# Influence of Local Bedrock on the Clay Mineralogy of Pre-Woodfordian Tills of the Grand River Lobe in Columbiana County, Ohio[1]

RICHARD W. VOLPI AND JOHN P. SZABO, Department of Geology, University of Akron, Akron, OH 44325

ABSTRACT. The clay mineralogy of three pre-Woodfordian tills of the Grand River lobe in Columbiana County, Ohio, shows the influence of the underlying Pennsylvanian strata of the Allegheny Plateau. The mean diffraction intensity ratios (DI) of these sandy tills range from 0.5 to 0.7. These ratios are comparable to those of the underlying bedrock; 60% of the variance of the clay mineralogy may be attributed to the bedrock. Weathered bedrock and weathered older drift are possible sources of kaolinite. Locally entrained Pennsylvanian sandstone clasts at the base of the glacier may have acted as tools for extensive abrasion of softer argillaceous shales. This abrasion may have produced tills having a higher kaolinite content than those near the edge of the Allegheny Escarpment in north-central Ohio.

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## INTRODUCTION

Clay mineralogy has been used as a means to differentiate lithologies among tills. Willman et al. (1963) delineated two major source areas of tills in Illinois. The Michigan lobe deposited illitic tills, whereas glaciers flowing from the northwest into Illinois deposited tills dominated by expandable clay minerals. Also, individual till sheets could be differentiated by the relative amounts of various clay minerals. Hallberg (1980) employed clay mineralogy to differentiate tills in eastern Iowa; Ruhe and Olson (1978) used it to distinguish between different provenances of loess in Indiana. Monaghan and Larson (1986) and Monaghan et al. (1986) correlated and differentiated various tills in Michigan using clay mineralogy.

In northeastern Ohio, Droste (1956a, 1956b), Droste and Doehler (1957), and Droste and Tharin (1958) showed that clay mineralogy changed with depth in weathering profiles developed in tills. Willman et al. (1966) examined weathering profiles in Illinois and attempted to quantify changes with depth. They developed the diffraction intensity ratio (DI) which has come into general use. Szabo and Fernandez (1984) used DIs to differentiate among tills of the Cuyahoga lobe of Ohio. They hypothesized that the older pre-Woodfordian Mogadore Till contained more kaolinite and chlorite because of incorporation of Pennsylvanian bedrock. The major purpose of this study is to test the hypothesis of Szabo and Fernandez (1984) by examining the clay mineralogy of pre-Woodfordian tills of the glaciated Appalachian Plateau in an area underlain entirely by Pennsylvanian rocks. Additionally, the causes of vertical and lateral variations in clay mineralogy, if they exist, will be addressed.

STUDY AREA. The study area (Fig. 1) is located in Columbiana County in east-central Ohio. The bedrock underlying Columbiana County is flat-lying Pennsylvanian strata. The upper portion of the Pottsville Group, all of the Allegheny Group, and much of the Conemaugh Group crop out above stream level (White and Totten 1985). Strata consist of sandstones, shales, and minor amounts of limestones. Continuous and discontinuous coal beds also are scattered throughout the area.

Columbiana County was glaciated by the Grand River sublobe of the Erie lobe. At its maximum advance, the glacier covered a little more than the northern half of Columbiana County (Fig. 1). Till is the dominant surficial material in the northern portion of the county, whereas the southern unglaciated portion of the county consists of an extensively dissected upland. All drainage from Columbiana County is toward the south and eventually enters the Ohio River.

GLACIAL GEOLOGY. Newberry (1874) produced the first organized report on glacial geology of northeastern Ohio. Wright (1884, 1889) traced the glacial boundary across Ohio. Leverett (1902) described characteristics and thicknesses of glacial deposits in the area as well as their morphology, distribution, and relative age. For over 50 years G. White mapped the morphology of glacial deposits and determined the stratigraphy of tills. His numerous publications on northeastern Ohio have been summarized in an Ohio Geological Survey Bulletin titled "Glacial Geology of Northeastern Ohio" (White 1982). He also worked with several coinvestigators on the Pleistocene stratigraphy of northwestern Pennsylvania (White et al. 1969). White and Totten (1985) recognized several pre-Woodfordian tills in Columbiana County, which may correlate to those found preserved in a rift structure by Lessig and Rice (1962) at Elkton in the central part of the county.

Pre-Woodfordian tills are the oldest glacial drift found in Columbiana County (Fig. 2). They are from oldest to youngest: Slippery Rock Till, Mapledale Till, and Titusville Till. The Slippery Rock Till is stratigraphically the lowest and oldest glacial deposit in the area. Slippery Rock Till always is weathered and is a reddish-brown sandy clay loam, containing few pebbles (White et al. 1969). Locally a paleosol is developed in it. The Mapledale Till is a yellowish-brown silt loam and rarely is found cropping out at the surface (White and Totten 1985). It usually is oxidized and well leached due to extensive weathering during the Sangamonian Interglaciation. The overlying Titusville Till is an olive-gray loam that oxidizes to olive brown or yellowish brown. Three or more till sheets (or beds) of Titusville Till were deposited during a major and pulsating advance (White and Totten 1985). The 40,000-year age of the Titusville Till (White et al. 1969) has been questioned and reevaluated by Totten (1987). He

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proposed that dated sediments may be younger than the Titusville Till, and that the Titusville Till could even be Illinoian in age.

In northeastern Ohio, Woodfordian tills overlie the Titusville Till and are, from oldest to youngest: Kent Till, Lavery Till, Hiram Till, and Ashtabula Till (White 1960). The Kent Till is a sandy, friable, yellowish-brown loam; it is thin, rarely unoxidized, and unleached. During the youngest advance into Columbiana County, Lavery Till was deposited in the northwestern portion of the county. Lavery Till is a thin, dark brown, clay loam and usually is oxidized and leached (White and Totten 1985). During other ice advances of the Grand River lobe, the Hiram Till was deposited as far south as Mahoning County, and the Ashtabula Till was deposited along the south shore of Lake Erie. Weathering and fluvial erosion have been the dominant geologic processes in Columbiana County since the final ice retreat.

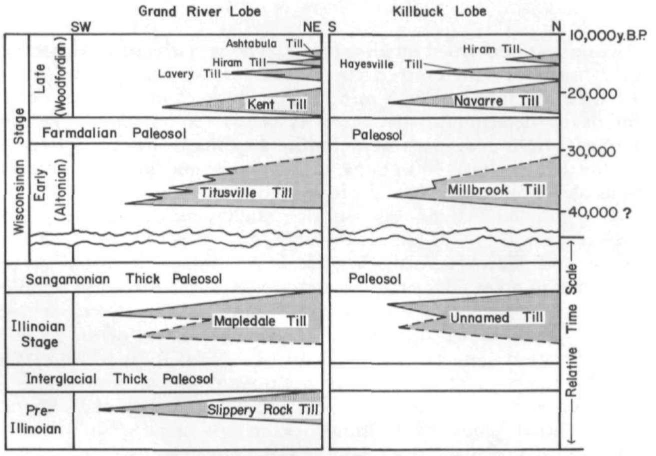

FIGURE 2. Pleistocene stratigraphy of the Grand River and Killbuck lobes (modified from White 1971).

## METHODS AND MATERIALS

Exposures and outcrops of till were studied in active strip mines, in inactive strip mines, along road cuts and along stream cuts, most of which are found in eastern Columbiana County (Fig. 1). Sections were measured with a steel tape. Field descriptions included Munsell color, texture, structure, consistency, degree of leaching, degree of oxidation, depth of leaching, and depth of oxidation. In uniform till, samples were taken every 0.5 m and on either side of contacts; in nonuniform till (i.e., till interbedded with sand stringers or gravel lines), samples were taken at representative intervals.

Textural analysis (<2 mm) was performed on all till samples using pipetting methods of Folk (1974); the silt-clay boundary was 4 $\mu$. Quartz-feldspar ratios (Q/F) were determined for all till samples using a cathodoluminescence technique (Ryan and Szabo 1981). A minimum of 300 grains in the fine-sand fraction was counted (using half the field of view) before the quartz-feldspar ratio was calculated. Percentages of calcite and dolomite in the less than 0.074-mm size fraction were determined gasometrically with a Chittick apparatus (Dreimanis 1962). Lithologic analysis of the coarse sand

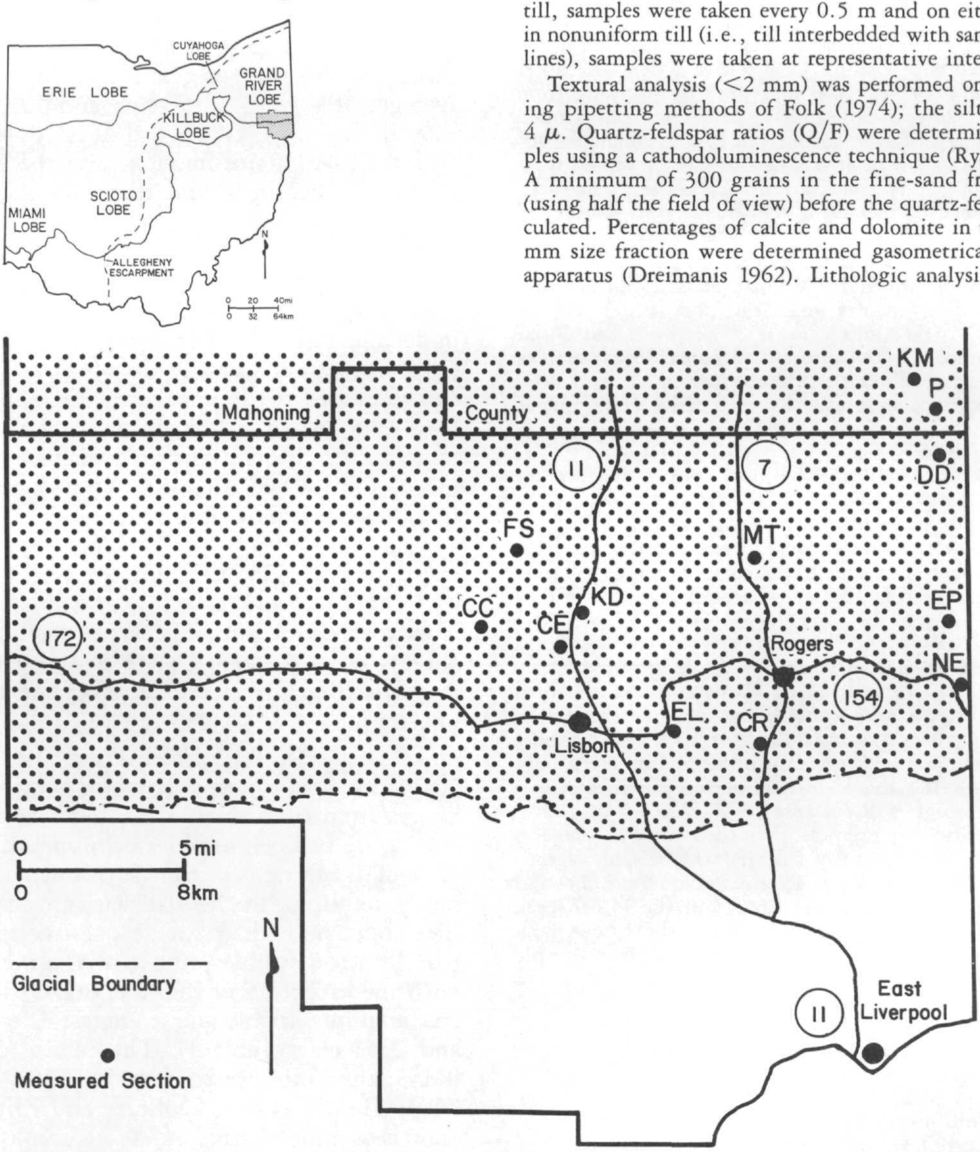

FIGURE 1. Locations of study area, glacial boundary, and measured sections in Columbiana County, Ohio (modified from White and Totten 1985). Patterned area has been glaciated.

fraction was performed on all samples. The very coarse-sand fraction (1-2 mm), herein referred to as coarse sand, was placed in an alizarine red solution for 5 min. The amount of magnesium in the carbonates determines what intensity of red results. Limestones are stained bright red, whereas dolomite fragments are left relatively unaffected. At least 300 grains were counted and identified with a binocular microscope, a steel probe, and a solution of 6 N HCl.

Clay mineral analysis was performed following the general procedure of Carroll (1970). Approximately 50 g of till were placed in a beaker and allowed to slake in at least 250 mL of deionized water. For shale samples, pulverized material was used. After the samples set for 24 h, they were agitated for 10 min with an electric stirrer. About 75 mL of sediment/water mixture then was decanted into two separate containers. About 20 mL of 2 N HCl was added to one set of beakers to remove any iron chlorites (Foos, pers. comm.) which occur with kaolinite on X-ray diffractograms. If clays flocculated, a small amount of sodium hexametaphosphate was added to disperse the flocculant. Each sample was allowed to set (approx. 1 h) until the 2-$\mu$ fraction remained in suspension. After this, a portion of the 2-$\mu$ fraction was pipetted from the containers and placed on circular glass slides to form an oriented mount (Carroll 1970). Samples were air-dried and then glycolated for at least 24 h before being X-rayed. Some samples were heated to 450°C and 600°C to aid in identification of chlorite and kaolinite.

Samples were X-rayed with a Phillips APD 3720 diffraction machine using nickel-filtered copper $K\alpha$ radiation at 40 kv and 30 ma. Scanning was from 2° $2\theta$ at a rate of 0.02° $2\theta$ per sec. Areas under the peaks centered at 7 and 10 Å, as well as the background intensity, were determined with Phillips quantitative systems software. The area under the 10-Å peak was measured by scanning from 8.500° $2\theta$ to 9.750° $2\theta$ at a rate of 0.01° $2\theta$ per sec. Background was determined by measuring the intensity at 8.500° $2\theta$ and 9.750° $2\theta$. The area under the 7-Å peak was measured by scanning from 12.000° $2\theta$ to 13.000° $2\theta$ at a rate of 0.01° $2\theta$ per sec. The background was determined by measuring the intensity at 12.000° $2\theta$ and 13.000° $2\theta$.

The areas under the 7- and 10-Å peaks were used to determine the diffraction intensity ratio (DI) (Willman et al. 1966). The DI is calculated by dividing the area under the 10-Å (illite) peak by the area under the 7-Å (kaolinite-chlorite) peak (Ruhe and Olson 1978). Acidified samples were compared to nonacidified samples to determine the relative amount of chlorite present in each. The X-ray diffraction patterns were used for qualitative clay mineral identification.

Clay minerals were identified with guides by Droste (1956a, 1956b), Carroll (1970), Brindley and Brown (1981), and Starkey et al. (1984). Heating of samples to 450°C slightly reduces the smaller orders, but has no effect on the (001) peak. Heating the sample to 600°C causes lower orders to disappear and the (001) peak to intensify. Diffractograms of samples placed in 2 N HCl solution and exposed to a heat lamp for 2 h showed no or very diminished chlorite peaks.

Vermiculite, illite, and kaolinite were the clay minerals examined in this study. In the till samples chlorite was the most unstable clay mineral when subjected to weathering (Droste 1956a, 1956b). Weathered chlorite alters to vermiculite by hydration of the brucite structure. As chlorite alters to vermiculite, the 14-Å peak becomes less intense and shifts toward 14.6 Å. It is unaffected by glycolation (Starkey et al. 1984). If a mixed-layered vermiculite-chlorite is present, the 14.6-Å peak will collapse to 10 Å when heated to 450°C. The 14.6-Å peak may reappear when the sample is heated to 600°C depending on the amount of chlorite still present. Vermiculite has a broad 14.6 Å which is stronger than the 7.14- and 4.76-Å peaks. Glycolaton of the sample may shift the 14.6-Å peak slightly higher. Heating vermiculite will collapse the 14.6-Å peak to approximately the 10-Å peak position; heating the sample to 600°C may collapse the 10-Å peak to approximately 9.3 Å or may have no effect at all.

Unweathered crystalline illite has intense, sharp 10-Å (001) and 5.0-Å (002) peaks and is unaffected by glycolation or by the heat treatment (600°C). Weathered illite shows asymmetry on the low angle side of the 10-Å peak, indicating that the illite structure has started to hydrate into mixed-layered clay mineral. The degree of asymmetry will indicate how much mixed layering is present. The heat treatment of 450°C collapses the mixed-layered clay to 10 Å.

If chlorite is present, identification of kaolinite may be problematic because it also has basal spacings of 7.14 Å (001), and 3.58 Å (002) that are shared by chlorite. If there are questions on which mineral is present, there are several ways to determine if the mineral in question is chlorite, kaolinite, or both. Upon heating to 600°C, the peaks on diffractograms of well-crystallized kaolinite will disappear, and the chlorite peaks migrate to the 14-Å position (Starkey et al. 1984). If both minerals are present and highly crystalline, the kaolinite peak will be slightly less than 25° $2\theta$, and the chlorite peak will be slightly higher than 25° $2\theta$. Droste (1956b) also suggested that the maximum intensity of the 7 Å-14 Å ratio for iron chlorite is 3, with anything above 3 indicating the presence of kaolinite. Finally, placing the sample in a solution of 2 N HCl will remove almost all of the iron chlorite.

## RESULTS

Three distinctively different pre-Woodfordian tills are found in the study area and are classified as unnamed pre-Woodfordian till A, unnamed pre-Woodfordian till B, and Titusville Till. Both unnamed tills underlie the Titusville Till which has been dated at least 40 ka in Pennsylvania (White et al. 1969).

UNNAMED TILLS. Unnamed till A underlies Titusville Till and overlies argillaceous bedrock at the Center Mine (CE), Coal Crusher (CC), and Negley (NE) sections (Fig. 1). The thickness of unnamed till A ranges from 0.5 to 2.1 m and averages 1.5 m. Unnamed till A is gray, sandy, firm, unoxidized, and calcareous. The matrix texture is highly variable but averages 50% sand, 31% silt, and 19% clay (Table 1). The till has 1.3% calcite and 4.1% dolomite in the less than 0.074-mm size fraction, and the Q/F is 9.2. The DI is 0.7; kaolinite and illite are the dominant clay minerals (Fig. 3a).

Three-tenths of a meter and 1.4 m of unnamed till B are found at the K&D (KD) and Crawford (CR) sections, respectively (Fig. 1). This unnamed till is found under the Titusville Till at the K&D section and is the only unit exposed at the Crawford section. The age of this unnamed till is unknown, but again it must be at least 40 ka based on the age of the Titusville Till which it underlies. The till is a yellowish-brown, friable, oxidized, and leached silt loam. Erratics, pebbles, and coal fragments are noticeably absent. The matrix texture is variable and averages 27% sand, 58% silt, and 15% clay (Table 1). The Q/F for the K&D section is 22.5, and the fine-sand fraction of the Crawford section is exclusively quartz. The DI is 0.5; kaolinite, illite-smectite, and vermiculite are the dominant clay minerals (Fig. 3b). Correlation of the unnamed tills is uncertain.

TITUSVILLE TILL. The Titusville Till is found in all sections except the Crawford section. Its thickness ranges from 0.75 to 10.4 m and averages 4 m. It occurs above bedrock or older drift and below the younger Kent Till. It ranges from a yellowish-brown, friable, sandy, oxidized, leached till with iron stains along partings to an unoxidized, olive or olive gray, firm, sandy till. Erratics, pebbles, and coal fragments are common with the exception of the D&D (DD) section. The matrix is quite variable and averages 39% sand, 39% silt, and 22% clay (Table 1). The calcite content averages 0.1%; the dolomite content is 2.4%; and the Q/F is 14.4. The DI is 0.6; kaolinite and illite are the dominant clay minerals (Fig. 4).

TITUSVILLE TILL WEATHERING PROFILE. Physical and chemical weathering of tills produces alteration of clay minerals within zones of a vertical weathering pro-

TABLE 1

*Summary of laboratory analyses of tills in Columbiana County, Ohio.*

| Unit | Sand (%) | Silt (%) | Clay (%) | Calcite (%) | Dolomite (%) | Quartz/ feldspar (Q/F) | Diffraction intensity ratio (DI) |
|---|---|---|---|---|---|---|---|
| Kent Till | | | | | | | |
| $\bar{x}$ | 40.3 | 33.7 | 26.0 | 0.9 | 3.7 | 12.6 | 0.7 |
| SD | 13.0 | 13.6 | 10.6 | 0.6 | 0.6 | 3.0 | 0.2 |
| *N* | 15 | 15 | 15 | 4 | 4 | 15 | 5 |
| Titusville Till | | | | | | | |
| $\bar{x}$ | 39.1 | 39.0 | 21.9 | 0.4 | 2.4 | 14.4 | 0.6 |
| SD | 7.2 | 10.8 | 8.8 | 0.2 | 0.9 | 3.8 | 0.2 |
| *N* | 109 | 109 | 109 | 65 | 65 | 109 | 58 |
| Unnamed Till A | | | | | | | |
| $\bar{x}$ | 50.4 | 30.7 | 18.9 | 1.3 | 4.1 | 9.2 | 0.7 |
| SD | 15.7 | 10.7 | 8.8 | 0.8 | 1.7 | 5.9 | 0.1 |
| *N* | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Unnamed Till B | | | | | | | |
| $\bar{x}$ | 26.8 | 58.2 | 15.0 | 0.6 | 0.0 | 22.6 | na* |
| SD | 6.0 | 12.7 | 10.1 | 0.0 | 0.0 | 3.8 | |
| *N* | 9 | 9 | 9 | 9 | 9 | 3 | |

*Not analyzed

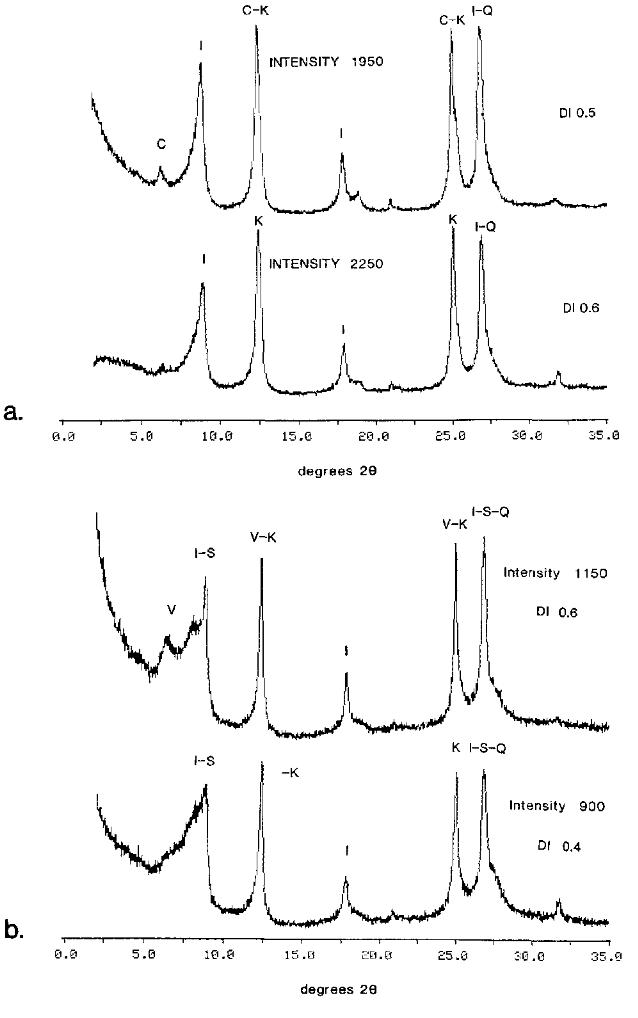

FIGURE 3. X-ray diffraction patterns of typical glycolated oriented mounts of unnamed tills. a. Unnamed till A: top unacidified, bottom acidified. b. Unnamed till B: top unacidified, bottom acidified. C, chlorite; I, illite; K, kaolinite; V, vermiculite; I-S, mixed-layered illite-smectite; Q, quartz; DI, diffraction intensity ratio. Note that the area under the peak to the left of the word "intensity" is measured in counts on all diffractograms in this study.

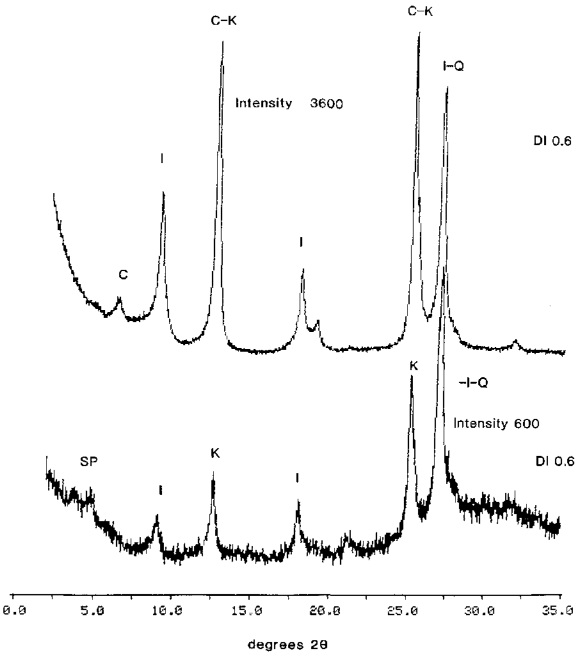

FIGURE 4. X-ray diffraction patterns of a typical glycolated oriented mount of Titusville Till: top unacidified, bottom acidified. C, chlorite; I, illite; K, kaolinite; Q, quartz; DI, diffraction intensity ratio; SP, systems peak, inherent in the electronics of the X-ray unit. Note that acidification also has reduced the intensity of the illite peak.

file (Willman et al. 1966). In this study, the weathering profile of the Titusville Till is gradational upward from the unweathered till. In the gray, unoxidized, unleached till, kaolinite, illite and chlorite show sharp distinctive peaks and are the dominant clay minerals (4 m, Fig. 5). In the slightly weathered, yellowish-brown, calcareous till (2.5 m, Fig. 5) the 14-Å chlorite shifts slightly toward a lower $2\theta$ angle. This indicates that the brucite layer in the chlorite structure is starting to hydrate to vermiculite. Hydration of all brucite layers does not start at the same time, nor does it proceed at a constant rate (Droste 1956b); hence a mixed-

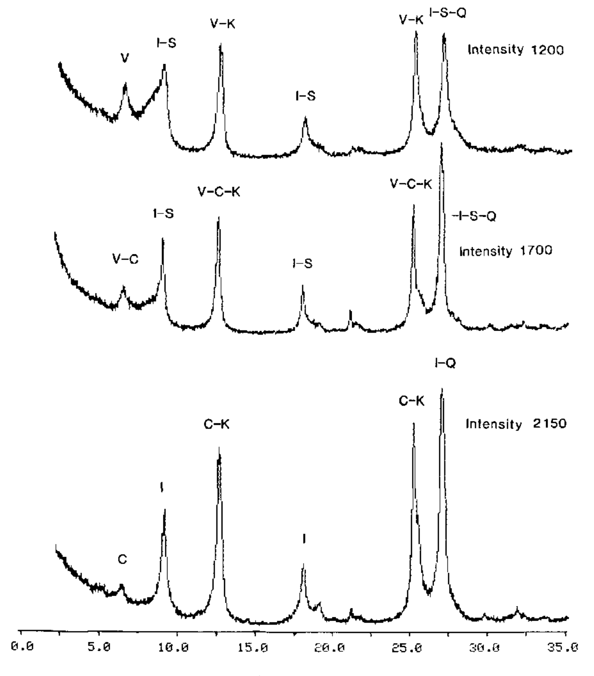

FIGURE 5. X-ray diffraction patterns of glycolated oriented mounts from a weathering profile in Titusville Till at Center Mine section (CE). Top diffractogram is from a sample at a depth of 0.2 m; middle diffractogram, 2.5 m; and lower diffractogram, 4 m. C, chlorite; I, illite; K, kaolinite; V, vermiculite; Q, quartz; I-S, mixed-layered illite-smectite.

layered chlorite-vermiculite clay is produced. Also, the 10-Å illite peak starts to shift slightly toward a lower $2\theta$ angle, indicating hydration of the structure probably due to the removal of potassium from between the mica sheets (Droste 1956a). The 7-Å kaolinite peak remains unaffected. Moving up the weathering profile (0.2 m, Fig. 5), the noncalcareous, yellowish-brown till shows a characteristic 14.3-Å vermiculite peak, the result of complete hydration of the chlorite structure.

## DISCUSSION

This study assumed that the source area of the pre-Woodfordian tills in Columbiana County remained constant. As a result, the kaolinite content in the pre-Woodfordian tills in Columbiana County may be caused by several local factors: incorporation of kaolinite-rich unweathered and, to a minor extent, weathered Pennsylvanian argillaceous strata into the till; incorporation of pre-existing drift into the till; and incorporation of kaolinite-rich underclays associated with Pennsylvanian coal beds into the till.

Pre-Woodfordian tills of Columbiana County have low DIs compared to other pre-Woodfordian tills in north-central Ohio (Szabo 1987), indicating that either large amounts of chlorite or kaolinite or minor amounts of illite are present. Comparison of acidified and unacidified samples indicated that the majority of clay minerals present are kaolinite and illite; chlorite and chlorite-vermiculite are present in minor amounts. Results of the present study were comparable to those for the Mogadore Till of the Cuyahoga lobe (Szabo and Fernandez 1984). Szabo and Fernandez (1984) suggested that the low DI of the Mogadore Till, which correlates to the Titusville Till of the Grand River lobe, might be caused by the incorporation of kaolinite-rich Pennsylvanian bedrock.

Gross and Moran (1971) showed how the Q/Fs of the Titusville Till increased with the distance the glacier had traveled across predominantly quartz-rich sandstone, implying dilution of the Titusville Till by local bedrock. It is suggested here that incorporation of pre-existing drift and local Pennsylvanian argillaceous strata resulted in a relative increase in the kaolinite content and in a relative decrease in illite content in pre-Woodfordian tills of Columbiana County.

In order to demonstrate the influence of local substrate material on the tills, their clay mineralogies were compared to those of various underlying rocks and sediment. Clay mineral analyses were performed on unweathered Pennsylvanian shales and the overlying pre-Woodfordian tills. The DIs of the shales were consistently under 1.0 and averaged 0.7 (Table 2, Fig. 6a). Likewise the DIs of the unweathered pre-Woodfordian tills were consistently under 1.0 and averaged 0.6 for the Titusville Till and 0.7 for the unnamed pre-Woodfordian Till A. A correlation coefficient ($r$) of 0.77 and corresponding coefficient of determination ($r^2$) of 0.60 was found between the bedrock DIs and those of the overlying till (Fig. 7). The results of the analysis indicated that roughly 60% of the variance in clay minerals present in the till is attributable to the variance in local Pennsylvanian bedrock. Weathered bedrock also was eroded by the ice; the DI of weathered shale in the study area was 0.5 (Fig. 6b). Any weathered bedrock that is incorporated into the glacier sole would add to the kaolinite content while diluting the illite content.

Highly weathered drift older than the Titusville Till has a DI of 0.4 (Fig. 8a), which is considerably less than unweathered till. The larger amount of kaolinite in weathered drift may be due to weathering of aluminosilicate minerals or in response to equilibrium between aluminum and silicon oxides. These findings were comparable to those of Levine and Ciolkosz (1983), who indicated that the clay content of weathering profiles in tills increases with increasing age and that kaolinite is the dominant clay mineral.

Underclays, which are associated with the numerous coal beds in the area, had DIs of around 0.3 (Fig. 8b). These underclay beds are quite variable in thickness, ranging from a few centimeters to 2 m, and their clay mineralogy is dominated by kaolinite (Williams et al. 1968). Any incorporation of these underclays into the basal part of the glacier would affect greatly the relative kaolinite and illite contents of basal till.

We suggest that the overall composition of pre-Woodfordian tills in the study area depends on two factors: 1) the multi-lithologic source material consisting of bedrock and of older Quaternary sediments; and 2) the comminution of this material to clay-size particles

TABLE 2

*Summary of diffraction intensity ratios (DI) of bedrock and unweathered till units used in this study.* $\bar{x}$, *mean; SD, standard deviation;* N, *number of samples.*

| Unit | $\bar{x}$ | SD | $N$ |
|---|---|---|---|
| Kent Till | 0.7 | 0.2 | 5 |
| Titusville Till | 0.6 | 0.2 | 58 |
| Unnamed Till A | 0.7 | 0.1 | 5 |
| Shale | 0.7 | 0.1 | 34 |

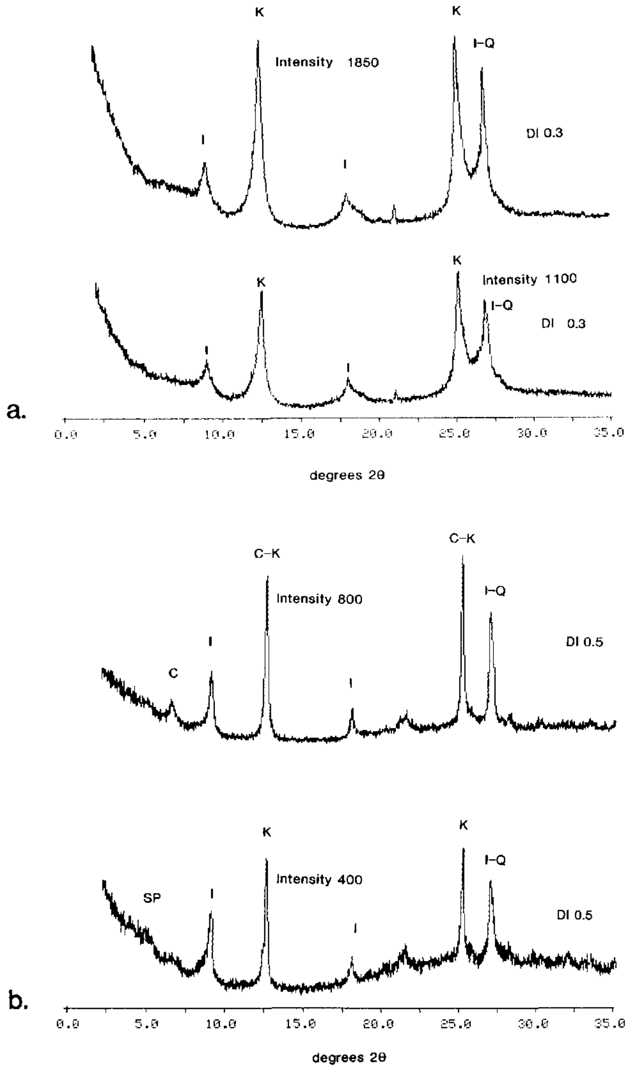

FIGURE 6. X-ray diffraction patterns of typical glycolated oriented mounts of Pennsylvanian bedrock. a. Siltstone: top unacidified, bottom acidified. b. Weathered shale: top unacidified, bottom acidified. C, chlorite; I, illite; K, kaolinite; Q, quartz; DI, diffraction intensity ratio; SP, systems peak (Fig. 4).

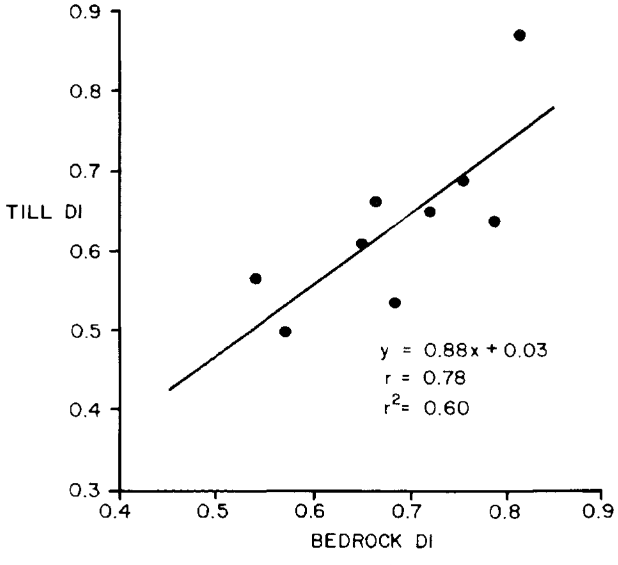

FIGURE 7. Correlation between mean diffraction intensity ratios (DI) of bedrock and those of overlying tills for 8 sections in Columbiana County, Ohio. The correlation coefficient is significant at $P = 0.05$.

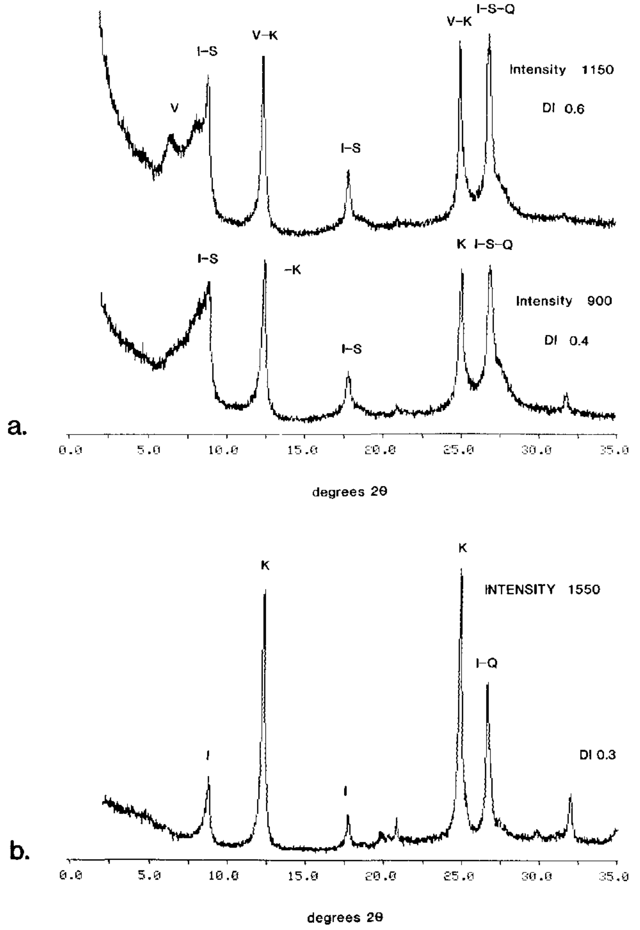

FIGURE 8. X-ray diffraction patterns of glycolated oriented mounts. a. Highly weathered drift: top unacidified, bottom acidified. b. Unacidified underclay. I, illite; K, kaolinite; V, vermiculite; I-S, mixed-layered illite-smectite; Q, quartz; DI, diffraction intensity ratio.

during glacial erosion and transport, which depends upon durability of the rocks, mode and position of transport, and distance of transport (Dremanis and Vagners 1971, Clark 1987). The process of comminution is a combination of crushing and abrasion. It is difficult to assess how much comminution is the result of crushing and how much is a result of abrasion (Haldorsen 1981).

Most subglacial tills, even those from coarse-grained bedrock, may be rich in silt- and clay-size particles, which could not be produced by crushing alone and probably were formed by abrasion (Drewry 1986). Abrasion probably takes place in the zone of traction between bedrock and subglacial debris or near the base of the glacier among englacial debris. The most favorable conditions for rapid abrasion of the glacier bed are where a glacier sole containing hard rock particles flows across a hard rock surface onto a softer rock (Sugden and John 1984). Similar conditions likely existed when the Grand River sublobe flowed into Columbiana County. Quartz-rich Pennsylvanian sandstone clasts probably were entrained and transported in a debris-rich zone at the base of the glacier, which passed over softer Pennsylvanian argillaceous shales which were subjected to extensive abrasion. Some of the rock flour may have been transported away by basal meltwater, but a substantial portion was incorporated into the basal layer either by regelation (Boulton 1972) or by tractive forces that the ice exerts on the particles.

Just how far the glacier must flow over the Pennsylvanian bedrock before the till acquires the mineralogy of the local bedrock is uncertain and particularly dependent on thermal conditions at the base of the ice. Gross and Moran (1971) stated that 50% of the Titusville Till was derived from within 32 km of the site of deposition. They were looking, however, at the Q/F and were concerned mainly with the addition of more resistant, quartz-rich sandstone into the till. Clark (1987) suggested that the composition of tills is affected by the topography of underlying bedrock. Long transportation distances occurred as the ice followed bedrock depressions, whereas shorter distances dominated in areas of bedrock highs. Szabo (1987) demonstrated how the composition of tills was diluted as ice overrode the Allegheny Escarpment in north-central Ohio 100 km west of the study area. It is suggested here that the influence of topographically high Pennsylvanian bedrock underlying the area glaciated by the Grand River sublobe on the clay mineralogy of tills is much greater because of the quartz-rich till derived from sandstones abrading the soft argillaceous strata at a rapid rate and the incorporation of these rocks into the tills.

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