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STATISTICAL CONFIRMATION OF THE FIELD DISCRIMINATION OF TILL UNITS WITH PARTICULAR REFERENCE TO A LOCAL RADNOR SECTION IN WOODFORD COUNTY, ILLINOIS

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ABSTRACT

An outcrop of Radnor Till (Illinoian) in Woodford County, Illinois revealed the presence of multiple, thin till units, each having unique lithologic characteristics. Sand-silt-clay ratios, clay and carbonate compositions and pyrite contents were determined for 37 samples representing four till units. Analysis of variance and discriminant analysis of the compositional data support the uniqueness of each till unit. It is suggested that the ill units represent deposition from separate icelobe advances, including lobes from both Lake Erie and Lake Michigan sources.

INTRODUCTION

While examining an exposure of the Radnor Till Member of the Glasford Formation (Jubileean Substage of the Illinoian) we noted the presence of a lacustrine silt in the middle of the till. It became apparent that either, 1) a small ice-marginal lake existed during a minor retreat of a major ice lobe, or 2) a more extensive lake existed between two separate ice advances. In the first case, the tills above and below the silt should be similar and would be a single, but slightly interrupted, deposit. In the second case, it could be expected that the tills above and below the silt would have different characteristics. It would also mean that the Radnor Till, at least at this location, is composed of multiple till units instead of a single till deposit. Additional field evidence supported the second choice.

The status of our present knowledge of the Radnor Till and the possible significance of a new interpretation of this part of the Pleistocene section was discussed with John Kempton of the Illinois State Geological Survey (ISGS). During the discussion he pointed out that there had been very little statistical analyses of till data done in the state. It was at his suggestion that this study was begun and our goals became 1) to try to determine if the Radnor Till is indeed made of multiple till units, and 2) to see if advanced statistical tests could be useful in confirming or denying field evidence for a multiple-till hypothesis. This study was not meant to redefine Radnor stratigraphy, nor to be an end in itself. Rather, we hope that the results of our small-scale study will motivate other glacial stratigraphers to try to unravel the details of Illinois geochronology and will further the use of statistical techniques in problem solving.

LOCATION AND METHODS OF STUDY

The outcrop of Radnor Till that is the object of this study is exposed along a cut-bank of a small tributary that feeds into the Mackinaw River. It is located in the NW/4, NE/4, NW/4, Sec. 12, T25N, R1W, Woodford County, Illinois (Figure 1). The outcrop is a vertical face cut into the Eureka Moraine and is exposed for a maximum of approximately 5 m vertically and for approximately 160 m intermittently along the stream. About 200 m to the northwest Wisconsinan units, including the Robein Silt (Farmdalian) and the Tiskilwa and Snider Till Members of the Wedron Formation (Woodfordian), have been identified above the Radnor along a road-cut. Additional till is exposed along the Mackinaw River, approximately 130 m to the east and 5-6 m lower in elevation from the main outcrop under study. This lower till is also included in the Radnor on the Quaternary Deposits of Illinois Map (Lineback, 1979a).

The outcrop along the cut-bank was studied in the field in an attempt to identify distinctive units. Multiple samples from each unit were collected at each end and in the middle of the exposure. In addition, five samples were collected over a distance of 50 m from the Radnor Till exposed along the Mackinaw River. All the samples were analyzed by the ISGS for sand-silt-clay proportions, expandable clay-illite-kaolinite + chlorite proportions and x-ray analysis of calcite and dolomite (reported as counts per second). The authors performed standard Chiddick analyses of carbonate content (Dreimanis, 1962) using ISGS laboratory facilities. Finally, we examined heavy mineral separates from the sand fraction of the samples to see if there is any significant variation in pyrite content. A Radio Shack TRS-80 Microcomputer and a Radio Shack taped statistical program (Advanced Statistical Analysis, Hebbler, 1979) were used to calculate means, standard deviations and variances for each category of analyses. An analysis of variance (ANOVA) was then made of each type of data to determine if significant differences existed between sample populations. Also, a linear step-wise discriminant analysis (Klecka, 1975) of all the data, except pyrite analyses, was run using Illinois State University's AS 5000 computer. In order to check the discriminant analysis method, we also ran this test on published data from field-differentiated tills in Vermillion County.

FIELD UNITS

An exposure of the Radnor Till runs NE-SW along the south side of a tributary to the Mackinaw River. A sketch of the section is shown in Figure 2. A maximum of 5 m of cut-bank exposure is visible near the northeastern end. Only about 3 m of exposure exists at the southwestern end 160 m upstream. A stream meander interrupts the continuity of the whole exposure, but the till units can be carried through easily, except that the till under the lake silt is not exposed at the southwestern end. The lowest till unit studied occurs to the east along the Mackinaw River.

Individual till units were distinguished in the field by a combination of the following characteristics: 1) color, 2) degree of compactness, 3) ability to produce a ball or ribbon by rolling the till between one's fingers (a function of clay content), 4) bedding planes, 5) the presence or absence of blocky or columnar structure, 6) sand lenses along bedding planes, 7) separation by a lacustrine silt, 8) termination of structural joints against bedding planes, 9) unit pinchouts, and 10) the relative amount of coarse-grained constituents: pebbles, cobbles, and boulders. Many of the above features are illustrated in Figure 2.

Using the above criteria we were able to distinguish five separate till units within the designated Radnor Till at this location and along the Mackinaw River. Statistical data were obtained for four of these. The fifth till, 15-20 cm thick, is exposed for only a short distance at the southwestern end (shown pinching-out in Figure 2) and is not extensive enough to provide significant sampling. The separate till units sampled in this study, from oldest to youngest, are 1) a gray till exposed along the Mackinaw River, 2) a gray till below the lacustrine silt, 3) a gray till above the lacustrine silt, and 4) a brown till (Figure 2).

Gray till along the Mackinaw River

A gray till is exposed for about 50 m along the western bank of the Mackinaw River during low stream flow. Approximately 3 m of till are exposed, with some question as to whether or not this includes the top of the unit. The relationship between this till and the gray till below the lacustrine silt can not be seen due to vegetative cover between this outcrop and the outcrop where the overlying tills are exposed. This till is grayish-brown, 10 YR 5/2 (moist); light gray, 10 YR 7/2 (dry). It is very sandy, with abundant pebbles and cobbles throughout and contains numerous gravel lenses. It is hard, massive and contains structural joints.

Gray till below the silt

Less than one-half meter of the top of another gray till is exposed in the bottom of the tributary stream. The thickness of the till is unknown. This till is gray, 5 Y 5/1 (moist); light gray, 5 Y 6/1 (dry). It is a little less sandy than the underlying till, but is equally massive, compact and hard.

Lacustrine silt

The lacustrine silt separates two units of the Radnor Till and its presence introduced the question that initiated this study. It is approximately ½-⅔ m thick and has widely-spaced joints. It varies in color from dark gray to dark grayish-brown to black, depending on the organic content. Dark layers contain abundant plant debris, including pieces of wood, whereas light bands contain less organic matter. The entire silt unit contains abundant insect carapaces and crushed gastropods, 1-2 mm in size. An average of 16 mechanical analyses yields 6.8% sand, 78.5% silt and 14.7% clay. Clay composition is 19.1% expandable clay, 57.2% illite and 23.7% kaolinite + chlorite. Greater than 95% of the heavy minerals consist of extremely fine, granular pieces of irregularly-shaped pyrite which appear to be authigenic.

Gray till above the silt

The till above the lacustrine silt thins to 20-30 cm at the northeastern end of the outcrop from a maximum thickness of 2 m in the middle. It is gray, 5 Y 5/1 (moist); light gray, 5 Y 6/1 (dry). It is less sandy and pebbly than the other tills, except that the upper 30 cm contains a moderate abundance of cobbles and pebbles. The upper part has a platy structure with 5-10 cm spacing, becoming more massive down from the top. It does not appear to be quite as compact as the lower tills. It also contains widely-spaced structural joints.

Brown till

Although the yellowish-brown color, 10 YR 5/4 (moist), and very pale brown color, 10 YR 7/4 (dry), clearly distinguish this till from the gray tills, other field criteria are also present. It is less compacted than the others, possesses a blocky structure, particularly near the base, and has sand lenses at the base. Joints in the underlying tills terminate against the base of the brown till. This unit is from approximately ½ m to 2 m thick. The brown till is overlain in this outcrop by Peoria Loess, though the Robein Silt and Wisconsinan tills are present above the Radnor uphill to the south, where the moraine is higher.

QUANTITATIVE LITHOLOGIC DATA

Standard analyses for tills were completed for each till unit, including 1) a mechanical separation into sand, silt and clay fractions; 2) a division of the clay fraction into expandable clays (montmorillonite), illite and the sum of kaolinite + chlorite; and 3) carbonate analyses. Means and standard deviations of the results are shown in Table 1. Triangular plots of the first two types of analyses are shown in Figure 3. Although the tills plot in overlapping fields, the distribution of points suggests differences in the tills.

The carbonate analyses were done by two methods, one of which determines the number of X-ray counts per second for each of calcite and dolomite, and the second, the Chiddick method, in which wet-laboratory procedures are used to determine weight-percent calcite and dolomite. Results of the Chiddick tests are shown in Figure 4, in which it is seen that there is a widespread variation and an inverse relationship in the quantities of calcite and dolomite for the gray till above the silt. There is a smaller grouping of points for the gray till along the Mackinaw River. The other tills show a wide scatter of points with no significant relationships within the till units. Also, the general scatter of points for each till unit is too broad to distinguish any particular till unit by its calcite or dolomite content. Overall, the dolomite content is approximately 2.5 to 3 times the calcite content.

The X-ray technique is the method most commonly used by the ISGS. A comparison of the two methods is shown in Figure 5, in which X-ray counts are plotted against weight percents determined by the Chiddick method. The X-ray data alone show some differences in the various till units, in spite of some field overlap. However, our analyses show no correlation between the two types of analysis, in which a wide range of X-ray counts correspond with little variation in Chiddick analyses. This is contrary to expectations that the number of X-ray counts would increase with increasing weight-percent carbonate.

Moore (1981) has shown that Wisconsinan tills deposited from Lake Michigan ice lobes have a high pyrite content (57% of heavy minerals in Iroquois County) relative to tills deposited from Lake Erie ice lobes (5%). Heavy mineral analyses were conducted in an effort to determine if the tills in this sequence are the result of deposition by more than one ice lobe. Sand fractions of the tills were immersed in tetrabromoethane and the heavy mineral concentrates thus obtained were run through a magnetic separator to remove magnetite. The remaining fraction was analyzed by grain counting to determine the percentage of pyrite. The object of this

Table 1—Means (a) and standard deviations (b) of analytical data. 1) brown till, 2) gray till above silt, 3) gray till below silt, and 4) gray till along the Mackinaw River. Given in percent unless indicated CPS (counts per second).

		1 (N = 10)	2 (N = 14)	3 (N = 8)	4 (N = 5)
Sand	(a)	37.7	31.7	37.6	44.8
	(b)	6.0	9.4	5.7	1.0
Silt	(a)	42.7	48.0	40.9	36.6
	(b)	2.6	9.6	5.8	1.2
Clay	(a)	22.4	20.3	22.1	18.5
	(b)	4.1	5.2	8.8	1.6
Exp. Clay	(a)	6.2	7.9	9.9	17.9
	(b)	1.5	6.6	5.6	1.8
Illite	(a)	83.1	72.5	72.2	65.4
	(b)	1.9	6.6	7.2	1.3
K + C	(a)	10.8	19.5	17.9	16.7
	(b)	2.4	4.1	1.9	2.7
Calcite-X-ray (cps)	(a)	22.5	23.4	14.9	30.6
	(b)	3.2	9.3	5.5	4.7
Dolomie-X-ray (cps)	(a)	36.7	32.9	22.8	36.2
	(b)	10.2	7.9	6.6	5.0
Calcite-Chiddick	(a)	6.6	7.0	5.6	7.6
	(b)	0.5	1.9	2.0	0.5
Dolomite-Chiddick	(a)	17.6	19.1	18.3	18.3
	(b)	0.7	2.2	1.9	0.5
Pyrite	(a)	5.6	19.5	5.6	9.7
	(b)	5.9	6.0	1.7	3.3

was to determine if different ice lobes, coming from different directions, might be a factor in explaining multiple till units in the Radnor. Our results (Table 1) indicate that the gray till above the silt zone contains 2-3 times as much pyrite as the other till units, suggesting the possibility of different sources areas.

STATISTICAL TESTS

The lithologic data discussed above and presented in Table 1 and Figures 3-5 represent standard types of numerical data used in making quantitative comparisons of tills. The above data, however, can be subjected to rigorous statistical analyses, although these procedures have not been widely utilized in the literature on Illinois tills. One exception is Moore (1981) who used analysis of variance (ANOVA) and least significant difference tests to statistically differentiate Wisconsinan-age tills. One of our research objectives was to subject our data to two statistical techniques, one-way analysis of variance and discriminant analysis. Both of these techniques are viable methods of comparing sample data of sedimentary units.

A simple single-factor analysis of variance was done for each of the eleven types of data (in which each type of data can be treated as a variable) and the four till units. The F-ratios reported in Table 2 were determined by observing the variance among the four till units relative to the variance within each unit. These computed F-ratios were then compared to the tabled values of F at both the $\alpha = .05$ and $\alpha = .01$ levels of significance. Statistically significant differences among the four till units were found to exist for eight of the eleven variables. Alternatively, no statistically significant differences among the till units, based on the F-ratios for the variables clay, Chiddix-calcite, and Chiddix-dolomite, were found to exist.

Table 2—ANOVA for data from four tills. Starred items indicate significant (*) and highly significant (**) differences between groups.

	D.F.	*F-Ratio*	*Level of Significance*
Sand	3-34	4.056	.014*
Silt	3-34	3.943	.016*
Clay	3-34	0.706	.558
Exp. Clay	3-33	6.290	.002**
Illite	3-33	12.700	.000**
K + C	3-33	14.366	.000**
X-ray Cal.	3-31	5.476	.004**
X-ray Dol.	3-34	5.119	.005**
Chid. Cal.	3-21	1.690	.199
Chid. Dol.	3-21	1.089	.376
Pyrite	3-21	6.412	.002**

A second analysis of variance was performed in which only adjacent till units were compared for each variable independently. The results of this analysis are reported in Table 3. In this analytic situation a fewer number of variables yielded statistically significant F-ratios. When the brown till samples were compared to the gray till above silt samples, only three variables yielded statistically significant differences between these two groups (illite, kaolinite + chlorite, and pyrite). In the second situation, the gray till above silt samples were compared to the gray till below silt samples. Statistically significant differences between these two groups exist for the variables X-ray calcite, X-ray dolomite, and pyrite. No significant differences among till units existed for the remaining variables. The third comparison was between the gray till below silt samples and the samples of tills along the Mackinaw River. In this situation four variables yielded statistically significant differences between the two till units. These were X-ray calcite, X-ray dolomite, sand and expandable clay. Because statistically significant differences exist for only a few of the analytic variables, it appears that no single variable can be used to separate till units. However, differences in the till units are greatly magnified when variables are statistically combined using step-wise discriminant analysis.

Discriminant analysis as a multivariate statistical technique has become increasingly more widely utilized as a research tool for differentiating two or more *a priori* defined groups within a classification system. Secondly, discriminant analysis can also be used for assigning new observations to a group with a minimum probability of error. In this research ten analytic variables were utilized. Discriminant analysis combined these variables into a single index and generates a linear discriminant function. Because of the variety of options available, the authors utilized the SPSS discriminant analysis program (DISCRIMINANT). We opted for the step-wise variable selection rather than the direct method in which all variables would have simultaneously entered the analysis. The specific step-wise selection criterion utilized was Wilks' lambda. In this step-wise procedure the single variable from the set of variables which has the highest discriminating power enters the analysis first. In turn, the second variable selected from the remaining list of variables is that variable which, in conjunction with the first, has the second highest discriminating power. The process of variable entry continues until a minimum F-value or tolerance level is achieved.

Table 4 summarizes the discriminant analysis. The most powerful discriminating variable is Chiddix-dolomite, with a corresponding Wilks' lambda of .318 and an equivalent $F_{(d.f.=3,30)} = 21.4$. As the analysis proceeds the variables entered in steps 2 through 8 are: X-ray dolomite, silt, illite, Chiddix-calcite, sand, K+C and X-ray calcite, respectively. Although ten variables were available for selection, only eight were selected until the minimum F was achieved. The variables, clay and expandable clay, never entered the analysis because of their low discriminating power. This was to be expected because the values for the variables sand, silt and clay were expressed as percentages in which the percentages summed to one-hundred percent. Thus, once sand and silt had entered the analysis, the value for clay was predetermined. A similar line of reasoning pertains to the variable of expandable clay.

Table 3—Significance levels for ANOVA, comparing data from sets of two adjacent till units: 1) Brown till/gray till above silt; 2) gray tills above and below silt; 3) gray tills below silt and along the Mackinaw River. Starred items indicate significant (*) and highly significant (**) differences.

	1	*2*	*3*
Sand	.604	.127	.018*
Silt	.116	.078	.131
Clay	.293	.560	.598
Exp. Clay	.532	.515	.010*
Illite	.000**	.908	.328
K + C	.000**	.328	.654
X-ray Cal.	.774	.039*	.001**
X-ray Dol.	.302	.006**	.003**
Chid. Cal.	.649	.210	.056
Chid. Dol.	.122	.508	.973
Pyrite	.010*	.005**	.080

Table 4—Canonical discriminant functions. Starred items are the three canonical discriminant functions to be used in the remaining analysis.

Function	*% Variance*	*Cumulative %*	*Canon. Correl.*
1*	74.18	74.18	0.956722
2*	18.02	92.21	0.851013
3*	7.79	100.00	0.729195

After Func.	*Wilks' Lambda*	*Chi-Sq.*	*D.F.*	*Significance*
0	0.010936	121.92	24	0.0000
1	0.129139	55.265	14	0.0000
2	0.468274	20.485	6	0.0023

The first discriminant function alone accounted for 74.18 percent of the variance with a canonical correlation of .9567. After the first function was determined, Wilks' lambda was .129 with a corresponding χ (Chi)^2 = 55.26, with α = .001. The second canonical discriminant function, in turn, accounted for an additional 18.02 percent of the variance with a canonical correlation of .85. Thus, the cumulative variance accounted for by these two functions was 92.21 percent.

Based on discriminant function scores, each observation was allocated *a posteriori* to one of the four groups. Table 5 shows the classification results. Of the thirty-four individual samples, 97.06 percent had been correctly classified according to the *a priori* classification. Only one sample from the gray till above silt group was classified into the gray till below silt group on the basis of that sample's discriminant scores. The results obtained from this discriminant analysis are further re-enforced by examining the distribution of individual samples plotted by group in Figure 6.

The application of discriminant analysis to solve geological problems is relatively new and it has been most commonly used in sedimentologic studies of clastic materials (Flores and Shideler, 1982; Kloven and Billings, 1967; Davies and Ethridge, 1975). To our knowledge this technique has not been used in the study of till problems in Illinois. As a matter of checking the reliability of the discriminant analysis method, we tried the technique on known and better-defined tills already described by the ISGS. We used published quantitative lithologic data for three Illinoian tills, the Radnor, Vandalia and Smithboro, in Vermilion County. The data is from the Higginsville, Collison Branch, Emerald Pond and Harmattan sites published by Johnson, et al. (1972, p. 83-89). The discriminant analysis clearly defined the individual tills (Figure 7).

Table 5—Classification results of step-wise discriminant analysis. Groups: 1) brown till; 2) gray till above silt; 3) gray till below silt; 4) gray till along Mackinaw River.

		Predicted Group Membership			
Group	*Cases*	*1*	*2*	*3*	*4*
1	10	10	0	0	0
		100%	0%	0%	0%
2	12	0	11	1	0
		0%	91.7%	8.3%	0%
3	7	0	0	7	0
		0%	0%	100%	0%
4	5	0	0	0	5
		0%	0%	0%	100%

DISCUSSION

Five individual till units have been distinguished in the field along approximately 160 m of stream-cut exposure of the upper part of the Radnor Till. The variation in physical and compositional characteristics of each unit, the pinching out of one unit and presence of a lacustrine silt separating two of the units indicate that the Radnor Till at this location is composed of a series of relatively thin, individual tills, instead of a single till. Standard compositional data were obtained from 37 samples taken from four of the units. The fifth unit was too small to sample adequately. Quantitative lithologic data, subjected to ANOVA tests, show significant differences when all four tills are compared. However, the differences are less apparent when only adjacent tills are compared. When all data are combined into a discriminant analysis and the results displayed graphically, the four tills plot into separate clusters, supporting the distinctions made in the field. It is clear that the application of discriminant analysis is a useful tool for distinguishing tills, particularly when other types of data plots and tests prove inconclusive. The discriminant analysis test shows the combined effect of the variations in all of the types of data and is most useful when there are subtle variations in many different types of data from two or more till units. The effectiveness of this test is well-demonstrated in the analyses of the gray tills above and below the silt, for which two triangular plots of compositional data each show two overlapping fields of widely-scattered points (solid circles and open squares, Figure 3) and for which the ANOVA test does now show significant differences in many characteristics in a direct comparison of the two tills. However, the discriminant analysis clearly distinguished the units.

One might ask to what extent the above statistical techniques might be applied. These techniques have not been widely used in till analysis and it is not known what all the applications might be. It is certainly not our intent to suggest defining till stratigraphy on the basis of analytical or statistical data, as we realize that the fundamental units must be distinguishable in the field. Our application here was to support field work within a localized geographic area and to distinguish adjacent tills in a continuous section. We do not know to what lateral extent, within a till unit, statistical data would be useful. Using paired samples Moore (1981, p. 109) concluded that compositional variation within a single till increases with distance between sample points. Therefore, statistical differences recognizable by ANOVA for two distant populations from the same horizon would likewise increase, suggesting that statistical tests would not be useful as a long-distance correlation technique.

Carbonate analyses of Illinois tills have been reported commonly in one of two ways, either as a weight-percent (Lineback, 1979b) or as X-ray counts per second (Willman and Frye, 1970), but usually not in both ways. Which of the two ways is more reliable or useful has not been agreed upon by workers in the field. We ran both types of analyses for this study and found that for this area, plots of X-ray analyses distinguished the separate till units better than the Chiddick analyses did. However, in the step-wise discriminant analysis, the Chiddick-dolomite was the most discriminating single variable. We also compared the results of both types of analyses in this study and found no correlation between the two methods, with wide ranges of counts per second for carbonate contents lying within relatively narrow weight percentage limits. This is not what one would expect and the reasons for these results are not clear. This suggests that either there was a consistent error in our laboratory procedure for the chiddick analyses (which we doubt is this case), or one of the two methods is not consistently accurate and reliable. A larger-scale comparison where both types of data are available from other tills might solve this problem.

Many till studies include heavy mineral analyses of the sand fraction of the till. Opaque minerals are usually lumped together. We specifically counted the pyrite grains because Moore (1981) showed that Wisconsinan tills deposited from Lake Michigan lobes contained a higher pyrite content that tills deposited from Lake

Erie lobes. Assuming the same would hold for Illinoian tills, our data suggest that the gray till above the silt is a Lake Michigan lobe deposit. By comparison, the other three tills are Lake Erie lobe deposits. Also, early in this project we considered the possibility that the brown till was the oxidized top of the underlying gray till. However, the presence of euhedral pyrite crystals and fresh, sharp, angular pyrite fragments show that this brown till has not been extensively oxidized and other compositional data confirm that the two tills are indeed different.

If is quite clear from this outcrop that the Radnor Till is composed of more than a single till. There is no reason to believe that this outcrop is unique, so it seems logical to suspect that the Radnor on a larger scale is also made to multiple tills. Our data show that the individual till units are sufficiently different to suggest that they probably represent individual ice advances, including lobes from different source areas. Thus, one must conclude that, whereas the Radnor is used as a single map unit, its depositional history is much more complex than the concept of one till deposited by one simple ice advance. This is further emphasized by the development of a lake (or swamp), with associated trees, between two of the advances. Although the lacustrine silt could be a very local occurrence, a similar organic silt occurs within the Radnor Till at the Lake Bloomington spillway (ISGS, 1972, p. 16) and was encountered in the Radnor in water-well boreholes for the City of Normal (SW/4, Sec. 32, T24N, R1E), at Kappa (SW/4, Sec. 28, T26N, R2E), for the City of Bloomington (NW/4, Sec. 12, T25N, R2E), and in two private wells (Ctr., Sec. 35, T24N, R1E and NW/4, Sec. 29, T25N, R3E), according to well-logs from well files at the ISGS. In addition, a large exposure of till along the Panther Creek tributary to the Mackinaw River (SW/4, Sec. 17, T26N, R1E), contains a section of Vandalia Till (?) with overlying Radnor Till and Tiskilaw Till (Wisconsinan). An organic-rich silt zone with small gastropods occurs at the same stratigraphic level here as at our study area. We suggest that the silt horizons at all of these locations are correlative and that deposition occurred in an extensive lake or swamp or in numerous, contemporaneous ice-marginal swamps or shallow lakes. The maximum distance between all of these sites is 23 km north-south and 29 km east-west.

If the Radnor, or any other till, as a map unit is actually made of multiple till units, each having different compositional characteristics, then some fundamental problems arise in trying to identify the till by using sand-silt-clay, clay composition and carbonate content signatures. No one set of figures can be said to be characteristic of the formation and a mean signature derived from the same formation at diverse sample sites may actually be a meaningless composite from many different tills, perhaps even representing different ice-lobe sources. Such signatures are commonly used to identify tills in Illinois. Our findings suggest that sampling should be done in such a manner as to avoid sampling thin, multiple tills in the name of a single till.

CONCLUSIONS

The Radnor Till (Illinoian) is not a simple till marking a single ice advance. Instead, it is composed of multiple, thin till units, each representing an individual ice advance. Variation in pyrite content suggests that both Lake Erie and Lake Michigan lobes were involved. A lacustrine silt containing abundant wood fragments and gastropods, within the Radnor Till, indicates a relatively extensive glacial retreat that separates a pre-silt Lake Erie lobe till from a post-silt Lake Michigan lobe till. This perspective greatly complicates any effort to interpret the Illinoian glacial geochronology based on mapped tills as currently defined. The glacial history is more complicated than previous investigations have shown.

Each of the till units has a unique composition in terms of sand-silt-clay ratios, clay and carbonate compositions and pyrite content. Whereas graphical plots of some of the compositional data may show overlapping fields and even analyses of variance do not indicate significant differences between adjacent tills, the overall uniqueness of each till unit is emphasized through the use of a step-wise discriminant analysis of the data. This statistical test combined all of the differences in till characteristics and proved useful in supporting the individuality of till units distinguished in the field.

It is common to see in the literature compositional means and standard deviations that are used as signatures in identifying tills. The presence of multiple till units within a formation or a member, such as the Radnor Till Member, may greatly reduce the significance of these means if the samples are derived from diverse outcrops, hence, possibly from different till units.

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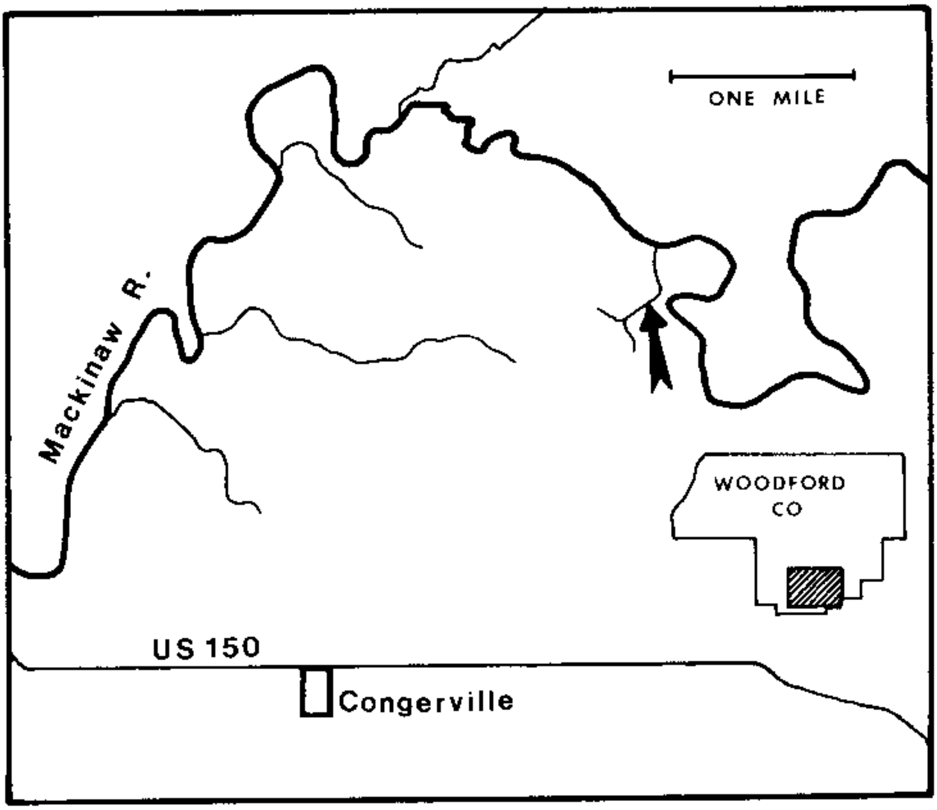

Figure 1—Location map of Radnor Till outcrops of this study.

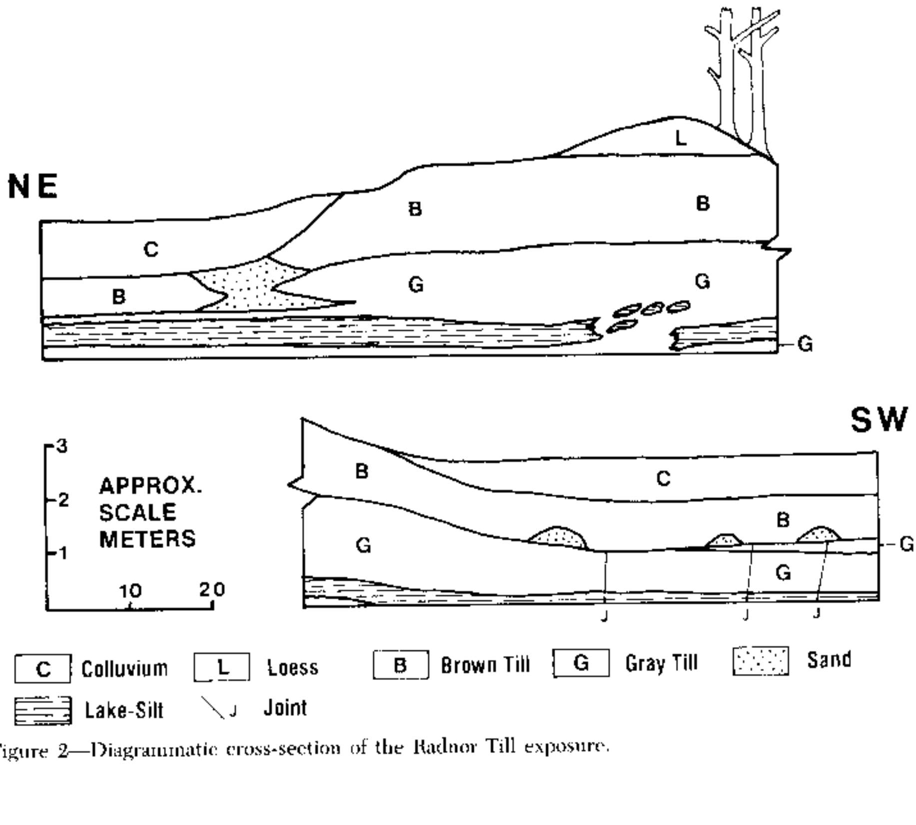

Figure 2—Diagrammatic cross-section of the Radnor Till exposure.

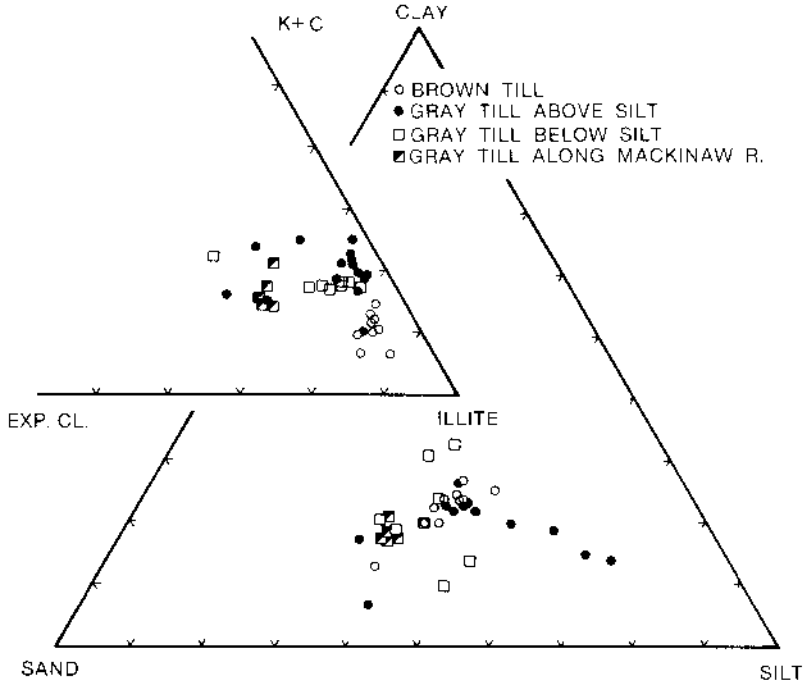

Figure 3—Graphical representation of mechanical analyses and clay analyses for the Radnor Till.

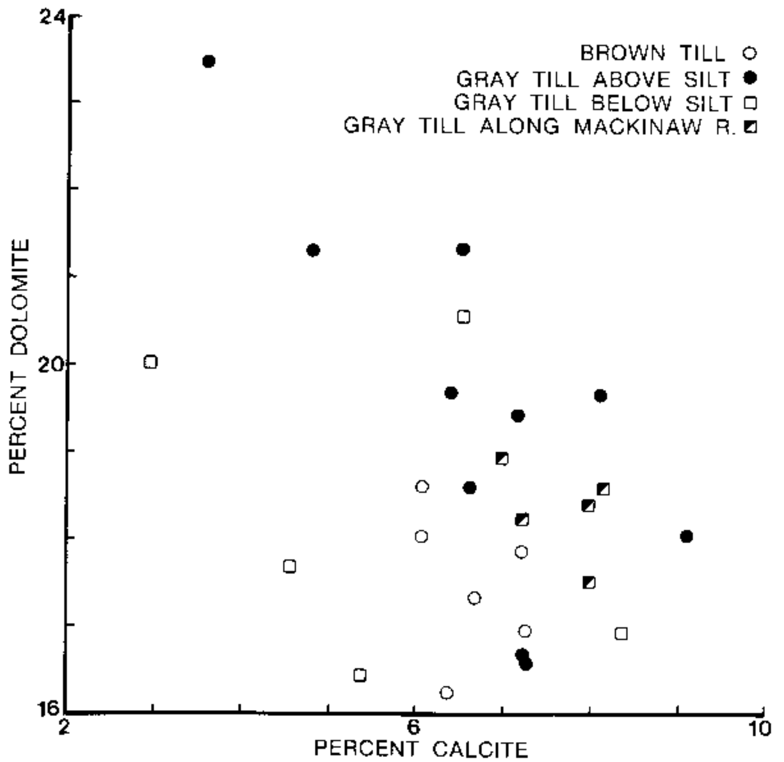

Figure 4—Chiddick analyses of weight-percent calcite and dolomite in the Radnor Till samples.

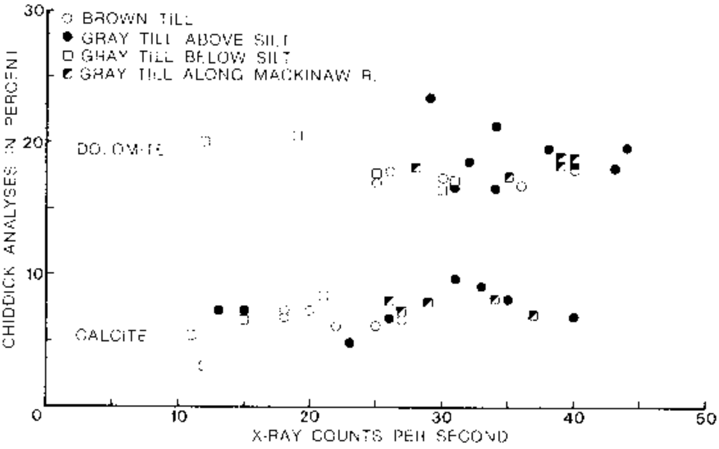

Figure 5—Comparison of weight percent and X-ray counts for carbonate content.

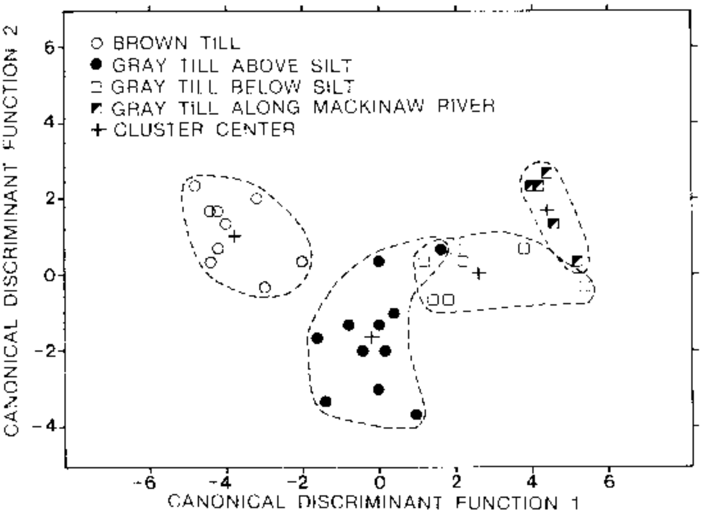

Figure 6—Discriminant analysis of Radnor Till data.

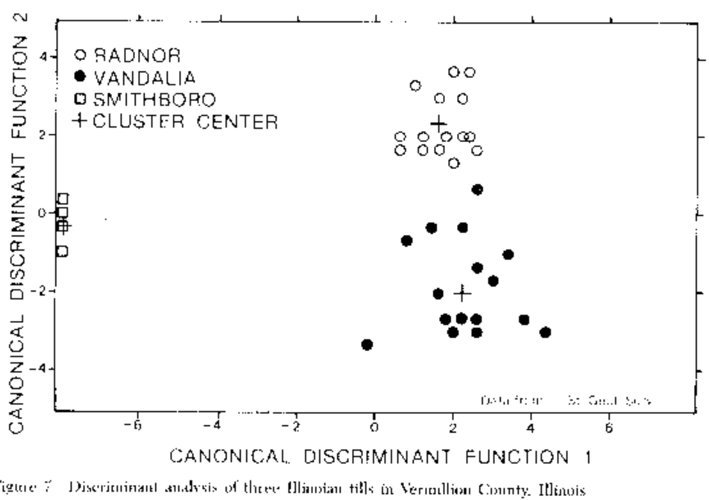

Figure 7—Discriminant analysis of three Illinoian tills in Vermilion County, Illinois.