PETROGRAPHIC SIMILARITY OF WISCONSIN TILLS IN MARION COUNTY, INDIANA

by

W. HARRISON

Indiana Department of Conservation

GEOLOGICAL SURVEY

Report of Progress No. 15

1959

STATE OF INDIANA
Harold W. Handley, Governor

DEPARTMENT OF CONSERVATION
E. Kenneth Marlin, Director

GEOLOGICAL SURVEY
John B. Patton, Acting State Geologist
Bloomington

Report of Progress No. 15

PETROGRAPHIC SIMILARITY OF WISCONSIN TILLS IN MARION COUNTY, INDIANA

by

W. Harrison

Printed by authority of the State of Indiana

BLOOMINGTON, INDIANA

September 1959

For sale by Geological Survey, Indiana Department of Conservation, Bloomington, Ind.
Price 50 cents

SCIENTIFIC AND TECHNICAL STAFF OF THE GEOLOGICAL SURVEY

JOHN B. PATTON, Acting State Geologist
BERNICE M. BANFILL, Administrative Assistant to the State Geologist
MARY BETH FOX, Mineral Statistician

COAL SECTION

CHARLES E. WIER, Geologist and Head
G. K. GUENNEL, Paleobotanist
S. A. FRIEDMAN, Geologist
HENRY H. GRAY, Geologist
HAROLD C. HUTCHISON, Geologist
RICHARD C. NEAVEL, Coal Petrographer
LARRY LAWRENCE, Geological Assistant

DRAFTING SECTION

WILLIAM H. MORAN, Chief Draftsman
ROBERT E. JUDAH, Geological Artist-Draftsman
MICKY P. LOVE, Geological Draftsman
JOHN E. PEACE, Senior Geological Draftsman

EDUCATIONAL SERVICES

R. DEE RARICK, Geologist and Head

GEOCHEMISTRY SECTION

R. K. LEININGER, Spectrographer and Head
MAYNARD E. COLLER, Chemist
LOUIS V. MILLER, Coal Chemist
E. M. CRAIG, Geochemical Assistant

GEOPHYSICS SECTION

MAURICE E. BIGGS, Geophysicist and Head
ROBERT F. BLAKELY, Geophysicist
CHARLES S. MILLER, Instrument Maker
ALBERT J. RUDMAN, Geophysicist
JOSEPH F. WHALEY, Geophysicist
GLEN L. WORKMAN, Driller
JERRY B. FOX, Assistant Driller
ARTHUR WAYNE AYNES, Geophysical Assistant

GLACIAL GEOLOGY SECTION

WILLIAM J. WAYNE, Geologist and Head
W. HARRISON, Geologist

INDUSTRIAL MINERALS SECTION

DUNCAN J. McGREGOR, Geologist and Head
GARY R. GATES, Geologist
SEYMOUR S. GREENBERG, Petrographer
JACK L. HARRISON, Clay Mineralogist
NED M. SMITH, Geologist
JACK A. SUNDERMAN, Geologist

PALEONTOLOGY SECTION

ROBERT H. SHAVER, Paleontologist and Head

PETROLEUM SECTION

T. A. DAWSON, Geologist and Head
G. L. CARPENTER, Geologist
ANDREW J. HREHA, Geologist
STANLEY KELLER, Geologist
ARTHUR P. PINSAK, Geologist
HOWARD SMITH, Geologist
DAN M. SULLIVAN, Geologist
FRANK H. WALKER, Geologist
GEORGE ABBOTT, Draftsman
JAMES CAZEE, Geological Assistant
PHILLIP W. CAZEE, Geological Assistant

PHOTOGRAPHIC SECTION

GEORGE R. RINGER, Photographer and Head

PUBLICATIONS SECTION

GERALD S. WOODARD, Editor and Head

Page

TABLES

[In Appendix II]

PETROGRAPHIC SIMILARITY OF WISCONSIN TILLS IN MARION COUNTY, INDIANA

By W. Harrison

ABSTRACT

Two to four till sheets were deposited in Marion County, Ind., by the East White sublobe of the Ontario-Erie major lobe of the Wisconsin ice sheet. Fraction analyses (mineralogy and lithology versus size) were made for 11 till samples from 4 outcrop localities near the corners of Marion County. The composition of each of 16 Wentworth size fractions (between 0 and 32 mm) was determined for each sample. True weight relationships were obtained from the particle-frequency data following experimental determination of the average grain weight for each mineral and rock type in a given size fraction. The fraction analyses were then expressed in weight percent.

Correlation of till samples from the four outcrop localities was attempted according to these assumptions: (1) parts of at least one formerly continuous till sheet are present in Marion County, (2) remaining segments of this till sheet crop out at the four localities chosen for study, (3) individual till sheets are homogeneous and distinguishable one from another, and (4) a given till sheet can be ascertained by finding the group of four samples (one from each outcrop locality) that shows the highest degree of textural and (or) compositional similarity.

Plotting of the fraction-analysis data on triangular diagrams indicates that the 11 till samples are too similar in texture and composition to satisfy assumption four, and it is probable that assumption 3 is invalid. The pronounced textural and compositional similarity of the till samples implies uniformity of glacial processes throughout the area of investigation and suggests but slight variation in the materials of the source area between successive glaciations.

INTRODUCTION

THE CORRELATION PROBLEM

When areal geologic mapping is done by the Indiana Geological Survey in counties covered by glacial drift, it is necessary to determine the Pleistocene stratigraphic sequence. For most areas this involves identification and correlation of multiple tills, but till-sheet correlation from outcrop to outcrop can be very difficult in areas where the tills were deposited by the same glacier lobe. This is especially true if the ice incorporated materials of like texture and composition during each succeeding readvance.

Multiple tills of Wisconsin and Illinoian age in Marion County, Ind., were deposited by the East White sublobe (Horberg and Anderson, 1956, table 1) of the continental ice sheet. There were at least two distinct glaciations of Marion County by this sublobe during "classical" Wisconsin time, and the drift boundaries ("Shelbyville" and "Champaign" on fig. 1) corresponding to these two glaciations are clearly discernible throughout central Indiana. In addition to the two obvious glaciations by the East White sublobe, it is possible that glaciations by earlier equivalents of the lobe deposited two "preclassical Wisconsin" tills in Marion County (cf. C^{14} dates for till and for unweathered silt unit above basal till at locality B, Appendix I). These tills may also be of Illinoian age. Evidence for three glaciations of Marion County by the East White sublobe (or equivalent) appears to be present at localities A and B (fig. 2; Appendix I); evidence of two glaciations is present at localides C and D (fig. 2; Appendix I). A fourth, but partial glaciation of the county, is indicated by the uppermost till at locality B (fig. 2; Appendix I).

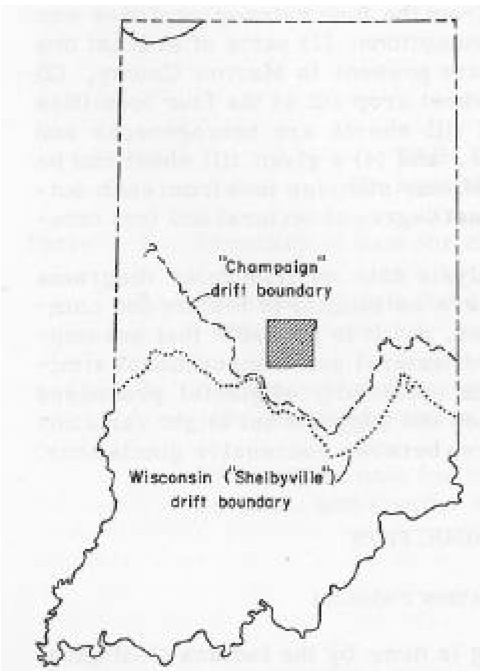

Figure 1. --Map of Indiana showing location of Marion County and boundaries of two main drift sheets deposited by the East White sublobe.

In addition to their very similar appearance in the field, the lower Wisconsin tills in Marion County do not everywhere occur in association with key beds (fossiliferous silts, etc.) by which they might be differentiated. This study was undertaken to find out if there might be significant differences in texture or composition (or both) between the various till sheets, which would permit their correlation from outcrop to outcrop. The petrology of the tills will be treated in a report on the geology of Marion County (Harrison, in preparation).

APPROACH

Mineralogic and lithologic properties of till particles are known to be a function of size (Davis, 1951; Horberg and Potter, 1955; Jorstad, 1957). Fraction analyses (mineralogy and lithology versus size), therefore, are used in this study for the purpose of describing accurately the tills investigated. For correlating or differentiating various tills or for making inferences involving till sedimentation, it seems desirable to express fraction analyses in weight percent.[1] To do so requires weight-per-grain determinations, and these have been carried out here. Accurate weight-per-grain determinations require weighing 100 or more grains, and the larger size grades have to be filled out if they are deficient in number of particles. Volumetric sampling (p. 9) of the tills (cf. also Sahlstrtöm, 1910) has been used for the purpose of increasing the particle frequency in the larger grades.

Techniques used in the field and laboratory are described in detail because (1) they are to be used in a statewide study of the composition of Indiana's tills, (2) evaluation of the detailed results requires some understanding of the precision of the techniques of analysis, and (3) a few workers will wish to know the procedures involved in analysis when they contemplate similar work of their own. A reader interested mainly in results and interpretations will find them discussed on pages 17-19.

PREVIOUS STUDIES

Papers by Davis (1951) and by Horberg and Potter (1955) are somewhat similar to the present report. These workers made fraction analyses of tills in Kansas and Illinois, respectively. Shepps (1953) correlated samples of Wisconsin till from northeastern Ohio on the basis of texture, but correlation of till samples using both

[1]It is possible, for instance, that two till sheets in the same geologic section will yield similar particle-frequency data (number percent values), when the particles in one of them are of slightly different size or density. Only by converting the number-percent values to weight-percent values can the differences be apprehended. Similarly, an upstream sample of a till sheet may not show any variation in terms of number-percent values with a downstream sample; there may be a significant variation, however, in the weight percent values. See Carroll (1957, p. 403) for an example of the importance of weight-percent values in differentiating heavy-mineral suites of river sands.

texture and composition has not been attempted previously.

ACKNOWLEDGMENTS

Jack L. Harrison, Clay Mineralogy Laboratory, Indiana Geological Survey, made the X-ray diffraction analyses. John E. Brueckmann and Howard W. Pee assisted in the field and laboratory. Radiocarbon age determinations were made in the laboratory of the U. S. Geological Survey.

FIELDWORK

AREA OF INVESTIGATION

All samples for this study were taken from Marion County, Ind. (fig. 1), which lies within the Tipton Till Plain of the Till Plains Section of the Central Lowlands Province. The entire county was glaciated at least twice during the Wisconsin Stage by the East White sublobe of the Ontario-Erie major lobe of the continental ice sheet. Drift boundaries corresponding to these two glaciations are shown on figure 1. (The glacial transport vector that appears on figure 2 was drawn perpendicular to the glacier-surface contours of a paleo-glacier map [Harrison, 1958, fig. 6] of the East White sublobe.)

SAMPLING

Samples for fraction analysis were taken from till sheets exposed in five measured sections (fig. 2; Appendix I). The measured sections are located at the corners of an area that is roughly square in outline. Precise locations and descriptions of the measured sections are given in the Appendix. Each of the sampled tills occurs as a distinct unit in outcrop, and each till is assumed to have been deposited by a separate advance of the ice-sheet margin. This assumption seems reasonable because the same stratigraphic sequence found at each sampled section also can be found in other exposures less than a mile away; that is, each stratigraphic sequence is very probably continuous, and the outwash materials between tills represent ice-free conditions; they are not merely lenses of outwash incorporated during a single glacial advance.

All sampling for size analysis was carried out on visibly unweathered till; that is, horizon 5 of the weathering profile (Leighton and MacClintock, 1930). Channel samples were taken in such a manner that all particles as much as 50 mm in intermediate diameter were included; "channel sampling" consisted of collecting lumps of till from the bottom to the top of the unoxidized zone until about 50 lb (23 kg) were obtained. When a crumbly particle of pebble size (> 4 mm) or larger was encountered, its size (intermediate diameter) was estimated, it was separately bagged, and it was brought into the laboratory for identification.

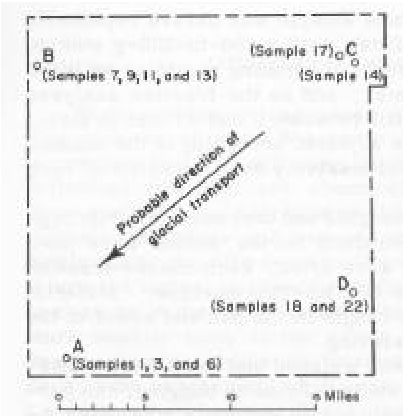

Figure 2. --Map of Marion County showing sampling localities. Sample numbers are not in consecutive order because they correspond to a series of sample numbers used in Harrison's report on the geology of Marion County, appendices A and E (in preparation).

Volumetric sampling of the tills was required in the size grades (fractions) between 4 and 32 mm because these grades lacked sufficient particles to permit meaningful estimates of true fractional composition. Successive slices of each till about 1 inch by 3 inches were mined at a number of spots (selected at random) until several buckets had been filled. Every crumbly particle encountered was bagged for later identification. These additional volumetric samples were washed in the field until each size grade up to 32 mm contained at least 100 particles (including any crumbly ones encountered while mining). The care involved in this method of sampling was rewarded when it was determined that in one till (sample 1) 32 percent of the particles in the small-pebble (4 to 8 mm) fraction were crumbly and would certainly have been missed if the till had not been sampled as it was.

To obtain a measure of particle concentration in the sizes greater than the 32 mm limit, an area of 30 square feet (2. 79 square meters) was marked off on a fresh face of the unleached part of each till sheet. All particles greater than 32 mm in size within this area were dug out, sized, and brought into the laboratory for identification.

LABORATORY WORK

SIZE ANALYSIS

Sieve analysis.--Till samples were dried at room temperature and then gently crushed with an iron pestle in a wooden drawer lined with kraft paper. The 50-1b (23-kg) bulk sample was passed repeatedly through a Jones-type sample splitter until a 100-to-200-g sample remained. (The splitter was capable of handling particles as large as 32 mm in intermediate diameter, and so the fraction analyses are accurate for the part of the till between 0 and 32 mm in size.) The laboratory sample weight was adjusted according to the number of large particles appearing in successively smaller splits of each channel sample.

Each laboratory sample was weighed and then wet-sieved through an 0.062 mm sieve. (U. S. Standard Series sieves were used throughout.) After the samples were dried, each coarse fraction was sieved by shaking 15 minutes in a Ro-Tap machine. Material passing the 0. 062-mm sieve was caught in the pan and added to the fine fraction obtained in the wet sieving.

Each of the sieve fractions was weighed and bagged for subsequent mineralogic and lithologic study. Prior to bagging, the percentage of aggregates in each sand fraction was estimated under the binocular microscope; the percentage (if there was one) was deducted from the raw weight, as suggested by Folk and Ward (1957, table 1). The maximum percentage of aggregates noted in any fraction was 7 percent, but few of the sand fractions exhibited aggregates. Corrected weights were cumulated, and the cumulative percentages (tables 1, 2, and 3, Appendix II) were taken from these cumulated weights (cf. Folk and Ward, 1957, table 1).

Pipette analysis.--The fine portion (<0. 062 mm) was analyzed by the pipette method of Krumbein and Pettijohn (1938, p. 166-172). Specific-gravity determinations (cf. Dallavalle, 1943, p. 275) of the particles of the fine portions (<0.062 mm) of two till samples (9 and 13) were made according to the procedure outlined in the U. S. Department of Agriculture Bulletin 1216 (1928). Two specific gravity values (2.716 and 2.712) were obtained. Settling velocities then were computed according to Stokes[1] law (Krumbein and Pettijohn, 1938, p. 96); a specific-gravity value of 2.71[2] and a laboratory-temperature value of 24° C were used. Sodium oxalate (0.01 N concentration) was found to be a suitable peptizer. All the samples

---

[2] This value is toward the lower limit of a range of specific gravity values cited by Peck and Reed (1954, p. 48) for till particles of the Chicago area.

were run during the same period of time at a nearly constant laboratory temperature.

The weight-percent data from the sieve and pipette analyses are listed in tables 1, 2, and 3 (in Appendix II). Descriptive terms (“sand,” “silt,” etc.) for various size fractions are after Wentworth (1922).

LITHOLOGIC AND MINERALOGIC ANALYSIS

Studies of major and minor chemical constituents of the silt-clay portions of upper Wisconsin tills led Forslev (1957, p. 1728) to conclude that “the silt-clay [portion] of moraines deposited by an individual ice lobe are chemically homogeneous.” Studies by Gravenor (1951, p. 66), Kruger (1937), and Krumbein (1933, p. 405) indicate that types and amounts of heavy minerals found within a single till or the tills deposited by a single lobe are uniform. Thus, it seemed logical to expect significant differences, if they existed, to show up in the major constituents of the tills as readily as, if not more readily than, in the minor contributors. For this reason heavy-mineral studies or thorough lithologic breakdowns are not used in the assessment of till-sample composition which follows.

Clay and silt fractions.--The 3 clay fractions and the 4 silt fractions of each till sample were obtained for X-ray study according to the following steps:

(1) the <62-μ portion was separated from the original channel sample by dry sieving.

(2) a split weighing about 100 g was made of the <62-μ portion by using a multiple-cone splitter (designed and described by Kellagher and Flanagan, 1956a, p. 215).

(3) The split was suspended in a settling tube under the same conditions as obtained for pipette analysis of the original sample; settling was begun.

(4) As soon as the 62-to-31-μ fraction had settled, the remaining suspension was siphoned off and discarded. (Siphoning was started early enough to permit the siphon tube to reach the bottom of the suspension at the moment that the smallest particles in the desired fraction had settled out.)

(5) Steps 3 and 4 were repeated 4 more times with fresh solutions. (The fifth siphonate contained little in the way of suspended solids and the settled fraction was assumed to be clean.)

(6) The fraction was dried at 105° C and stored for later mineralogic analysis.

(7) A new 100-g split of the <62-μ portion of the same sample was made and placed in a settling tube; settling was begun.

(8) A 250-ml volume of the suspension containing the <31-µ portion was siphoned off at the proper time.

(9) The <31-µ suspension was siphoned into a 6-oz (13 cm high) narrow-mouthed Armstrong bottle and evaporated nearly to dryness at 105° C.

(10) Steps 8 and 9 were repeated until enough sediment was present to insure that a suitable sized 31-to-16-µ fraction would be obtained after completion of steps 3 through 6. (The Armstrong bottle made an excellent settling tube for step 3. Resuspension of the <31-µ portion was accomplished with a counter-rotating mixer.)

(11) Steps 7 through 10 were repeated for each successively smaller fraction that was desired.

(12) Steps 1 through 11 were repeated for all 11 samples.

X-ray analyses were performed on oriented samples of the five finest fractions and on unoriented samples of the four coarsest fractions of the silt-clay portion; that is, the two fractions between 0. 0039 and 0. 0156 mm were studied by both methods. Semiquantitative estimates of the amounts of the main constituents of each of the 77 fractions were made from the diffraction tracings by Jack L. Harrison, Clay Mineralogy Laboratory, Indiana Geological Survey. The values determined for the different mineral components are believed accurate to ± 30 percent and are listed in table 1 (Appendix II). The mixed-layer material (table 1) is an interlayering of illite and an expandable component which may be called montmorillonite. Glycolation of the samples indicates that only one sample (17) contains sufficient montmorillonite (<5 percent) for detection. If montmorillonite is present in the other samples, it is masked by chlorite. Kaolinite may be present, but the amount is too small to detect. The heading "Miscellaneous" (table 1) includes approximately 80 percent feldspar.

Coarsest silt and sand fractions.--Grain counts ranging in number from 98 to 333 grains were made from splits of the sand fractions and converted to weight percent following a method described by Kellagher and Flanagan (1956b, p. 225). Categories under "Mineral Grains" included "quartz," " chert," "feldspar (potash, sodic, calcic)," and "dark minerals." Under "Rock Fragments" were the categories "limestone," "dolomite," "shale," "igneous," and "metamorphic." A "miscellaneous" category was used, largely for opaque particles, plagioclase, and light-colored minerals in the finer sizes and for graywacke and quartzite fragments in the coarser sizes. Orthoclase was the main feldspar contributor in the sand sizes, and so only the category "orthoclase" appears in table 2 (Appendix II).

Samples of the sand fractions were split with the multiple-cone splitter (Kellagher and Flanagan, 1956a, p. 215). (The apparatus was cleaned conveniently with a stream of compressed air after each pass of material.) While the 0.062-to-0.125-mm and 0.125-to-0.25-mm fractions were being split, some of the grains adhered to the funnels. Whether or not selective sorting may have occurred in the grains that stuck to the funnels is not known.

The grains of each fractional split were stained according to the technique described by Reeder and McAllister (1957).[3] This technique effectively stained the orthoclase grains yellow, the microcline greenish yellow, and the plagioclases differing intensities of purple.

All the grains were identified within a 3-week period by the author. The fact that the feldspar grains were stained permitted the differentiation of "igneous rock fragments" from "quartz grains" because small pieces of feldspar adhering to quartz grains showed up clearly. Some of the "igneous" rock fragments could have been metamorphic fragments. The reverse is not the case, however, because most "metamorphics" were easily identifiable fine-grained schist and gneiss fragments.

Limestone rock fragments were not differentiated from pure calcite grains. Limestone and dolomite fragments were differentiated under the binocular microscope on the basis of their relative speeds of effervescence in a drop of dilute HCl. The relative speed of effervescence of limestone versus dolomite rock fragments was estimated by comparison with the effervescence speeds of fragments of the same size which had been identified more positively by Ramsden's test (1954, p. 282) or by spectrographic techniques. The limestone rock fragments of this study include the "dolomitic limestones" described by Ramsden (1954, p. 282) as analyzing as much as "about 40 percent $MgCO_3$ in bulk."

The coarsest silt fraction (0.031 to 0.062 mm) was studied in a different manner from the sand fractions. A hand-quartered split of each sample was treated with silver nitrate and potassium chromate solutions (Krumbein and Pettijohn, 1938, p. 496) in order to distinguish between the calcite and dolomite grains under the petrographic and binocular microscopes. Each sample was subjected to the silver nitrate solution for slightly more than 2 minutes and to the potassium chromate for 1 minute. The distinction between the dolomitic limestone and dolomite rock fragments appeared to be nearly identical to that rendered by Ramsden's technique, and it was assumed that identification of these lithologies was uniform between both the sand and silt sizes. Dolomite grains were distinguished

---

[3] After the author had experimented with the technique and had corresponded with McAllister, he modified the technique so that 3:1::water:HF was used for 3 minutes and so that grains were immersed in both staining solutions for 5 to 8 minutes.

from quartz grains by use of immersion oil (*n* = 1.548).

Weights per grain in each mineral- or rock-fragment category in a given size were determined experimentally by weighing approximately 100 grains of each type and dividing this weight by the grain frequency. The grains that were weighed were taken from composite samples formed from the 11 sieved portions of each grade size. Thus, the weight-per-grain values obtained for a given fraction are average values and do not vary with each sample. Ideally, the weight-per-grain values should be determined for each sample; practically, however, this is too time consuming. In some fractions sufficient grains for a meaningful weight determination are not available.

Grains were weighed on a semimicro balance with weights that had been calibrated with reference to National Bureau of Standards weights. The values of the weights per grain that were obtained are shown in figure 3. This graph was used for estimating grain weights in size fractions for which sufficient grains for a meaningful weight determination were unavailable. Both the grain weights determined experimentally and those estimated by extrapolating (fig. 3) appear in table 2 (Appendix II). Values given in table 2 for "chert" and "miscellaneous" particles were estimated to occur along the center line of the distribution of points on figure 3.

Particle-frequency data were converted to weight-percent values by substitution in the following equation:

(Weight percent) $$n = \frac{F_n d_n}{\sum_{i=1}^{n} (F_i d_i)}$$ in which *F* is the grain frequency and

d is the weight per grain.

Granule and pebble fractions.--The granule and pebble fractions of the tills were studied both under the binocular microscope and in some 86 thin sections of questionable particles. All the particles were classified according to categories based on those set forth in "Classification of Rocks" (Travis, 1955). Under "Sedimentary Rock Fragments" the categories "limestone," "dolomite," "chert," "shale" "sandstone," and "other" were used. A special record of graywacke particles was kept in the "sandstone" category, and a record for tillite particles was kept under the heading "other." Under "Igneous Rock Fragments" were the categories "acidic (syenite-monzonite-granite)," "basic (theralite to granodiorite)," and "ultrabasic (peridotite, etc.)" and the subcategories "aphanitic," "porphyritic," and "phaneritic" under each heading (cf. Travis, 1955). Under "Metamorphic Rock Fragments" were "light," "intermediate" (including red or brown), and "dark" (including green) and

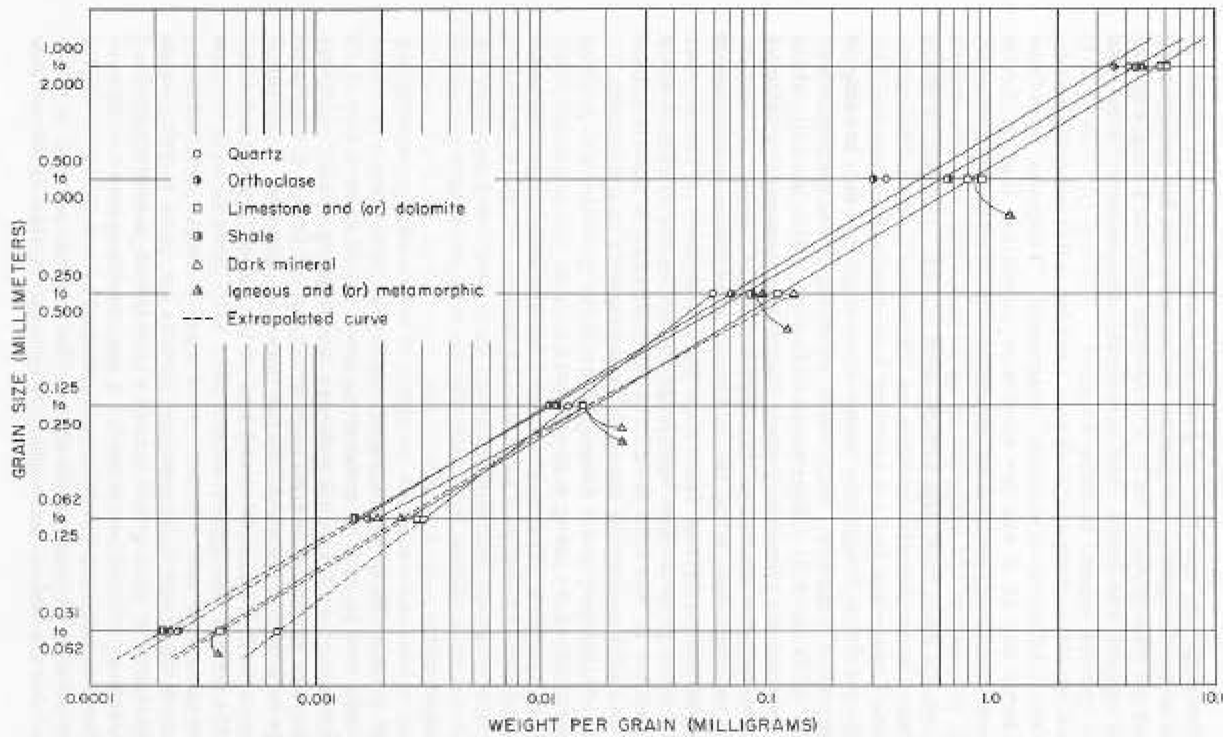

Figure 3.--Graph used in estimating average grain weight for each rock and mineral type in the 0.031-to-0.062-mm fraction, for "dark mineral" grains in the 0.250-to-0.500-mm fraction, and for "igneous and metamorphic" grains in the 0.062-to-0.125-mm fraction.

two subcategories “massive or granulose” and “lineate or foliate.” Several of the foregoing categories were combined for the presentation of the data given in table 3 (Appendix II). Not a single ultrabasic fragment was found, and so only the designations “acid” and “basic” igneous appear in table 3.

Ramaden’s technique (1954) was used for differentiating “dolomite” from “dolomitic-limestone” fragments. “Dolomite” is defined in the same way as it was for sand-size particles; that is, “rock composed mainly of the mineral dolomite with either a theoretically normal proportion (50 percent) or up to about ten percent excess $CaCO_3$ in the molecule” (Ramsden, 1954, p. 282). Particles which could have been identified either as “dolomite” or as “dolomitic limestone” amounted to no more than 3 percent of any sample.

All quartzite fragments were placed under the heading of “Metamorphic”; that is, they were considered “metaquartzites” (Travis, 1955, p. 21). Graywackes (Travis, 1955, p. 22), which were considered sedimentary-rock fragments, commonly exhibited a chlorite-sericite matrix in thin section.

All the particles in the 16- to 32-mm size range were cracked for identification; it was from this size that moat of the 86 thin sections were ground. The knowledge gained by the intensive study of the pebbles in this size permitted identification of almost all the particles in the remaining sizes without cracking or sectioning.

The weight-per-grain values (table 3) for granules and pebbles were determined by using a precision balance; 100 particles were weighed at one time. These values are based on weighings of pebbles of various lithologies drawn from all 11 samples (cf. p14). Crumbly particles that had been bagged in the field were used in computing number-percent values but could not be used in weight-per-grain determinations.

Large pebbles and cobbles.--A measure of the relative concentration of large pebble (32 to 64 mm) and cobble (64 to 256 mm) particles in the tills was gained by measuring areas of 30 square feet (2. 79 square meters) on fresh till surfaces and digging out all particles in these size grades. Weight-per-grain values (table 4, Appendix II) were determined for the particles from each outcrop. (Additional fragments in the required sizes had to be mined from each till.) Thus, the weight-per-grain values (table 4) in these sizes vary from sample to sample and are not based upon a single determination resulting from an artificial combined sample (cf. p. 14). Lithologies were assessed in each grade size in which it was possible to collect a sufficient quantity of particles for a reasonable estimation of percent composition, and the dominant lithologies are listed in table 4 in order of decreasing contribution. The number percent of crystalline (igneous and metamorphic) fragments is also listed in table

4.

Boulders.--It was impossible to obtain an adequate measure of the boulder concentration in each till for comparative purposes. A special effort was made, however, to determine the boulder lithologies of the tills studied. Number-percent values for the various lithologic types in the boulder size are given in table 4.

ATTEMPTED CORRELATION OF TILL SAMPLES

Inspection of tables 1 through 3 (Appendix II) indicates the pronounced similarity of the till samples in terms of both texture and composition. Although the 11 till samples are very similar, a simple attempt was made to correlate samples from the 4 localities. The following assumptions were involved: (1) parts of at least one formerly continuous till sheet are present in Marion County, (2) remaining segments of this till sheet crop out at the four localities chosen for study, (3) individual till sheets are homogeneous and distinguishable one from another, and (4) a given till sheet can be ascertained by finding the group of four samples (one from each outcrop locality) that shows the highest degree of textural and (or) compositional similarity.

Textural and compositional data for the 11 samples are shown in figures 4 and 5. It is possible to scan these triangular diagrams for four-sample groups. After locating a four-sample group it is then possible to investigate it to see if the samples are distributed according to assumption 4; that is, one sample at each locality. If the samples are found to be distributed ideally, it is then possible to compare their implied correlation with the tentative correlation of the tills made in the field, which is based upon stratigraphic and geomorphologic data.

The first difficulty in the analysis just described is that the selection of four-sample groups from figures 4 and 5 is highly subjective. The second difficulty is that any of the groups which *might* be selected as being unique is usually composed of samples that occur at only two or three of the four outcrop localities. In only one set of samples (1, 7, 17, and 22 of the clay-mineral contrast) (fig. 5) does there appear to be a possible group, and that possible group is composed of samples that could not be correlated on the basis of field evidence. This clay-mineral contrast is also the poorest of the four contrasts, inasmuch as all the original data are accurate to ± 30 percent. (Each of the contrasts of figure 5 suffers to a certain degree from the approximate clay-mineral data.)

The only acceptable conclusion after studying figures 4 and 5 is a negative one; namely, the tills are too similar to permit cor-

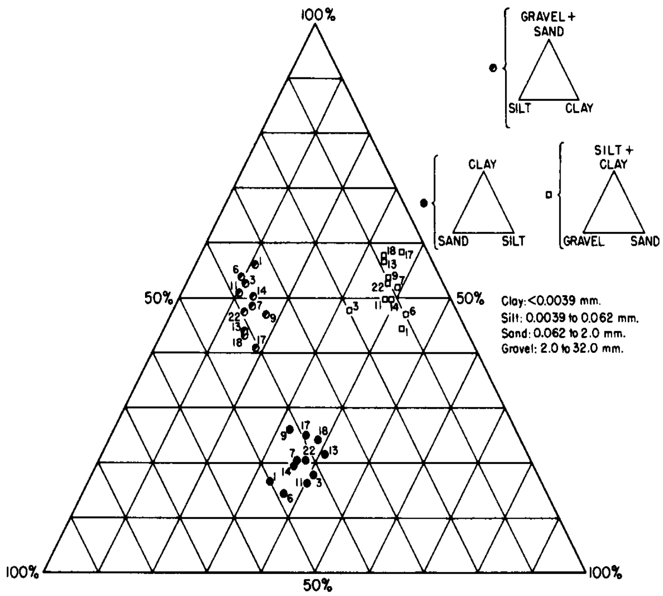

Figure 4.--Textural attributes of 11 till samples in the 0-to-32 mm size range (in weight percent).

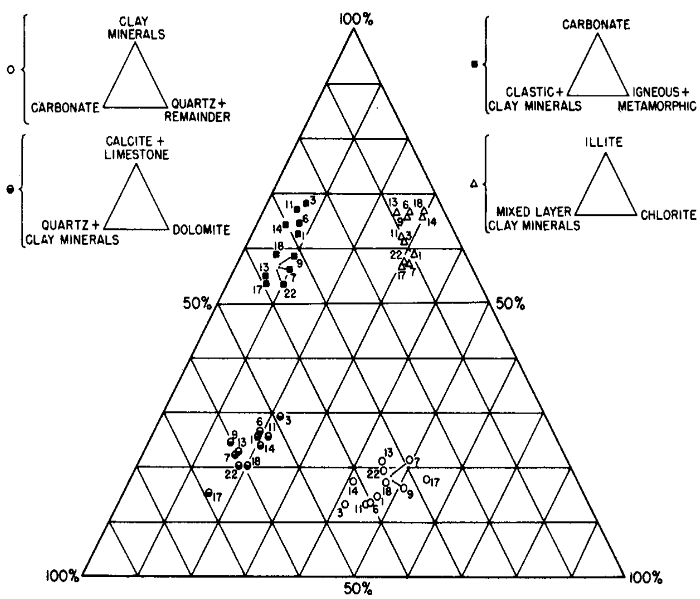

Figure 5.--Compositional attributes of 11 till samples in the 0-to-32 mm size range (in approximate weight percent).

relation by the methods used in the study. A second conclusion is implied: the till sheets deposited by the East White sublobe in Marion County are not distinguishable petrographically one from another.

It should be mentioned here that a more thorough attempt to correlate the till samples (according to the foregoing assumptions) also was made. This attempt involved assessment of the similarity of various four-sample groups by means of the X^2 (chi-square) statistic. Percentage data (cf. Walker and Lev, 1953, p. 94) and *R x C* tables (Snedecor, 1953, p. 204) were used in over 1,500 X^2 "tests" of homogeneity (similarity) of various 4-sample combinations. (The X^2 analysis was programmed for the IBM 650 computer.) The resulting X^2 values were used qualitatively for ranking sample groups according to their degrees of similarity. The results of these analyses were always the same: the groups composed of the most-similar four samples were made up of samples that occur at only two or three of the four outcrop localities.

SUMMARY AND CONCLUSIONS

Till sheets deposited by the East White sublobe in Marion County, Ind., are too similar in texture and composition to be differentiated by the methods used in this study. Correlation of samples of the multiple tills might be possible by means of weight-per-grain determinations for each of the sand, granule, and pebble fractions of each sample followed by detailed statistical analyses based on raw weight and grain-count data. Only the most critical correlation problems, however, would warrant the great amount of work required by such an approach, and it is even doubtful that significant differences between till sheets would be found.

The pronounced similarity of the till sheets deposited by the East White sublobe suggests uniformity of glacial processes within the area of investigation and implies only slight changes in the texture and composition of materials of the source area between successive glaciations.

LITERATURE CITED

Carroll, Dorothy, 1957, A statistical study of heavy minerals in sands of the South River, Augusta County, Va.: Jour. Sed. Petrology, v. 27, p. 387-404, 4 figs., 15 tables.

Dallavalle, J. M. , 1943, Micromeritica: 428 p., 100 figs. , 82 tables, New York, Pitman.

Davis, S. N. , 1951, Studies of Pleistocene gravel lithologies in northeastern Kansas: Kans. Geol. Survey Bull. 90, p. 173-192, illus.

Folk, R. L., and Ward, W. C. , 1957, Brazos river bar: a study in the significance of grain-size parameters: Jour. Sed. Petrology, v. 27, p. 3-26, 19 figs., 1 table.

Forslev, A. W., 1957, Geochemical study of some late Wisconsin tills (abs.): Geol. Soc. America Bull., v. 68, p. 1727-1728.

Gravenor, C. P. , 1951, Bedrock source of tills in southwestern Ontario: Am. Jour. Sci. , v. 249, p. 66-71, 1 fig., 1 table.

Harrison, W., 1958, Marginal zones of vanished glaciers reconstructed from the preconsolidation-pressure values of overridden silts: Jour. Geology, v. 66, p. 72-95, 8 figs. , 1 table.

-----in preparation, The geologyof Marion County, Ind.: Ind. Geol. Survey Bull.

Horberg, Leland, and Potter, P. E. , 1955, Stratigraphic and sedimentalogic aspects of the Lemont drift of northeastern Illinois: Ill. Geol. Survey Rept. Inv. 185, 23 p., 5 figs., 3 tables.

-----and Anderson, R. C., 1956, Bedrock topography and Pleistocene glacial lobes in central United States: Jour. Geology, v. 64, p. 101-116, 2 figs., 2 tables.

Jorstad, F. A. , 1957, Blokk-og steintellinger i solor: Norsk geol. tidsskr., v. 37, p. 257-266.

Kellagher, R. C. , and Flanagan, F. J., 1956a, The multiple-cone sample splitter: Jour. Sed. Petrology, v. 26, p. 213-221, 2 figs. , 7 tables.

-----1956b, A comparison of two methods for converting grain counts to weight percent composition: Jour. Sed. Petrology, v. 26, p. 222-227, 4 figs., 2 tables.

Kruger, F. C. , 1937, A sedimentary and petrographic study of certain glacial drifts of Minnesota: Am. Jour. Sci. , ser. 5, v. 34, p. 345-363, 2 figs., 9 tables.

Krumbein, W. C. , 1933, Textural and lithologic variations in glacial till: Jour. Geology, v. 41, p. 382-408, 10 figs. , 3 tables.

-----and Pettijohn, F. J. , 1938, Manual of sedimentary petrography: 549 p., 265 figs., 53 tables, New York, Appleton.

Leighton, M. M., and MacClintock, Paul, 1930, Weathered zones of the drift sheets in Illinois: Jour. Geology, v. 38, p. 28-53.

Peck, R. B. , and Reed, W. C. , 1954, Engineering properties of Chicago subsoils: Ill. Univ. Bull., v. 51, Eng. Expt. Sta. Bull. 423, 62 p., 48 figs., 5 tables.

Ramsden, R. M. , 1954, A color test for distinguishing limestone and dolomite: Jour. Sed. Petrology, v. 24, p. 282.

Reeder, S. W., and McAllister, A. L., 1957, A staining method for the quantitative determination of feldspars in rocks and sands from soils: Canadian Jour. Soil Sci., v. 37, p. 57-59, 1 table.

Sahlström, K. E. , 1910, Ett drumlinomrade i Nãrke: Sveriges geol. understökning, ser. C., no. 222, 12 p., 2 pls., 8 figs.

Shepps, V. C. , 1953, Correlation of the tills of northeastern Ohio by size analysis: Jour. Sed. Petrology, v. 23, no. 1, p. 3448, 11 figs.

Snedecor, G. W. , 1953, Statistical methods: 4th ed., 485 p., 28 figs., 217 tables, Ames, Iowa, Iowa State Coll. Press.

Travis, R. B. , 1955, Classification of rocks: Colo. School of Mines Quart., v. 50, no. 1, 98 p., 66 pls., 4 figs.

U. S. Department of Agriculture, 1928, Tentative standard methods of sampling and testing highway materials: U. S. Dept. Agriculture Tech. Bull. 1216, 132 p.

Walker, H. M. , and Lev, J. , 1953, Statistical inference: 510 p. , 63 figs. , 119 tables, New York, Henry Holt Co.

Wentworth, C. K. , 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, p. 377-392, 3 figs.

This page is intentionally blank

APPENDIX I

Locations and field descriptions of five Pleistocene sections (fig. 2) where tills were sampled. Sample numbers are not in consecutive order because they correspond to a aeries of sample numbers used in Harrison's report on the geology of Marion County, appendices A and E (in preparation).

This page is intentionally blank

LOCALITY A

Samples 1, 3, and 6: SW¼SW¼ sec. 14, T. 14 N., R. 2 E., Bridgeport Quadrangle. North-facing stream cut downstream 200 feet from dam; ground-moraine area. Altitude of surface is 730 ft (223 m).

	Ft	m
Wisconsin Stage:		
Till, oxidized upper two-thirds; soil on top (sample 1)	20.0	6.1
Sand or granule gravel, oxidized, undulating; horizontally continuous for 80 feet	2.0	0.6
Till, discontinuous where cut out by overlying unit, unoxidized (sample 3)	2.2	0.7
Silt, unoxidized, fosailiferous (wood) upper Part	1.1	0.4
Pebble gravel, slightly oxidized	0.3	0.1
Till, dense, gray (sample 6)	2.3	0.7

Stream level (when lowest)

LOCALITY B

Samples 7, 9, 11, 13: SE¼SE¼ sec. 29, T. 17 N. , R. 2 E. , Zionsville Quadrangle. North-facing stream cut. Altitude of surface is 885 ft (270 m).

	Ft	m
Wisconsin Stage:		
Till, oxidized upper two-thirds and leached top 3.2 ft (1.0 m) (sample 7)	24.1	7.3
Till, interbedded with gravel	1.3	0.4

	Ft	m
Wisconsin Stage—Continued		
Coarse sand grading upward into gravel, slightly oxidized, lenticular but continuous over 20 feet -	1.3	0.4
Till, dense, unoxidized; slightly more bouldery than till above, especially at base (sample 9) -	44.6	13.6
Outwash, gravel at base; sand (coarse) at middle; gravel at top; all slightly oxidized, continuous over 60 feet -	3.6	1.1
Till, dense, gray, continuous; C^{14} date (W-814) of > 38,000 years for wood in base (sample 11) -	3.3	1.0
Silt, laminated, uncontorted, calcareous, unoxidized; wood and shells present in upper part; C^{14} date (W-578) of > 37,000 years for wood fragments- -	2. 0	0. 6
Till, dark-gray, dense (sample 13) - - - - - - - - - - - - - - - - -	11. 3	3. 4
Stream level (when lowest)		

LOCALITY C

Sample 14: NE¼SW¼SW¼ sec. 28, T. 17 N., R. 5 E., McCordsville Quadrangle. North-facing stream cut 150 ft (46 m) west-northwest of house. Altitude of surface is 825 ft (252 m).

	Ft	m
Wisconsin Stage:		
Till, silty, oxidized 17 ft (5.2 m); leached 3 ft (0.9 m) (sample 14) -	33.2	10.0
Sand and gravel, beds contorted; slightly oxidized -	5.2	1.6
Stream level (when lowest)		

Sample 17: SE¼NW¼NW¼ sec. 29, T. 17 N. , R. 5 E., McCordsville Quadrangle. South-facing stream cut 800 ft (242 m) east of Fall Creek. This cut shows the sand and gravel break between the lower and upper till in the area. This break is presumed to correlate with the sand and gravel at collecting site of sample 14. Altitude of surface of cut is 773 ft (236 m). Altitude of upland surface is 835 ft (254 m).

	Ft	m
Wisconsin Stage:		
Sand and gravel, slightly oxidized -	4.0	1.2
Till, dense, gray (sample 17) -	3.0	0.9
Stream level (when lowest)		

LOCALITY D

Samples 18 and 22: SE¼ sec. 33, T. 15 N., R. 5 E., Acton Quadrangle. North-facing stream cut 150 ft (46 m) east of Senour Road. Ground-moraine area. Altitude of surface is 816 ft (249 m).

	Ft	m
Wisconsin Stage:		
Till, oxidized upper one-half (sample 18) - - - - - - - - - - - - - - - -	28.0	8.5
Silt, hums-rich, dark-gray- -	0.1	- -
Sand, medium-coarse; oxidized in places - - - - - - - - - - - - - - - - -	1.0	0.3
Silt, unfossiliferous, contorted, unoxidized - - - - - - - - - - - - - - -	0.5	0.2
Silt, slightly fossiliferous, wood-bearing, contorted -	2.0	0.6
Cobble gravel -	0.5	0.2
Till, gray, dense (sample 22) -	3.0	0.9
Stream level (when lowest)		

This page is intentionally blank

APPENDIX II

This page is intentionally blank

Table 1.--*Summary o f data for clay and silt fractions*

Grade size (mm)	Sample No.	Weight percent	Cumulated weight percent	Mineralogy						
				Quartz	Calcite	Dolomite	Illite	Chlorite	Mixed layer clay minerals	Misc. (mostly feldspar)
	1	8.05	100.00	15	5	5	45	25	5	T[2]
	3	8.22	100.00	15	10	5	45	20	5	T
	6	8.20	100.00	5	T	5	60	20	10	- -
	7	10.42	100.00	15	5	T	50	25	5	T
	9	16.00	100.00	15	10	5	45	20	5	T
<0.00098	11	3.34	100.00	10	--	5	45	25	15	T
	13	7.83	100.00	10	--	5	55	20	10	- -
	14	1.69	100.00	10	5	5	55	20	5	- -
	17	1.85	100.00	5	--	5	55	25	10	- -
	18	1.36	100.00	10	5	5	55	20	5	T
	22	10.30	100.00	--	--	--	55	30	15	- -
	1	2.93	91.95	20	5	5	40	20	5	5
	3	2.52	91.78	20	10	10	35	20	5	T
	6	3.36	93.80	20	T	5	50	20	5	T
	7	3.73	89.58	25	5	5	40	20	5	T
0.00098	9	1.48	84.00	30	10	10	30	10	5	5
to	11	7.06	96.66	25	--	10	40	20	5	T
0.00195	13	7.20	92.17	15	--	5	50	20	5	5
	14	11.53	98.31	10	--	5	55	25	5	- -
	17	16.58	98.15	30	5	5	30	20	5	5
	18	13.86	98.64	25	5	10	35	20	T	5
	22	3.41	89.70	25	--	10	40	15	5	5
	1	3.49	89.02	20	5	10	35	20	5	5
	3	3.69	89.26	20	10	15	35	15	5	T
	6	3.48	90.44	25	T	10	40	20	5	T
	7	4.45	85.85	25	5	10	35	15	5	5
0.00195	9	6.36	82.52	30	10	10	30	10	5	5
to	11	3.61	89.60	30	--	15	30	15	5	5
0.0039	13	4.61	84.97	30	--	5	40	15	5	5
	14	4.07	86.78	25	--	10	35	20	5	5
	17	5.13	81.57	35	5	5	30	15	5	5
	18	6.75	84.78	25	--	10	40	20	T	5
	22	4.62	86.29	25	--	10	35	20	5	5

Table 1.--.*Summary of data for clay and silt fractions*--Continued

Grade size (mm)	Sample No.	Weight percent	Cumulated weight percent	Mineralogy[1] Quartz	Calcite	Dolomite	Illite	Chlorite	Mixed layer clay minerals	Misc. (mostly feldspar)
0.0039 to 0.0078	1	6.02	85.53	25	10	15	25	15	5	5
	3	5.09	85.57	25	15	20	20	10	5	5
	6	5.43	86.96	30	10	15	25	15	- -	5
	7	7.43	81.40	30	10	15	25	10	5	5
	8	4.78	76.18	30	15	15	20	10	- -	10
	11	5.64	85.99	35	5	20	20	10	5	5
	13	7.64	80.36	30	- -	10	35	15	5	5
	14	5.84	82.71	25	5	15	30	15	5	5
	17	7.55	76.44	40	10	10	20	10	5	5
	18	9.06	78.03	35	10	15	25	10	- -	5
	22	7.19	81.67	35	5	15	20	15	5	5
0.0078 to 0.0156	1	6.26	79.51	30	10	20	20	10	5	5
	3	8.52	80.48	25	15	20	20	10	5	5
	6	6.42	81.53	30	15	25	15	5	- -	10
	7	7.21	79.97	30	10	25	5	15	10	5
	9	7.56	71.38	30	15	20	15	5	- -	15
	11	8.50	80.35	35	10	25	20	5	- -	5
	13	8.37	72.72	35	10	20	20	5	- -	10
	14	7.12	76.87	35	15	30	10	5	- -	5
	17	8.03	68.89	40	10	15	15	5	5	10
	18	8.10	68.97	35	15	25	15	5	- -	5
	22	7.61	74.48	40	10	25	15	5	- -	5
0.0156 to 0.0312	1	7.72	73.25	35	10	40	- -	--	- -	15
	3	8.04	73.96	35	20	30	- -	--	- -	15
	6	6.62	75.11	40	20	35	- -	--	- -	5
	7	9.24	66.76	40	15	30	- -	--	- -	15
	9	8.96	63.82	35	20	25	- -	--	- -	20
	11	10.63	71.85	40	15	30	- -	--	- -	15
	13	9.94	64.35	45	20	25	- -	--	- -	10
	14	9.25	69.75	40	15	35	- -	--	- -	10
	17	9.03	60.86	40	10	40	- -	--	- -	10
	18	8.95	60.87	40	15	35	- -	--	- -	10
	22	7.33	66.87	45	15	30	- -	--	- -	10

	1	9.56	65.53	35	15	35	- -	- -	- -	15
	3	13.43	65.92	35	10	40	- -	- -	- -	15
	6	15.02	68.49	35	15	40	- -	- -	- -	10
	7	9.32	57.82	40	15	30	- -	- -	- -	15
0.031	9	8.04	54.86	35	15	25	- -	- -	- -	25
to	11	10.43	61.22	30	10	50	- -	- -	- -	10
0.062	13	10.59	54.41	45	10	35	- -	- -	- -	10
	14	10.10	60.50	35	15	40	- -	- -	- -	10
	17	11.15	51.83	45	15	30	- -	- -	- -	10
	18	9.05	51.92	45	10	40	- -	- -	- -	5
	22	11.99	59.54	40	15	35	- -	- -	- -	10

[1] Numbers indicate percentages of total fraction ± 30 percent.

[2] Trace.

Table 2.--*Summary of data for coarsest silt and sand fractions*

Grade size (mm)	Sample No.	Adjusted weight percent	Cumulated weight percent	Mineralogy and lithology[1]																			
				Quartz		Chert		Orthoclase		Limestone		Dolomite		Shale		Igneous		Metamorphic		Dark mineral		Miscellaneous	
				NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP
				(0.00067)*				(0.00024*		(0.00037)*		(0.00037)*		(0.00021)*		(0.00036)*				(0.00023)*		(0.00037)*	
	1	9.56	65.53	26	42	0	0	0	0	10	9	43	38	13	7	0	0	0	0	8	4	0	0
	3	13.43	65.92	22	34	0	0	0	0	12	10	54	47	1	1	2	2	0	0	4	2	5	4
	6	15.02	68.49	33	48	0	0	1	0	34	27	28	21	1	0	0	0	0	0	5	3	0	0
	7	9.32	57.52	35	50	0	0	0	0	18	14	41	33	4	2	1	1	0	0	1	0	0	0
0.031	9	8.04	54.86	31	46	0	0	0	0	25	20	33	27	4	2	0	0	0	0	2	1	5	4
to	11	10.43	61.22	32	48	0	0	0	0	21	17	44	35	0	0	0	0	0	0	3	2	0	0
0.062	13	10.59	54.41	39	55	0	0	0	0	14	11	38	28	6	3	1	1	0	0	4	2	0	0
	14	10.10	60.50	27	41	0	0	0	0	17	14	49	41	2	1	1	1	0	0	4	2	0	0
	17	11.15	51.83	48	63	0	0	0	0	21	15	28	21	0	0	0	0	0	0	2	1	0	0
	18	8.05	51.92	32	47	0	0	1	1	9	7	52	42	3	1	0	0	0	0	3	2	0	0
	22	11.99	59.54	28	42	0	0	0	0	14	12	53	44	2	1	1	0	0	0	2	1	0	0
				(0.0030)		(0.0021)*		(0.0017)		(0.0028)		(0.0028)*		(0.0015)		(0.0024)*		(0.0024)*		(0.0018)		(0.00021)*	
	1	11.09	55.97	50	55	1	1	2	1	15	15	19	19	6	3	0	0	1	1	1	1	5	4
	3	11.35	52.49	52	56	1	1	0	0	19	19	18	18	4	2	0	0	0	0	3	2	3	2
	8	12.07	53.47	60	64	0	0	1	1	16	16	13	13	4	2	1	1	0	0	2	1	3	2
	7	10.59	48.20	72	77	0	0	1	1	5	5	8	8	4	2	1	1	1	1	5	3	3	2
0.062	8	10.77	46.82	68	74	1	1	2	1	6	6	7	7	8	5	0	0	2	2	2	1	4	3
to	11	10.36	50.79	65	71	1	1	1	1	9	9	8	8	6	3	2	2	1	1	3	2	4	3
0.125	13	9.62	43.82	53	58	0	0	2	1	17	18	9	9	5	3	1	1	2	2	5	3	6	5
	14	10.49	50.40	56	60	0	0	2	1	19	19	15	15	4	2	1	1	0	0	1	1	2	1
	17	9.71	40.68	79	83	0	0	2	1	4	4	6	6	3	2	1	1	0	0	4	3	1	0
	19	9.94	42.87	69	73	0	0	1	1	10	10	7	7	4	2	4	3	1	1	3	2	1	1
	22	9.85	47.55	77	82	2	1	0	0	4	4	5	5	5	3	2	2	1	1	2	1	2	1
				(0.0133)		(0.0135)*		(0.0109)		(0.0155)		(0.0155)*		(0.0120)		(0.0160)		(0.0160)*		(0.0159)		(0.0135)*	
	1	12.46	44.18	70	69	1	1	4	3	10	11	4	5	4	4	1	1	0	0	2	2	4	4
	3	8.34	41.14	71	69	0	0	4	4	10	11	8	9	1	1	2	2	0	0	2	2	2	2
	6	11.18	41.40	66	64	0	0	7	6	14	16	1	1	3	3	4	5	1	1	2	2	2	2
	7	10.38	37.61	68	66	0	0	4	3	18	20	1	1	4	4	4	5	1	1	0	0	0	0
0.125	9	9.92	36.05	72	71	0	0	3	3	14	16	1	1	6	5	1	1	1	1	0	0	2	2
to	11	10.02	40.43	73	72	1	1	3	2	8	9	3	3	6	7	4	5	1	1	0	0	1	0
0.250	13	8.68	34.20	54	53	0	0	8	7	26	29	1	1	5	4	1	1	1	1	2	2	2	2
	14	10.78	39.91	73	72	0	0	3	2	14	16	1	1	3	3	2	2	1	1	1	1	2	2
	17	10.74	30.97	79	78	0	0	3	3	9	10	0	0	4	4	2	2	0	0	2	2	1	1
	18	9.45	32.93	67	65	0	0	5	4	14	16	1	1	5	5	6	7	1	1	1	1	0	0
	22	10.36	37.70	68	65	1	1	2	2	9	10	11	12	2	2	3	4	1	1	2	2	1	1
				(0.0593)		(0.0900)*		(0.0716)		(0.1127)		(0.1130)		(0.0870)		(0.0876)		(0.0902)		(0.1340)*		(0.0900)*	
	1	9.75	32.42	57	43	1	0	2	2	28	40	2	3	5	6	4	5	1	1	0	0	0	0
	3	6.21	32.80	59	45	0	0	4	4	20	28	9	12	3	3	3	4	1	1	1	2	0	0
	6	9.28	30.22	49	36	0	0	5	4	28	39	3	4	6	6	6	7	1	1	1	2	1	1
	7	8.05	27.23	48	35	0	0	3	3	23	31	8	11	6	6	10	12	1	1	0	0	1	1

0.250	9	7.25	26.11	50 36	0 0	2 2	22 30	10 14	3 3	11 13	1 1	0 0	1 1
to	11	7.30	30.41	36 24	0 0	1 1	32 40	9 11	5 5	13 14	1 1	1 2	2 2
0.500	13	6.96	25.52	43 31	0 0	1 1	21 28	9 12	12 12	6 7	2 2	1 2	5 5
	14	8.37	29.13	46 33	0 0	2 1	19 26	14 19	4 4	12 14	1 1	0 0	2 2
	17	8.09	20.23	61 47	0 0	1 1	13 19	5 7	0 0	15 19	1 1	1 2	3 4
	18	6.33	23.48	40 27	0 0	1 1	22 29	14 18	8 8	11 12	3 3	1 2	0 0
	22	8.15	27.34	53 39	0 0	1 1	18 25	13 18	4 4	10 12	1 1	0 0	0 0
				(0.349)	(0.530)*	(0.301)	(0.909)	(0.807)	(0.658)	(0.811)	(0.830)		(0.530)*
	1	6.06	22.67	26 13	4 3	0 0	36 48	9 l1	8 8	9 11	3 4	0 0	5 4
	3	4.14	26.59	18 9	2 1	2 1	43 53	11 12	8 8	13 14	1 1	0 0	2 1
	6	6.57	20.94	28 14	1 1	3 2	28 38	4 5	16 16	15 l8	2 3	0 0	3 3
	7	6.09	19.18	23 11	2 2	0 0	33 43	12 14	15 14	11 13	2 2	0 0	2 1
0.500	9	5.09	18.18	19 9	1 1	0 0	40 50	6 7	11 9	17 19	2 2	0 0	4 3
to	11	5.99	23.11	22 11	1 1	2 1	48 60	8 9	11 10	6 7	1 1	0 0	1 0
1.000	13	5.46	18.56	15 7	0 0	0 0	36 44	15 16	6 5	17 18	4 5	0 0	7 5
	14	5.58	20.76	20 10	1 1	2 1	47 58	8 9	8 7	10 11	1 1	0 0	3 2
	17	4.93	12.14	28 15	3 2	7 3	30 42	11 14	5 5	12 15	2 3	0 0	2 1
	18	4.72	17.15	11 5	1 1	2 1	42 50	10 11	17 15	11 12	4 4	0 0	2 1
	22	5.41	19.19	16 8	4 3	4 2	41 52	8 9	12 11	10 11	2 2	0 0	3 2
				(4.13)	(4.40)	(3.80)	(5.73)	(6.02)	(4.45)	(4.76)	(4.90)		(4.70)*
	1	4.75	16.61	7 5	4 3	1 1	59 62	14 16	4 3	7 6	2 2	0 0	2 2
	3	3.20	22.45	4 3	2 2	0 0	50 53	18 20	6 5	14 12	4 4	0 0	2 1
	8	4.58	14.37	4 3	4 3	0 0	44 48	13 15	13 11	19 17	2 2	0 0	1 1
	7	4.28	13.09	6 5	1 1	0 0	51 55	14 16	12 9	10 9	4 4	0 0	2 1
1.00	9	3.86	13.79	7 4	1 1	1 1	52 56	12 14	14 12	11 10	1 1	0 0	1 1
to	11	4.46	17.12	2 2	2 2	0 0	65 68	13 14	9 7	4 3	4 3	0 0	1 1
2.00	13	3.79	13.10	3 2	1 1	2 1	47 51	13 15	17 14	15 14	2 2	0 0	0 0
	14	3.89	15.18	4 3	2 2	1 1	49 51	22 24	5 4	11 10	5 4	0 0	1 1
	17	2.63	7.21	8 6	0 0	1 0	37 41	15 17	15 13	17 16	6 6	0 0	1 1
	18	3.73	12.43	2 2	3 2	0 0	54 58	12 13	17 14	10 9	1 1	0 0	1 1
	22	3.63	13.78	1 1	4 3	0 0	58 62	10 11	11 9	8 7	7 6	0 0	1 1

[1]Numbers in parentheses indicate weight per grain (mg).
NP - umber percent.
WP - weight percent.

*Estimated from extrapolations of figure 3 or as described in text (p.14).

Table 3.--*Summary of data for granule and pebble (to 32 mm) fractions*

Grade size (mm)	Sample No.	Adjusted weight percent	Cumulated weight percent	Lithology'																			
				Limestone		Dolomite		Chert		Shale		Sandstone		Siltetone		Misc. and tillite		Acid igneous		Basic igneous		Metamorphic	
				NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP	NP	WP
				(0.036)		(0.046)		(0.043)		(0.029)		(0.040)		(0.028)				(0.047)		(0.030)		(0.050)	
	1	4.05	11.88	37	33	24	28	2	2	7	5	4	4	4	3	0	0	10	11	2	2	10	12
	3	3.90	19.25	46	42	27	32	2	2	10	8	2	2	0	0	0	0	7	8	2	2	4	5
	6	3.76	9.79	52	49	24	29	3	3	9	7	4	4	1	1	0	0	5	6	1	1	1	1
	7	4.13	8.81	44	40	28	33	3	3	11	8	1	1	1	1	0	0	5	6	1	1	6	8
2 to 4	9	4.28	9.93	43	40	30	35	1	1	10	7	5	5	1	1	0	0	5	6	1	1	3	4
	11	3.67	12.66	50	46	27	32	1	1	9	7	3	3	1	1	0	0	6	7	1	1	2	3
	13	3.35	9.31	59	57	19	23	2	2	10	8	2	2	4	3	0	0	3	4	1	0	0	0
	14	4.43	11.29	56	51	32	37	2	2	2	1	2	2	2	2	0	0	2	3	0	0	2	3
	17	2.89	4.58	52	50	22	27	1	1	17	13	4	4	1	1	0	0	1	1	0	0	2	3
	18	3.49	8.70	51	48	26	31	3	4	12	9	0	0	1	1	0	0	5	6	1	1	1	1
	22	3.72	10.15	42	99	31	36	3	3	10	7	2	2	1	1	0	0	8	9	1	1	2	3
				(0.241)		(0.224)		(0 .214)		(0.184)		(0.223)		(0.223)				(0.228)		(0 .241)		(0.245)	
	1	4.23	7.81	34	35	23	22	1	1	4	3	4	4	1	1	0	0	5	5	2	2	26	27
	3	2.97	15.95	50	53	23	22	4	4	8	6	5	5	3	3	0	0	5	5	1	1	1	1
	6	3.14	6.03	54	56	18	17	4	4	3	2	5	5	3	3	0	0	9	9	1	1	3	3
	7	3.43	4.68	45	47	21	21	5	5	10	8	4	4	4	4	0	0	3	3	1	1	7	7
4 to 8	9	3.49	5.65	42	44	25	25	1	1	9	7	3	3	4	4	0	0	10	10	2	2	4	4
	11	3.42	8.99	65	67	14	13	2	2	4	3	2	2	4	4	0	0	4	4	1	1	4	4
	13	1.68	5.96	49	51	19	l8	4	4	6	5	6	6	4	4	0	0	8	8	2	2	2	2
	14	6.86	6.86	56	58	30	29	1	1	4	3	0	0	3	3	0	0	4	4	0	0	2	2
	17	1.69	1.69	50	54	17	17	3	3	22	16	1	1	1	1	0	0	4	4	1	1	1	1
	18	3.74	5.21	47	50	29	28	5	5	9	7	3	3	1	1	0	0	3	3	1	1	2	2
	22	2.51	6.43	59	61	18	17	4	4	5	4	6	6	0	0	0	0	5	5	2	2	1	1
				(2.30)		(2.10)		(1.80)		(1.42)		(2.63)		(1.18)		(2.33)		(2.31)		(2.38)		(2.57)	
	1	3.58	3.58	55	56	20	18	2	2	3	2	3	4	0	0	1	1	6	6	1	1	9	10
	3	0.00	12.38	68	70	16	15	4	3	0	0	0	0	2	2	0	0	7	7	1	1	2	2
	6	2.89	2.89	57	59	15	14	7	6	4	2	4	5	0	0	1	1	8	8	1	1	3	4
	7	1.25	1.25	62	64	14	13	4	3	4	3	2	2	1	1	0	0	9	9	2	2	2	2
8 to 16	9	2.16	2.16	49	52	19	16	4	4	9	6	3	4	2	1	1	1	7	7	1	1	5	6
	11	5.57	5.57	60	62	18	17	7	6	3	2	3	4	1	1	2	2	3	3	1	1	2	2
	13	4.28	4.28	56	58	18	17	4	4	4	3	2	2	2	1	2	2	4	4	1	1	7	8
	14	0.00	0.00	65	67	11	10	2	2	7	5	1	1	0	0	1	1	8	8	1	1	4	5
	17	0.00	0.00	60	64	11	12	5	4	11	7	1	1	2	1	1	1	2	2	0	0	7	8
	18	1.47	1.47	58	61	14	14	1	1	12	8	2	2	0	0	2	2	5	5	1	1	5	6
	22	3.82	3.92	59	60	13	12	4	3	4	3	4	5	0	0	2	2	8	8	2	2	4	5

				(15.4)	(17.5)	(14.1)	(14.4)	(17.6)	(19.2)	(21.0)	(19.3)	(22.5)	(30.9)
	1	0.00	0.00	69 64	9 10	1 1	0 0	11 12	3 3	0 0	4 5	1 1	2 4
	3	12.38	12.38	67 61	11 11	1 1	1 1	7 7	0 0	0 0	6 7	2 2	5 9
	6	0.00	0.00	47 41	13 13	5 4	2 1	8 8	0 0	2 2	14 15	4 5	5 9
	7	0.00	0.00	60 53	10 10	3 2	1 1	3 3	0 0	3 4	12 13	2 2	6 11
16 to 32	9	0.00	0.00	61 54	10 10	2 2	3 2	1 1	0 0	3 4	12 13	1 1	7 12
	11	0.00	0.00	61 58	12 13	14 12	2 2	4 4	3 4	1 1	0 0	0 0	3 6
	13	0.00	0.00	59 54	10 10	3 3	7 6	10 11	0 0	0 0	6 7	0 0	5 9
	14	0.00	0.00	67 61	12 12	3 3	2 2	2 2	2 2	1 1	5 6	0 0	6 11
	17	0.00	0.00	44 39	9 9	8 6	8 7	12 12	3 3	0 0	8 7	1 1	9 16
	18	0.00	0.00	61 57	17 17	2 2	4 3	6 7	3 3	0 0	3 3	1 1	3 6
	22	0.00	0.00	56 51	11 11	1 1	10 8	4 4	1 1	2 2	8 9	2 2	5 9

[1] Numbers in parentheses indicate weight per grain (g).
NP -number percent.
WP - weight percent.

Sample No.	Measure[1]	Grade Size (mm)			Weight percent total	Dominant lithology in grade sizes:[2]			
		32 – 64	64 – 128	128 – 256		32 – 64 (mm)	64 – 128 (mm)	128 – 256 (mm)	>256 (mm)
1	A	4	0	0		1 ls.	- - - - -		
	B	4	0	0		2 dol.	- - - - -		
	C	142	1,140	0		3 cryst.	- - - - -		
	D	2.1	0	0	2.1	4 14	- - - - -		
3	A	11	0	1		1 ls.	cryst.		Sample of 42 boulders shows crystallines 67 percent limestones 19 percent, clastics 10 percent, and dolimite 4 percent
	B	12	0	1		2 dol.	ls..		
	C	145	561	4,770		3 cryst.	- - - - -		
	D	6.4	0	17.7	24.1	4 19	51		
6	A	13	3	1		1 ls.	cryst.		
	B	14	3	1		2 dol.	ls.		
	C	168	919	1,370		3 cryst.	dol.		
	D	8.7	10.2	5.1	24.0	4 22	56		
7	A	6	1	0		1 ls.	- - - - -	Only very small sample taken	
	B	6	1	0		2 cryst.	- - - - -		
	C	142	496	0		3 dol.	- - - - -		
	D	3.2	1.8	0	5.0	4 24	- - - - -		
9	A	7	1	0		1 ls.	- - - - -		
	B	7	1	0		2 dol.	- - - - -		
	C	158	1,150	2,300		3 cryst.	- - - - -		
	D	4.1	4.3	0	8.4	4 17	- - - - -		
11	A	8	0	0		1 dol.	- - - - -		
	B	8	0	0		2 cryst.	- - - - -		
	C	207	0	0		3 ls.	- - - - -		
	D	6.1	0	0	6.1	4 30	- - - - -		
13	A	9	0	0		1 ls.	- - - - -		
	B	10	0	0		2 dol.	- - - - -		
	C	147	380	0		3 cryst.	- - - - -		
	D	5.4	0	0	5.4	4 21	- - - - -		
14	A	8	1	0		1 ls.	- - - - -		
	B	8	1	0		2 dol.	- - - - -		
	C	148	1,350	0		3 cryst.	- - - - -		
	D	4.4	5.0	0	9.4	4 20	- - - - -		

17	A	6	0	0		1 ls.	- - - - -		
	B	6	0	0		2 dol.	- - - - -		
	C	114	0	0		3 cryst.	- - - - -		
	D	2.5	0	0	2.5	4 30	- - - - -		
16	A	9	1	0		1 ls.	- - - - -		
	B	9	1	0		2 dol.	- - - - -		
	C	141	490	0		3 cryst.	- - - - -		
	D	4.7	1.8	0	6.5	4 13	- - - - -		
22	A	6	1	0		1 ls.	- - - - -		
	B	6	1	0		2 dol.	- - - - -		
	C	139	906	0		3 clastic	- - - - -		
	D	3.1	3.4	0	6.5	4 5	- - - - -		

[1] A - Particle frequency in area of 30.00 sq ft (2.79 sq m).
B - Number percent (based on total number particles).
C - Weight per grain (g); all types included.
D - Weight percent (relative to total weight of all particles).

[2] Nos. 1, 2, and 3 - Relative abundances of llthologic types (first, second, and third moat abundant).
No. 4 - percentage of crystalline (igneous and metamorphic) particles in sample.
ls. - limestone
dol. - dolomite
cryst. - crystalline.