soil reaction was determined with a glass electrode pH meter in 1 : 1 soilwater paste.

Cation exchange capacity was determined by saturating with NH_4OAc (Metson, 1956, pp.103–105). Exchangeable cations were extracted and exchangeable Ca and Mg were determined by a Versene titration (Metson, 1956, pp.108–109). The Mg determination was modified to complex interfering ions. Exchangeable K was determined with a flame spectrophotometer.

Free iron oxides were extracted and determined by the method described by Jackson (1956, pp.57–58). K and Na in H saturated fine silt and clay fractions were determined according to Jackson (1958, pp.318–320).

The silt and clay fractions were prepared for X-ray diffraction analysis on glass slides according to Jackson (1956, pp.171–249), except that 0.3 ml and 0.5 ml of 10 per cent glycerol solution were applied to 50 mg of 0.2–0.08 μ and <0.08 μ clay fractions, respectively. X-ray analyses were made with a Norelco generator, proportional counter, and recorder. Copper Ka (35 kV and 20 mA) radiation filtered with nickel was used with 1° divergence slit, 0.003 in. receiving slit, and 1° scattering slit. Scanning rate was 2°2 θ per min. The K saturated clay and fine silt samples were heated for 4 hr at 300°, 400° 500°, and 550°C and X-ray diffraction records were made after each heating. Coarse and medium silt samples saturated with K were heated for 4 hr at 550°C and X-ray analyses were made.

Per cent mica in the fine silt and clay fractions was calculated from the total K content assuming 10 per cent K_2O to equal 100 per cent mica (Mehra and Jackson, 1959). Sodium was allocated to mica assuming 8 per cent Na_2O in 100 per cent mica.

Kaolinite was determined by the selective dissolution method of Hashimoto and Jackson (1960) modified to fit these samples. Gibbsite was dissolved before kaolinite by boiling a H^+ saturated sample dried at 110°C for 2.5 min in 0.5 N NaOH. Silica dissolved by this treatment was allocated to amorphous silica. The sample was resaturated with H^+ , heated for 1 hr at 550°C and then kaolinite was removed by boiling in NaOH as for gibbsite. Removal of the minerals was checked by X-ray analysis and successive boiling of the samples. Results were compared with determinations by quantitative differential thermal analysis using fired amphibole asbestos diluent with a sample to diluent ratio of 1 : 3. Samples were heated so that the rate of temperature increase was about 10°C per min in a nitrogen atmosphere. Reference minerals were fractionated from U.S. Bureau of Standards Bauxite (No. 69A) and poorly crystalline Georgia kaolinite. The kaolinite was kindly furnished by Dr. H. H. Murray of the Georgia Kaolin Co., Elizabeth, New Jersey. Corrections were made for impurities in the reference samples.

RESULTS AND DISCUSSION

The soil characteristics investigated were similar among three non-graphitic and among three graphitic Madison soil profiles, therefore, results are presented for one soil profile of each group. One of the profiles was formed over quartz mica schist and the other was formed over graphitic mica schist. Quantitative clay mineral analyses were made only on the samples reported. Particle size analyses, free iron analyses, and clay mineral analyses by X-ray diffraction were made on selected horizons of the four profiles not reported. Chemical analyses like the ones reported, except for free iron analyses, were made on all six Madison soil profiles.

Particle Size Distribution

Surface horizons were sandy loams and B2 horizons were clays and sandy clay (Table 1). Coarse clay was the most abundant clay fraction throughout both profiles. An increase in the ratio of medium to coarse clay with depth indicated greater illuviation of the finer clay. Clay showed maximum accumulation in the B2 horizons. Silt generally decreased with increasing depth in both profiles.

Chemical Properties

Free iron oxides (Table 2) showed maximum accumulation in the B2 horizons of all profiles. The iron oxides distribution indicated that the processes of eluviation and illuviation had been taking place (Byers and Anderson, 1932).

The sandy upper horizons generally were more acid than the B2 horizons.

Higher cation exchange capacities in surface than lower horizons probably were because of the 4 to 8 per cent organic matter present and higher percentages of vermiculite-chlorite intergrade in surface horizons.

Mineralogical Properties of Clay and Fine Silt Fractions

As feldspar was not detected in these fractions, the total K and Na contents of clays (Tables 3 and 4) were attributed largely to the mica component. Mica, as used here, includes both discrete mica which gives a 10Å X-ray peak and mica layers which are interstratified with other minerals. Per cent mica in the fine silt and coarse clay fractions usually decreased with particle size and with increasing depth (Table 3, Fig. 1). Important amounts of Na were present in the fine silt and clay fractions. The Na may have been mixed with K in the mica as no paragonite X-ray peak was observed. The decrease in K : Na ratio with a decrease in particle size indicated greater weathering of layers which contained more K as

TABLE 1.—PARTICLE SIZE DISTRIBUTIONS OF TWO PROFILES OF THE MADISON SOIL

Horizon	Depth, inches	Particle-size, μ							
		>50 %	<2 %	50-20 %	20-5 %	5-2 %	2-0.2 %	0.2-0.8 %	<0.08 %
MADISON SANDY LOAM									
A1	0-2	62.3	11.3	12.6	11.1	2.7	6.7	3.6	1.0
A3	2-5	56.8	14.4	13.8	11.8	3.2	8.7	4.8	0.9
B1	5-10	43.6	30.6	11.4	11.2	3.2	18.9	10.8	0.9
B21	10-20	28.0	54.2	5.2	10.8	1.8	31.1	21.6	1.5
B22	20-29	48.4	36.3	7.4	6.4	1.5	18.6	16.8	0.9
B3	29-40	69.4	15.7	6.8	6.6	1.5	8.7	6.7	0.3
GRAPHITIC MADISON SANDY LOAM									
A1	0-4	58.0	11.1	12.7	14.8	3.4	7.8	2.5	0.8
A3	4-8	58.8	12.5	10.2	14.8	3.7	9.2	2.7	0.6
B1	8-12	43.7	28.5	10.0	13.7	4.0	18.0	9.6	1.0
B2	12-34	31.4	51.6	7.1	7.9	2.0	29.7	20.4	1.5
B3	34+	69.7	13.1	8.6	7.4	1.2	8.5	4.3	0.3

TABLE 2.—CHEMICAL CHARACTERISTICS OF TWO PROFILES OF THE MADISON SOILS

Horizon	Depth, inches	pH 1:1	Soil C.E.C.	EXCHANGEABLE CATIONS					Base satura- tion* %	Free Fe ₂ O ₃ %
				Ca	Mg	K	Ca+Mg+K	meq/100 g soil		
MADISON SANDY LOAM										
A1	0-2	4.2	8.24	0.36	0.58	0.10	1.04	13	2.8	
A3	2-6	4.9	6.55	0.34	0.46	0.10	0.90	14	3.4	
B1	6-10	4.3	5.36	0.58	0.82	0.14	1.54	29	6.4	
B21	10-20	4.4	6.36	—	0.77	0.19	—	—	10.9	
B22	20-29	5.3	5.06	0.42	0.64	0.09	1.15	23	9.6	
B3	29-40	5.1	3.18	0.32	0.52	0.09	0.93	29	7.1	
GRAPHITIC MADISON SANDY LOAM										
A1	0-4	4.6	13.85	0.74	0.56	0.24	1.34	11	2.8	
A3	4-8	4.8	5.51	0.39	0.10	0.07	0.56	10	3.1	
B1	8-12	5.0	5.16	0.91	0.62	0.17	1.70	33	6.1	
B2	12-34	5.4	6.95	0.36	—	0.17	—	—	12.2	
B3	34+	5.2	2.58	0.48	0.12	0.14	0.74	29	8.4	

* $\frac{(\text{Ca} + \text{Mg} + \text{K}) \times 100}{\text{C.E.C.}}$

TABLE 3.—TOTAL POTASSIUM AND SODIUM FOR SELECTED FRACTIONS OF THE MADISON SOIL

Horizon	Depth, inches	5-2 μ		2-0.2 μ		0.2-0.08 μ	
		%K ₂ O	%Na ₂ O	%K ₂ O	%Na ₂ O	%K ₂ O	%Na ₂ O
MADISON SANDY LOAM							
A1	0-2	3.90	1.05	2.50	0.86	0.82	0.40
A3	2-5	4.18	1.19	2.57	0.97	0.74	0.43
B1	5-10	3.90	1.02	1.96	0.73	0.71	0.38
B21	10-20	2.96	0.77	1.48	0.51	0.80	0.35
B22	20-29	2.15	0.60	1.30	0.54	0.78	0.40
B3	29-40	0.89	0.27	1.01	0.40	0.78	0.42
GRAPHITIC MADISON SANDY LOAM							
A1	0-4	5.58	—	4.30	—	1.79	—
A3	4-8	5.38	—	4.44	—	1.58	—
B1	8-12	5.51	—	3.90	—	1.30	0.43
B2	12-34	4.46	1.14	2.89	—	1.26	0.40
B3	34+	1.60	0.42	1.93	—	1.22	0.38

found by Cook and Rich (1963) by laboratory "weathering" of mica or smaller initial particle size for the higher Na mica. The latter interpretation is supported by the absence of any trend in K : Na ratio with depth. A small amount of feldspar in the fine silt was indicated by X-ray diffraction and some of the Na and K may have been from that source in those fractions.

The fine clay was largely kaolinite and gibbsite (Fig. 1). Montmorillonite and vermiculite-chlorite intergrade also were present. Since part of the montmorillonite was interstratified with vermiculite or 2 : 1-2 : 2 intergrade, it probably was formed from the 14Å mineral. The presence of only about 1 per cent fine clay indicated that montmorillonite did not tend to accumulate in this weathering environment. Although present in appreciable quantities in coarse fractions, kaolinite, gibbsite, and vermiculite-chlorite intergrade did not accumulate as fine clay (Table 1).

The clay mineral composition of the coarse and medium clay fractions (Table 4) are based on separate chemical analyses except for the vermiculite

TABLE 4.—CLAY MINERAL COMPOSITION OF THE NONGRAPHITIC MADISON SOIL

Horizon	Depth, inches	Q*	Mi	VC	Kl	Gb	Am
<i>2-0.2μ</i>							
A1	0-2	D	36	28	17	17	2
A3	2-5	D	38	25	17	18	2
B1	5-10	ND	29	18	26	25	3
B21	10-20	ND	21	21	26	29	3
B22	20-29	ND	20	23	26	29	2
B3	29-40	ND	15	21	36	25	3
<i>0.2-0.08μ</i>							
A1	0-2	ND	13	24	33	25	5
A3	2-5	ND	12	26	28	27	7
B1	5-10	ND	12	23	29	30	6
B21	10-20	ND	12	23	29	30	6
B22	20-29	ND	13	24	27	30	6
B3	29-40	ND	13	20	31	30	6

*D = detected, ND = not detected, Q = quartz, Mi = mica, VC = vermiculite-chlorite intergrade, Kl = kaolinite, Gb = gibbsite, Am = amorphous silica.

that is obtained by difference. The trends in mineral content agree with the X-ray intensities in Fig. 1 and with differential thermal curves some of which are shown in Fig. 2. The mica content, based on total K_2O and Na_2O , is higher than might be expected from X-ray intensities. It is evident from other work (Rich and Obenshain, 1955; Rich, 1960; Dixon and Jackson, 1962) that 15 per cent or more mica based on K_2O may not be shown as a discrete 10\AA X-ray peak and that higher amounts often show only small peaks and broad humps produced by interstratified systems.

While mica was more abundant in coarse clays of A than B horizons, kaolinite was a major layer silicate in clay fractions of all other horizons. Kaolinite increased considerably with depth through the B3 horizons.

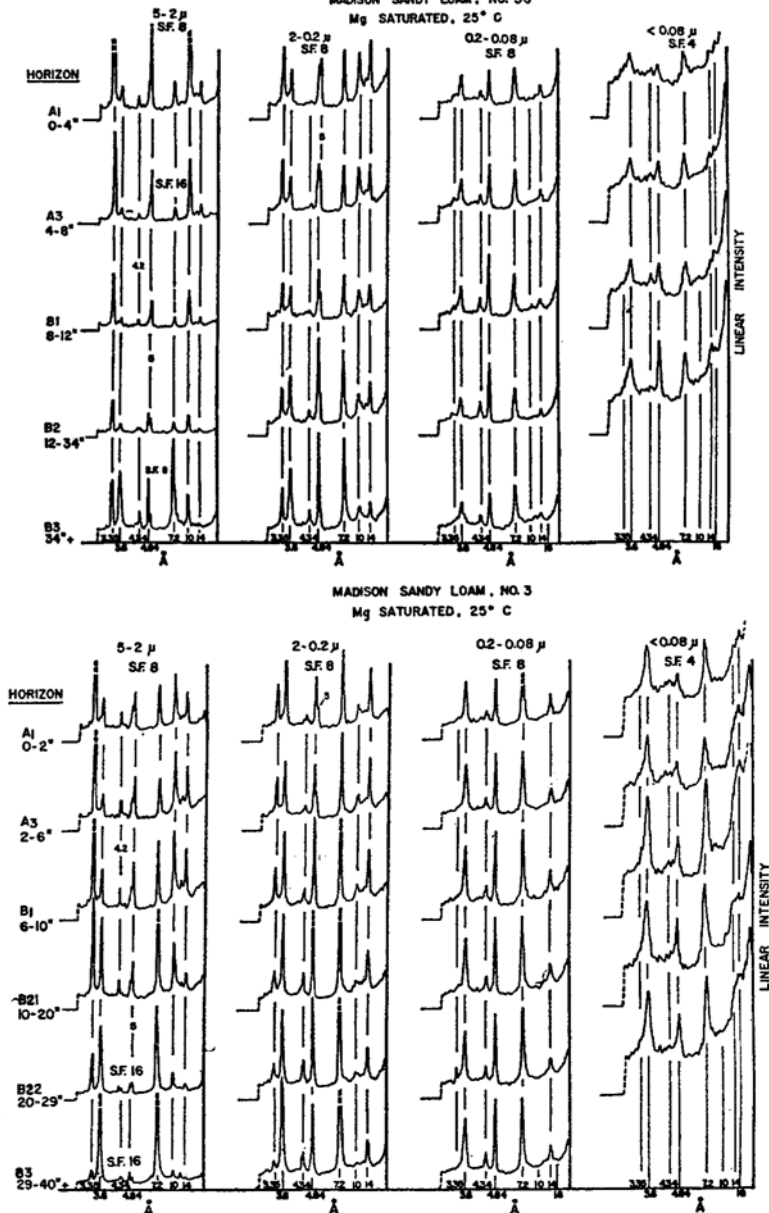


FIGURE 1.—X-ray diffraction curves for glycerated fine fractions of non-graphitic Madison and graphitic Madison. Number 3G is the graphitic profile.

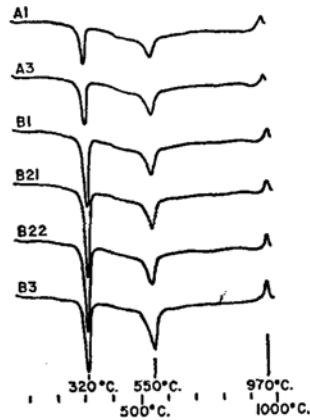


FIGURE 2.—Differential thermal curves for 2-0.2 μ clay from the non-graphitic Madison soil.

The abundance of kaolinite in the B2 and B3 horizons indicated that conditions for its formation were more favorable in the less acid lower horizons as suggested by Rich and Obenshain (1955). The increase in the proportion of vermiculite and mica to kaolinite nearer the surface probably was because of removal of weathering products in solution and suspension and continuous replenishing of vermiculite and mica by weathering of coarser fractions. This interpretation was supported by the decrease in quartz and the increase in mica with increasing depth for coarse silt (Fig. 3) and sand fractions.

Conditions for formation of gibbsite were evidently more favorable in lower horizons also. As minerals weathered near the surface, components of the soil solution moved downward through the profile. Higher concentration of organic chelates and higher acidity in surface than subsoil horizons would contribute to aluminum leaching to greater depths in the profile. That higher amounts of gibbsite were not present in lower horizons might have been because of some resilication of gibbsite to kaolinite, a postulation offered by Alexander *et al.* (1941) and McCaleb (1959).

The clay of the graphitic Madison profile indicated less weathering than for the nongraphitic one. More mica was present in the coarse and medium clay of graphitic than nongraphitic Madison (Fig. 1 and Table 3). Kaolinite was lower in coarse and medium clays of the graphitic than in the nongraphitic profile. Gibbsite was lower in the coarse clay of graphitic than nongraphitic Madison, and was about the same in the medium clays of both profiles. These differences in weathering were not attributed to the influence of the small amount of graphite present.

Mineralogical Properties of Coarse and Medium Silt and Sand

Quartz was the most abundant mineral in the upper part of the profile (Fig. 3), and it decreased with depth while mica increased and was most abundant in the lower portion of the profile. The variations in quartz and mica contents with depth were evident on visual inspection of the sand fractions. Particularly significant was the occurrence in these coarse

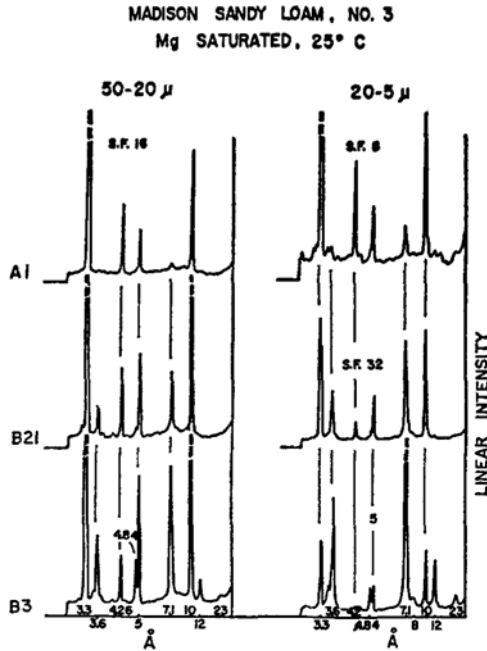


FIGURE 3.—X-ray diffraction curves for glycerated silt fractions of the nongraphitic Madison soil. S.F. is scale factor.

fractions of kaolinite and gibbsite. The higher amounts of these minerals in both the coarse and medium silt fractions occurred in the nongraphitic Madison profile. Kaolinite was the most abundant mineral of the medium silt fraction in the lower portion of this profile (Fig. 3). The occurrence of such high amounts of gibbsite and kaolinite in the coarse and medium silt fractions further substantiated the high degree of weathering indicated by morphological investigations and studies of the clay fractions. A question arises as to the source of these minerals in medium and coarse silt fractions. While much of the gibbsite and kaolinite of clay size resulted from translocation of solution products, it is suggested that these minerals found in larger fractions resulted from direct weathering in place of feldspars and

possibly micas. Other workers (Alexander *et al.* 1941; McCracken, 1963; Alexander and Cady, 1962) have observed feldspar and biotite weathering directly to kaolinite and gibbsite.

High amounts of kaolinite and gibbsite in the silts further substantiated the high degree of weathering of these soils. Examination of weathered parent rock by optical methods revealed mica and feldspar pseudomorphs composed of kaolinite and possibly gibbsite. In thin sections of slightly weathered rock it was estimated that two-thirds to three-fourths of the mica had been altered. Obviously, proximity to rock, at a reasonable depth, is no indication of low intensity of weathering.

CONCLUSIONS

Mica and intergradient vermiculite–chlorite were the most abundant minerals in clays of A horizons. Kaolinite and gibbsite were the most abundant clay minerals in B horizons. The high amounts of kaolinite and gibbsite in the lower profile indicated these minerals were formed from leaching products.

Morphological investigations and laboratory analyses showed that Madison soils are highly weathered. The particle size and free iron oxide distribution and soil structural variation with depth indicated destruction of mica, feldspar, garnet and other more weatherable minerals in the upper horizons and translocation of their weathering products down the soil profile as described by classical concepts of soil formation. However, the greater amounts of gibbsite and kaolinite in the lower horizons gave them higher weathering indices than for surface horizons. This is evident from content of these minerals in the fractions and more striking when considered on the whole soil basis.

The coarse silt and sand fractions showed an increase in mica with depth and a decrease in quartz; this indicated greater weathering intensity near the surface as generally expected in a well-drained soil. The presence of kaolinite and gibbsite in the coarse fractions of lower horizons probably means that they formed in those layers by direct weathering from feldspar and mica.

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