

Lithofacies and Mineralogy of the Late Wisconsinan Navarre Till in Stark and Wayne Counties, Ohio¹

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ABSTRACT. The Navarre Till deposited by ice of the Killbuck lobe in Stark and Wayne counties is the oldest till of late Wisconsinan age in northeastern Ohio. The type section of the Navarre Till is located near the margin of glaciation in Stark County. Interpretations of the diamict at the type locality include a meltout till overlying shale. Other sections in the study area consist of meltout or flow tills which occur as stratified or massive diamicts interbedded with silts, sands, and gravels. Diamict interpreted as lodgement till occurs only at one section.

The Navarre Till is platy, oxidized yellowish-brown, and has a matrix texture of 38% sand, 42% silt, and 20% clay. Oxidized, unleached samples average 0.5% calcite and 2.3% dolomite whereas unoxidized samples contain up to 7% total carbonate in the <0.074-mm fraction. Quartz-feldspar ratios vary greatly and average 10.5. Navarre diamict at its type section does not represent the full range of lithofacies in the area, but the texture and composition of the diamict at the type section is representative of all lithofacies found in the area.

Navarre Till may be distinguished from Illinoian(?) Millbrook Till (type locality in Wayne County) based on its degree of consolidation and oxidized color. At some localities, Navarre Till is separated from Millbrook Till by a weathering profile. Navarre Till closely resembles Millbrook Till in lithofacies, carbonate mineralogy, and matrix texture. These similarities result from inferred similar source areas for the two ice advances as well as the incorporation of the older Millbrook deposits into Navarre sediments.

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INTRODUCTION

Previous studies of glacial deposits of the Killbuck lobe of northeastern Ohio (White 1961, 1967, 1982; DeLong and White 1963) have stressed classification of tills by laboratory-derived analytical data to be used for stratigraphic delineation and for correlation of lithostratigraphic units. Interpretations of the lateral and vertical variations within glacial stratigraphic units, as well as similarities between different stratigraphic units, have been clarified by examining the influence of local bedrock on mineralogy and texture of diamicts (Szabo and Angle 1983, Volpi and Szabo 1988) and by determining the environment and mode of deposition of these glacial deposits (Eyles et al. 1983). The purpose of this study is to determine the environments of deposition of Navarre Till using lithofacies models (Eyles et al. 1983) and to compare laboratory and field data from Navarre deposits both within and between lithofacies in Stark and Wayne counties in northeastern Ohio. Because there is some confusion in distinguishing weathered Navarre Till from weathered Millbrook Till (Totten and Szabo 1987), lithofacies and laboratory analyses of Navarre deposits are compared to those of older Millbrook deposits within the study area.

Study Area

The study area (Fig. 1) is located in Wayne County and western Stark County. Pennsylvanian rock underlies western Stark County and includes the Pottsville and Lower Allegheny groups. These strata consist of continuous and discontinuous coal beds separated by shale, sandstone, clay, and limestone. Pennsylvanian rock extends into

southwestern Wayne County, but Mississippian strata underlie most of Wayne County. Sections in Wayne County contain exposures of shale and sandstone members of the Cuyahoga and Logan formations.

Ice of the Killbuck lobe glaciated Wayne and western Stark counties several times. At its maximum extent, ice that deposited Navarre Till covered all of Wayne County and all but the extreme southern part of western Stark County (Fig. 1). Gently sloping ground moraine dominates the physiography of the northern two-thirds of Wayne County and of western Stark County. The subdued relief is produced by varying thicknesses of glacial deposits over gently rolling bedrock hills. In the southern third of these counties, glacial sediments become thin on bedrock hills as underlying bedrock topography becomes more pronounced. Local relief increases to a maximum of 110 m in southwestern Stark and southeastern Wayne counties (DeLong and White 1963). Glacial deposits thicken in many valleys in the southern third of the study area. Drainage in the study area is toward the Ohio River.

Glacial Geology

Early observations of glacial deposits in the study area were made by Newberry (1874), who described the kames of the Buck Hill moraine in western Stark County near Canton. Wright (1884, 1890) traced the glacial boundary across Stark County and described deposits along the margin. Leverett (1902) distinguished the deposits of western Stark County from those east of Canton and described glacial deposits at specific sites in Wayne County. Conrey (1921) produced a detailed description of glacial deposits in Wayne County emphasizing gravels, sands, alluvium, and lacustrine deposits. Ver Steeg (1930, 1931, 1934) and Stout et al. (1943) described the thickness of drift and drainage changes in buried valleys in Stark and Wayne counties.

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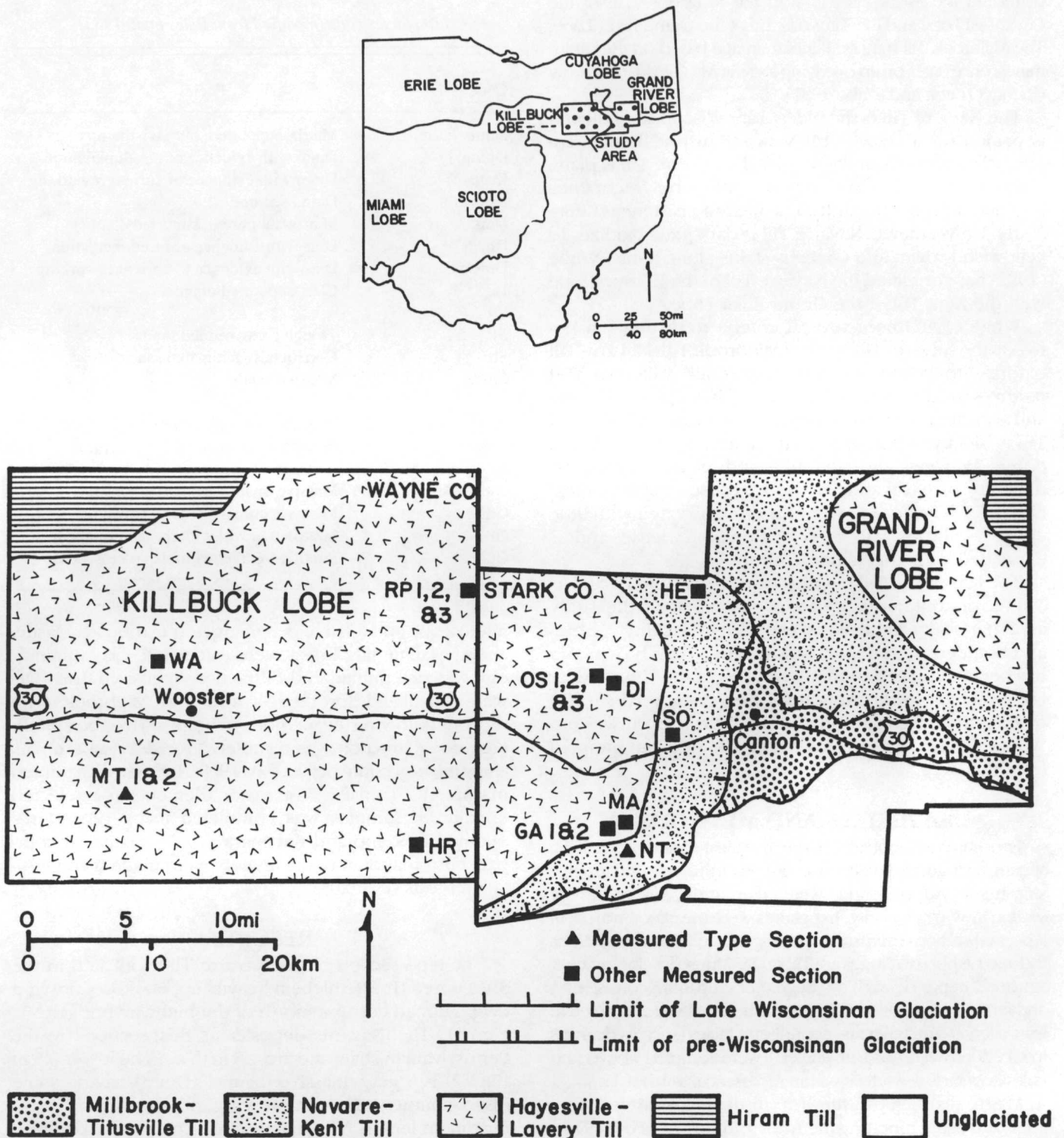


FIGURE 1. Location of measured sections in the study area near the glacial boundary in Stark and Wayne counties.

Extensive mapping and laboratory analyses of glacial deposits in Stark and Wayne counties by White (1961) resulted in classification of tills as lithostratigraphic units. White (1961) described the type sections for the Millbrook, Navarre, and Hayesville tills (from oldest to youngest) of the Killbuck lobe. Although pre-Millbrook tills have been reported in the study area, they are found in only a few

exposures and have not been investigated.

The type section of the Millbrook Till (MT, Fig. 1) is near the village of Millbrook, Plain Township, Wayne County. The Millbrook Till has a high degree of consolidation and is weakly calcareous, massive, sandy, and pebbly till containing many cobbles and boulders. It oxidizes from dark gray to an olive-brown; iron and manganese oxides

are deposited along joints and around pebbles. White (1982) has correlated the Millbrook Till with the Mogadore Till of the Cuyahoga Lobe and the Titusville Till of the Grand River Lobe. The Millbrook Till may be Illinoian in age based on thermoluminescence dates on an overlying loess at Mt. Gilead in Morrow County (Totten and Szabo 1987).

The Navarre Till is the oldest Late Wisconsinan till and is named for its type locality near Navarre, Bethlehem Township, Stark County (NT, Fig. 1). Navarre Till is platy, calcareous, sandy, and moderately pebbly, contains boulders and cobbles, and has a mealy consistency (White 1961). Unweathered Navarre Till is dark gray, oxidizes to yellowish-brown, and contains stains along joints. White (1982) has correlated the Navarre Till of the Killbuck lobe with the Kent Till of the Grand River Lobe.

White (1982) uses several criteria to distinguish between the Navarre Till and the Millbrook Till. Navarre Till oxidizes to yellowish-brown, whereas, Millbrook Till oxidizes to olive-brown. Navarre Till has a platy structure and also often contains numerous sand stringers; Millbrook Till is blocky and massive. The degree of consolidation differs between the two tills and is determined by difficulty of excavating a fresh exposure with a pick. Navarre Till is loose or mealy and is excavated with little effort. Millbrook Till is very firm and dense and is excavated with considerable effort.

The Hayesville Till overlies Navarre Till and occurs as a thin, discontinuous deposit over much of the study area. It is a silty, calcareous, clay-rich till lacking cobbles and boulders. It generally oxidizes to a dark brown and has been correlated to the Lavery Till of the Grand River Lobe (White 1961). Although the younger Hiram Till overlies the Hayesville Till in a small part of northwestern Wayne County, no sections were measured and sampled from that area.

MATERIALS AND METHODS

Exposures and outcrops were investigated at type sections, stream, railroad, and highway cuts, and both active and inactive strip mines. Auger borings were taken at the Millbrook type section in Wayne County. Exposures were measured with steel tape, and sections extensively photographed. Field descriptions included lithofacies logging (Table 1), Munsell color, texture, structure, depth of leaching, degree of oxidation, consistency, and fabric interpretations. Uniform lithofacies were sampled at least every 0.5 m, whereas, nonuniform facies (such as diamicts interbedded with sand or gravels) were sampled above and below contacts as well as within representative lithofacies.

Matrix textures (<2 mm) of all diamict samples were analyzed using pipetting methods and sieving (Folk 1974). Calcite and dolomite contents of the <0.074-mm fraction were determined gasometrically using a Chittick apparatus (Dreimanis 1962). Cathodoluminescence techniques (Ryan and Szabo 1981) were used to determine quartz-feldspar ratios (Q/F) for all samples. A minimum of 300 grains of the fine-sand fraction were counted for this procedure. The lithology of the very coarse-sand fraction (1-2 mm) herein referred to as coarse sand was analyzed. These sands were stained for 5 min in alizarine red solution to facilitate identification of carbonate. A minimum of 300 grains were counted using a binocular

TABLE 1

Lithofacies code (modified from Eyles et al. 1983).

Code	Facies
Dmm	Matrix-supported, massive diamict
Dmm(r)	Dmm with evidence of re sedimentation
Dmm(c)	Dmm with evidence of current reworking
Dmm(s)	Dmm, sheared
Dms	Matrix-supported, stratified diamict
Dms(r)	Dms with evidence of re sedimentation
Dms(c)	Dms with evidence of current reworking
Dc	Clast-supported diamicts
St	Trough cross-bedded sands
Sh	Horizontally laminated sands
Sm	Massive sands
Fl	Fine-grained with laminations
Fm	Fine-grained, massive
Gms	Massive, matrix-supported gravel
Gm	Massive, crudely bedded gravel
Gt	Stratified gravel with trough crossbeds
Gp	Stratified gravel with planar crossbeds

microscope and relative percentages of carbonate, clastic, and crystalline lithologies were calculated. Clay mineralogy was determined and diffraction intensity ratios (DI) were calculated for the Navarre and Millbrook type sections following the methods of Volpi and Szabo (1988). Free-iron extraction was completed for selected samples using the procedure of Jackson (1969). Inductively coupled plasma (ICP) analysis of major elements for selected unoxidized samples was completed using procedures outlined in Szabo and Katzmark (1987). Statistical comparisons of laboratory parameters were made using two-tailed t-tests ($P = 0.05$).

RESULTS

The type section of the Navarre Till is located in the SW1/4, sec. 16, Bethlehem Township, Stark County in a deep railroad cut 16 m north of the highway bridge (NT, Fig. 1). The Navarre deposits at this section overlie Pennsylvanian shale and are 4.8 m thick. The lower 0.5 m (Fig. 2) is a gray, massive diamict (Dmm) having some discontinuous yellowish-brown sand stringers of 3-cm maximum length. The diamicts are completely oxidized above a depth of 4.3 m. The lower lithofacies (Dmm, Fig. 2) averages 38% sand, 37% silt, and 26% clay. It has 0.5% calcite and 2.1% dolomite in the <0.074-mm fraction and a Q/F of 9.3. Clastics (64%) dominate the coarse-sand fraction compared to carbonates (13%) and crystallines (17%). A sample 20 cm above the bedrock contained 20% coal fragments in the coarse-sand fraction. A 10-cm thick sand layer (Sm, Fig. 2) separates the lower massive diamict from a 3.2-m thick upper massive diamict (Dmm, Fig. 2). The upper diamict is yellowish-brown and firm to friable; it averages 40% sand, 42% silt, 18% clay, 0.6% calcite, and

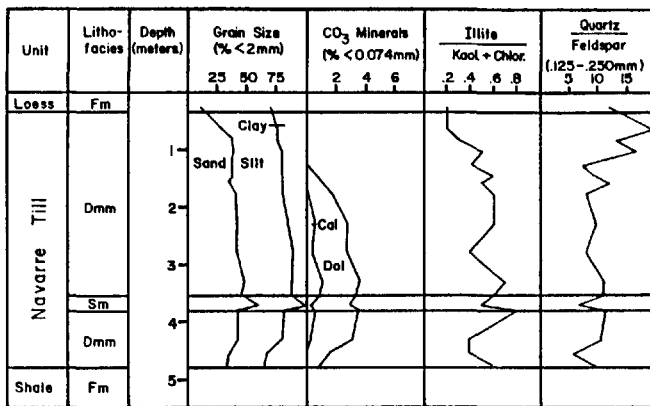


FIGURE 2. Laboratory analyses of diamicts at the type section of the Navarre Till in Bethlehem Township, Stark County.

2.0% dolomite. Its Q/F is 11.5 and the coarse-sand fraction is again dominated by clastics (72%) and contains 18% crystallines and 10% carbonates. This diamict has a platy structure and numerous pebbles, some stained by iron and manganese. Sand stringers separate the plates, and coal fragments occur throughout the section. This sequence is capped by 45 cm of silt loam (Fm, Fig. 2) which is completely weathered and has a composition of 11% sand, 59% silt, and 30% clay.

Although the type section is composed of predominantly massive diamicts (Dmm), other lithofacies of Navarre Till are found at several other locations. At the Southway section (SO, Fig. 1), both Dms and Dmm(s) lithofacies were observed. At this section, Navarre deposits lie directly on Pennsylvanian shale, and the lower 0.25 m of Navarre diamict is classified as Dmm(s), having smear laminations or "smudges" of shale inclusions. The sequence of Navarre diamicts above the Dmm(s) is similar to that of the type section.

Extensive Dms lithofacies were described from samples taken at the Rupp Construction Company (RP2, Fig. 1) in eastern Wayne County. Here, about 4 m of Navarre diamicts lie unconformably on 3.5 m of Millbrook deposits (Fig. 3). The Millbrook diamicts include a highly consolidated basal Dmm overlain by less consolidated Dms and Dmm. Lithofacies of the Navarre diamicts include about 2 m of massive diamicts (Dmm) of similar consolidation as the upper Millbrook diamicts. These grade upward into 2 m of stratified, matrix-supported Navarre diamicts (Dms).

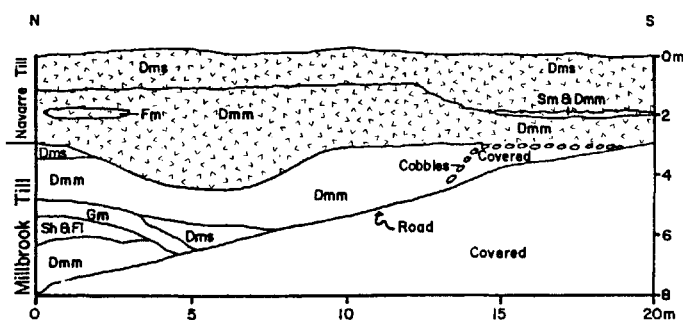


FIGURE 3. Cross section of an exposure (RP2, Fig. 1) in the Rupp pit showing Navarre diamicts overlying Millbrook diamicts.

Weathering profiles in both the Navarre and Millbrook diamict sequences are found at the south end of RP2 (Fig. 3). Unoxidized, unleached, blocky, very firm Millbrook Dmm is exposed at a depth of 3.9 m and extends upsection to a depth of 3.3 m. This massive diamict is difficult to excavate because of its high degree of consolidation and a large pebble and cobble content. These diamicts have a texture of 44% sand, 39% silt, and 17% clay; contain 4.7% dolomite; have a Q/F of 9.6; and consist of 19% carbonates, 58% clastics, and 24% crystallines in the coarse-sand fraction. Unoxidized Millbrook Dmm grades upward into firm to friable, olive-brown Dmm having numerous sand lenses and few cobbles. This oxidized Dmm is 0.5 m thick and contains 44% sand, 51% silt, and 5% clay. This diamict has a Q/F of 12.7 and contains a trace of calcite, 4.9% dolomite, 17% carbonates, 61% clastics, and 21% crystallines.

A sharp contact and a cobble layer at a depth of 2.8 m separates the oxidized Millbrook Dmm from overlying unoxidized Navarre diamicts. Thirty centimeters of light gray, firm to friable Dmm exhibits a platy structure and has sand stringers. This diamict contains 45% sand, 49% silt, 6% clay, 0.7% calcite, and 6.2% dolomite. Its Q/F is 11.5 and its coarse-sand fraction is composed of 12% carbonates, 57% clastics, and 30% crystallines. Unoxidized Navarre Dmm grades upward into yellowish-brown Dmm having hematite stains around pebbles and more numerous sand stringers than the unoxidized Dmm. Oxidized Dmm has a texture of 46% sand, 47% silt, and 7% clay; and consists of 0.8% calcite and 2.9% dolomite. Its Q/F is 14.9 and its coarse sand consists of 14% carbonates, 60% clastics, and 26% crystallines.

The upper 1.8 m of Navarre deposits (Fig. 3) are stratified diamicts (Dms) which break along very thin, horizontal beds of sand between diamict layers. The number of thin sand layers increases in the lower 0.4 m of Dms. The Navarre Dms contains 41% sand, 48% silt, and 11% clay and has a Q/F of 14.6. This diamict is leached to a depth of 1.5 m; unleached Dms contains 0.1% calcite and 3.9% dolomite. The coarse-sand fraction has 10% carbonates, 67% clastics, and 25% crystallines. Laboratory data for Dms at this section is representative of all sampled stratified Navarre diamicts (Table 2).

An additional lithofacies was observed at the Gang Sand and Gravel pit (GA2, Fig. 1) just south of Navarre. The exposure contains 1.5-3 m of resedimented Navarre diamict Dmm(r) overlying 1.5 m of massive to crudely stratified gravel (Gms) which contain interbedded, horizontally-laminated sands and current-reworked diamicts (Dmcs). The contact between the Dmm(r) and the Gms is wavy and contains abundant inclusions of Dmm up to 0.5 m in diameter. This contact has numerous load structures, and the diamicts above the contact exhibit characteristics of Lawson Type II flow tills having a plug zone which may have been rafted over a liquified zone (Lawson 1979). The average texture for all Dmm(r) samples in the study area is 43% sand, 40% silt, and 15% clay (Table 2). The Q/F is 8.3 and the <0.074-mm fraction contains 0.4% calcite and 2.7% dolomite. The coarse-sand fraction contains 60% clastics, 20% crystallines, and 18% carbonates.

Although four different lithofacies of Navarre diamicts

TABLE 2

Summary of laboratory analyses of all lithofacies of Navarre diamicts in the study area.

Lithofacies	Sand (%)	Silt (%)	Clay (%)	Calcite (%)	Dolomite (%)	Q/F	Carbonate (%)	Clastic (%)	Crystalline (%)	Other (%)
Dmm										
\bar{X}	37	43	20	0.5	2.2	10.4	9	71	18	2
S	8	8	9	0.3	1.1	3.6	5.4	8.2	5.5	3.7
N	80	80	80	23	45	80	79	79	79	79
Dms										
\bar{X}	42	45	13	0.2	3.1	14.2	8	66	25	1
S	10	10	7	0.2	1.1	4.3	6.3	6.1	1.9	1.1
N	7	7	7	7	7	7	7	7	7	7
Dmm(r)										
\bar{X}	43	41	16	0.4	2.7	8.3	18	60	20	2
S	4	6	5	0.3	0.7	1.4	2.5	8.2	6.5	0.9
N	10	10	10	9	10	10	10	10	10	10
Dmm(s)										
\bar{X}	16	38	46	0.2	1.9	7.5	0	93	1	6
S	-	-	-	-	-	-	-	-	-	-
N	1	1	1	1	1	1	1	1	1	1

\bar{X} = mean, S = standard deviation, N = number of samples.

were found in sections at 11 localities, Dmm(r) was observed at two sites and Dmm(s) was observed at only one locality. The Navarre diamicts observed were dominated by Dmm and Dms lithofacies. Massive diamicts are characterized by platy structure and discontinuous, horizontal sand stringers. Although the same characteristics are present at many sections in northeastern Ohio, there is some confusion in distinguishing weathered diamicts of the Navarre Till from similar diamicts of the Millbrook Till (Totten and Szabo 1987). Because of the confusion, the Millbrook type section was also measured and analyzed.

The type section of the Millbrook Till is located in the SE1/4, SE1/4, Sec. 25, of Plain Township, in Wayne County (MT, Fig. 1). Samples were taken from a road cut as well as from an auger boring (Fig. 4). The lower 0.4 m of the section overlies sandstone and consists of sand containing few pebbles and granules. Almost 5 m of Millbrook diamict (Dmm) overlies the sand; the lower 1.25 m of this diamict are unleached, oxidized, and very friable. The upper 3.55 m of the Millbrook diamict is unoxidized and unleached, but contains lenses of oxidized sand and partially to completely oxidized diamict. The weathered Millbrook diamict (Dmm) is olive-brown and generally has a firm consistency. The consistency of the diamict near sand lenses becomes more friable. This lithofacies contains gray pebbles, 1-3 cm in diameter, as well as numerous hematite-stained granules. The average texture of the Millbrook diamict (Table 3) at its type section is 36% sand, 41% silt, and 23% clay. It contains 0.3% calcite and 2.3% dolomite in the <0.074-mm fraction and has a Q/F of 6.1. The coarse-sand lithology is dominated by clastics (72%) and also contains 12% carbonates and 9% crystallines.

The Navarre deposits are separated from the Millbrook

diamicts by 20 cm of calcerous sand (boring 2, Fig. 4) and 20 cm of silt (Fm, exposure 1, Fig. 4). The Navarre diamict is unleached, partially oxidized, and 1-1.4 m thick. This

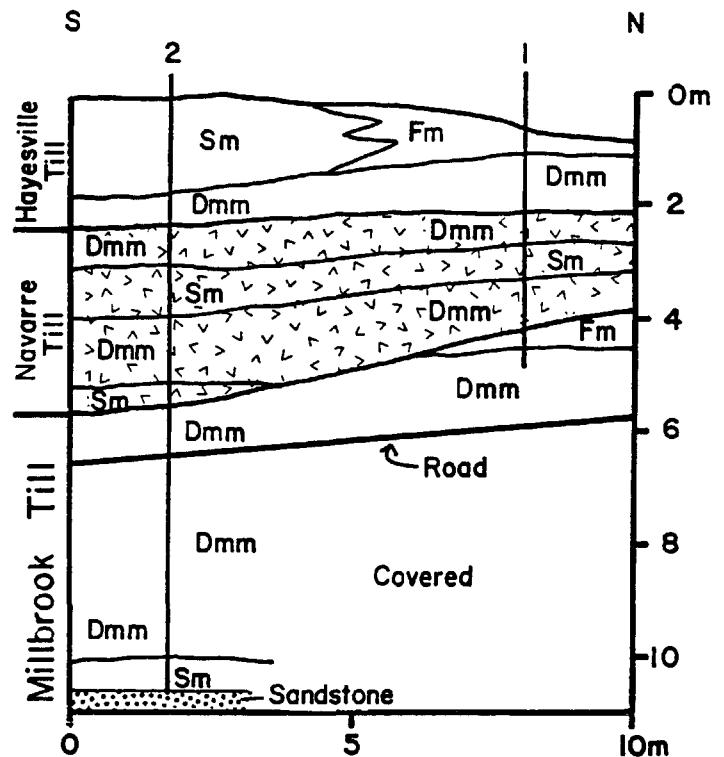


FIGURE 4. Cross section of the type section of the Millbrook Till in Plain Township, Wayne County. Cross section is constructed from descriptions and samples from an exposure in a road cut (1) and an auger boring (2).

TABLE 3

Summary of laboratory analyses of diamicts from the Navarre and Millbrook type sections.

Lithofacies	Sand (%)	Silt (%)	Clay (%)	Calcite (%)	Dolomite (%)	Q/F	Carbonate (%)	Clastic (%)	Crystalline (%)	Other (%)	DI
Navarre Dmm											
\bar{X}	39	40	21	0.6	2.0	10.9	10	70	18	2	0.5
S	5	4	7	0.3	0.7	3.8	5.6	7.7	3.2	2.9	0.2
N	15	15	15	7	10	15	15	15	15	15	5
Millbrook Dmm											
\bar{X}	36	41	23	0.3	2.3	6.1	12	72	9	1	0.7
S	5	6	2	0.5	0.9	1.5	2.8	7.5	3.5	1.2	0.2
N	9	9	9	9	9	9	9	9	9	9	6

\bar{X} = mean, S = standard deviation, N = number of samples.

oxidation produces a brighter, more yellowish-brown color than the Millbrook diamict. The Navarre Dmm lithofacies is very friable and contains fine pebbles which are often surrounded by gray clay. A yellowish-brown, highly calciferous, 1.25 m-thick sand lens separates the lower Navarre Dmm from a yellowish-brown, firm to friable upper Navarre Dmm (Fig. 4). The average texture of the Navarre Dmm at the Millbrook type locality is 37% sand, 38% silt, and 25% clay. This Navarre lithofacies contains 0.3% calcite, 2.9% dolomite, and a Q/F of 7.2. The coarse-sand lithology contains 76% clastics, 16% carbonates, and 6% crystallines.

Hayesville diamict, 0.6 m thick, overlies Navarre diamicts, has brown stains along vertical partings, and contains both brown and orange stains around numerous sedimentary clasts. This pebbly, silty diamict (Dmm) contains 31% sand, 42% silt, and 27% clay. It has been completely leached and has a Q/F of 6.2. The coarse-sand lithology contains 85% clastics, 12% carbonates, and only 3% crystallines. The Hayesville deposits are capped by a 0.3-1.7 m-thick silty, sand layer (Sm, Fig. 4).

DISCUSSION

The four different lithofacies of the matrix-supported Navarre diamicts sampled in this study suggest a variety of modes of deposition from Navarre ice in the study area. Deposition by lodgement (Dmm(s)) was found in only the SO section west of Canton (Fig. 1). Interpretations of additional environments of deposition can be made using lithofacies logs and field descriptions of other Navarre diamicts. Two dominant features present in many of the massive units (Dmm) are discontinuous horizontal sand stringers and a platy or fissile structure. These two genetic features, coupled with a generally low degree of consolidation of the massive Navarre diamicts, are interpreted to be a result of an in-situ melt-out of basal tills below stagnant ice. Dominance of melting processes, as opposed to sublimation, which is common in polar regions, results in a loss of other structures in englacial deposits (Eyles 1983) and produces massive diamicts similar to those of this study. Lithofacies Dms, Dms(r), and Dmm(r)

(GA2 and RP2, Fig. 1) indicate that active supraglacial deposition occurred above the basal melt-out zone. At RP2 (Figs. 1, 3), the more massive basal meltout deposits grade up into crudely stratified diamicts. The resedimented "flow tills" such as those at GA2 (Fig. 1) are generally more consolidated than either the Dms or Dmm Navarre lithofacies. A change in consolidation of flow tills compared to other lithofacies is common during the resedimentation process (Eyles 1983).

Statistical comparisons of laboratory parameters among three of the lithofacies of Navarre diamicts showed some significant differences (Table 4). The Dmm and Dms lithofacies differed in the amounts of clay, calcite, dolomite, and crystallines, and in Q/F. There was a significant difference between the means of the Dms and Dmm(r) lithofacies for Q/F and the percent carbonates in the coarse-sand fraction. The Dmm and Dmm(r) lithofacies differed significantly in the amounts of sand, carbonates, and clastics. Some compositional differences among lithofacies may be attributed to vertical position within the ice sheet. Material derived from englacial load may have originated from distant sources, whereas, that derived from the base of the ice represents a local source.

The full variety of Navarre diamicts is not found at the type section, where only Dmm occurs. However, the comparison of Dmm at the type section to Dmm at all localities showed no significant differences (Table 4). The type section is representative of the Dmm lithofacies found throughout the study area. Additionally, there are no statistical differences in texture and composition (Table 4) between Navarre diamicts at the type section and those from other sections. The texture and composition of Navarre diamicts at the type section (Table 3) may be considered representative of all Navarre diamicts in the type area.

A further complication is that field descriptions of some lithofacies of Navarre diamicts are often quite similar to those of the Millbrook diamicts. Navarre diamicts (Dmm) and Millbrook diamicts (Dmm) in the study area were compared statistically (Table 4). Percent crystallines and Q/F of Dmm at the two type sections differed. Comparison of all Millbrook diamicts to all Navarre diamicts, regardless

TABLE 4

Results of t-tests comparing various sample groups.

Comparison	Sand (%)	Silt (%)	Clay (%)	Cal. (%)	Dol. (%)	Q/F	Carbonate (%)	Clastic (%)	Crystalline (%)	DI	Fe Extract	Elemental Composition
Dmm vs Dms (all Navarre occurrences)			+	+	+	+			+	na	na	na
Dmm vs Dmm(r) (all Navarre occurrences)	+						+	+		na	na	na
Dms vs Dmm (r) (all Navarre occurrences)						+	+			na	na	na
Dmm (Navarre type section) vs Dmm (all Navarre occurrences)										na	na	na
Diamicts (all Navarre occurrences) vs diamicts (Navarre type section)										na	na	na
Diamicts (Navarre type section) vs diamicts (Millbrook type section)						+			+		na	na
Diamicts (all Navarre occurrences) vs diamicts (all Millbrook occurrences)					+	+	+			na	na	+ (B.Ti)
Unweathered Navarre diamicts vs unweathered Millbrook diamicts		+	+							na	na	na

+ indicates a significant difference ($P = 0.05$), na = not applicable.

of facies (Table 4), showed statistical differences for dolomite, Q/F, and carbonate in the coarse-sand fraction. Unweathered Navarre and Millbrook diamicts (Dmm) differ in their average silt and clay contents (Table 4). This difference is misleading because several unweathered Navarre samples were collected close to underlying shale. Incorporation and comminution of shale may have increased the clay content of the overlying diamicts.

The degree of consolidation of diamicts (Dmm) in this study was evaluated using the criteria developed by White (1982) and Totten and Szabo (1987). The degree of difficulty in excavation permitted us to identify massive Millbrook diamicts in six of the 11 measured sections and at six other localities in the study area. At these locations, the Millbrook diamicts were all more difficult to excavate than any Navarre diamicts found in the area. The higher degree of consolidation of the Millbrook massive diamicts may have been produced as a much thicker Millbrook glacier deposited the Millbrook diamicts under more pressure, or these deposits may have been consolidated further by Navarre ice. Navarre Dmm were more consolidated than Navarre Dms, but less consolidated than Millbrook Dms. The lesser degree of consolidation of the Navarre Dms may be attributed to its platy structure resulting from thin horizontal sand beds.

Although field descriptions of the degree of consolidation and type of structure of massive Navarre diamicts

differ considerably from those massive Millbrook diamicts, the genetic characteristics of the stratified, oxidized Millbrook Dms lithofacies, and the same Navarre lithofacies, produce a very similar field description. For example, Navarre and Millbrook Dms lithofacies at RP2 (Fig. 3) only differ slightly in oxidized color and have similar laboratory analyses. This similarity in Navarre and Millbrook diamicts may be a result of a similar source of glacial sediments, especially the Paleozoic sedimentary rocks that are a major source of glacial sediments in northeastern Ohio (Szabo and Angle 1983). In addition, similar mineralogy also may be produced by Navarre ice eroding older Millbrook sediments.

This study confirms that the Navarre deposits represent a separate glacial event, and that they may be distinguished from older Millbrook deposits. Further evidence is provided by occasional weathering profiles such as that found at the RP2 section. This study suggests that there are difficulties in using the Navarre type section as a model for all Navarre diamicts. The type section does not contain the full range of facies present in the study area and contains a thicker Dmm than is found in any other section. Stratigraphic correlation and delineation in the study area by laboratory analyses alone is, therefore, not valid without careful lithofacies logging and consideration of genetic characteristics of Navarre deposits when comparing them to older Millbrook deposits.

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