**TILL-FABRIC ANALYSIS OF THE FARMDALE DRIFT
OF NORTHWESTERN ILLINOIS**

A Thesis
Presented to
the Faculty of the Graduate School
University of Missouri

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Glen S. Soderstrom
June 1958

The undersigned, appointed by the Dean of the Graduate Faculty, have
examined a thesis entitled TILL-FABRIC ANALYSIS OF THE FARM-
DALE DRIFT OF NORTHWESTERN ILLINOIS

presented by Glen S. Soderstrom

a candidate for the degree of Master of Arts

and hereby certify that in their opinion it is worthy of acceptance.

Chauncey S. Holmes
April 30, 1958

A. G. Soderstrom
April 30, 1958

James E. Collier
May 7, 1958

"Any movement of a natural object is reflected in the position that the object assumes under the influence of that movement. This fact is self evident to anyone who looks at a wheat field in a strong wind, a weather vane, a log drive in a stream, or any one of countless other movements of objects in nature."

-Eleanora Bliss Knopf-

ACKNOWLEDGMENTS

The writer is grateful to Dr. C. D. Holmes for his guidance and encouragement. Thanks are due Dr. A. G. Unklesbay who read the manuscript and offered helpful advice. To Richard Barnett the writer is grateful for the help rendered in the making of the orientation template. The writer received much assistance and inspiration from his wife, Rosemary Nordstrom Soderstrom, and his fellow graduate students at the University of Missouri offered many helpful suggestions.

TABLE OF CONTENTS

Page

ABSTRACT.....	vii
CHAPTER	
I. INTRODUCTION TO THE PROBLEM.....	1
The Problem.....	1
Definitions.....	4
Approach to Study.....	5
II. HISTORY OF TILL-STONE ORIENTATION STUDIES....	6
Fact of Till-Stone Orientation.....	6
Methods Used.....	7
Holmes' method.....	7
Krumbein's method.....	9
Other contributions.....	11
III. THE FARMDALE DRIFT.....	13
Location, Size, and Drainage.....	13
Areal extent and structural setting.....	13
Bedrock relationships.....	15
Drainage.....	15
Age of the Drift.....	16
History.....	16
Evolution of the Farmdale substage.....	18
Character of the Drift.....	20
General statement.....	20
Color and texture.....	20
Absence of end-moraines.....	21

CHAPTER	Page
IV. PROCEDURE.....	22
Experimental Design.....	22
General statement.....	22
Problems of sampling.....	22
Collecting Procedure.....	23
General statement.....	23
Method.....	23
Laboratory Procedure.....	24
Representing Data.....	27
Rose diagrams.....	27
Stereographic diagrams.....	29
V. TILL-FABRIC ANALYSIS.....	30
Analysis by Stations.....	30
Station 1.....	31
Station 2.....	32
Station 3.....	35
Station 4.....	37
Station 5.....	39
Inferred Ice-Flow Direction.....	41
VI. DISCUSSION AND CONCLUSIONS.....	45
Mode of Deposition.....	45
Imbrication of Stones.....	50
Glacio-Aqueous Features.....	52
Summary.....	52
BIBLIOGRAPHY.....	54

LIST OF ILLUSTRATIONS

FIGURES	Page
1. Index map showing stations and inferred ice-flow directions.....	2
2. Pink Farmdale till at Mt. Carroll.....	3
3. Calcareous Farmdale till near Pecatonica.	3
4. Illinoian till in Rock Island.....	3
5. Method of marking the stones in the outcrop	25
6. Reorienting and measuring stones in the laboratory.....	28
7. Contoured stereographic diagram of Stations 1-3.....	33
8. Rose diagrams of Station 1.....	34
9. Rose diagrams of Station 2.....	36
10. Rose diagrams of Station 3.....	38
11. Rose diagrams of Station 4.....	40
12. Rose diagrams of Station 5.....	42
13. Mesotil on Illinoian till.....	49
14. Varve-like gravels, sands, and silts.....	51
TABLES	
I. List of Indicators.....	10
II. Classification of the Pleistocene series.	14
III. Per cent of imbricated stones and long - and intermediate-axis dips, thirty degrees or less.....	50

TILL-FABRIC ANALYSIS OF THE FARMDALE DRIFT OF
NORTHWESTERN ILLINOIS

by

Glen S. Soderstrom

ABSTRACT

Till-fabric analyses were made at five stations, three in Farmdale till, one in Farmdale drift too sandy and sorted to be termed till, and one in Illinoian till for comparison. Local inferred ice-flow directions were plotted from each station. From the three fabric analyses in Farmdale till, the direction of flow of the Farmdale glacier in northern Illinois was inferred to be from N. 60° E. to N. 75° E. to the southwest. The results were compared with known striae near the region studied and found to correspond.

CHAPTER I

INTRODUCTION TO THE PROBLEM

In attempting to solve the problem of the glacial succession of the Pleistocene epoch, the Wisconsin age in particular, increasing attention has been focused on the provenance of the drifts. To do this one must determine the direction of ice flow of the different ice sheets. Bedrock striae, polishing, friction cracks, and drumlins and drumloidal forms are usually used to infer the direction of ice flow. Another of the methods of determining ice-flow direction is an analysis of the arrangement of the component materials in the till, commonly called the till fabric. This is the type of study described in the pages that follow.

I. THE PROBLEM

The present study was undertaken to determine the direction of flow of the ice sheet that deposited the Farmdale drift of northwestern Illinois. To accomplish this, till-fabric analyses were made to determine the preferred orientation of stones in the till at five selected sample sites (Figure 1). Three of the sites (Stations 1, 2, and 4) were located in Farmdale till (Figures 2 and 3), a fourth (Station 5) in Farmdale drift

Figure 2. Pink Farmdale till in gravel pit in NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 24, T. 24 N., R. 4 E., about two miles south of Mt. Carroll. Ice contact gravels to left.

Figure 3. Calcareous Farmdale till in roadcut in SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 9, T. 27 N., R. 10 E., about two and a half miles north of Peca-tonica.

Figure 4. Calcareous Illinoian till in roadcut in NW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 31, T. 18 N., R. 1 W., on Thirty-eighth Street in Rock Island. The mattock marks the position of the mesotil that separates the underlying till from the overlying Peorian loess.

too sandy and sorted to be classified as actual till, and a fifth (Station 3) in Illinoian till (Figure 4) for comparison.

II. DEFINITIONS

In the true sense of the word till is unstratified and unassorted glacial drift that is deposited by a glacier without further movement by wind or water. Drift includes all the material carried by the ice even though wind or water might have been the final carrying agent. Till fabric, the arrangement of component materials in undisturbed till (Holmes, 1941, p. 1301), is a type of current fabrics--in the case of till the current being that of flowing glacial ice. Certain stones imbedded in glacial till tend statistically to lie with their long axes parallel or near parallel to the direction of glacier flow at the time of deposition while other stones have a preference for alignment at right angles (transverse) or nearly so to the current direction. This preferred orientation was best defined by Eleanora Bliss Knopf (1938, p. 17):

In the strictest sense, any object has an orientation, because the position in space of any object can be definitely related to certain fixed co-ordinates, geographic or otherwise. A preferred orientation means that out of all possible orientations a significant number of objects have assumed a certain orientation or orientations in preference to all others. This preferred orientation must be statistically determined in order to evaluate its significance.

Till-fabric analysis may be used to determine the direction of ice flow at places where no striae or other like criteria for ice-flow direction are available. Furthermore, it may be used to locate mineral deposits by tracing drift fragments to their sources and may, along with other data, be used to determine the glacial succession within a given area.

III. APPROACH TO STUDY

All the fabrics were represented by rose diagrams (Figures 8--12), and contoured stereographic diagrams (Figure 7) were made of the long-axis plots for the first three stations. Frequency distributions of the first three stations were also made and the mean directions obtained from this were compared to the inferred directions of the till-fabric analysis. Observations were also made to determine or ascertain the presence or absence of imbrication of stones upstream to glacier flow as has been claimed by Harrison (1957 b, p. 283).

The refinements of till-fabric analysis introduced by Holmes (1941) and so largely neglected by later workers (Harrison, 1957; Wright, 1956; et al.) were used to interpret the fabric patterns. Ice-flow directions were inferred from the results obtained.

CHAPTER II

HISTORY OF TILL-STONE ORIENTATION STUDIES

In the latter part of the nineteenth century when the study of glacial deposits occupied many of the world's leading geologists, few glacial geologists recognized that the "heterogeneous till" was not the pell-mell mixture it was supposed to be and that the stones in the till actually had a tendency toward preferred orientations. It was not, in fact, until the present century was over one-third spent that geologists started looking for preferred orientations in till. These studies have been carried out more in the Scandinavian and Baltic countries than anywhere else in recent years.

I. FACT OF TILL-STONE ORIENTATION

The fact that stones in till are not oriented at random is not new with this study. Holmes (1941) gives a historical summary of till-stone orientation studies up to 1939. He did the first serious quantitative work on the subject in his study of glacial till near the margin of the Allegheny Plateau in central New York. He determined the vector properties of the stones and calculated the effect of the scalar properties on those vector properties. Pettijohn (1957, p. 13) has defined the two properties:

Although the geometrical properties of a sediment are commonly described as textural or structural, they may also be classified as scalar or vectorial. A scalar property is one which has magnitude but not direction, whereas a vector property has both magnitude and direction. The long diameter of a pebble in a gravel, for example, is a scalar property; its orientation is a vector property. Vector properties are in general properties acquired at the time of deposition as a result of the earth's gravitational or magnetic fields (geopetal and geomagnetic fabrics) or as a response to current flow (current fabrics).

II. METHODS USED

Holmes' method. Holmes (1941) investigated 31 localities, measuring and recording 1180 stones ranging in length from 3 to 25 centimeters. He recorded the form, roundness, dimensions, and attitude of the stones as they were removed from their original positions in the undisturbed till. The strike and dip of the long axis and the dip of the intermediate axis were recorded to the nearest 5-degree interval and the length, width, and thickness of each stone were recorded to the nearest centimeter. He classified each stone in one of six forms: discoid, ovoid, tabular, wedge-form, rhombohedroid, and varihedroid. Half-discoids and half-ovoids were recorded as separate groups. For purposes of comparison, because of their similarity of form, discoids and tabular stones were grouped together. Most of the preceding terms are familiar to sedimentologists. Rhombohedroid forms are those having two sets of

parallel or subparallel sides. Varihedroids are stones having a variety of surfaces making this type so irregular in form that a sixth group was considered necessary. In addition he recorded the presence of facets and striae and noted the lithology of each stone.

Holmes' study showed that stones having an intermediate-axis dip of 0 to 15 degrees displayed a marked tendency toward parallel or near parallel alignment. Stones having intermediate-axis dips of 75 to 90 degrees displayed decided transverse trends. Stones with intermediate-axis dips of 20 to 70 degrees statistically showed an intermediate alignment between parallel and transverse. These relationships show that factors in the transportational environment are equally important in determining till fabric. He also concluded (p. 1331) that, ". . . symmetry of form conduces to strength and uniformity of depositional orientation." He brought out that stones in glacial transportation may gain and lose parallel orientation at least once and probably many times before their final deposition.

Holmes presumed that parallel orientation was normally acquired by sliding on the well-defined contact between the till floor and the overriding glacial ice. This deposition by "plastering-on" (Fairchild, 1907) resulted in the inherent till fabric. Transverse orientation was thought to be brought about by rotation of the particle

about its long axis. It was thought, however, that sometimes particles could rotate about their intermediate axes or if the short and intermediate axes were nearly equidimensional, rotation about the shortest axis could occur. Deposition occurs when the stone is thrust into the till floor by the overriding glacier (Holmes, 1941, p. 1345).

Elongate stones are the more responsive to conditions tending to change their transportational orientation. A parallel-oriented stone may be induced to begin rotation by collision with other particles or by irregularity of the till floor.

Holmes determined transverse and parallel indicators from the fabrics studied. The transverse indicators are stones which, because of their form, degree of roundness, axial ratios, and intermediate-axis dips or certain combinations of any of these, are statistically oriented normal to the direction of glacier movement. Parallel indicators are those stones which show statistically preferred orientations parallel to ice movement. These are listed in Table I.

Krumbein's method. Krumbein (1939) made a similar study on pebbles from glacial till, an outwash terrace, and a beach. He recorded the direction and plunge of the longest axis and the orientation of the maximum projection plane of the stone (the plane including both the long and intermediate axes). He concluded that neither the long

TABLE I
LIST OF INDICATORS

Transverse Indicators

Stones with intermediate-axis dips of 75--90 degrees statistically show transverse orientation.

Rhombohedraloids of "c" and "d" roundness in 75--90 group
(Except those of axial ratio 1:1, roundness "d").

Wedge-forms of "d" roundness (75--90).

Ovoids 1:1.

Ovoids roundness "c".

Parallel Indicators

Stones whose intermediate-axis dips do not exceed 15 degrees are statistically associated with parallel orientation.

Rhombohedraloids of "d" roundness (0--15).

Sharply angular "d" rhombohedraloids of 1:1 and 3:2 axial ratio.

Rhombohedraloids of "c" roundness, 2:1 ratio.

Ovoids "a" and "b" (0--15) except subequidimensional.

Ovoids of 2:1 axial ratio.

Wedge-forms in all groups except "d" of 75--90.

Tabular stones of "c" and "d" roundness (0--15).

Subequidimensional stones of "d" roundness with long axis less than 5 cm. except varihedroids

NOTE: There is a tendency for increased preference for parallel orientation with decreasing difference in axial lengths.

axis alone nor the maximum plane alone could describe the position of the pebble in space except in the case of pebbles of discoidal and cylindrical form.

Other contributions. Many foreign workers have studied the orientation of elongate stones in the drift. Lundqvist (1949) concluded that in end-moraines the long axes of stones were oriented normal to the trend of the moraine ridge; but Galloway (1956), to the contrary, discovered that the long axes of stones in a recent Norwegian moraine were statistically parallel to the ridge. Hoppe (1952) found that the long axes of stones in hummocky dead-ice moraine in northern Sweden were preferentially oriented normal to the local ridge or the curving edge of an ice-block depression. The variance in these workers' results is perhaps caused by their failure to apply the effects of form, roundness, and axial ratios to their analyses.

Dreimanis and Reavely (1953), in an attempt to differentiate between two tills along the north shore of Lake Erie, applied certain refinements of the Holmes method and achieved similar results but noted an insignificant amount of transverse peaks in the group of stones with axial dips of 75 to 90 degrees. Glen, Donner, and West (1957) reviewed laboratory methods in attempting to ascertain the mechanism by which till stones become oriented. Their experiments indicated that form and roundness as well as axial ratios influenced the position

of the stone relative to the direction of the flow.

Sitler and Chapman (1955), in studying the micro-fabric of till, noticed a "wrap-around" texture (p. 264) of silt-sized particles and interpreted this as representing post-depositional compaction. Harrison (1957 b, p. 285) pointed out that silt-size particles might easily be affected by drying of the till prior to thin-sectioning and any "anisotropy" might thereby be accentuated.

Harrison (1957) attempted a quantitative fabric analysis of clay till near Chicago using essentially the method defined by Krumbein (1939) and concluded that the bulk of the till fabric is inherited from the transportational environment. Form and roundness relationships were not considered by him. Wright (1956) studied elongate stones in the Wadena drumlins of Minnesota and found that the long axes of the stones were statistically oriented parallel to the long axes of the drumlins. Both Harrison and Wright found instances where there was a tendency for the long axes of the stones to be imbricated upstream to inferred glacier flow.

CHAPTER III

THE FARMDALE DRIFT

The discovery of Farmdale drift in northwestern Illinois by Shaffer (1954 b) gave certain validations for the Farmdale sub-age that had previously been based on a loess-like silt with a soil profile overlain by Peorian loess in Tazewell County. As mapped by the Illinois Geological Survey, the Farmdale substage is represented by pro-Wisconsin loess, silts, and drift lying between the Sangamon weathered zone and the Iowan loess. The present classification of the Pleistocene series is presented in Table II.

I. LOCATION, SIZE, AND DRAINAGE

Areal extent and structural setting. The Farmdale drift is found in an area in northwestern Illinois that stretches from the Belvidere lobe on the east and the Green River lobe on the south to the Driftless Area on the west and northwest (Figure 1, p. 2). The area includes parts of eastern Jo Daviess, Stephenson, Winnebago, northwestern Boone, Ogle, Carroll, northern Whiteside, and northern Lee counties and lies within the Rock River Hill Country of Leighton, Ekblaw, and Horberg (1948, p. 25). The region is crossed from north to south by the Wisconsin arch and its

TABLE II
CLASSIFICATION OF THE
PLEISTOCENE SERIES

<u>Stage</u>	<u>Substage</u>
Recent postglacial	
Wisconsin glacial	Valders Mankato Cary Tazewell Iowan Farmdale
Sangamon interglacial	
Illinoian glacial	
Yarmouth interglacial	
Kansan glacial	
Aftonian interglacial	
Nebraskan glacial	

southern extension, the La Salle anticline, and is penetrated on the west by the Savanna-Sabula anticline and to the east by the northwest-trending Sandwich fault-zone.

Bedrock relationships. The drift is remarkably thin on the upland areas which are underlain by nearly horizontal dolomites and shales of the Niagaran and Alexandrian series (Silurian), and by the Maquoketa shale, Galena dolomite, Decorah shale, and the Platteville limestone (Ordovician). The drift thins still more toward the Driftless Area. Glacio-aqueous deposits are abundant, especially near major stream valleys, and fresh unoxidized till is relatively rare in the area studied. The topography appears to be bedrock-controlled and corresponds in appearance more to the Driftless Area on the west than to the morainal area on the east although this difference is gradational from west to east. According to Flint (1931, p. 424), "The topography of this upland merits the adjective 'subdued' partly because its relief is necessarily slight owing to control by high base level, and partly because glaciation and the accumulation of loess have delicately smoothed out some of the slight irregularities in the landscape profiles caused by outcrops of the more resistant strata. . . ."

Drainage. The principal drainage of the area is roughly southwestward through the Rock River system with

its tributaries, Kishwaukee River, Pecatonica River, Rock Creek, and other tributaries. Part of the area to the west is drained by Apple and Plum rivers and their tributaries.

II. AGE OF THE DRIFT

History. Chamberlin and Salisbury (1885, p. 265) regarded the drift of northern Illinois south of the moraine (now regarded as Cary) to the southwest of Madison, Wisconsin, as belonging to one of the more ancient drift sheets of the interior. Leverett (1899) mapped the drift in part as Iowan and tentatively Illinoian. He wrote (p. 26):

In the portion of Illinois north from the latitude of Rock Island the Iowan drift occupies a large part of the interval between the glacial boundary and the outer moraine of the Wisconsin series. A drift, tentatively referred to the Illinoian, forms the surface sheet in that region in Stephenson County and parts of Winnebago, Ogle, Whiteside, Carroll, and Jo Daviess counties.

Leverett (1913) suggested that the drift of northwestern Illinois, western Wisconsin, and southeastern Minnesota might be a late stage of the Illinoian and a correlative of the Iowan drift of Iowa, interpreting (1939) the absence of recessional moraines and the thinness of the drift as indicating stagnation during the dying-out phase of a glacial stage. This evidence, he thought, was more in

keeping with a late phase of the Illinoian rather than the opening phase of the Wisconsin glacial stage. For this reason he proposed the name Late Illinoian or Iowan.

Key (1931) thought that the Iowan drift sheet was closely related to the Wisconsin drift sheet in age because the Peorian loess separating the two was calcareous in some places where it separated calcareous Iowan till from younger, calcareous till.

Alden (1918) offered the suggestion that some of the drift south of Belvidere and east of Dixon might be the product of a greater advance of the early Wisconsin ice than had formerly been suspected. He added (p. 160):

After consideration of all factors in reference to the pre-Wisconsin drift the writer is convinced that the conditions were, in general, the same in the tracts north and south of the state line, and he is led to the conclusion already stated (p. 152) that the uppermost drift outside the moraines of the Wisconsin stage in southern Wisconsin and northern Illinois (at least in that part of it examined by himself--Boone County, north of Kishwaukee River; Winnebago County; eastern Stephenson County; Ogle County; northern Lee County; and northeastern Whiteside County) is of practically the same age throughout instead of representing two or more distinct stages of glaciation. . . .

In 1923 Leighton (1923, p. 267) discovered the Belvidere lobe and extended the Green River lobe westward. (Both are regarded now as Shelbyville in age.) He regarded the drift west of the Belvidere lobe as Illinoian in age. Flint (1931) also regarded the drift west of the Belvidere lobe as Illinoian.

Evolution of the Farmdale substage. In 1920 Leighton had observed a loess-like silt beneath the Peorian and above the Sangamon soil zone in a stream cut on Farm Creek near Peoria which in 1926 he called Late Sangamon loess (1926, p. 170). He later called the loess Farmdale (Leighton and Willman, 1950, p. 603) from the town of Farmdale, Tazewell County, Illinois, believing it to be a pro-glacial loess having valley relationships to the Illinois River valley (ancestral Mississippi), the present Mississippi Valley below the mouth of the Illinois River, and the Wabash and lower Ohio valleys. This valley-train relationship was thought by him to imply an extension of the Wisconsin ice sheet during the Farmdale sub-age into this drainage basin prior to the Iowan sub-age.

Shaffer (1954 b) announced the discovery of Farmdale drift in northwestern Illinois. Additional study (1956) led him to believe that the Farmdale drift was the oldest drift in the area. He stated (1956, p. 7):

It is interesting to note that the age of the bulk of the drift west of the Bloomington moraine and the Marengo Ridge was regarded as probably or tentatively Illinoian until Leighton's work in 1923. His westward extension of the Wisconsin drift emphasized the fact that west of the Belvidere lobe and extending to the east border of the unglaciated area there was a drift that was older than the Belvidere lobe (Shelbyville). The only possibilities for its age assignment then were Illinoian or older because the Farmdale substage of the Wisconsin stage was then unrecognized. However, Leighton noted that this older drift seemed less weathered than the Illinoian drift farther south and southwest in Illinois. Later, after he recognized the Farmdale

loess as Wisconsin, his feeling that the difference in weathering might denote an age younger than Illinoian prompted the present study.

The work of Leighton and Willman (1950, p. 602) placed the Farmdale as the initial substage of the Wisconsin glacial stage, separated from the Illinoian by the Sangamon soil profile and overlain by Iowan loess. Suess (1954, p. 470) took two wood samples from the Farmdale loess at the type exposure and received radiocarbon age values of 22,900 $\pm$ 900 and 25,100 $\pm$ 800. Ruhe, Meyer, and Scholtes (1957) questioned the relative ages of the Farmdale and Iowan substages. They claimed that an older group of radiocarbon ages greater than 29,000 years dated the Iowan substage and pre-Iowan deposits. A younger group of ages dated from 22,900 to 25,100 years belonged to the Farmdale substage and on this basis the Iowan substage would be older than the Farmdale. Ages of 14,000 to 17,000 years were ascribed to Tazewell deposits by Ruhe et al.

At present there is no Iowan drift mapped as such in Illinois although Shaffer (1954 a, p. 455) suggested the possibility that the Tazewell substage and the Iowan substage might be contemporaneous and, ". . . on the basis of priority Shelbyville would be redefined as Iowan. These matters merit further field investigation."

III. CHARACTER OF THE DRIFT

General statement. The Farmdale drift is different from older drifts in Illinois in that it is remarkably thin, particularly on upland areas. Deposits of stratified drift occur throughout the area with kames, eskers, and crevasse fillings common. The Farmdale drift has not yet been found overlying Illinoian drift. Where Farmdale drift is overlain by a loess, the loess is generally referred to as Peorian. The latter term as used now includes all loesses upward from the Iowan substage. Where Farmdale drift is overlain by a loess and another drift sheet, the loess is termed Iowan or pro-Shelbyville (Shaffer, 1956, p. 16).

Color and texture. Farmdale till, where fresh, is light pink to salmon in color (7.5 YR 8/4 dry). It has been classified as silty sand (Shaffer, 1956, p. 21) according to the classification of Shepard (1954, p. 157). The total depth of leaching (loess and drift where the loess is from 2 to 3 feet thick) averages 4.5 feet. No gumbotil was found on the Farmdale drift in this study. Leighton and MacClintock (1930) have shown that leaching in loess proceeds faster than in till. Where Farmdale till is overlain by 3 or more feet of loess, the total depth of leaching is generally greater than where the loess cover is thin. Fresh Farmdale till was seldom found during the present study for in most places the till is oxidized to a reddish or rusty brown.

In most places the till stones were weathered only to a slight degree. Basic rocks were altered moderately to the extent that some had a weathering rind on them. At several localities a rock type resembling diorite seemed highly weathered. With the exception of the leached till at Station 1 near Mt. Carroll, the till contains from 82 to 88 per cent carbonate rocks (limestone and dolomite undifferentiated).

Absence of end-moraines. The absence of end-moraines on the Farmdale drift despite the stony nature of the drift is a problem yet to be solved. This has been taken as evidence that the Farmdale glacier quickly melted down after reaching its maximum extent (Flint, 1931; Leverett, 1939; and Shaffer, 1956).

CHAPTER IV

PROCEDURE

Since previous quantitative work on till fabric had indicated that pattern maxima could vary from one horizon to another higher or lower one, it was felt that in this study a better representative sample of the drift sheet could be obtained by sampling from a vertical surface. In this way an average of two or more possible horizons (if present) would be represented.

I. EXPERIMENTAL DESIGN

General statement. The field approach was designed to parallel closely the work of Holmes (1941) in order to include all the refinements determined by him. He made all his measurements of properties of till stones in the field. Using a mattock to prepare a horizontal surface of about 2 square feet in undisturbed till, he uncovered each stone with a prospector's pick, measuring the critical elements of the stones with an orientometer similar to the one shown in Figure 6, page 28. Although the minimum number of stones recorded by him at any one station was 100, statistical results showed that 50 stones sufficed.

Problems of sampling. In the present study an attempt was made to take a representative sample of 50

stones from each sample site. Since the work of Holmes and Harrison indicated that till-fabric patterns may vary from one horizon to another higher or lower one, it was thought, in this study, that a better sample of the drift as a whole might be obtained by sampling randomly from a vertical surface on the till exposure. This posed problems of collecting for the scalar properties could not often be determined without removing the stone from the till. Removal of the stone destroyed the orientation. It was essential therefore to find a way to remove the stone from the drift so that all the scalar features could be observed and at the same time the orientation of the stone would be preserved. Karlstrom's method (1952), explained below, was used to mark the stone in the till for reorientation in the laboratory where the spatial attitude of the stone could be reconstructed.

II. COLLECTING PROCEDURE

General statement. The method of collecting was such that the till stones were marked, while in the outcrop, in such a way that they could be reoriented later in the laboratory for vector and scalar measurements.

Method. A straight vertical face on the exposure was prepared with a mattock and spade--an area of approximately 3 feet square was generally used. The bearing

of the exposure face was read with a compass and recorded in the field notebook. A whisk broom and small brush were used to expose and prepare the surfaces of particles for marking, taking care not to dislodge the stones. Fifty stones were collected from each station. Stones varying in length from 1 to 12 centimeters were collected during the present study. Each was marked in the outcrop before removal with the vertical orientation template as shown in Figure 5. The template is a lucite plate one-fourth of an inch thick, 4 inches wide, and 5 inches long. Slots three-eighths of an inch wide were cut into the plate in the form of a cross. An inset bubble level was aligned with the horizontal arm of the cross. The template was leveled in front of the particle and a cross made on the stone by guiding a red Blaisdell china-marking pencil (number 169) along the template cross as is shown in Figure 5. A small "X" was placed in the lower left quadrant of the marked face of the stone before it was removed from the till for reorientation reference in the laboratory.

III. LABORATORY PROCEDURE

An orientometer made of a straightedge, protractor, and plumb bob; a circle marked off into 5-degree arcs drawn on a piece of illustration board; a lump of modeling clay; and a transparent lucite plate upon which a vertical

Figure 5. Marking the till stone in the till exposure. A cross is marked on the stone, an "X" placed in the lower left-hand quadrant, and the stone is ready for removal.

line and horizontal lines are drawn were used to reorient the stones in the laboratory. The lucite plate was fastened in an upright position to a square piece of board upon which the cardboard circle was pinned. The circle was rotated for each sample so that the vertical lucite plate was parallel to the compass direction of the outcrop face from which the sample had been taken. The "stage" was leveled and the marked stone placed in the modeling clay mount at the center of the circle. Orientation of the particle was made by adjusting the particle in the mount so that lines on the particle coincided with lines on the plate when viewed from the front. Because of the irregular surface of the particles, the projected lines appeared straight and at right angles only when the particle was viewed from one direction, the one normal to the plane of the exposure face in which the stones were marked.

After the stone had been placed in its original attitude, the direction and dip of its long axis was measured with the orientometer and recorded to the nearest 5-degree interval. The dip of the intermediate axis was also noted. The relative lengths of the three axes of each stone were recorded so that the ratio of the long axis to the intermediate axis could be compiled. All stones collected were treated in this manner.

Each stone was classified in one of five major form groups: ovoid, tabular (includes discoids), wedge-

form, rhombohedroid, and varihedroid after Holmes (1941, p. 1306). Four degrees of roundness were used as follows: sharply angular, "d"; slightly rounded, "c"; moderately rounded, "b"; and well rounded, "a". A comparison chart for ready estimation of particle roundness in the maximum projection plane has been published by Krumbein (1941, p. 69). His roundness .1 and .2 corresponds to roundness "d", .3 and .4 to "c", .5 and .6 to "b", and .7 and above to "a". A roundness higher than .7 is seldom achieved by till stones. The measuring and reorientation of a stone is illustrated in Figure 6.

IV. REPRESENTING DATA

Rose diagrams. Rose diagrams, showing the long-axis directions of the stones plotted, were used for the graphic representation of all five till-fabric stations (see Figures 8-12). Using a suitable scale, direction lines were drawn for the stones in each 5-degree interval with the length of each line representing the number of stones recorded for that direction. From each station a composite pattern (also possibly compound since the stones were taken from a vertical surface and could have included variations of horizons) was made and in turn broken down into fabric-pattern groups on the basis of intermediate-axis dips. Individual pattern groups were made for stones

Figure 6. Stage for reorienting the till stones. A cardboard circle is mounted on a leveled wooden block with attached lucite plate upon which a vertical line and horizontal lines are drawn. The marked stone is mounted on the modeling clay and lined up with the cross-lines on the lucite plate. Strikes and dips of the axes, and other linear elements, are measured with the orientometer and circle which is graduated in 5-degree intervals.

with intermediate-axis dips of 0 to 15 degrees, 20 to 70 degrees, and 75 to 90 degrees. Additional patterns were made for transverse indicators and parallel indicators (see Table I, page 10). The data representation is similar to that of a histogram but with the rose diagram the angular relationships can be more graphically illustrated. A dot above each diagram indicates North.

Stereographic diagrams. For the first three stations contoured stereographic diagrams of the long-axis pole plots were made according to the method described in Knopf and Ingerson (1938). See Figure 7, page 33. These diagrams show both axial direction and axial dip. The long-axis orientations of the stones were plotted on a Schmidt equal-area projection of a hemisphere 20 centimeters in diameter. This hemisphere is taken as a lower half of a sphere whose projection plane is horizontal and circular. Compass directions are marked along the periphery and dips are recorded from 0 degrees at the periphery to 90 degrees at the center. The per cent concentration of the projected axes were determined with a two-per-cent counter on a one-centimeter grid, and isopleth lines were drawn at convenient intervals. North is indicated by a dot above each diagram.

CHAPTER V

TILL-FABRIC ANALYSIS

Five fabric patterns were analyzed in the course of the present study (see map, Figure 1, page 2). The pattern of Station 1 represents leached Farmdale till near Mt. Carroll; of Station 2, calcareous, oxidized Farmdale till north of Pecatonica; of Station 3, calcareous Illinoian till in Rock Island; of Station 4, fresh Farmdale till south of Mt. Morris; and of Station 5, sandy calcareous Farmdale drift three miles north of Byron.

I. ANALYSIS BY STATIONS

Using the Holmes method of till-fabric analysis, the inferred direction of ice flow of the depositing glacier was determined. Comparisons were made with known striae and like features near the region. As previously mentioned, each composite fabric pattern was broken down and patterns were made according to intermediate-axis dips as well as the transverse and parallel indicators. A stone was not plotted in one of the latter two patterns unless it satisfied two or more of the criteria listed in Table I, page 10.

In each of the Figures containing rose diagrams, diagram "A" is a composite fabric pattern, "B" is the

fabric pattern of stones having an intermediate-axis dip of 0 to 15 degrees, "C" is the pattern of stones having an intermediate-axis dip of 20 to 70 degrees, "D" is the pattern of stones with intermediate-axis dips of 75 to 90 degrees, "E" is the pattern of transverse indicators, and "F" is the pattern of parallel indicators.

Station 1. A fabric analysis from leached Farmdale till in a gravel pit, NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 24, T. 24 N., R. 4 E., elevation 740 feet, two miles south of Mt. Carroll. The section:

	Thickness	
	Ft.	In.
Wisconsin		
Peorian, topsoil and loess, leached, yellow brown.....	4	6
Farmdale, till, clay-bound, sandy, pebbly, leached, red till with high percentage of chert and quartzite pebbles and cobbles.....	6	0 $\frac{1}{2}$

The fabric sample was taken from a kame-like mound near the intermittent Johnson Creek. The topography to the south and east is essentially youthful with intermittent drainage. The topography to the north and west is mature and drained by the East River. This station is located near the Driftless Area. Of the stones collected, 74 per cent had long axes dipping 30 degrees or less. Sixty per cent of the long or intermediate axes dipped upstream to the inferred direction of glacier movement. Owing to the leached nature of the till, carbonates made up 10 per

cent of the stones while chert and quartzite made up 48 and 14 per cent, respectively.

Inspection of the composite diagram, pattern A of Figure 8, discloses two maxima, one due East and the other N. 65° E. This trend persists in pattern B but patterns C and D are not indicative of any definite direction. The transverse indicators, pattern E, along with the parallel indicators in pattern F, indicate an inferred ice-movement direction from N. 65° E. The stereographic diagram of Figure 7 is not indicative of any particular direction. No relationship of the patterns obtained to topographic slope could be determined at this station.

Station 2. A fabric analysis of calcareous Farmdale till in a roadcut, SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 9, T. 27 N., R. 10 E., about two and one half miles north of Pecatonica, elevation 840 feet. The section:

	Thickness	
	Ft.	In.
Wisconsin		
Pecorian, topsoil, black; and loess, leached, brown.....	1	4
Farmdale, till, leached, pebbly, chocolate brown.....	2	0
Till, calcareous, sandy, yellow gray to pink.....	4	4 $\frac{1}{2}$

This station is located on a maturely dissected upland north of the Pecatonica River. The sample site is located on the divide between Pink Creek to the northeast and Pecatonica River to the south. The slope is approximately 6 feet per 100 feet S-SW. Fifty-eight per cent of

FIGURE 7
CONTOURED STEREOGRAPHIC DIAGRAMS

FIGURE 8

ROSE DIAGRAMS OF STATION 1

the intermediate axes dipped 30 degrees or less and 74 per cent of the long axes dipped 30 degrees or less. Eighty-two per cent of the till stones were carbonates. Only 22 per cent of the long or intermediate axes dipped upstream to glacier flow.

The fabric patterns of Figure 9 display a marked correlation between B and F (both have statistical preference for parallel orientation). A resembles C and neither give an indication of flow direction. Patterns D and E (both have a statistical preference for transverse orientation) show a striking similarity. This station's patterns agree remarkably well with the findings of Holmes. Here as at Station 1 the ice flow is interpreted as coming from N. 65° E. The stereographic diagram for this station (figure 7, page 33) agrees with the rose diagrams.

Station 3. A fabric analysis of Illinoian till in a roadcut, NW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 31, T. 18 N., R. 1 W., on Thirty-eighth Street in Rock Island. Elevation about 650 feet. The section:

	Thickness	
	Ft.	In.
Wisconsin		
Peorian, yellow loess, slightly calcareous.....	40	0
Sangamon, soil, gray, hard mesotil...	1	3
Illinoian, till, calcareous, yellow brown, siderite cobbles, coal fragments.....	7	0 $\frac{1}{2}$

This locality was on a bluff above the present valley of the Mississippi River. The slope here was 20 feet per

FIGURE 9

ROSE DIAGRAMS OF STATION 2

100 to the northwest, the same as the inferred ice-flow direction at this station. This coincidence is discussed later. Forty per cent of the long or intermediate axes dipped to the southeast from which direction the ice is believed to have come. Seventy-two per cent of the till stones were carbonates and 68 per cent of the intermediate axes dipped 30 degrees or less while 74 per cent of the long axes dipped 30 degrees or less.

The fabric pattern A of Figure 10 shows two maxima, one N. 40° E. and the other N. 45° W. Patterns B and F bear this out while patterns D and E seem inconclusive. This station was located near the margin of the Illinoian lobe as it moved west and to the northwest across what is now the Mississippi River valley. Near the glacier margin the direction of ice flow may have varied considerably and therefore this may account for the apparent indefiniteness of this station pattern. The stereographic diagram in Figure 7 shows a pronounced northwest trend with a slight transverse maximum. Largely on this evidence the direction of flow was plotted as going toward N. 45° W.

Station 4. A fabric analysis of calcareous Farmdale till in roadcut, NE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 1, T. 23 N., R. 9 E., 3 miles west of Oregon and 2 miles south of Mt. Morris. Elevation 840 feet. The section:

A
(Composite)

B
(I. A. 0-15)

C
(I. A. 20-70)

D
(I. A. 75-90)

E
(Transverse)

F
(Parallel)

FIGURE 10

ROSE DIAGRAMS OF STATION 3

	Thickness	
	Ft.	In.
Wisconsin		
Peorian, topsoil and loess, leached, yellow brown.....	2	0
Farmdale, till, sandy, leached, brown	1	0
Till, sandy, calcareous, pink to gray.....	3	0 ⁴

This fabric analysis was taken from a station on the youthfully dissected upland near the tributary of Gale Creek. The slope here was 8 feet per 100 S-SE. Eighty-eight per cent of the till stones were carbonate rocks. Thirty-six per cent of the long or intermediate axes dipped upstream to inferred glacier flow. Fifty-two per cent of the intermediate axes dipped 30 degrees or less and 70 per cent of the long axes dipped 30 degrees or less.

Pattern A of this station in Figure 11 would be misleading as to ice-flow direction but the transverse and parallel indicators in E and F give an inferred direction of ice flow from N. 70° E. Pattern D shows a similarity to pattern E if the bunching of stones about a direction of N. 55° W. in the former is considered.

Station 5. A fabric analysis of Farmdale drift in a roadcut in NW¹/₄ sec. 18, T. 25 N., R. 11 E., 3 miles north of Byron, elevation about 760 feet. The section:

A
(Composite)

B
(I. A. 0-15)

C
(I. A. 20-70)

D
(I. A. 75-90)

E
(Transverse)

F
(Parallel)

FIGURE 11

ROSE DIAGRAMS OF STATION 4

	Thickness	
	Ft.	In.
Wisconsin		
Peorian, topsoil and loess, leached, brown.....	1	6
Farmdale, pebbly sand, leached, rusty brown.....	3	0
Sand with pebbles, cobbles, cal- careous, gray to brown.....	3	6 1/2

This station is on the upland near the east fork of Mill Creek, where the slope is about 3 feet per 100 SE. Eighty-eight per cent of the stones were carbonates and 76 per cent of the stones dipped upstream to the inferred ice-flow direction. Seventy-eight per cent of the till stones had intermediate-axis dips of 30 degrees or less and 78 per cent of long-axis dips were 30 degrees or less. The drift here was too sandy and sorted to be termed till. The sample from this station had the highest percentage of ovoids (34 per cent while the average of all stations was 22.1 per cent). Stones at this spot had on the average the highest degree of roundness of the five stations.

The composite pattern in Figure 12 is symmetrical about an East-West maximum but the parallel indicators are bunched within 15 degrees of N. 25° E. Pattern D is transverse to this as would be expected.

II. INFERRED ICE-FLOW DIRECTION

From the preceding till-fabric analyses, conclusions regarding the ice-flow direction of the Farmdale glacier

FIGURE 12

ROSE DIAGRAMS OF STATION 5

lobe may now be drawn. Stations 1, 2, and 4 (Figure 1, page 2) are separated from each other by 30 to 35 miles but display a remarkable harmony of pattern. Both 1 and 2 have inferred local ice-flow directions of N. 65° E. and 4 has an inferred ice-flow direction of N. 70° E. From the fabric patterns of the Farmdale till analyzed in this study it appears that the Farmdale ice sheet moved from northeast to southwest with a bearing of N. 60° E. to N. 75° E., allowing for a 5-degree variance from till-fabric data.

Since much of the work on till-stone orientation has involved finding the average direction of the stones, frequency distributions of long-axis directions were compiled at the first three stations and the results compared with the inferred ice-flow directions established by the Holmes method. The mean direction (arithmetic mean or average) at Station 1 was N. 15° E. (inferred direction by Holmes method: N. 65° E.); at Station 2, N. 10° E. (inferred direction by Holmes method: N. 65° E.); and at Station 3, N. 5° W. (inferred direction: N. 45° W.). It is evident that the mean directions are out of harmony with the inferred directions. This could be foretold by inspection of the composite rose diagrams since several maxima as much as 170 degrees apart were noted at all three localities.

No striae were found during the course of this study for all of the bedrock sites visited were in the Galena dolomite which presents a rather "rotten" appearing surface in outcrop upon which striae were not readily preserved, if ever made. Leverett (1899, p. 88) reported several striae sites found by Mr. I. M. Buell. These trend from N. 65° E. to N. 75° E. and are shown in Figure 1, page 2. This seems to support the inferred movement of the Farmdale ice sheet.

CHAPTER VI

DISCUSSION AND CONCLUSIONS

Now that the fabrics have been analyzed it is possible to make some deductions about the mode of deposition of the Farmdale till. Evidence for the presence or absence of the imbrication of stones upstream to glacier movement was not conclusive. The current study raised some questions as to the relationship of the glacio-aqueous material to the Farmdale substage.

I. MODE OF DEPOSITION

Results of the till-fabric analyses closely paralleled results of Holmes (1941). He proposed (p. 1312) that, ". . . constant deposition of the basal load--a 'plastering-on'--seems probable except under conditions tending to depress the pressure-melting-point isogeotherm into the floor beneath the glacier." He went on to state (p. 1321) ". . . compactness of the till with its imbedded stones is believed to be an original depositional character and seems to be logically related to gradual accumulation ('plastering-on') beneath the weight of the moving glacier; it implies a well-defined contact between the ice and its till floor." Stones in contact with the glacier floor or along shear planes in the ice would move

by sliding controlled by prominent flat surfaces on the stones. Stones carried above the floor would be subject to rotation about an axis lying in the plane of uniform shear and normal to the direction of ice flow. These rotating stones could have been thrust into the till floor by higher and faster moving debris. Studies by Glen, Donner, and West (1957) seemed to support this hypothesis.

Harrison (1957 b, p. 288) compared four different hypotheses, "Hypothesis one: The ground moraine is the result of permanent deposition from a rotational orientation by gradual accumulation of the till beneath a moving glacier." According to him this is Holmes' hypothesis. He (Harrison) makes no mention of orientation by sliding. His second hypothesis reviewed (p. 290) was: "The ground moraine fabric is the result of shear of deposited till by movement of the overriding glacier." The third (p. 291): "The ground-moraine fabric is the result of till deposition by successive mudflows originating from the edge of the melting glacier." And his final hypothesis, (p. 291): "The bulk of the ground moraine fabric is inherited, with only a slight degree of modification, from that fabric which is developed in the transportational environment."

It is readily seen that hypotheses one and three

are merely modifications of hypothesis four. Hypothesis two is the only one that would result in a secondary fabric. Harrison failed to recognize this. In the case of hypotheses one and four, the transportational environment is moving glacial ice, in hypothesis three the transportational environment is moving mud and associated debris.

Harrison thought that the fabric-pattern (maxima of disk- and blade-shaped particles defined vanished slip-planes of the debris-charged basal zones. Demorest (1942) indicated that these planes do exist in glaciers. This in fact is the consensus of most glacial geologists today although they may differ in opinion as to the character of these planes. Planes of shear may exist associated with the basal friction of the glacier and where debris-charged basal layers are overridden by faster-flowing layers of ice. According to the theory of obstructed extrusion flow, these shear planes would be more abundant near the terminus of the glacier and end-moraines therefore ought to give good transverse peaks in fabric patterns if deposition from rotation, as explained by Holmes, has occurred. Glen, Donner, and West (1957) found this to be true in studies of narrow-band tills.

Harrison's results of fabric analysis in the Marseilles end-moraines (1957 b, p. 283) reveal strong transverse peaks at nine stations. He concluded (p. 283) that

there "generally was no good correspondence between the preferred-orientation directions of end-moraine till fabrics and former glacier movements. . . ." He blamed post-depositional solifluction activity, frost heave, and disturbance by plants and man for this lack of parallel orientation.

In the present study only the fabric at Station 3 shows an essential relationship to slope direction. This fabric was obtained from a roadcut in a bluff along the Mississippi River at Rock Island, Illinois. The till was overlain by a horizontal mesotil (see Figure 13) which originally extended horizontally across the present Mississippi Valley. The surface slope to the northwest, which is the inferred ice-flow direction, must have formed after the Sangamon mesotil had developed; and any post-depositional movement of the Illinoian till would have had to come before the formation of the mesotil. If solifluction may explain transverse alignment, it should be shown why it does not affect or influence parallel alignment.

It is concluded therefore that strong transverse fabric peaks are a result of the transportational environment and may be predicted in places where obstructed flow has occurred, such as at the terminus of a glacier.

Figure 13. The mattock pick marks the position of the mesotil zone on the Illinoian till at Station 3. The mesotil was very hard but was not as fine-textured as gumbotil.

II. IMBRICATION OF STONES

The studies of Harrison (1957 b, p. 283) indicated that at many localities there was a strong tendency for the particles in the till to dip upstream to glacier movement. In this study only one sample (the one from Station 5) had what might be a significant amount of stones dipping upstream to inferred ice-flow direction. Seventy per cent of either the long axes or intermediate axes dipped upstream. But the drift at this station was too sandy and too sorted to be termed till. Table III gives a summary of the per cent of stones dipping upstream to inferred ice-flow direction at all five stations.

TABLE III

PER CENT OF IMBRICATED STONES AND LONG- AND
INTERMEDIATE-AXIS DIPS, THIRTY
DEGREES OR LESS

	Stations					Average
	1	2	3	4	5	
Per cent imbricated stones.....	60	22	40	36	70	46
Per cent long-axis dips (30 or less).	74	74	74	70	78	74
Per cent Inter. dips (30 or less)....	64	58	68	52	78	64

On the basis of the per cent imbricated stones shown in Table III, it is concluded that in this study the evidence was not conclusive enough to actually prove or disprove that stones in glacial till are imbricated upstream. An inspection of the analysis data showed a tendency for axial dips to be grouped at 30 degrees or less. Long-axis dips showed a remarkable constancy of percentage of dip.

Figure 14. Varve-like gravels, sands, and silts from a gravel pit 5 miles east of Freeport. These are typical of the glacio-aqueous deposits associated with the Farmdale drift.

It is not understood why this is so (see Table III), perhaps it is coincidence but this evidence might warrant further study.

III. GLACIO-AQUEOUS FEATURES

Figure 14 shows some varve-like deposits from a gravel pit 5 miles east of Freeport in the Pecatonica River valley. Hershey (1896) called these gravels, sands, and silts, the "Silveria" formation. The valley relationships of these deposits were interpreted by Flint (1931, p. 422) to be deposits made in glacial lakes that filled all the major valleys as the Farmdale ice melted away from the top down. These glacio-aqueous deposits are common in the region and have caught the attention of most of the glacial geologists that have worked in the area. Many of the geologists have called these deposits, glacio-lacustrine, but they disagree on the origin, number, and relative sizes of the lakes in which these sediments were deposited. It seems that the lacustrine history of northern Illinois has yet to be deciphered.

IV. SUMMARY

Till-fabric analysis of the Farmdale drift has shown that the Farmdale glacier lobe moved from N. 60° E. to N. 75° E. to the southwest. This movement seems to follow from the Lake Michigan lowland to the Green River

lowland south of Morrison. The composite patterns at the three stations in Farmdale till do not give definite indication of ice-flow direction (Figures 8, 9, and 11), but the parallel and transverse indicator patterns do. The failure of other workers to make use of these refinements (Harrison, 1957; Galloway, 1956; Hoppe, 1952; Lundqvist, 1949; et al.) has resulted in questionable interpretations of inferred ice-flow directions.

According to the till-fabric analyses, the Farmdale lobe seems to have moved to the south of the Driftless Area and terminated in the Green River lowland. No end-moraines have yet been found at the terminus of the Farmdale drift sheet.

BIBLIOGRAPHY

- Alden, W. C., 1918, The Quaternary geology of southeastern Wisconsin, U. S. Geol. Survey Prof. Paper 106, 356 p.
- Chamberlin, T. C., and Salisbury, R. D., 1884-1885, Driftless area of the upper Mississippi valley, U. S. Geol. Survey, Sixth Ann. Rept., pp. 199-322.
- Demorest, Max, 1942, Glacier regimens and ice movements within glaciers, Am. Jour. Sci., v. 240, pp. 31-66.
- Dreimanis, A., and Reavely, G. H., 1953, Differentiation of the lower and upper till along the north shore of Lake Erie, Jour. Sed. Pet., v. 23, pp. 238-259.
- Fairchild, R. F., 1907, Drumlins in central New York, New York State Mus. Bulletin 111, pp. 1-443.
- Flint, R. F., 1931, Glaciation in northwestern Illinois, Am. Jour. Sci., v. 21, no. 221, pp. 422-440.
- Galloway, R. W., 1956, The structure of moraines in Lyngsdalen, north Norway, Jour. Glaciol., v. 2, pp. 730-733.
- Glen, J. W., Donner, J. J., and West, R. G., 1957, On the mechanism by which stones in till become oriented, Am. Jour. Sci., v. 255, pp. 194-205.
- Harrison, P. W., 1957 a, New technique for three-dimensional fabric analysis of till and englacial debris containing particles from 3 to 40 mm. in size, Jour. Geol., v. 65, pp. 98-105.
- , 1957 b, A clay-till fabric: its character and origin, Jour. Geol., v. 65, pp. 275-308.
- Hershey, O. H., 1896, Silveria formation, Am. Jour. Sci., Ser. 4, v. 152, pp. 324-330.
- Holmes, C. D., 1941, Till fabric, Geol. Soc. America Bull., v. 52, pp. 1299-1354.
- Hoppe, G., 1952, Hummocky moraines regions, with special reference to the interior of Norrbotten, Geografiska Annaler, v. 39, pp. 19-31.

- Horberg, Leland, 1950, Bedrock topography of Illinois, Ill. Geol. Survey Bull. 73, 111 p.
- Karlstrom, Thor N. V., 1952, Improved equipment and techniques for orientation studies of large particles in sediments, Jour. Geol., v. 60, pp. 489-493.
- Kay, George F., 1931, The relative ages of the Iowan and Wisconsin drift sheets, Am. Jour. Sci., v. 221, pp. 158-172.
- Knopf, E. B., and Ingerson, Earl, 1938, Structural petrology, Geol. Soc. America Memoir 6, 270 p.
- Krumbein, W. C., 1939, Preferred orientation of pebbles in sedimentary deposits, Jour. Geol., v. 47, pp. 673-706.
- _____, 1941, Measurement and geologic significance of shape and roundness of sedimentary particles, Jour. Sed. Pet., v. 11, pp. 64-72.
- Leighton, Morris M., 1923, The differentiation of the drift sheets of northwestern Illinois, Jour. Geol., v. 31, pp. 265-281.
- _____, 1926, A notable type Pleistocene section, the Farm Creek exposure near Peoria, Ill., Jour. Geol., v. 34, pp. 167-174.
- _____ and MacClintock, Paul, 1930, Weathered zones of the drift sheets of Illinois, Jour. Geol., v. 38, pp. 28-53.
- _____, Ekblaw, G. E., and Horberg, C. L., 1948, Physiographic divisions of Illinois, Jour. Geol., v. 56, pp. 16-33.
- _____, and Willman, H. B., 1950, Loess formations of the Mississippi valley, Jour. Geol., v. 58, pp. 599-623.
- Leverett, Frank, 1899, The Illinois glacial lobe, U. S. Geol. Survey Mon. 38, 817 p.
- _____, 1913, Iowan drift (Abstract), Geol. Soc. America Bull., v. 24, p. 698.

_____, 1939, The place of the Iowan drift, Jour. Geol., v. 47, pp. 398-407.

Lundqvist, G., 1949, The orientation of the block material in certain species of flow earth, Geografiska Annaler, v. 31, pp. 335-347.

Pettijohn, F. J., 1957, Sedimentary Rocks, Harper, New York, 690 p.

Ruhe, R. V., Meyer, Rubin, and Scholtes, W. H., 1957, Late Pleistocene radiocarbon chronology in Iowa, Am. Jour. Sci., v. 255, pp. 671-689.

Shaffer, P. R., 1954 a, Extension of Tazewell glacial sub-stage of western Illinois in eastern Iowa, Geol. Soc. America Bull., v. 65, pp. 443-456.

_____, 1954 b, Farmdale drift, Science, v. 119, pp. 693-694.

_____, 1956, Farmdale drift in northwestern Illinois, Ill. Geol. Survey Rept. Inv. 198, 25 p.

Shepard, F. P., 1954, Nomenclature based on sand-silt-clay ratios, Jour. Sed. Pet., v. 24, pp. 151-158.

Sitler, R. F., and Chapman, C. A., 1955, Microfabrics of till from Ohio and Pennsylvania, Jour. Sed. Pet., v. 25, pp. 262-269.

Suess, H. E., 1954, U. S. Geol. Survey radiocarbon dates I, Science, v. 120, pp. 467-473.

Wright, H. E., Jr., 1957, Stone orientation in Wadena drumlin field, Minnesota, Geografiska Annaler, v. 39, pp. 19-31.

University Libraries
University of Missouri

Digitization Information for Theses and Dissertations project.
Scanned from microfilm; no subsequent editing done.

Local identifier

Source information

Identifier	Microfilm reel# T1958-59-T1958-70
Format	Microfilm
Content type	Text
Notes	

Capture information

Date captured	2019
Scanner manufacturer/model	ScanPro 3000 /e-ImageData
Scanning software	PowerScan 3000(TM) v5.341
Optical resolution	600 dpi
Compression	LZW
Color settings	bitonal
File types	tiff
Notes	Scanned from microfilm; no editing done.

Derivatives - Access copy

Editing software	Photoshop
Resolution	600 dpi
Color	grayscale
File types	pdf
Notes	Converted from tiff to pdf using Adobe Acrobat Pro DC.