

Properties of the Fractured Glacial Till at the Madison County, Ohio, Field Workshop Pit Site¹

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ABSTRACT. Water and contaminants obviously do move through the so-called impermeable glacial tills in Ohio. This study was conducted to illustrate the extensive presence of fractures in the till and to quantify the differences in hydraulic conductivity and physical and chemical properties between the fracture-affected zones and the till matrix. *In situ* measurements of the saturated hydraulic conductivity were made in small boreholes positioned either in the matrix or intersecting the fractures. Soil samples from both the fracture faces and the matrix were analyzed for particle size distribution, clay mineralogy, calcite, dolomite, and iron content. Hydraulic conductivity measured in boreholes intersecting fractures was 1.25×10^{-5} cm/sec (0.018 in/hr), one order of magnitude greater than in boreholes in the matrix. Particle size distribution was the same for the fracture faces and the matrix. The fracture faces showed no significant change in total clay content and a slight increase in expandable clay. Calcite content was 62% greater, dolomite content was 6% lower, and iron content was 73% lower on the fracture faces as compared to the matrix. The fractures affected approximately 7% of the soil volume.

OHIO J SCI 100 (3/4):107–112, 2000

INTRODUCTION

The Ohio Academy of Science 1997 Summer Field Workshop on Joints and Fractures in Ohio Tills: Site Investigation Techniques & Field Hydraulic Measurements was held at The Ohio State University's Molly Caren Agricultural Center near London in Madison County, OH. The motivation for organizing and presenting this workshop was to illustrate the extensive presence of fractures in the so-called impermeable tills, and to demonstrate various investigation and measurement techniques for site assessments in areas with known or suspected fractured tills. Evidences of ground water contamination from sources such as leaking landfills, septic leach fields, and food processing wastewater lagoons indicate that these tills are not impermeable, and, in fact, that substantial amounts of water and contaminants can move through the tills. There is a need to increase awareness of the fractures and to understand more about their origin, their properties, and their contribution to ground water recharge and contaminant transport. Our initial goal was to demonstrate an *in situ* method for measuring hydraulic conductivity and to quantify the difference in hydraulic conductivity between the fractures and the till matrix. Ultimately we expanded our scope to include characterizing physical and chemical differences between the fracture-affected zones and the till matrix.

MATERIALS AND METHODS

Field Workshop Site

The site is located in Deer Creek Township, Madison County, OH, at 39°56'51.33" N latitude, 83°25'39.17" W longitude. A large pit was excavated to allow participants at the field workshop to walk down into the pit to

observe the fractures at several levels and to appreciate their three dimensional orientation.

The construction of this pit is described in detail in Christy and others (2000) with accompanying photographs. The site is representative of the Late Wisconsinan age till deposits in west central Ohio. Cores from vertical and angle boring drill rigs were taken adjacent to the pit to demonstrate the relative usefulness of cores to indicate the presence and intersecting nature of the fractures as seen in the pit. Discussions at the pit during the field workshop included a geologic history of the area, possible mechanisms causing formation of the fractures, soil profile description, and hydraulic conductivity measured in the fractures and the matrix.

Geologic Description

The study site is located on the proximal side of the London recessional moraine. This moraine is a portion of the body of dominantly loam and silt loam textured Wisconsinan glacial till which in central Ohio is located between the Powell moraine and the Reesville moraine (Pavey and others 1999). This till body can be traced westward into Indiana and Illinois (Mickelson and others 1983). Deposition of the London moraine is dated at 16,100 to 16,700 yr BP and has been designated as the Darby Till (Mickelson and others 1983). The till characteristically has 15 to 25% clay and 10 to 15% limestone rock fragments (carbonate). (Also see Brockman and Szabo 2000.)

Soil Series Description

The soils of the study site are dominantly an association of Miamian, Lewisburg, Celina, and Crosby soils (Gerken and Scherzinger 1981). These soils represent a toposequence of soils ranging in drainage from well to somewhat poorly drained. The Lewisburg and Celina are both moderately well drained soils with the Lewisburg

¹Manuscript received 27 August 1999 and in revised form 15 January 2000 (#99-26).

having thinner sola. All of these soils are considered to have developed from loam textured glacial till of Wisconsinan age.

The major study pit was located in a unit of Lewisburg silt loam on a 0-2% slope. The Lewisburg soil is classified as fine, mixed, mesic Typic Hapludalf. A typical Lewisburg profile described in Madison County follows (Gerken and Scherzinger 1981).

Ap – 0 to 229 mm (0 to 9 in); brown (10YR 4/3) silt loam; moderate medium granular structure; friable; many roots; few pebbles; neutral; abrupt smooth boundary.

Bt – 229 to 381 mm (9 to 15 in); dark yellowish brown (10YR 4/4) clay loam; weak coarse prismatic structure parting to moderate medium subangular blocky; firm; common roots; patchy dark yellowish brown (10YR 4/4) clay films on horizontal and vertical faces of peds; 5 percent pebbles; slightly acid; abrupt wavy boundary.

B_{ct} – 381 to 533 mm (15 to 21 in); yellowish brown (10YR 5/4) clay loam; moderate coarse subangular blocky structure; firm; few roots; patchy dark yellowish brown (10YR 4/4) clay films on horizontal and vertical faces of peds; common light gray (10YR 7/1) weathered limestone fragments; 8 percent pebbles; slight effervescence; mildly alkaline; clear wavy boundary.

C₁ – 533 to 838 mm (21 to 33 in); yellowish brown (10YR 5/4) loam; few fine distinct light brownish gray (10YR 6/2) mottles; massive; firm; 12 percent pebbles; strong effervescence; moderately alkaline; gradual wavy boundary.

C₂ – 838 to 1143 mm (33 to 45 in); yellowish brown (10YR 5/4) loam; common medium distinct light brownish gray (10YR 6/2) mottles; massive; firm; 12 percent pebbles; strong effervescence; moderately alkaline; gradual wavy boundary.

C₃ – 1143 to 1542 mm (45 to 60 in); yellowish brown (10YR 5/4) loam; massive; firm; 12 percent pebbles; strong effervescence; moderately alkaline.

Sampling of the Pit

The field workshop pit had benches constructed at approximately 1.1 m (42 in), 1.9 m (73 in), and 2.7 m (108 in) below the ground surface. Saturated hydraulic conductivity measurements were made on the upper bench at 1.1 m (42 in) depth (Fig. 1) using the Compact Constant Head Permeameter (also known as the Amoozemeter) described by Amoozegar (1989). This technique involves maintaining a constant head of water in a 51 mm (2 in) diameter by 254 mm (10 in) deep cylindrical borehole and monitoring the water use over a period of time. Data were collected for two such holes, one intersecting a fracture and the other within the matrix (Fig. 2). Because the flow rates were very slow, readings were taken after 18 to 24 hours to increase the accuracy of the measurements. Bulk soil samples were taken from 0.9 to 1.1 m (36 to 42 in), 1.3 to 1.4 m (50 to 56 in), 1.7 to 1.8 m (66 to 72 in), and 2.1 to 2.2 m (82 to 88 in) for determining particle size analysis, carbonate content, and clay mineralogy of the

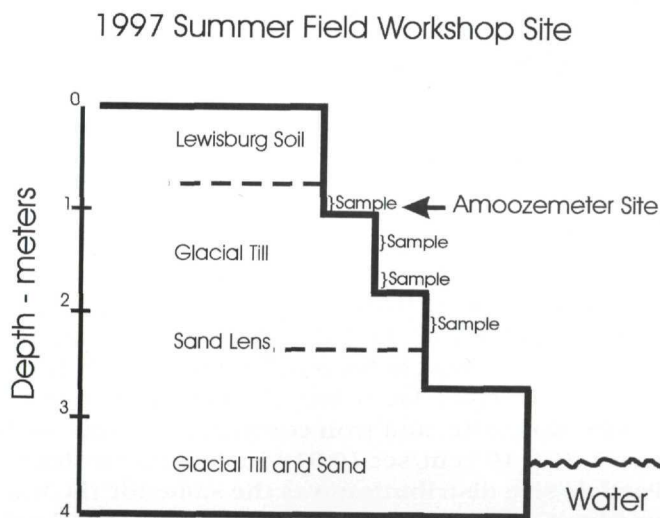


FIGURE 1. Schematic view of the field workshop pit showing the locations where soil samples were taken and where the saturated hydraulic conductivity tests were performed.

till matrix. The water table, as measured in the pit on 28 August 1997, was located at 3.6 m (140 in) below the soil surface.

Sampling at An Adjacent Site as Follow-up

The pit was closed the day following the field workshop due to other site use considerations and safety issues. This meant that we no longer had access to this exact location for follow-up. There were insufficient data available from the field workshop pit to allow for any meaningful interpretation of the measurements of hydraulic conductivity. Also, while we had collected till matrix samples, we had not made any effort to examine



FIGURE 2. Photograph showing the 50 mm diameter boreholes used for hydraulic conductivity tests. Note the coin (the quarter above and to the left of the right hole) used for scale, and the size and arrangement of the fracture-affected zones relative to the boreholes.

or identify any physical or mineralogical differences between the matrix and the fractures. Thus we decided to return to the proximity of the pit and obtain additional samples for analysis and to conduct additional hydraulic conductivity determinations. This new site, approximately 91 m (300 ft) N of the original pit, was located at 39°56'52.84" N latitude and 83°25'39.42" W longitude. The soil at this site was located in a Crosby soil mapping unit, the somewhat poorly drained member of the toposequence.

Trenches were dug to 1.3 to 1.4 m (50 to 56 in) depth, and hydraulic conductivity tests were performed as before centering on the fracture zones and within the matrix using the Amoozemeter. Samples of the material excavated from the trenches used for the hydraulic conductivity tests were collected and used for particle size analysis, bulk density, clay mineralogy, calcite, dolomite, and iron content. These determinations were made using the following methods of analysis. Particle-size analysis of the less than 2 mm fraction was performed using modified pipette methods of Kilmer and Alexander (1949) and the Soil Survey Staff (1984). Bulk density was determined using modified methods of Brasher and others (1966) and Soil Survey Staff (1984). Clay mineralogy was determined by x-ray diffraction using the method described by Burras (1992). Calcite and dolomite contents were determined by the gasometric method of Dreimanis (1962) utilizing a Chittick apparatus. The citrate-bicarbonate-dithionite-extractable (CBD) iron was determined by the method of McKeague and Day (1966).

Tracings of the matrix polygons and their surrounding gray zones imbedded within the brown matrix were made onto transparent 279 by 381 mm (11 by 15 in) chart sheets (Bruning Areagraph Chart No. 4850) having 30 dots per 6.45 cm² (1 in²). These tracings were used to calculate the fraction of the total area of the trench floor that was fracture-affected by counting the number of dots contained within the gray zone boundaries and dividing by the total number of dots on the page.

In order to compare the physical and chemical properties of the till matrix with the adjacent fracture faces, samples of the bulk till with fracture faces were taken from 1.3 to 1.4 m (50-56 in) depth in the adjacent study site. The blocks were taken to the laboratory and the surface 6 to 12 mm (0.25 to 0.5 in) of the fracture faces was scraped to remove the gray coatings. Care was taken to not include any of the reddish-brown band interior to the face. This gray material and the brown material from the interior of the blocks (matrix) were then analyzed for physical and chemical properties.

RESULTS

Saturated Hydraulic Conductivity

Hydraulic conductivity values were determined within and between fracture-affected zones for one set of boreholes in the field workshop pit and from eight other tests at the adjacent site. The mean value of saturated hydraulic conductivity in the fracture-affected zones was $1.25 \times 10^{-5} \pm 0.694 \times 10^{-5}$ cm/sec (0.018 ± 0.010 in/hr), while the mean value in the matrix was $1.11 \times 10^{-6} \pm 0.556 \times 10^{-6}$ cm/sec (0.002 ± 0.001 in/hr).

Area of Fracture-affected Zones

Based on ten different locations where the fracture pattern was traced onto the areagraph chart sheets, the fracture-affected zones represent 7.1% of the area in the horizontal plane.

Particle Size Analysis, Dolomite, and Calcite

The results from the analysis of the samples taken from the field workshop pit site are shown in Table 1, and data from the adjacent study site are shown in Table 2. Similar data on the properties of the glacial till from other selected sites in western Ohio are shown for comparison in Table 3. Comparison of the data suggests that the till at the field workshop site is very similar to till throughout much of western Ohio.

TABLE 1

Physical and chemical properties of the glacial till in the field workshop pit, Madison County, OH.

Depth meters						
	>2 mm	Sand	Silt	Clay	Calcite	Dolomite
	%					
0.91-1.07	19.7	30.2	49.0	20.8	11.7	30.9
1.27-1.42	29.1	29.7	48.5	21.8	10.2	31.5
1.68-1.83	26.0	29.3	49.2	21.5	8.9	30.9
2.08-2.24	22.2	29.2	50.4	20.4	10.2	30.8

Clay Mineralogy

Clay types and their relative percentages in the samples of till from the adjacent study site are shown in Table 4. Table 5 shows data from other till samples in western Ohio for comparison.

DISCUSSION

Saturated Hydraulic Conductivity

The soil survey report for Madison County (Gerkin and Scherzinger 1981) lists the permeability (saturated hydraulic conductivity) ranges for the C horizon (upper

TABLE 2

Physical and chemical properties of the fracture face and the matrix in the glacial till at 1.27-1.42 meters depth in the adjacent study site, Madison County, OH.

Unit						Iron CBD	Bulk Density gm/cc
	Sand	Silt	Clay	Calcite	Dolomite		
	%						
Fracture face	31.6	47.0	21.4	14.9	28.8	0.3	—
Matrix	30.4	47.4	22.2	9.2	30.5	1.1	2.02*

*oven dry moisture basis

TABLE 3

Properties of glacial till from selected sites in western Ohio. (Examples taken from literature and thesis.)

County	Soil	Depth meters	Sand	Silt	Clay %	Calcite	Dolomite	Bulk Density gm/cc
Miami(1)	Kokomo	0.96-1.30	32.8	53.6	13.6	6.2	31.3	1.89*
Miami(1)	Kokomo	1.09-1.30	28.4	55.2	16.4	5.3	30.2	1.86*
Miami(1)	Kokomo	1.17-1.45	24.7	56.1	19.2	3.8	23.0	1.97*
Miami(1)	Kokomo	1.09-1.24	30.0	50.6	19.3	5.5	35.4	1.94*
Preble(2)	Celina	1.47-1.78	44.6	39.9	15.5	6.9	29.6	1.90**
Preble(2)	Celina	1.17-1.42	35.9	45.5	18.6	9.1	34.1	1.88**

*oven dry moisture basis

** 1/3 bar moisture basis, (1) Konen 1995, (2) Wilding and others 1971

till) of the Lewisburg and Crosby soils as 4.23×10^{-5} to 1.41×10^{-4} cm/sec (0.06-0.2 in/hr) and 4.23×10^{-5} to 4.23×10^{-4} cm/sec (0.06-0.6 in/hr), respectively. These values are based on visible structural features in the soil profile. The values we measured in boreholes intersecting fracture-affected zones were always less than the lower end of the range reported in the soil survey report, and the values we measured in the matrix were at least one order of magnitude lower still. This suggests that the soil survey report values could be used as an optimistic estimate of the saturated hydraulic conductivity in the till.

Ground water flow is commonly modeled using Darcy's Law (Darcy 1856) stated as:

$$V = K(dh/dL),$$

where V = ground water velocity (L/T), K = saturated hydraulic conductivity (L/T), dh/dL = hydraulic gradient (L/L) or change in hydraulic pressure head (h) over distance (L), and time = (T). In reality, the matrix serves more as a storage reservoir and most of the flow occurs within the fractures. When the water table falls and a downward gradient exists, water moves downward through the fractures and water from the matrix tends to

move slowly to the fractures. When the water table rises, water moves back into the matrix from the fractures.

Using the mean values of saturated hydraulic conductivity measured in the boreholes, and assuming a hydraulic gradient of 1 m/m under continuously saturated flow, a molecule of water could move a distance of 3.9 m (155 in) through the fractures in one year, but a distance of only 0.4 m (14 in) if moving through the till matrix. Thus, the primary pathway of ground water recharge and contaminant transport is through the fractures.

Area of Fracture-affected Zones

The fracture-affected zones represent approximately 7% of the area of the horizontal plane through which water flows downward to recharge the ground water. The other important feature is the cross-sectional dimension of the matrix polygons. While we did not measure these polygons carefully, and because they are not regular in shape and size, we can only estimate the cross-sectional area based on the scale of the photographs taken to document the fracture patterns. The polygons range generally from 0.1 to 0.2 m² (1 to 2 ft²) in area (see Fig. 1). Thus for site investigation, the size of the probe used to collect samples is important relative to the size of these polygons. Probes smaller than the average area of the polygons have less chance to intersect with and illustrate the nature of the fractures between the polygons.

Particle Size Analysis, Dolomite, and Calcite

The Wisconsinan till sheet of central and western Ohio south of the Powell and Union City moraines is considered relatively uniform in chemical and physical properties. Fractures in the till are found throughout this area (Tornes and others 2000). Properties of the till of central and western Ohio as compared with the study area are shown in Tables 1, 2, and 3. The sand and silt contents of the field day pit and the adjacent study site in Madison County are within the range of those from the reported sites in Miami and Preble Counties. The

TABLE 4

Clay mineral, quartz and goethite analysis of fracture face and matrix samples taken from 1.27-1.42 meters depth in the adjacent study site.

	Illite	Vermiculite	Kaolinite	Chlorite	Quartz	Expandable	Goethite
	%						
Fracture Face	70	<5	5	10	<5	10	0
Till Matrix	70	10	5	5	<5	5	<5

TABLE 5

*Clay mineralogy of glacial till from selected sites in western Ohio.
(Examples taken from literature and unpublished lab data.)*

County	Soil	Depth meters	Illite	Vermiculite	Kaolinite %	Chlorite	Quartz
Preble*	Celina	1.17-1.42	65	10	<5		<5
Auglaize ^o	Morley	1.96-2.26	80	10	<5	<5	>5
Madison**	Brookston	1.98-2.29	78	14	<5	<5	<5
Preble**	Celina	1.78-2.21	77	11	<5	<5	<5
Darke**	Celina	1.52-1.90	68	11	<5	<5	<5

*Wilding and others 1971

**Ohio State Soil Characterization Laboratory, unpublished data

clay content is slightly higher at the Madison County sites. The till is dominantly loam and silt loam in texture with clay content ranging from 13 to 25%, silt ranging from 40 to 55% and sand ranging from 25 to 45%.

The characteristics of the till at the field workshop pit and the adjacent study site are clearly typical of western Ohio tills. The particle size distribution is very similar to published values, as are the amounts of calcite and dolomite. Also there appears to be very little difference in these characteristics between the fracture zones and the matrix. This implies neither removal nor accretion of materials within the fractures. The fracture faces have at their surfaces a gray zone of up to 13 mm (0.5 in) thickness. The fracture-affected zones are often 25 mm (1 in) wide as seen from the photographs and tracings. Inside this zone is a thin reddish-brown band. These features suggest that iron has been mobilized and transported out of the fracture zones. During high water table events, anaerobic conditions apparently develop within the fracture zones, resulting in reduction of iron to a soluble form. Subsequently, during lowering of the water table, this soluble iron is transported away leaving behind a bleached area seen and interpreted as a fracture zone.

Calcite and dolomite contents are also similar throughout central and western Ohio. The carbonate is dominantly dolomite with the dolomite content ranging from 23 to 35% and the calcite content ranging from 4 to 9% (Table 3). The dolomite in the pits in this study were within this range (Tables 1 and 2), and the calcite ranged only slightly higher with a maximum of 12%.

Bulk Density

Bulk density of the glacial till is high with a range from 1.8 to 2.1 gm/cc. An unpublished study of 26 samples of the glacial till in Preble County had a range of values from 1.9 to 2.1 gm/cc.

Clay Mineralogy

The clay fraction of the tills in the area south of the Powell/Union City moraine are dominated by illite and

have lesser amounts of vermiculite, kaolinite, chlorite and quartz and feldspars.

The clay mineralogy at the field workshop pit and the clay mineralogy of glacial till from selected sites in western Ohio are shown in Tables 4 and 5. In all cases, the dominant clay mineral is illite with lesser amounts of vermiculite, kaolinite, and chlorite. Table 4 compares the mineralogy of the fracture face with that of the matrix. The fracture face has more expandable clays and chlorite and less vermiculite as compared to the till matrix.

Fracture Face and Matrix

The physical and chemical properties of the fracture faces and the matrix are shown in Table 2. The particle-size distribution is the same within laboratory error for the faces and the matrix. The carbonate content is different. There is a 62% increase in the calcite content on the face and a 6% decrease in the dolomite content. Field soil scientists had usually attributed the light color on the fracture faces to a deposition of calcite and hypothesized that the face would be dominantly calcite. These results indicate that there is much less of an increase in calcite than had been expected. Iron in the samples was determined by the CBD method, which extracts both the crystalline and the non-crystalline iron oxides with little influence on the iron silicate minerals. The matrix of the till sample had a CBD iron content of 1.1% as compared to 0.3% for the fracture face (Table 2), a 73% reduction in iron content. The x-ray analysis of the material in the fracture face and the adjacent till matrix also indicates that iron in the form of goethite has been removed from the fracture face (Table 4). No goethite was found on the gray fracture faces while a finite amount (less than 5%) was identified within the matrix. Thus a major portion of the iron oxides on the fracture face has been reduced, mobilized and removed from the face. Although the reddish-brown band interior to the fracture face was not analyzed, it is assumed that a portion of the iron removed from the fracture face was precipitated in the band. This removal can be attributed to reducing conditions along the fracture faces (Vepraskas 1995).

SUMMARY AND CONCLUSIONS

In situ measurement of saturated hydraulic conductivity in fractured till reveals that the resultant conductivity values are highly dependent on where the tests are performed. Hydraulic conductivity measured within fracture-affected zones is one or more orders of magnitude greater than that measured within the unfractured till matrix. Published soil survey values of permeability within the C horizon of soils developed in glacial tills may be useful, in lieu of actual site measurements, for estimating rate of water movement in these tills, but may slightly overestimate the rate and amount of water moving through the profile.

A study of fractures in the till in east central Indiana (McBurnett and Franzmeier 1997) concluded that where the till was thin and overlying outwash, the fracture faces were coated with clay. Where the outwash was deep or absent the fracture faces were coated with carbonate. In our study the fracture faces have no increase in total clay content (Table 2) and only a slight increase in expandable clay (Table 4). There is an increase in calcite on the fracture face and a small decrease in dolomite (Table 2).

The uniformity of the physical and chemical properties of the glacial till in Central and Western Ohio along with the presence of fractures suggests that data on the till collected at the field workshop pit and adjacent study site can be applied to much of the till of the area.

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