

# Mineralogy of Weathered Wisconsin Till along a Fracture in the Root Zone<sup>1</sup>

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**ABSTRACT.** Subsampling of a large block of Wisconsin Ashtabula Till suggests that weathering progresses outward from fractures in the root zone. In the fracture zone pore waters have precipitated iron, calcite has been partially leached, and dolomite remains constant. Illite and kaolinite phases present in samples taken from near the fracture in yellowish-brown, oxidized till do not significantly differ from gray, unoxidized till from the same horizon. However, chlorite has been altered to vermiculite in samples proximal to the fracture. Diffraction intensity ratios ( $\text{illite}_{001}/\text{kaolinite}_{001} + \text{chlorite}_{002}$ ) increase near the fracture and decrease with distance away from the fracture. The concentration of goethite, the mineral responsible for the yellowish-brown color, decreases exponentially with respect to distance from the fracture. This oxidized zone has a greater sand content and lesser clay content than the unoxidized gray zone because free iron that coats the clay particles cements them into sand-size aggregates. Weathering processes in till adjacent to fractures are the same as those that form weathering zones in till landscapes.

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## INTRODUCTION

The occurrence of fractures in weathered and unweathered sediments associated with the glaciation of Ohio is well documented. Brockman and Szabo (2000) discuss the origin and distribution of fractures in tills occurring in over 35 counties; Tornes and others (2000) have demonstrated that vertical fractures occur in 95 soil series distributed over 55 counties in Ohio. Other occurrences of fractures in these types of deposits are noted in unpublished reports of the glacial geology of Sandusky, Seneca, Huron, Crawford, and Lorain counties in north-central Ohio (Angle 1987; Fernandez 1986; Totten 1985, 1987, 1989). Numerous M.S. theses supervised by John P. Szabo at the University of Akron contain section descriptions noting the occurrence of fractures, oxidation haloes extending into gray glacial sediments from fractures, and deposition of secondary minerals along them (Fig. 1).

Bruno (1988) studied the textural and mineralogical relations among lithofacies of the Late Wisconsin Ashtabula Till. This till consists of stratified and nonstratified diamictons, containing sand bodies and laminated fines, which are commonly exposed in lake bluffs between Euclid, OH, and the Ohio-Pennsylvania state line (Fig. 2). These lithofacies record the initial advance, melt back, subsequent readvance, and final meltback of the Ashtabula ice about 14,000 years ago (Szabo and Bruno 1997). Shear planes occur in some massive diamictons deposited as ice flowed upslope from the Erie Basin towards the Allegheny Plateau (Brockman and Szabo 2000). Some fractures may result from unloading by the retreat of the ice sheet; others are failure planes caused by removal of material through wave erosion at the toe of the bluffs during high stands of Lake Erie.



FIGURE 1. Photograph of the Ashtabula Till showing an oxidation halo around a fracture in the root zone, Geneva State Park, OH. Short black lines on the left of the scale in the photo are 1.0 cm in length.

Chemical weathering of tills produces alteration of clay minerals that can be observed in vertical weathering profiles (Droste 1956). Weathering proceeds gradually downward from the surface as chemical stability between mineral phases and geochemical environment is maintained. Likewise, percolating waters and increased aeration along joints and fractures in the root zone in till should cause weathering to proceed horizontally away from a fracture. The purpose of this study is to document changes in mineralogy and iron contents in a series of samples taken sequentially from a fracture into unweathered till.

## MATERIALS AND METHODS

An oriented specimen of Late Wisconsin Ashtabula Till was collected from the bluff of Lake Erie at Geneva State Park in Geneva, OH (Fig. 2). The matrix textures (% <2.0 mm) of the brown, oxidized till from near the joint plane and the more distal gray, unoxidized till near the center of the block were determined using the

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FIGURE 2. Location of Geneva State Park along the south shore of Lake Erie in Ashtabula County, OH.

settling method of Folk (1974). Percentages of calcite and dolomite (% <0.074 mm) were calculated from volumetric data generated by a Chittick apparatus (Dreimanis 1962).

Samples for powder x-ray diffraction analysis were shaved from the block of till at various distances from the fracture plane into the center of the specimen (Fig. 3); other samples were taken randomly from other locations in this block. Individual samples were gently disaggregated using a mortar and rubber pestle, and then subsampled using the cone-and-quarter technique. Powder mounts were prepared for "whole rock" analysis of each sample.

Free iron-oxide coatings were extracted using the citrate-bicarbonate-dithionite method (Jackson 1969) before samples were prepared for x-ray analysis. The supernatant liquid from the iron-extraction process was analyzed for iron concentration with a Perkins-Elmer atomic absorption spectrophotometer. Determination of the weight percent of iron extracted in each sample was calculated by dividing the concentration obtained from the analysis by the initial sample weight times 100 and reported as the free iron oxide content.

Mineral components were examined both as "whole rock" powder-packed samples and as oriented mounts of the clay fraction. Oriented mounts (<2.0  $\mu$ ) of each sample were prepared using centrifuge and suction methods modified from Starkey and others (1984). One set of oriented slides was scanned by x-ray diffraction both after air drying and overnight exposure in an ethylene glycol atmosphere. The second set was scanned after heating to 400° C for one hour and again at 550° C for one hour. X-ray diffraction analyses were performed on an automated Phillips 3100 diffractometer using

nickel-filtered Cu K $\alpha$  radiation at 40 kV and 30 ma. Samples were scanned at the rate of 0.02° 2 $\theta$  per sec. Powder-packed samples were scanned from 2° 2 $\theta$  to 50° 2 $\theta$ , whereas oriented mounts were scanned from 2° 2 $\theta$  to 35° 2 $\theta$ .

Minerals were identified with guides by Droste (1956), Carroll (1970), Brindley and Brown (1980), and Starkey and others (1984). Also, intensities, converted from counts, under the peaks centered at 0.700 and 1.000 nm, as well as background intensities, were determined with Phillips quantitative systems software. The gross intensity under the 1.000-nm 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. The background intensity or associated machine noise was also determined for that scan range, then software corrected for the background intensity to generate a corrected intensity. The intensity under the 0.700-nm 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. This gross intensity was also corrected for background intensity over this interval to produce a corrected intensity. The corrected intensities under the 0.700- and 1.000-nm peaks were used to determine the diffraction intensity ratio (DI) (Willman and others 1966). DI is calculated by dividing the intensity of the 1.000 nm (illite<sub>001</sub>) peak by the intensity of the 0.700 nm (kaolinite<sub>001</sub> and chlorite<sub>002</sub>) peak (Ruhe and Olson 1978).

## RESULTS

Two types of diamicton are contained within the sample. The upper facies (Fig. 3) consists of 10YR4/6 (Munsell 1954), yellowish brown, laminated calcareous diamicton containing 10YR4/4, weak, red, blebs. This stratified diamicton that may have formed through subglacial melt out is not representative of the remainder of the block and is not included in this study. The lower part of the block (Fig. 3) is a massive, silty, calcareous diamicton containing granules, and can be divided into two zones based on color. The left side of the block is

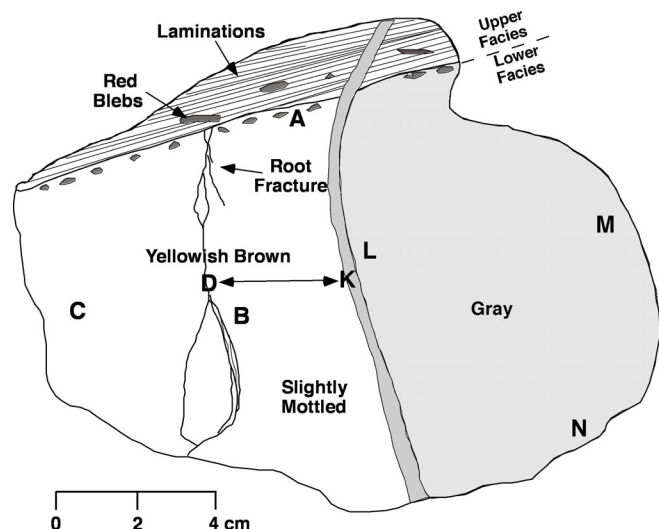


FIGURE 3. Sketch of the block of Ashtabula Till taken from Geneva State Park. Letters indicate the locations of subsamples within the block. Samples D through L were taken sequentially along the arrow.

10YR4/6, yellowish brown, whereas the right side is 10YR5/1, gray. The yellowish-brown zone has a fracture through its center, modified by root growth followed by fluid percolation.

The brown and gray parts of the block display some variation in matrix texture and carbonate content. The gray block contains 6% sand, 68% silt, and 26% clay, whereas the yellowish-brown block consists of 14% sand, 73% silt, and 13% clay. The total carbonate content of 6.6% of the gray till is larger than that of the yellowish-brown till which averages 4.4%. The two blocks have similar dolomite contents (3.4% vs. 3.8%) and differ significantly in their calcite contents. The gray block contains 2.8% calcite, whereas the yellowish-brown block has 1.0%.

The location of a series of scrapings (D through L) extending from the fracture to the gray part of block and the location of other samples are illustrated in Figure 3, and respective laboratory data are recorded in Table 1. "Whole rock" powder-packed samples of both gray and yellowish-brown samples display similar suites of clay minerals. The major mineral phases in the samples are illite (1.000 nm), kaolinite (0.700 nm), and chlorite (1.400 nm). Clay-size quartz (0.330 nm) and minor amounts of clay-size calcite (0.300 nm), dolomite (0.290 nm), and feldspars (0.317 nm) are consistently observed in the samples.

Among the clay minerals, the 1.000 nm illite peak (Fig. 4) remains sharp and is unaffected by glycolation and heating in all of the samples. The 1.400 nm chlorite peak from gray samples remains sharp and also is not affected by glycolation and heating, but in the yellowish-brown samples, this peak expands slightly after glycolation and decreases or collapses when heated (Fig. 4), indicating the presence of vermiculite (Droste 1956). The 0.700 nm kaolinite and chlorite peak is unaffected by glycolation, but collapses upon heating to 550° C. The mean DI varies between the gray and yellowish-brown samples (Table 1) and decreases with distance from the fracture (Fig. 5). The average DI of the yellowish brown samples is 2.1, whereas it is 1.1 for the gray samples. A Cochran-Cox *t*-test (Ferguson 1971) for groups having unequal variances show that these means are significantly different at the 5% level of significance.

The mineral phase of iron identified on the x-ray diffractogram is goethite having a peak at 0.245 nm. The mean iron contents of the yellowish-brown and gray samples (Table 1) differ significantly at the 5% level of significance. There is an apparent decrease in free-iron content with distance from the fracture in the yellowish-brown till to the unweathered gray till (Fig. 6). Within the gray till, iron content shows no significant trend with distance.

## DISCUSSION

The variations in texture and mineralogy of samples from the block of Ashtabula Till can be explained by weathering processes that not only proceed downward from the surface but also normal to fracture planes. The difference in texture between the yellowish-brown and gray samples is in the proportions of sand and clay.

TABLE 1

Summary of laboratory data.

Sample	DI (air dried)	Weight % Iron	Distance from Fracture (cm)
Brown			
A	1.9	3.15	rm***
B	2.9	1.87	rm
C	1.6	1.36	rm
D	1.8	3.42	0.0
E	1.8	2.16	0.5
F	2.8	1.79	1.0
G	2.2	1.50	1.5
H	1.9	1.34	2.0
I	1.6	1.12	2.5
J	1.7	0.92	3.0
W	2.9	na**	rm
$\bar{c}$ *	2.1	1.86	
$s^*$	0.5	0.83	
$n^*$	11	10	
Gray			
K	1.1	0.14	4.0
L	1.2	0.16	4.5
M	1.0	0.12	rm
N	1.1	0.16	rm
X	1.3	na	rm
$\bar{c}$	1.1	0.15	
$s$	0.1	0.02	
$n$	5	4	

\*  $\bar{c}$  = mean,  $s$  = standard deviation,  $n$  = number of samples.

\*\* not analysed

\*\*\* random sample

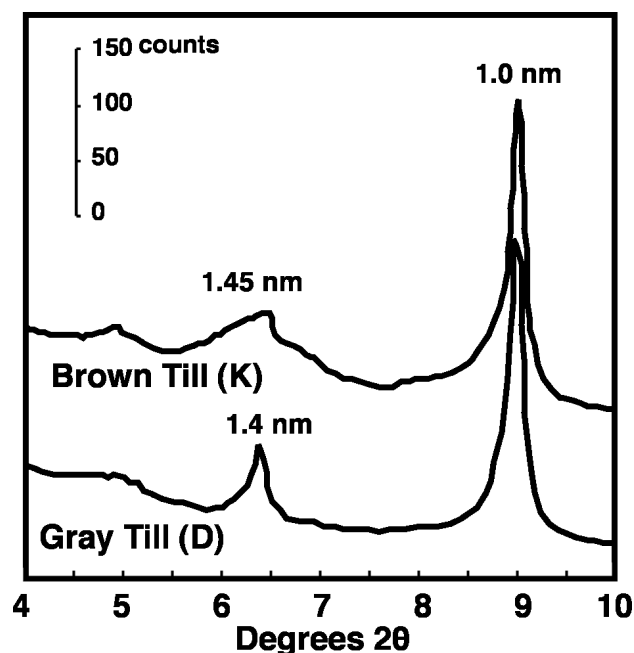


FIGURE 4. Smoothed x-ray diffraction patterns of glycolated samples of the oxidized brown till (K) and unaltered gray till (D). The illite peak (1.0 nm) remains unaffected, but the chlorite peak (1.4 nm) expands to vermiculite (1.45 nm) in the oxidized till.

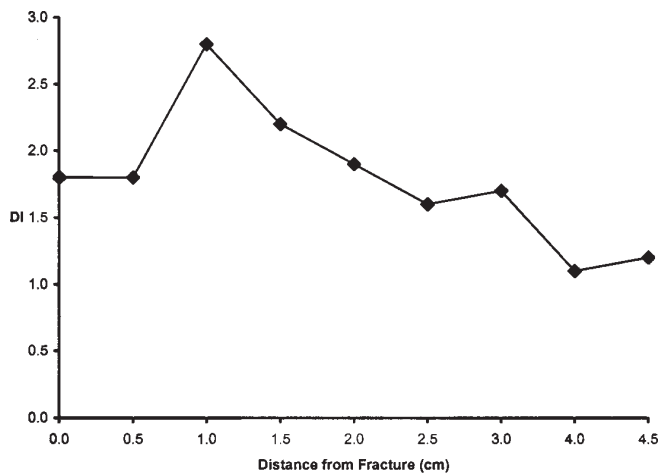


FIGURE 5. General decrease in DI away from the fracture in the till block.

The weathered sample appears to contain more sand and less clay than the unweathered sample. Clay particles in the yellowish-brown sample are slightly cemented by iron, forming sand-size aggregates that do not pass through the 0.063-mm sieve that is the lower limit of sand in this study. These concretions are soft enough to be crushed between the fingers.

Weathering has affected the calcite content of the yellowish-brown sample. The movement of percolating water in close proximity to the fracture has partially leached the calcite from the adjacent till. Dolomite contents are nearly identical and reflect the greater stability of dolomite to the initiation of weathering processes (Willman and others 1966).

Droste (1956) and Willman and others (1966) suggest that chlorite begins to alter before calcite is completely leached as weathering proceeds downward. Weathering proceeds as hydration of the brucite sheets of chlorite alters them to vermiculite, forming randomly mixed layers of chlorite-vermiculite. Eventually, well-crystallized illite is altered by hydration of intermica sheets to randomly mixed-layered illite-montmorillonite (Droste 1956). These changes should be reflected in the DIs of samples (Willman and others 1966). As chlorite weathers,

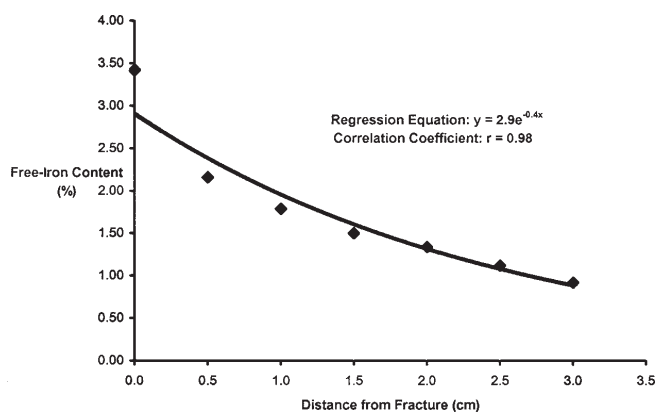


FIGURE 6. Exponential decay of free-iron content with distance from the fracture in the till block.

the denominator of DI decreases, which causes the DI to increase and, as illite begins to weather, the numerator of DI will begin to decrease which decreases the DI. Kaolinite remains unaffected in this process.

These changes in clay minerals are illustrated by the DIs of samples that vary with distance from the fracture in this study (Fig. 5). The decline in DI from 2.8, one centimeter from the fracture, to 1.8 at the fracture and the slight asymmetry of the illite peak at 1.000 nm suggest that illite is beginning to alter within 1.0 cm of the fracture. DIs decline to the average value, 1.1, of gray samples at 4.0 cm from the fracture. This implies that chlorite is less weathered in samples away from the fracture and not weathered in the gray samples at 4.0 cm and beyond.

The weight percent of free-iron oxides in the weathered till is a function of distance from the fracture. A best-fit line (Fig. 6) is expressed as an exponential-decay function having free-iron content as a function of distance from the fracture. This equation and correlation coefficient imply that 96% of the variation in free-iron content can be explained by distance from the fracture. In the unoxidized zone iron occurs as  $Fe^{+2}$ , either in solution or within iron-bearing phases such as chlorite. Oxygen-rich fluids are introduced into this zone along fractures. As oxygen diffuses into the till along the fracture, iron is oxidized from  $Fe^{+2}$  to  $Fe^{+3}$  and is precipitated as iron hydroxides. As iron is removed from solution by precipitation, it is replaced by iron that is diffusing toward the fracture from within the unoxidized till. The dual concentration gradients of iron and oxygen in this zone allow migration and further precipitation of free-iron oxides away from the fracture, resulting in the yellowish-brown stained till.

Percolating fluids in fractures play an active role in the weathering of minerals in tills in the fracture zone. These waters leach calcite from the till and cause goethite to precipitate as small (<1.0 mm) concretionary nodules on the fracture surface where oxidation is most intense, and as coatings on minerals in the oxidized zone. Furthermore, these iron coatings act as cement and bind the clay particles into sand-size grains. These coatings do not affect the clay mineralogy itself, but will hinder accurate textural determinations in oxidized tills.

The results of this study may be compared with those of Fausey and others (2000). In their study of the hydraulic conductivity of weathered till in the soil zone, they analyzed similar parameters as those in this study. A major difference between the studies is the depth from which samples were analyzed. The block of till used in this study was taken from below the depth of oxidation, whereas samples of till studied by Fausey and others (2000) were taken from soil horizons within 2.0 m of the surface in western Ohio. The tills of west-central Ohio are sandier than the tills deposited along the south shore of Lake Erie. Although tills in each study have a similar clay mineralogy and both contain goethite, carbonate contents of tills in west-central Ohio are more than five times those of tills from the Lake Plain in northeastern Ohio.

Superficially, the results of these two studies appear contradictory, but closer examination shows that the oxidation-reduction conditions are responsible for this difference. In west-central Ohio, Fausey and others (2000) sampled a pit dug through the soil profile at the top of the zone of oxidation, whereas in this study the sample block was excavated from the unoxidized zone that had been exposed through the rapid retreat of a lake bluff. Thus iron has been removed from the fracture surfaces in the zone of oxidation at the site in west-central Ohio, but precipitated along the fracture faces in the unoxidized zone along the lake bluff in northeastern Ohio. Similarly, calcite precipitates along fractures at the west-central site, but is dissolved along fractures at the northeastern Ohio location. Szabo and Ryan (1981) also noted the occurrence of calcite precipitates in fractures in Late Wisconsinan tills in northeastern Ohio.

If this study and that of Fausey and others (2000) are combined, two endpoints of a continuum between the oxidized zone at the surface and the unoxidized zone at depth are linked by common connection, the fracture. The weathering processes that affected the block of unweathered, fractured Ashtabula Till can be thought of as being representative of those processes that affected newly deposited till at the surface 15,000 years ago. The movement of weathering from the fracture plane into the till matrix may be similar to moving a weathering front from the surface downward into unweathered till. The description of fractured till by Fausey and others (2000) represents the end product of 15,000 years of weathering processes in which till is thoroughly oxidized. They describe a process whereby weathering has gone full circle to the point where high water table events actually cause reduction and removal of iron and leave a bleached, gray surface along the fracture. The continuum ranges from blocks of oxidized till delineated by bleached fractures near the surface, to blocks of largely unoxidized till bounded by brown, oxidized fractures at depth.

This study generally shows that weathering proceeds outward from fractures into the surrounding till. Weathering associated with fracture zones is a microcosm of the gradual mineral alteration that occurs from the surface downward to produce weathering zones in till. Thus, weathering along fractures enhances the downward formation of weathering zones, suggesting that fractured tills will weather more rapidly than unfractured tills.

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