

CLAY MINERALS IN PENNSYLVANIA SOILS* RELATION TO LITHOLOGY OF THE PARENT ROCK AND OTHER FACTORS—I

LEON J. JOHNSON

Department of Agronomy, The Pennsylvania State University, University Park, Pa. 16802

(Received 27 October 1969)

Abstract—Clay mineral data have been obtained on 348 soil profiles representing 117 different soil series from 28 of Pennsylvania's 67 counties. The surface rock from which the soils were formed ranged from Pre-Cambrian to Tertiary–Pliocene and includes igneous, metamorphic and various types of sedimentary rocks. Major attention was focused on the subsoil mineralogy. Mica was found to be the most predominant clay mineral in terms of amounts and frequency of occurrence. It is dominant or co-dominant in 82 per cent of the profiles. In shale derived soils it is important in 95 per cent of the cases and in 68 per cent of the limestone soils. Kaolinite is a prominent component of soils derived from sandstone and metamorphic rocks. Montmorillonite was detected in over half of the soils but is very infrequently a prominent component and is more frequently found in the poorly drained soils. A mica-kaolinite suite is characteristic of soils from Pennsylvanian age rock whereas soils derived from Devonian, Mississippian, and Ordovician age rock had a mica-chlorite suite. The chlorite is frequently found weathered to chlorite-vermiculite in a 1:1 ratio. Gibbsite, talc, and pyrophyllite have been identified but only rarely occur. A difference in clay mineral types is frequently found among different profiles of the same soil series. Soils derived from limestone and highly calcareous rock may have rather unusual clay suites such as the dominance of a well-crystallized trioctahedral chlorite, well crystallized mica, and soils approaching a monomineralic character in mica.

INTRODUCTION

It is commonly recognized that clay minerals play an important role in determining the physical and chemical properties of soils. They are also of unique value for understanding weathering and soil forming processes. Clay mineral analyses have, therefore, been an integral part of a soil characterization program that has been underway in Pennsylvania during the past decade.

In this time a considerable amount of data on clay mineral distribution in the soils of Pennsylvania has been accumulated. Many differences in the clay mineral composition among soil series and also among profiles within a series (Johnson *et al.*, 1963) have been found. What, it may be asked, are the factors that determine the clay mineral composition of a soil? Clay is ordinarily considered to be that portion of a soil that results from the processes of weathering acting on pre-existing minerals or amorphous material.

Barshad (1966) concluded that the chemical environment determines the kind and frequency distribution of clay minerals in a soil exclusive of those inherited from the parent material. A high base status produced by such things as highly basic parent material or poor drainage induce

montmorillonite formation. Kaolinite-halloysite formation is favored by a highly base depleting environment such as high rainfall, good drainage and high permeability. Intermediate conditions are conducive to vermiculite formation either by synthesis or mica alteration. Keller (1956) outlined in some detail the environmental conditions favorable for the genesis of the different clay mineral types.

According to Mitchell (1965) and MacKenzie (1965a) clay minerals in a soil may originate by means of three different mechanisms: (1) inheritance from parent material, (2) alteration and degradation of primary minerals, and (3) synthesis. These mechanisms operating under different environmental conditions together with the process of the translocation of material result in soil clay mineral composition becoming a function of soil depth. Weathering with its attendant alteration and synthesis is most intense at the soil surface and decreases in intensity with depth increase. This is the horizon depth function of Jackson *et al.* (1948) and leads, in many cases, to the development of a profile of weathering in which clay mineral distribution changes with depth. Examples of this in Pennsylvania soils were given by Johnson *et al.* (1963).

In this communication it is desired to examine the influence of parent rock on soil clay mineral

*Journal Series Number 3663.

composition. Attention, therefore, will be focused on the lower most soil horizon sampled. In the vast majority of cases this is a C-horizon, the soil parent material. It is here that the contribution of the parent rock would be least complicated by the aforementioned processes.

MATERIAL AND METHODS

Data have thus far been obtained on 348 soil profiles representing 117 different soil series. Twenty-eight of the 67 counties in Pennsylvania are represented. The counties sampled, Fig. 1, are so distributed over the state that all the major

which define the concept of the soil series to be sampled were such as to fall in the mid-range rather than near the extremes. Sampling sites were very carefully selected by the people who were most knowledgeable with the soils in the field. As a result the samples taken were the "best" available in terms of a modal profile. This point is worth keeping in mind, particularly when mineral variability within soil series is discussed later.

Clay mineral analyses were made on the $<2 \mu$ fraction obtained from soil samples which had been treated with hydrogen peroxide to remove organic matter and had the free oxides removed

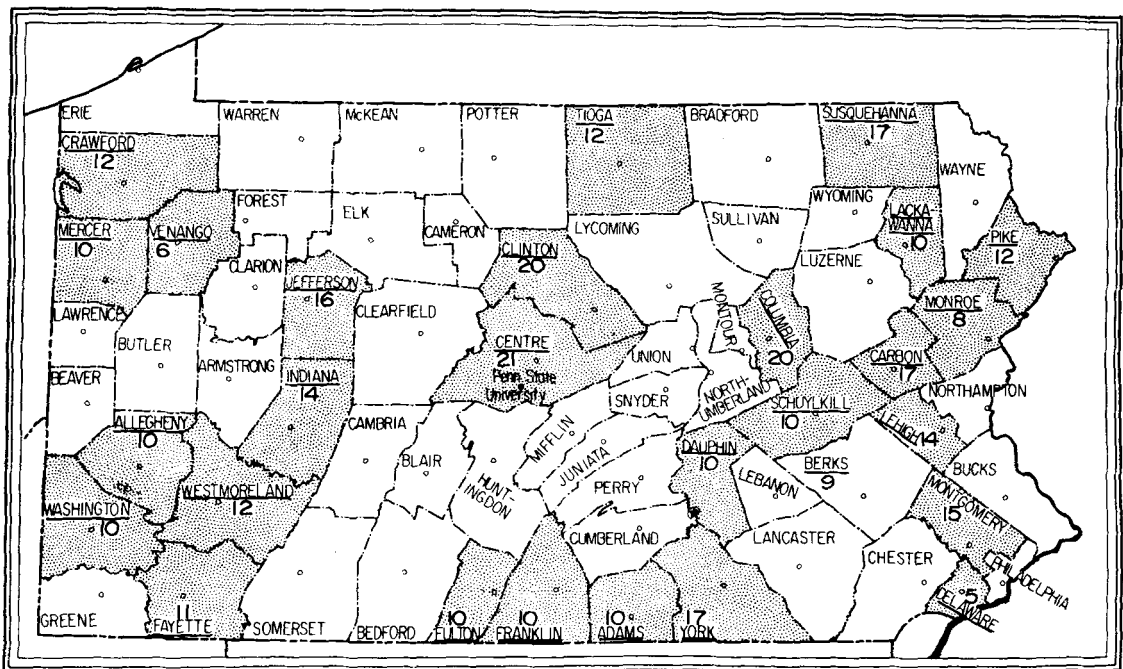


Fig. 1. Counties in Pennsylvania in which samples were obtained. The numerals indicate the number of profiles sampled. Counties are stippled except for Berks.

physiographic provinces within Pennsylvania are included. Since surface geology correlates very closely with physiography, soils formed from rocks of all the geologic periods exposed at the surface from pre-Cambrian through Tertiary Pliocene are represented. In most cases, factors other than the kind of parent rock were considered in the selection of the soil types sampled. But it is believed that the final sample distribution is such that the major features of the surface geology as to rock type and age are adequately represented to detect major trends.

The soil sampling sites were selected as to be modal. That is, the values of the soil parameters

either by the nascent hydrogen method of Jeffries (1947) or the citrate-dithionite-bicarbonate method of Aguilera and Jackson (1953) as modified by Kittrick and Hope (1963). Oriented mounts of the clay separates for X-ray diffraction analysis were made by drying a clay suspension on to a glass slide. A magnesium and a potassium saturated sample were prepared. Diffraction analyses were obtained for the magnesium saturated sample after air drying at room temperature and after ethylene glycol solvation by the method Kunze (1955). The potassium saturated sample was analyzed after air drying and after heating to 350° and 550°C.

Estimates of the amounts of the different clay

types in a sample are semi-quantitative being based on relative peak intensities. Soil clays that approached monomineralic character with respect to kaolinite, mica, and vermiculite were mixed in varying proportions by weight. X-ray diffractograms were prepared from these mixtures which were then used as standards to calibrate the semi-quantitative estimates.

RESULTS AND DISCUSSION

In the summarization of the data the soils were placed into various groups based on a number of different criteria such as parent rock type, geologic age of the parent rock, and soil order as defined in *Soil Classification, A Comprehensive System* (1960). Each group was then characterized by determining the percentage of the samples that have a given clay mineral type as a dominant or co-dominant (in cases where two or more minerals were of equal importance) constituent. A single clay mineral type was dominant in only about half the cases. Where two clay minerals were co-dominant the profile was counted twice. As a consequence, when the percentage figures within a group are summed the total exceeds one hundred in many instances.

The percentage data that resulted were then used to construct histograms illustrating the distribution of clay types within a soil grouping, Figs 2, 8, 9, 11 and 12. To simplify the graphs the clay mineral types were limited to three categories, illite, kaolin, and a third called "other", which

includes the 14 Å type minerals, vermiculite, smectites, and chlorite along with interstratified combinations of these plus illite in some cases. Beneath each group-classification shown on a figure are listed the number of soil profiles from which the percentage data were summarized. It may be noticed that all 348 profiles may not be included under each criterion of classification. For example, in Fig. 2 only 341 profiles are used. Seven of the profiles did not fit into any of the groups and consequently were omitted. It was felt that 3 or 4 profiles are insufficient to give reliable information. In the paragraphs that follow each of the criteria used to group the soil profiles is discussed separately.

Samples were selected to illustrate the clay mineral types found in various soils. Table 1 lists the soil series used and also includes other descriptive information of interest.

Lithology of the parent rock. The lithological criteria, Fig. 2, used to establish the groupings may appear to be rather general. Sandstone, for example, could very logically be subdivided into arkosic, graywacke, and quartzitic groups. The same may be said for the other categories. Since these subdivisions would be based on mineralogical and textural differences there would appear to be good justification to so proceed. This was not done for a number of reasons. In many cases the information available on the nature of the parent rock was insufficiently precise to permit subdivision. Subdividing would also have resulted in groups

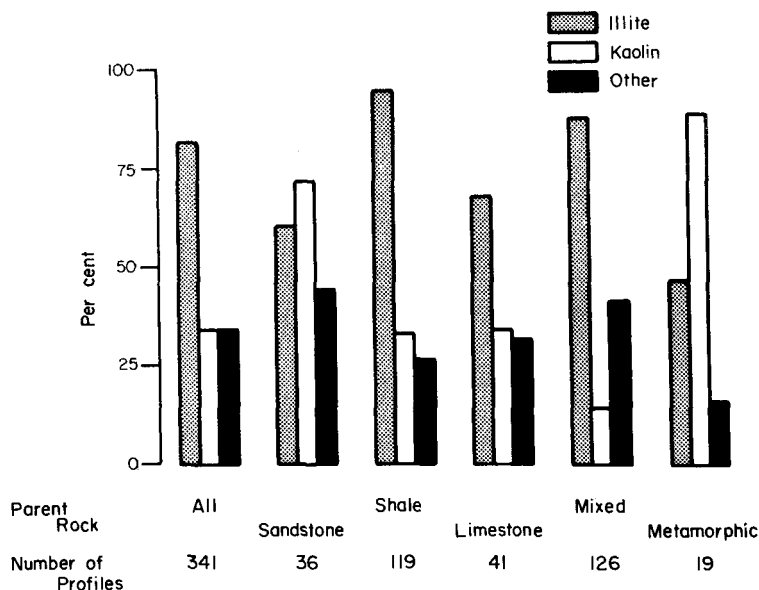


Fig. 2. Lithology of parent rock and distribution of clay types.

Table 1. Descriptive information on the soil series used to illustrate clay mineral types found in soils derived from different type parent rocks

Soils series	Sample number*	Soil horizon	Geology	Physiographic province	Pa. county	Soil order
<u>Sandstone</u>						
Dekalb	18-4-6	C ₁	Silurian-Tuscarora	Valley and Ridge	Clinton	Inceptisol
Dekalb	32-2-7	C ₁	Pennsylvania-Allegheny	Appalachian Plateau	Jefferson	Inceptisol
Gatesburg	14-11-6	B ₂₃	Cambrian-Gatesburg	Valley and Ridge	Centre	Spodosol
Clymer	54-5-8	C	Pennsylvania-Pottsville	Valley and Ridge	Schuykill	Ultisol
Clymer	54-6-7	B ₂₂	Pennsylvania-Pottsville	Valley and Ridge	Schuykill	Ultisol
<u>Shale</u>						
Bedington	22-8-8	C	Ordovician-Martinsburg	Valley and Ridge	Dauphin	Ultisol
Calvin	29-11-5	C ₂	Mississippian-Mauch Chunk	Valley and Ridge	Fulton	Inceptisol
Gilpin	33-6-5	C ₁	Pennsylvanian-Conemaugh	Appalachian Plateau	Jefferson	Ultisol
Leck Kill	19-15-5	C ₁	Devonian-Catskill	Valley and Ridge	Columbia	Ultisol
<u>Glacial Till</u>						
Ravenna	43-6-7	C _g	Wisconsin. Acid sandstone and shale. Pennsylvanian	Glaciated, Northwest	Mercer	Alfisol
Platea	20-11-8	11 B × 5g	Wisconsin. shales, Devonian	Glaciated, Northwest	Crawford	Alfisol
Erie	59-8-7	C	Wisconsin, Sandstone and shale, Devonian	Glaciated, Northeast	Tioga	Inceptisol
Wurtsboro	52-9-8	B' × 1	Wisconsin, Sandy, Devonian-Catskill	Glaciated, Northeast	Pike	Inceptisol
Canfield	45-10-7	B × 5	Wisconsin, Calcareous Devonian-Catskill	Glaciated, Northeast	Monroe	Alfisol
<u>Limestone</u>						
Duffield	28-11-7	C	Cambrian-Elbrook	Valley and Ridge	Franklin	Alfisol
Duffield	39-8-9	C ₁	Ordovician-Hershey, Myers-town	Valley and Ridge	Lehigh	Alfisol
Edom	14-1-4	C ₂	Ordovician-Trenton	Valley and Ridge	Centre	Alfisol
Edom	28-4-3	B ₃	Ordovician-Chambersburg	Valley and Ridge	Franklin	Alfisol
<u>Igneous and Metamorphic</u>						
Mount Lucas	1-16-6	C ₁	Triassic-Diabase	Piedmont	Adams	Alfisol
Mount Lucas	1-17-6	C ₂	Triassic-Diabase	Piedmont	Adams	Alfisol
Neshaminy	46-17-9	B ₃₂	Triassic-Diabase	Piedmont	Montgomery	Alfisol
Chester	23-2-7	C ₁	Pre-Cambrian-Baltimore-Gneiss	Piedmont	Delaware	Ultisol
Chester	23-3-8	C ₂	Lower Paleozoic-Wissahickon Gneiss	Piedmont	Delaware	Ultisol
Highfield	1-11-6	C ₁	Metarhyolite	Blue Ridge	Adams	Alfisol
Highfield	1-12-6	B ₃	Greenstone	Blue Ridge	Adams	Alfisol

*Number assigned by the Soil Characterization Laboratory, The Pennsylvania State University, Department of Agronomy.

†Age of till.

represented by only a small number of profiles. It was also felt that since the differences in mineral composition among rock categories are greater than within the categories more meaningful contrasts in clay mineralogy would result by not subdividing.

In Fig. 2 the category titled "mixed" includes those soils where the parent rock was described as being some combination of sandstone, siltstone, shale and limestone. Since there was no valid reason for placing these soils within one of the other categories, they were grouped together as mixed. In all cases the parent rock is sedimentary in type although in soils derived from glacial material some igneous or metamorphic erratics are present.

When all the soils, regardless of parent rock lithology, are combined into a single group it is seen in Fig. 2 that in over 75 per cent of the soils mica is the most prominent clay mineral in the parent material. This perhaps is not unexpected when it is recognized that over 94 per cent of the soils are derived from sedimentary rock and that a goodly portion of these sediments were of marine origin. Mica has been shown to be a rather prominent clay component in sedimentary rock of marine origin, Powers (1957). Ninety-five per cent of the shale derived soils have mica as a dominant clay mineral. In the "mixed" group mica is also the most prominent clay mineral constituent, an indication, perhaps, that shale is the more abundant parent rock than other rock types within this group. Limestone derived soils likewise are characterized by the importance of mica in the clay fraction. Clay composition in these soils closely parallels the clay petrology of shales which have been shown to have a predominance of mica, Weaver (1959).

Examples of clay suites from soils derived from Paleozoic shales are seen in Fig. 3 which illustrates the prominence of mica in these soils. It is dominant in each of the clay suites with exception of Gilpin (33-6-5), which is formed from Pennsylvanian shale and in which a well crystallized kaolinite is present in approximately an equal amount. This is also the case for soils formed on Triassic shales. The lower three diffractograms in Fig. 3 are from soils with a mica-chlorite combination that is typically found in soils derived from pre-Pennsylvanian shales.

Limestone derived soils likewise are characterized by the importance of mica in the clay fraction, Fig. 2. This again is in line with the results of Weaver (1959) who found the clay separate from limestones to have a predominance of mica. Another characteristic of limestone soils is the variability in clay mineralogy within a soil

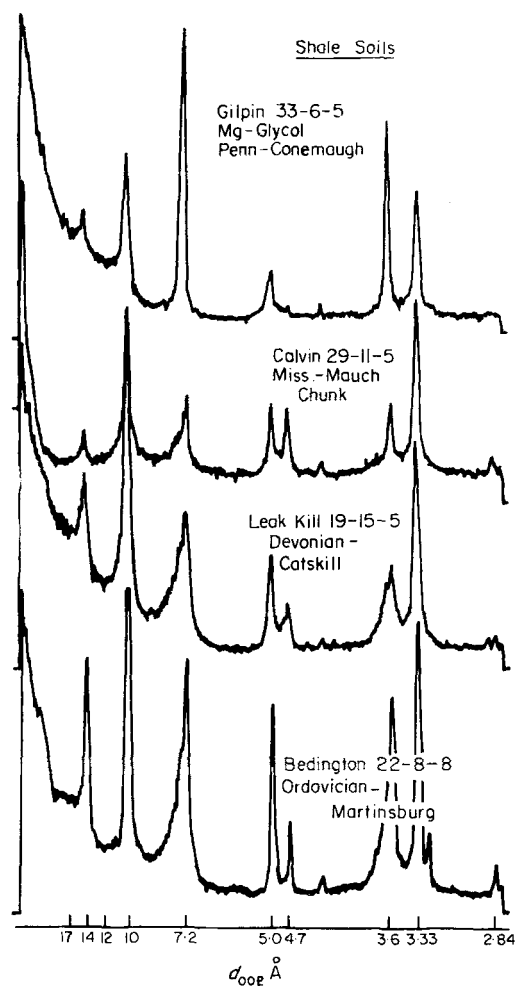


Fig. 3. Clay minerals in shale soils.

series and, in some soils, a quite unusual clay mineralogy. Clay suites from some limestone soils are illustrated in Fig. 4. The Duffield soils, 28-11-7 and 39-8-9, are derived from silty or argillaceous limestone. One, 39-8-9, has a greater amount of shaly impurity and is formed on what is locally called, in Lehigh County, Pa., "cement rock", an important raw material in the manufacture of Portland cement. The unique feature of this soil is an unusually well crystallized dioctahedral mica in the clay. Along with mica is a prominent montmorillonite component and trioctahedral chlorite. Intense folding and faulting of the rock in the sample area of this soil and the crystallinity of the mica and chlorite suggest metamorphism of the argillaceous material toward schist. The other Duffield, 28-11-7, likewise has unusually well crystallized chlorite and mica in the clay fraction.

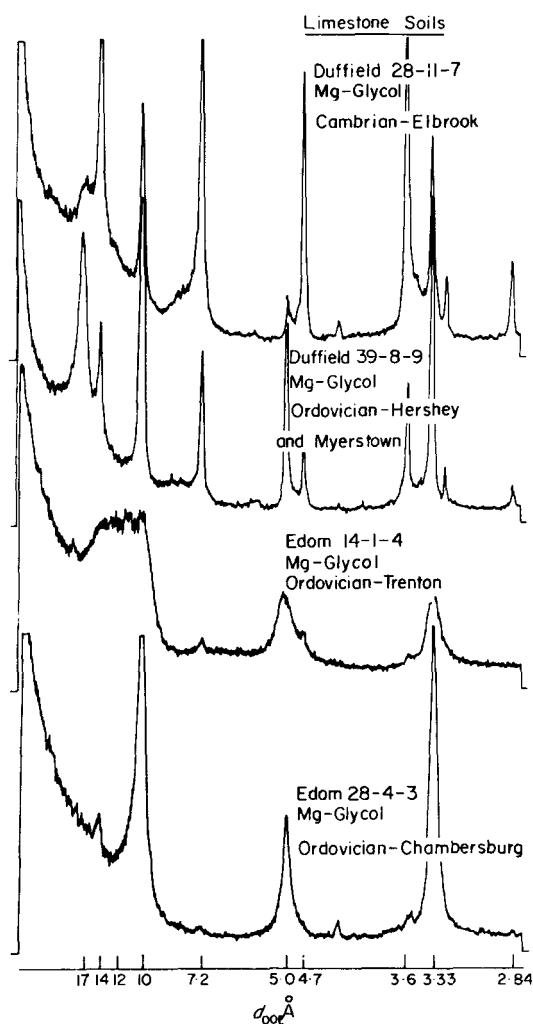


Fig. 4. Clay minerals in some limestone soils.

It is distinct in having a trioctahedral chlorite as the dominant component which is accompanied by a 1:1 interstratified chlorite-vermiculite. The mica in this soil is also unique in being trioctahedral. This is noticeable in Fig. 4 by the very low intensity of the 5.0 Å peak when compared to the 10 Å reflection. In Pennsylvania the overwhelming majority of mica in soils is dioctahedral. The parent rock of this Duffield (28-11-7) is part of the Cambrian Elbrook group which is adjacent to the South Mountain (northern extension of the Blue Ridge) in south central Pennsylvania. In this area the rock has been intensely folded and faulted and it seems likely that the clay suite in this soil is a product of metamorphic activity. Marble with white sericitic partings has, for example, been

reported within the Elbrook in other areas of the state, Jonas and Stose (1930). Another distinctive feature of this soil is the presence of large amounts of authigenic microcline in the fine sands, silt, coarse clay and even in detectable amounts in the fine clay ($<0.2 \mu$).

Clay fractions from two Edom soils developed from limestone, Fig. 4, are distinctly different. The one, 28-4-3, is dominated by mica and, for a soil clay, is very close to being monominerallic. An interstratified mica-montmorillonite is the major component of the other Edom, 14-1-4. The nature of the clay in this soil is very similar to Ordovician K-bentonites derived from volcanic ash reported intercalated in limestones in this same area, Centre County, Pa., by Weaver (1952). The parent rock for this soil is Ordovician-Trenton in age, Table 1.

The soil parent material derived from sandstone and metamorphic rock contrast with the others in having kaolinite as the most frequently occurring dominant clay mineral, Fig. 2. With the sandstone soils this is probably a manifestation of the inheritance mechanism. Glass (1958) has shown that kaolinite was more abundant in sandstones than in adjacent shales in some Pennsylvanian cyclothems of Illinois. Post-depositional weathering in the more permeable sandstone was postulated as a possible explanation. MacKenzie (1956b) examined a number of Scottish soils and found soils from sandstone predominantly kaolinitic and those from shales illitic.

Clay suites from sandstone derived soils are illustrated in Fig. 5. Dekalb (33-2-7) and Gatesburg (14-11-6) depict the dominance of kaolinite. Variability in clay mineralogy for this genre of soil is seen in the other Dekalb (18-4-6) and the two Clymer soils. Dekalb (18-4-6) has considerably less kaolinite but a much higher content of 14 Å phase which, in this case is dioctahedral vermiculite with some development of hydroxy-aluminum interlayers. The two Clymer soils are different even though they developed on the same aged rock, Pennsylvanian Post-Pottsville, within the same county, Schuylkill. Clymer, (54-5-8) is characterized by well crystallized kaolinite and mica whereas Clymer (54-6-7) contains a prominent 14 Å component (primarily vermiculite with a small amount of montmorillonite and chlorite), mica, kaolinite and has the unusual distinction for a soil of containing pyrophyllite. This occurrence of pyrophyllite is suggestive of incipient metamorphism of a hydrothermal nature in the parent rock. Ford and Dana (1932) reported pyrophyllite in thin coal seams in coal slates at Mahoney City, Schuylkill County.

Inheritance is not a valid explanation for the

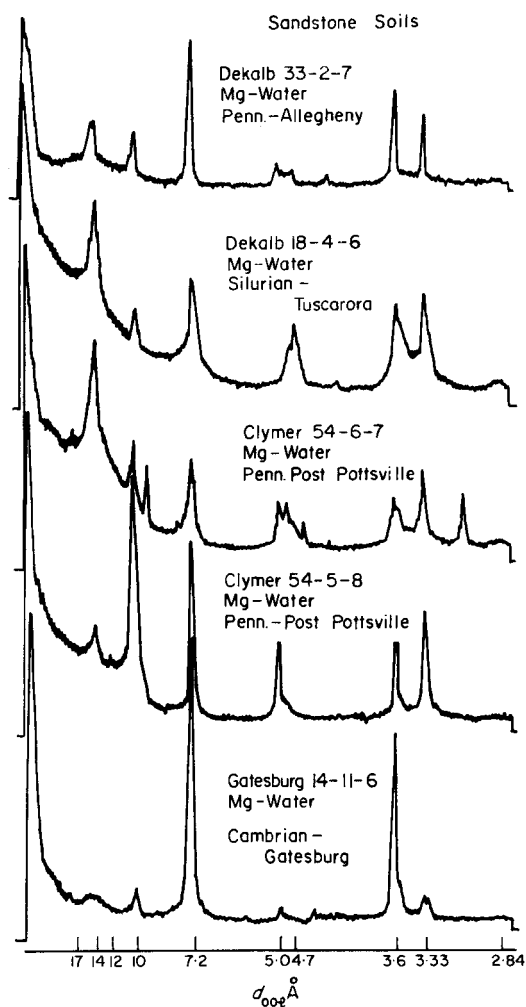


Fig. 5. Clay minerals in sandstone soils.

predominance of kaolinite in the soils associated with metamorphic rocks (schist, gneiss, metarhyolite, and slate), Fig. 2, since kaolinite would not be expected to be found as a constituent of these rocks with the exception of slate. In this case the kaolinite may better be construed as a product of weathering in the formation of the soil parent material. All these soils with one exception are located in the Piedmont physiographic province, the oldest weathering surface in Pennsylvania. In some of these soils gibbsite accompanies the kaolinite. Clay mineralogy of these soils is similar to that of soils formed in the Piedmont province in states farther to the south. The Manor, Chester, and Elioak soil series in Pennsylvania, for example, have similar clay mineralogy to the Appling and Cecil series occurring in the Carolinas, Virginia,

and Alabama (Rich, C. I., and Kunze, G. W., eds. 1959). In these soils kaolinite is dominant and is associated with gibbsite, vermiculite, vermiculite-chlorite, illite and in some cases montmorillonite. Examples of this are seen in the two Chester soils in Fig. 6. Both contain a large amount of kaolinite along with lesser amounts of vermiculite, mica, and montmorillonite. One, 23-2-7, has somewhat more montmorillonite and the mica has expandable layers interstratified. The other, 23-3-8, has distinct mica and detectable gibbsite. Kaolinite in 23-3-8 has a lower degree of crystallinity indicated by lower and broader diffraction peaks.

Another pair of samples of a soil developed on metamorphic rock are the two Highfields in Fig. 6. Both profiles were sampled in Adams County, Pennsylvania, and were described as being formed

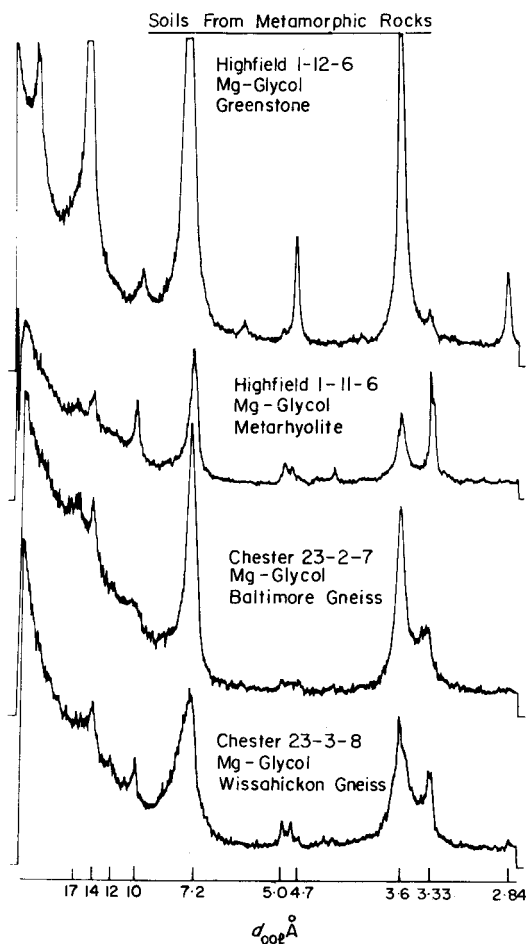


Fig. 6. Clay minerals in some soils derived from metamorphic rocks.

in material weathered from metarhyolite, 1-11-6, and metarhyolite with some greenstone in the sub-soil, 1-12-6. The diffractograms show a very striking contrast in clay types. Prominent kaolinite accompanied by mica, vermiculite and montmorillonite characterizes 1-11-6 whereas 1-12-6 is mostly a highly ordered 1:1 vermiculite-chlorite which has previously been described in some detail, Johnson (1964). Mineralogy of this sample, 1-12-6, indicates that the parent material for this soil resulted overwhelmingly from the weathering of greenstone.

Examples of clay minerals found in soil from igneous rock are illustrated in Fig. 7. The only *bona fide* unmetamorphosed igneous rock known to be exposed on the surface in Pennsylvania is diabase that was intruded into the Triassic sediments found in the Piedmont physiographic province of southeastern Pennsylvania. A group of soils (a catena) differing in internal drainage are known to develop on the diabase—Montalto (well drained), Mount Lucas (moderately well to

somewhat poorly drained) and Watchung (poorly drained). The Neshaminy (46-17-9) and Mount Lucas (1-17-6) have a dominance of a kaolin mineral along with some vermiculite, montmorillonite, and talc. In addition, Neshaminy has detectable amounts of mica, quartz, and feldspar. The kaolin mineral in these soils is unequivocally a product of *in situ* weathering and it appears to be similar to metahalloysite in that the basal diffraction peaks are non-integral, broad, and the $d_{001} \approx 7.31\text{--}7.44 \text{ \AA}$. It differs from metahalloysite in not having the asymmetrical diffraction phenomenon at $d \approx 4.47 \text{ \AA}$ that would be expected for a mineral with tubular morphology even though prepared as an oriented specimen. Perhaps it is a mineral with platy morphology but with a highly disordered stacking of the unit layers. An electron micrograph of this clay would be desirable for making a more positive identification. The other Mount Lucas (1-16-6) contains the same kaolin mineral although a major constituent is a montmorillonite type mineral which contains randomly interstratified layers of chlorite. According to the criteria of Chichester *et al.* (1969) the montmorillonite is a high charge or beidellite type. A magnesium saturated sample expands when solvated with ethylene glycol but not with glycerol.

Detectable amounts of talc are found in all three soils. It appears to be characteristically present in soils derived from Triassic diabase since it has been found in diabase soils at the extreme ends of the occurrence of diabase within the Piedmont of Pennsylvania, Adam and Bucks Counties.

Although the clay fraction of these soils is qualitatively similar and complex mineralogically—vermiculite, mica, montmorillonite, kaolinite, talc, and chlorite—the main constituents are montmorillonite in Mount Lucas (1-16-6) and a kaolin mineral in Mount Lucas (1-17-6) and Neshaminy (46-17-9). It is somewhat surprising to find both a kaolin mineral and montmorillonite being formed in the same environment since factors hypothesized to be favorable to the formation of these two minerals are incompatible (Barshad, 1966; Keller, 1956). Retention of calcium, magnesium, and free silica, which are associated with poor drainage for example, is conducive to smectite formation. Kaolinite would be anticipated under well drained conditions which promotes leaching and removal of bases and silica. It may be that the conditions for the formation of these two minerals are not mutually exclusive. Although the macro-environment may be favorable to one mineral, microenvironments within the same volume could be favorable to the other mineral. A feldspar grain, for example, may be weathering to kaolinite whereas a ferromagnesium mineral is simultaneous-

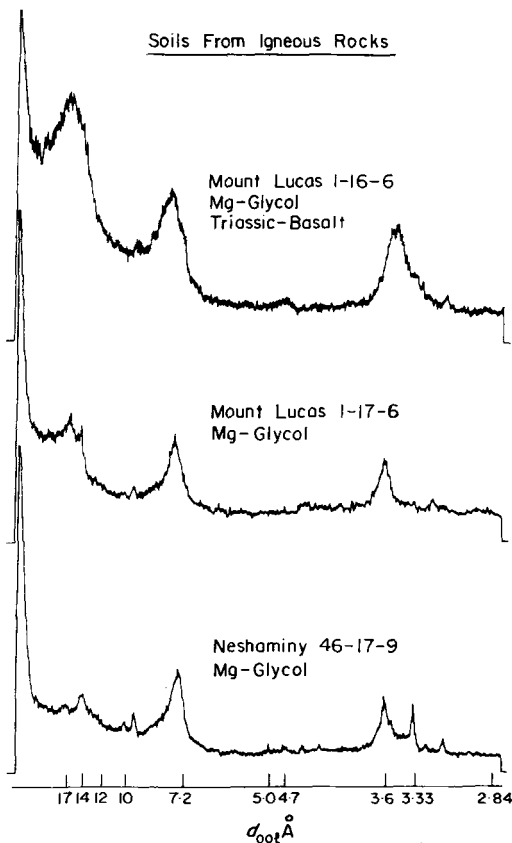


Fig. 7. Clay minerals in some soils derived from igneous (Triassic diabase).

ly being altered to a montmorillonite. In Fig. 7, the Neshaminy (46-17-9) is well drained and has a dominance of kaolinite. The Mount Lucas soils may represent two different degrees of drainage, 1-17-6 being somewhat better drained than 1-16-6 although both are more poorly drained than Neshaminy. Vermiculite in these soils is probably a weathering product of biotite which is found in the silt and fine sands.

In a recent analysis of the $Al_2O_3-SiO_2-H_2O$ system Kittrick (1969) indicated that kaolinite-montmorillonite is a stable association given the proper concentration of silica and alumina in solution and assuming magnesium to be an impurity in montmorillonite as a first approximation.

Geologic age of the parent rock. An analysis of Fig. 8 reveals two main groups. One, on the right hand side of the figure has kaolin as the most frequently occurring dominant clay mineral type.

one, the Triassic and Pennsylvania subgroup, has a much higher occurrence of kaolinite than the Mississippian, Devonian, and Ordovician subgroup. A mica-kaolinite suite is characteristic for this first subgroup, Fig. 3, Gilpin (33-6-5) for example. Glass *et al* (1956) have observed that Pennsylvanian shales are high in kaolinite content. Mitchell and Mitchell (1956) found that Carboniferous sediments gave rise to soils with kaolin mineral contents higher than previously found in any other Scottish soils. The kaolinite in the soils derived from Pennsylvanian shales is a moderately well crystallized mineral, typically having narrow, sharp basal diffraction peaks, Fig. 3, Gilpin (33-6-5). In contrast, the second sub-group is typified by a mica-chlorite suite, Fig. 3, Calvin (29-11-5), Leck Kill (19-15-5) and Bedington (22-8-8). The chlorite, in all cases where it was determined was found to be trioctahedral. It is assumed then

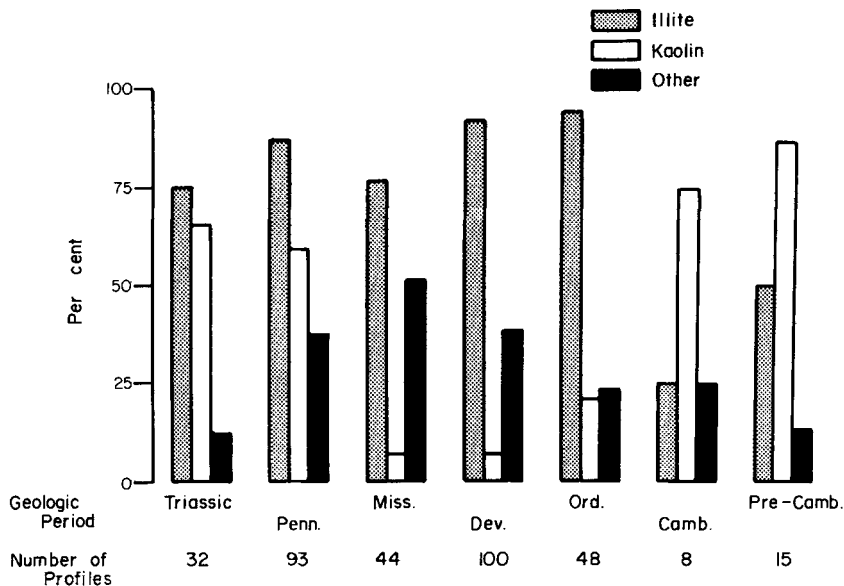


Fig. 8. Geologic age of parent rock and distribution of clay types.

The other group, Triassic through Ordovician, has mica as the most prominent clay type. In both cases, the rock lithology underlies this subdivision. The first group formed from Pre-Cambrian and Cambrian rocks is derived almost entirely from sandstone and metamorphic rocks which, as seen in Fig. 2, are associated with kaolinite, Chester soil. Fig. 6. Mica prominence in the second group is likewise assignable to the dominance of shale as the parent rock type. One feature of this second group is perhaps related to geologic age of the rock. This group can be subdivided into two subgroups;

that the chlorite inherited from these rocks is typically trioctahedral. This subdivision into mica-kaolinite and mica-chlorite mineral suites correlates with the estimate of variation in clay mineral of North American shales with time given by Weaver (1967). He stated that "...a major change in the make up of the clay mineral suite occurred relatively abruptly in the Upper Mississippian (usually at the base of the Chesterian age sediments). The clay minerals in the rocks of the pre-Upper Mississippian are approximately 90 per cent illite and chlorite with illite comprising 80-90 per

cent of the two. Post-upper Mississippian rocks have a complex suite with montmorillonite, mixed layer illite-montmorillonite and mixed-layer illite-montmorillonite and mixed-layer illite-montmorillonite are much more commonly found in soils derived from Pennsylvanian than in older rocks."

Glacial and alluvial parent materials. These distributions are seen in Fig. 9. In this figure the glacial soils are both combined together into one group and also subdivided into pre-Wisconsin and

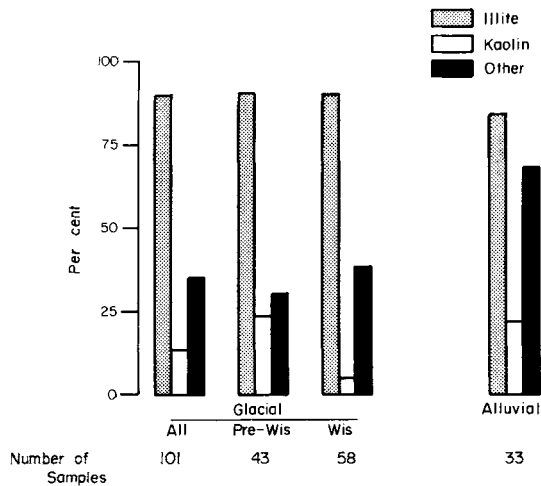


Fig. 9. Distribution of clay types in glacial and alluvial parent material.

Wisconsin age materials. The two groups are very similar. Pre-Wisconsin till does have a somewhat greater frequency of occurrence of kaolinite type clay. Whether this is ascribable to weathering or inheritance from the parent rock is not discernable. Glaciation in Pennsylvania occurred in the northeast and northwest quadrants of the state in an area where Devonian rocks are most commonly found. The similarity between the glacial, Fig. 9, and Devonian, Fig. 8, type distributions is readily apparent.

In Fig. 10 are a group of clays from soils developed in Wisconsin age glacial till. Both the Northeastern and Northwestern glaciated area of Pennsylvania are represented. The rocks in the area where the samples were taken are Pennsylvanian and Devonian in age and the till material is primarily a mixture of sandstone, siltstone and shale. Texture of the soils (silt loam, loam, and clay loams) suggests a dominance of shale in all except the Wurtsboro (52-9-8) in which a fine sandy loam texture indicates a greater influence of sandstone. Ravenna (43-6-7) is developed from Pennsylvanian rock and has the typical mica-kaolinite suite; the

two minerals being about equally abundant. The other four soils have a mica-chlorite suite with a dominance of mica. As previously mentioned this clay combination is typical for pre-Pennsylvanian shales, in this case, Devonian.

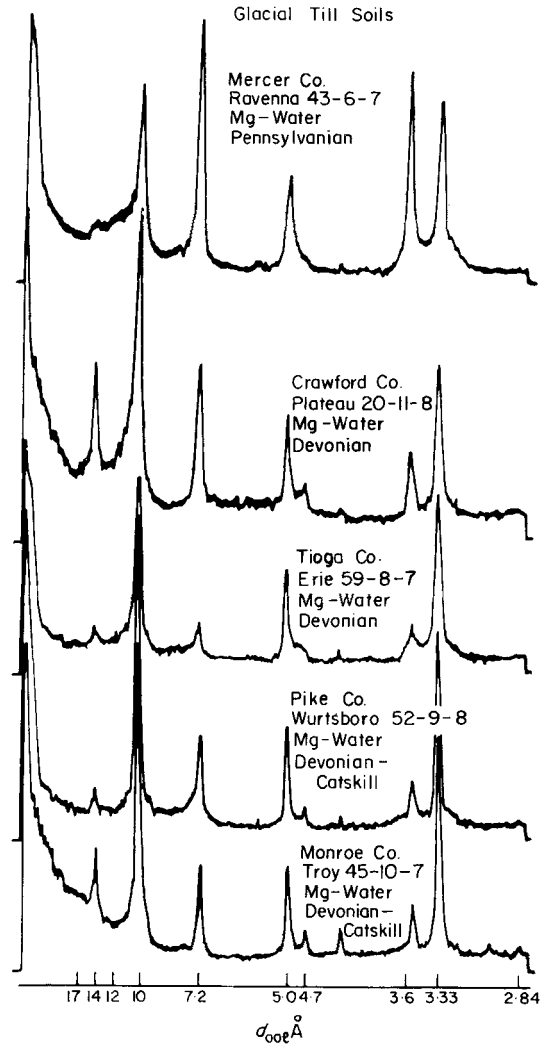


Fig. 10. Clay minerals of some glacial till soils.

Significance of the distribution of dominant clay types in the alluvial soil parent material is evident when the histogram in Fig. 9 is compared to that for "All" soils in Fig. 2. The prominence of the 14 Å group for the alluvial soils is a direct result of the mode of origin of these soils. In mature soils in Pennsylvania the A-horizon typically contains a greater proportion of the 14 Å-type clay minerals than the subsoil, Johnson *et al.* (1963).

This is a consequence of the weathering within the clay fraction taking place in the soil; mica → vermiculite → vermiculite-chlorite intergrade. With a predominance of sheet-type erosion favoring removal of surface soil over subsoil, alluvium should have a clay type distribution reflecting this preference. This is shown in Fig. 9.

Classification as to soil order. The great majority of soils in Pennsylvania fall into three of the soil orders established in *Soil Classification, A Comprehensive System* (1960)* – Inceptisols, Alfisols, and Ultisols. These three orders replace respectively, Sol Brun Acides, Gray-Brown Podzolic, and Red-Yellow Podzolic in *Soils and Men* (1938)†. The orders are listed in a sequence of increasing degrees of weathering.

Clay mineral type distribution with respect to these three soil orders is given in Fig. 11. The distribution of soils derived from the various rock lithologies is fairly uniform among the three orders with exception of the limestone soils of which all

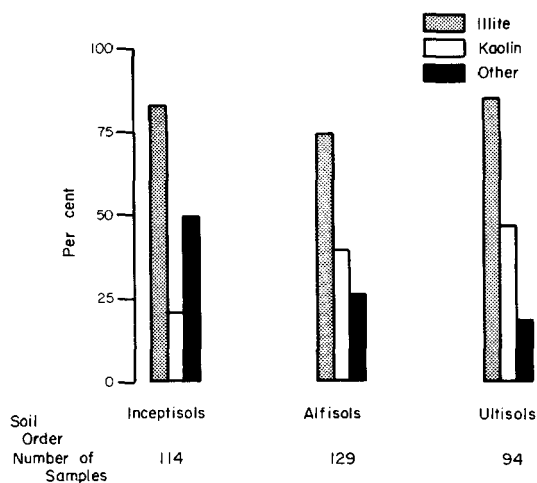


Fig. 11. Soil order and distribution of clay types.

but one are Alfisols. Mica is very similar in the three cases. The main difference is the greater frequency of kaolinite dominance in Alfisols and Ultisols when compared to Inceptisols. In the Inceptisols the 14 Å types are more prominent than in the other two. Although the distribution is in the correct direction for the degree of weathering of soils in these orders, the differences are not of sufficient magnitude to be definitive.

**Soil Classification, A Comprehensive System* (1960), U.S.D.A. 265 pp., Washington, D.C. 20402.

†*Soils and Men* (1938), Yearbook of Agriculture, U.S.D.A., 1232 pp., Washington, D.C. 20402.

Dominance of a single clay mineral type. In Fig. 12 are the histograms of the distribution of clay mineral types within a group of soils developed from similar rock type and in which a single clay mineral type is clearly dominant. Unlike the histograms in the other figures the summation of the three columns for each rock type here does equal 100 per cent. For almost all cases in the shale group mica is dominant. This again illustrates the importance of mica in shale. In the sandstone

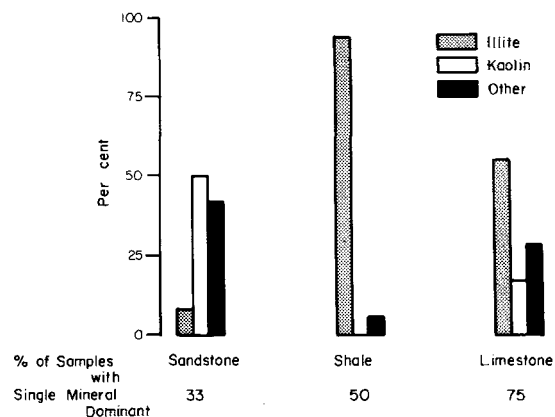


Fig. 12. Frequency of dominance of a single mineral type.

group kaolinite is most outstanding although the 14 Å type (primarily vermiculite and vermiculite-chlorite intergrade) is a close second. The reason for the prominence of the 14 Å material is not certain. Perhaps, as has been hypothesized by Glenn *et al.* (1960) this clay is a precursor of kaolinite. It is of interest in this respect that in those soils in which the vermiculite-chlorite clay is abundant there is no indication of increase of kaolinite between subsoil and surface which would be anticipated as you progress from less to greater weathering intensity. The main change is an increased heat stability of the vermiculite-chlorite clay at the surface. This, no doubt, is related to the increased development and stabilization of aluminum hydroxy type interlayers.

The limestone group has a more even type of distribution of clay types than shale with a preference for mica. It is within the limestone soils, though, that unusual clay mineral composition is often found. In a Duffield soil in Franklin County, Pa. a trioctahedral chlorite is a dominant component. Many Edom soil profiles approach a monominerallic character with mica as the clay mineral. Examples of this are illustrated in Fig. 4.

Drainage. That degree of drainage influences mineral weathering and mineral synthesis is well known. One relationship established is the associa-

tion of montmorillonite with impeded drainage. As a consequence of poor internal drainage leaching intensity is reduced and cations and silica released through weathering tend to remain in the soil. Iron is mobilized because of the occurrence of reducing conditions. This type of environment, especially where a source of magnesium is present, is favorable to the formation of montmorillonite, Ross and Hendricks (1945), Keller (1956), and Grim (1968). Conditions of this type in soils would be expected to be expressed most highly in the subsoil of an area of poor drainage. In Table 2 the soil samples have been grouped according to four

Table 2. Occurrence of montmorillonite type clay minerals as related to soil drainage class*

	WD	MWD	SPD	PD
	Per cent of Clay Fraction			
Dominant Detected	2	13	10	6
Not dominant	44	47	72	57
Not detected	54	40	18	37

*WD—Well drained; MWD—Moderately well drained; SPD—Somewhat poorly drained; PD—Poorly drained.

drainage classes. Within each drainage class the percentage of cases in which montmorillonite is (1) dominant, (2) detected but not dominant, and (3) not detected is listed. The data do indicate a definite bias for more frequent occurrence of montmorillonite in soils with poor drainage. This relationship is manifest even though all the soils of different parent rocks, textures, and age are lumped together, providing fairly strong evidence for its validity.

SUMMARY

The relationship between the clay mineral composition of the soil parent material (C-horizons) and parent rock lithology, age of rock, and a number of other factors has been examined. Parent rock is a major factor influencing, through inheritance, the kind of clay minerals found in soil parent materials. This is particularly true for sedimentary rocks, the minerals of which have already been subjected to at least one cycle of weathering. Mica, by far, is the most prevalent mineral and is particularly dominant in shale derived soils. Accompanying mica are a fairly well crystallized kaolinite in Pennsylvanian aged shales and chlorite in Mississippian, Devonian, and Ordovician shales. In many of these soils the chlorite is interlayered

with vermiculite in a 1:1 ratio. Sandstone soils are characterized by kaolinite but in some, particularly the Dekalb series, dioctahedral vermiculite and vermiculite-chlorite intergrade are common. Although mica is most frequently the dominant clay mineral in subsoils of limestone or highly calcareous parent rock, other clay types are often predominant. In some cases rather unique clay types are found to be dominant such as well crystallized trioctahedral chlorite and a well crystallized mica. Soil parent material formed from igneous and metamorphic rock is most often typified by kaolinite which, in these cases, is a product of weathering *in situ* rather than being inherited from the parent rock.

Illustrations are given to show the divergence in clay mineralogy between different profiles of the same soil series. Of all the soil series sampled where at least four or more profiles were analyzed differences in clay mineralogy were found in over 50 per cent of the cases.

Acknowledgments—The obtaining of the soil samples and much of the sample preparation work was accomplished by the Soil Characterization Laboratory, Department of Agronomy, The Pennsylvania State University. The efforts of Drs. R. P. Matelski, R. L. Cunningham, and G. W. Petersen and other personnel are gratefully acknowledged. Recognition is also given to J. J. Noll and staff of the Soil Conservation Service, U.S.D.A. in Harrisburg, Pa. for their contribution in selecting and describing the modal soil profiles on which this work is based.

REFERENCES

- Aguilera, N. H. and Jackson, M. L. (1953) Iron oxide removal from soils and clays: *Soil Sci. Soc. Am. Proc.* **17**, 3359–64 and **18**, 223, 350.
- Barshad, I. (1966) Factors affecting the frequency distribution of clay minerals in soils: *Clays and Clay Minerals* **14**, 207.
- Chichester, F. W., Youngberg, C. T. and Harward, M. E. (1969) Clay Mineralogy of soils formed on Mazaina pumice: *Soil Sci. Soc. Am. Proc.* **33**, 115–120.
- Ford, W. E. and Dana, E. S. (1932) *A textbook of mineralogy*: Wiley, New York, 4th Ed., p. 683.
- Glass, H. D., Potter, H. E. and Siever, R. (1956) Clay mineralogy of some basal Pennsylvanian sandstones, clays and shales: *Amer. Assoc. Petro. Geol. Bull.* **40**, 750, 754.
- Glass, H. D. (1958) Clay mineralogy of Pennsylvanian sediments in southern Illinois: *Clays and Clay Minerals* **5**, 277–241.
- Glenn, R. C. Jackson, M. L., Hale, F. D. and Lee, G. B. (1960) Chemical weathering of layer silicate clays in loess-derived Taina silt loam of southwestern Wisconsin: *Clays and Clay Minerals* **8**, 63–83.
- Grim, R. E. (1968) *Clay Mineralogy*: McGraw-Hill, New York, 4th Ed., Chap. 13.

- Jackson, M. L., Tyler, S. A., Weller, A. L., Bourbeau, G. A. and Pennington, R. P. (1948) Weathering sequence of clay-size minerals in soils and sediments. I. Fundamental generalizations: *J. Phys. Colloid Chem.* **52**, 1237–1260.
- Jeffries, C. D. (1947) A rapid method for the removal of free iron oxides in soils prior to petrographic analyses: *Soil Sci. Soc. Am. Proc.* **11**, 211–212.
- Johnson, L. J., Matelski, R. P. and Engle, C. F. (1963) Clay Mineral characterization of modal soil profiles in several Pennsylvania counties: *Soil Sci. Soc. Am. Proc.* **27**, 568–572.
- Johnson, L. J. (1964) Occurrence of regularly interstratified chlorite-vermiculite as a weathering product of chlorite in a soil: *Am. Mineralogist* **49**, 556–572.
- Jonas, A. I. and Stose, G. W. (1930) *Geology and mineral resources of the Lancaster quadrangle*. Pennsylvania Geological Survey, Harrisburg, Pa.
- Keller, W. D. (1956) Clay minerals as influenced by environments of their formation: *Bull. Am. Petr. Geol.* **40**, 2689–2710.
- Kittrick, J. A. (1969) Soil minerals in the Al_2O_3 - SiO_2 - H_2O system and a theory of their formation: *Clays and Clay Minerals* **17**, 157–168.
- Kittrick, J. A. and Hope, E. W. (1963) A procedure for the particle-size separation of soils for X-ray diffraction analysis: *Soil Sci.* **96**, 319–325.
- Kunze, G. W. (1955) Anomalies in the ethylene glycol solvation technique: *Clays and Clay Minerals* **3**, 88–93.
- MacKenzie, R. C. (1965a) The origin of clay minerals in soils: *Proc. of the Ussher Soc.* **1**, 134–151.
- MacKenzie, R. C. (1965b) Clay minerals of Scottish soils: *Pochovovedenie* **4**, 75–87.
- Mitchell, W. A. (1955) A review of the mineralogy of Scottish soil clays: *J. Soil Sci.* **6**, 94–98.
- Mitchell, B. D. and Mitchell, W. A. (1956) The clay mineralogy of Ayrshire soils and their parent rocks: *Clay Minerals Bull.* **3**, 91–97.
- Powers, M. C. (1956) Adjustment of land derived clays to the marine environment: *J. Sediment Petrol* **27**, 355–372.
- Rich, C. I., Seatz, L. F. and Kunze, G. W., eds. (1959) Certain properties of selected southeastern United States soils and mineralogical procedures for their study: *Southern Coop. Series Bull.* **61**, 135–146.
- Ross, C. S. and Henricks, S. B. (1945) *Minerals of the montmorillonite group, their origin and relation to soils and clays*. Geol. Surv. Prof. Paper 205-B. U.S. Dept. of the Interior, Superintendent of Documents, U.S. Government printing office. Washington D.C. 20402.
- Weaver, C. E. (1952) *Mineralogy and petrology of some Paleozoic clays from central Pennsylvania*. Ph.D. Thesis, The Pennsylvania State University, University Park, Pa.
- Weaver, C. E. (1959) The clay petrology of sediments: *Clays and Clay Minerals* **6**, 154–187.
- Weaver, C. E. (1967) Illite and the ocean: *Geochemica et Cosmochemica Acta* **31**, 2181–2196.

Résumé—On a obtenu des informations concernant les minéraux argileux sur 348 coupes de sol représentant 117 séries de sols différents à partir de 28 des 67 comtés de la Pennsylvanie. La roche de surface qui a été à l'origine de la formation des sols était de pré-cambrienne à tertiaire-pliocène et comprenait des roches ignées, métamorphiques et sédimentaires de types variés. L'attention s'est surtout concentrée sur la minéralogie du sol. Le mica était le minéral argileux le plus dominant en terme de quantité et de fréquence de venue. Il est dominant ou co-dominant dans 82% des coupes. Dans des sols dérivés du schiste, il est important à 95% et à 68% dans les sols calcaires. La kaolinite est un élément dominant des sols dérivés de roches métamorphiques et de grès. La montmorillonite a été trouvée dans plus de la moitié des sols, mais sa présence est très irrégulière en tant qu'élément dominant et on la trouve plus fréquemment dans les sols mal drainés. Une suite mica-kaolinite est caractéristique des sols de roches d'âge pennsylvanien tandis que les sols dérivés de roches d'âge dévonien, mississippien et ordovicien avaient une suite mica-chlorite. La chlorite se trouve fréquemment altérée par les intempéries en chlorite vermiculite rapport 1 : 1. Gibbsite, talc et pyrophyllite ont été identifiés mais se rencontrent rarement. On trouve fréquemment, parmi les différentes coupes des mêmes séries de sols, une différence entre les types des minéraux argileux. Les sols dérivés du calcaire et de roches hautement calcaires peuvent avoir des suites argileuses plutôt inhabituelles telles que la dominance d'une chlorite trioctaédrique hautement cristallisée, du mica bien cristallisé et des sols approchant un caractère monominéralique dans le mica.

Kurzreferat—Es wurden Tonmineraldaten von 348 Bodenprofilen erhalten, die 117 verschiedene Boden-serien aus 28 der 67 Provinzen Pennsylvaniens darstellen. Das Oberflächangestein, aus welchen die Böden gebildet waren, erstreckte sich vom Präkambrium zum Tertiär-Pliozän und umfaßt eruptives, metamorphisches und verschiedene Arten von Sedimentgestein. Der Mineralogie des Untergrundes wurde besondere Beachtung geschenkt. Es wurde festgestellt, daß in Bezug auf Mengen und Häufigkeit des Vorkommens Glimmer das vorherrschende Tonmineral bildet. Es ist vorherrschend, oder mitvorherrschend, in 82 Prozent der Profile. In den aus Schiefer stammenden Böden stellt es die Hauptmenge in 95 Prozent dar und in Kalksteinböden in 68 Prozent. Kaolinit ist ein prominenter Bestandteil von Böden, die aus Sandstein und metamorphem Gestein hervorgehen. Montmorillonit wurde in mehr als der Hälfte der Böden gefunden, stellt jedoch selten einen hervortretenden Bestandteil dar und findet sich häufiger in mangelhaft entwässerten Böden. Eine Glimmer-Kaolinit Folge ist kennzeichnend für Böden aus pennsylvanischem Gestein, während die aus devonischem, mississippischem und ordovizischem Gestein stammenden Gesteine eine Glimmer-Chlorit

Folge aufweisen. Der Chlorit wird häufig an Chlorit-Vermiculit in einem Verhältnis von 1:1 verwittert gefunden. Gibbsit, Talk und Pyrophyllit konnten festgestellt werden, kommen jedoch nur selten vor. Häufig wird unter verschiedenen Profilen der gleichen Bodenserie ein Unterschied in den Typen der Tonminerale festgestellt. Die aus Kalkstein und hoch-kalkhaltigen Gesteinen erhaltenen Böden weisen manchmal ungewöhnliche Ton-Folgen auf, wie etwa das Vorherrschen von gut kristallisiertem trioktaedrischem Chlorit, gut kristallisiertem Glimmer, sowie Böden, die sich einem monomineralischen Zustand im Glimmer nähern.

Резюме—Данные по глинистым минералам получены для 348 почвенных профилей, представляющих 117 различных почвенных серий 28 из 67 пенсильванских провинций. Возраст пород, из которых образовались почвы,—от докембрийского до третичного (плиоцен); это изверженные, метаморфические и различные осадочные породы. Основное внимание было сконцентрировано на минералогии подпочвенных грунтов. Найдено, что слюда как по количеству, так и по частоте обнаружения является наиболее распространенным глинистым минералом. Она преобладает или играет большую роль в 82% профилей. В сланцевых перетолженных почвах слюда является важнейшим компонентом в 95% случаев, а в известняковых почвах—в 68% случаев. Каолинит является преобладающим компонентом в почвах на песчаниках и метаморфических породах. Монтмориллонит был обнаружен в более чем половине изученных почв, но очень редко он представляет важный компонент; чаще всего монтмориллонит встречается в слабо дренированных почвах. Ассоциация слюда—каолинит характерна для почв, образованных на породах пенсильванского возраста, в то время как почвам, образованным на девонских, миссисипских и ордовикских породах, свойственна ассоциация слюда—хлорит. Хлорит часто выветрелый (хлорит-вермикулит в отношении 1:1). Гиббсит, тальк и пиррофиллит встречаются редко. Для различных профилей одних и тех же почвенных серий зачастую обнаруживались различия в типах глинистых минералов. Почвы на известняках и богатых известью породах могут содержать весьма необычные ассоциации глинистых минералов, например, с преобладанием хорошо окристаллизованного триоктаэдрического хлорита или хорошо окристаллизованной слюды, а также почвы, приближающиеся к мономинеральным по высокому содержанию слюды.