

STRATIGRAPHY, SEDIMENTOLOGY, AND PALEOMAGNETISM
OF PRE-ILLINOIAN GLACIAL DEPOSITS
NEAR KANSAS CITY, KANSAS AND KANSAS CITY, MISSOURI

by

Patrick M. Colgan

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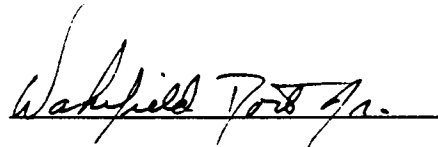
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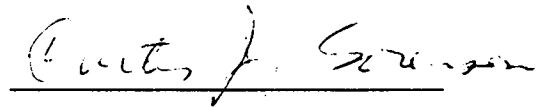
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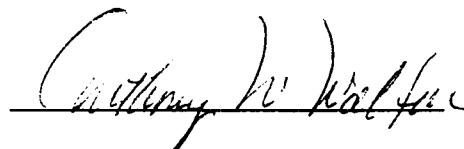
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B.S., University of Missouri-Kansas City, 1990

Submitted to the Department of Geology and the Faculty of the
Graduate School of the University of Kansas in partial fulfillment
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Professor in Charge

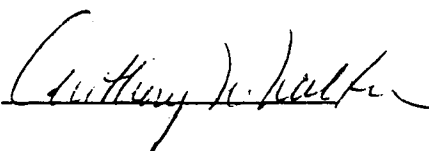




Committee Members

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ABSTRACT

Pre-Illinoian glacial deposits unconformably overlie Upper Pennsylvanian bedrock and underlie middle to late Pleistocene deposits near Kansas City, in Kansas and Missouri. Most areas are covered by only a thin residual lag of resistant rock types and weathered diamicton, but in buried bedrock valleys and on undissected uplands, drift up to 50 meters thick is present.

Lithofacies relations indicate that the pre-Illinoian sequence is internally conformable and represents a single episode of glaciation. In most sections, a sequence of proglacial outwash, subglacial till, and postglacial outwash or lacustrine deposits is present. In several sections, tills of similar composition are separated by outwash, glacially deformed outwash and resedimented till, indicating a locally fluctuating ice margin. Ice movement data shows that ice flow was generally south-southeast, but locally a southwest trend is present. Ice movement data and lithology suggest that the Dakota Lobe deposited drift in the area.

Paleomagnetic analysis indicates that tills in the area were deposited during a time of normal polarity, possibly since the last field reversal dated at approximately .75 Ma. Field relations indicate that deposits are older than terrace deposits containing a volcanic ash previously identified as .61 Ma Pearlette O Ash.

Grain size analysis of till matrix (<2 mm), small-pebble counts (4-8 mm), heavy mineral analysis (.0625-.125 mm), and magnetic susceptibility analysis of till matrix were performed to characterize sediment and aid in correlation. Grain size analysis shows that tills in the study area are relatively homogeneous with average texture for dark gray, unleached, and unoxidized samples being 40% sand, 43% silt and 17% clay. Light yellow, leached and oxidized samples are finer, with average textures of 34% sand, 40% silt, and 26% clay. Small-pebble counts indicate that between 10 and 50% of the 4-8 mm clasts are northern erratics, with a higher percentage of erratics found in oxidized and leached, upper tills than in unoxidized and unleached, lower tills. Heavy mineral assemblage is dominated by hornblende and opaques. Magnetic susceptibility analysis indicates that two grain-size populations of magnetite are present in tills. This effect is interpreted as being a result of diagenetic changes in both oxidized and unoxidized till. Unoxidized till matrix has a fairly narrow range of low field magnetic susceptibility and anhysteretic remanent magnetization indicating a narrow range of total magnetite content and grain size. Oxidized tills contain relatively finer magnetite than unoxidized tills.

Stratigraphy, paleomagnetism and lithology indicate that pre-Illinoian deposits in the study area are correlative to the Independence Formation in northeastern Kansas.

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LOCATION OF STUDY AREA

This study includes areas immediately to the north, west, and east of the Kansas City area (Figure 1). Data were collected from Wyandotte and Johnson Counties, Kansas as well as Platte, Clay, and Jackson Counties, Missouri. Most of the field work focused on areas west and north of Kansas City in Wyandotte, Platte, and Clay Counties, where thick glacial deposits are commonly exposed. Only reconnaissance field work was done in Johnson County, Kansas and Jackson County, Missouri, where deposits are thin, absent, or covered by urban development. Field work was carried on between the fall of 1990 and spring of 1992 with most work being done in the summer of 1991. Laboratory work was completed in spring 1992.

The study area was chosen because preliminary observations indicated that multiple glacial sequences might be present and because it has received relatively little study. It is located within an area important to the two-lobe model (Aber, 1982, 1985a, 1988a, 1991) of glaciation in Kansas. Additionally, urban growth has made exposures relatively plentiful.

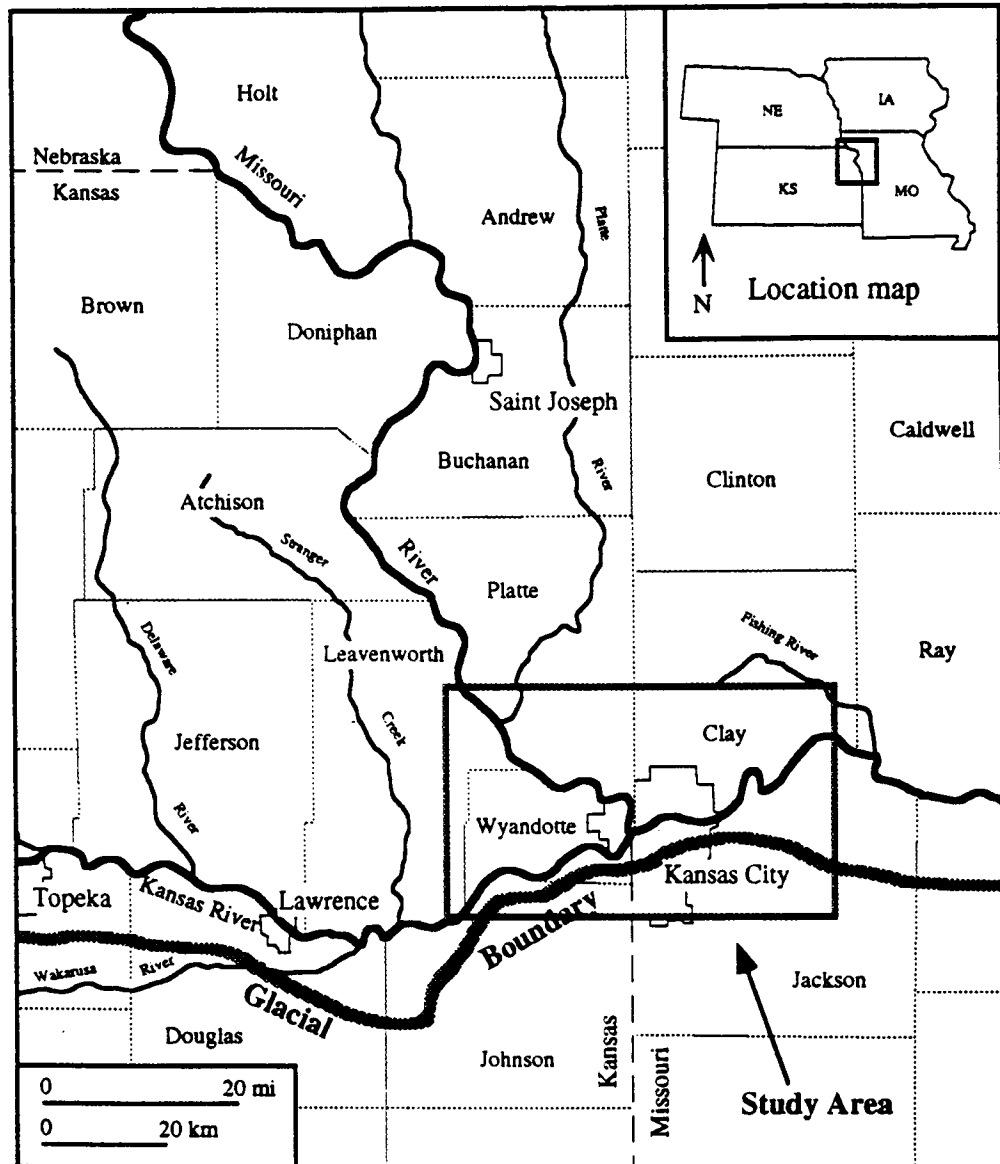


Figure 1. Map of northeastern Kansas and northwestern Missouri showing location of study area.

INTRODUCTION

Purpose and scope

Aber (1982, 1985a, 1988a, 1991) has proposed that two, pre-Illinoian lobes of the Laurentide ice sheet deposited glacial sediments in Kansas and Missouri (Figure 2). This model is analogous to the well-established pattern of James River and Des Moines Lobes (Flint, 1971), which developed in eastern South Dakota and central Iowa during the late Pleistocene. As ice advanced from northwestern Canada, it was split by the Coteau des Prairies upland in eastern South Dakota. Bedrock striations, till fabric, glaciotectionic structures, and stratigraphy show that a similar pattern developed during the early Pleistocene. Dakota Lobe entered Kansas and Missouri by way of Nebraska. Minnesota Lobe advanced through Iowa into Missouri and northeastern Kansas (Aber 1982, 1985a, 1988a, 1991).

This study was undertaken to determine if more than one ice lobe advanced to the vicinity of present day Kansas City, Kansas and Kansas City, Missouri. If this occurred, a two-lobe model predicts that either Dakota Lobe or Minnesota Lobe, or both lobes, deposited sediment in the area. If a single ice lobe was present in the area, ice movement data should indicate a single dominant ice flow direction. Two or more drift sequences and ice movement data indicating multiple flow directions could be present if both lobes reached the area.

Regional Pleistocene geology

Before the 1960's glacial deposits were assigned to the four-fold North American Stage classification (Figure 3), created at the turn of the century (Geikie, 1894; Chamberlain, 1895, 1896; Leverett, 1898; Shimek, 1909). This scheme, based primarily on the recognition of glacial and interglacial deposits, made the identification of Pleistocene deposits relatively simple. Fresh, uneroded deposits displaying glacial geomorphic features and complex depositional sequences were assigned a Wisconsin age. Older deposits eroded and without glacial landforms were classified according



Figure 2. Model of two-lobed pre-Illinoian glaciation of the Central Plains of North America. Glacial boundaries are from Flint (1971). After Aber (1982).

Stage	Reference	Type locality or region
Wisconsin	J. Geikie (1894) T.C. Chamberlin (1895) Originally East Wisconsin	State of Wisconsin
Sangamon	F. Leverett (1898) After Worthen (1873)	Sangamon County Illinois
Illinoian	T.C. Chamberlin (1896) Originally Illinois	State of Illinois
Yarmouth	F. Leverett (1898)	Yarmouth, Iowa
Kansan	T.C. Chamberlin (1895)	Northeastern Kansas Afton Junction, Iowa
Aftonian	T.C. Chamberlin (1895)	Afton Junction, Iowa
Nebraskan	B. Shimek (1909)	State of Nebraska

Figure 3. North American Glacial Stage classification showing glacial and interglacial stage names and original references. After Flint (1971)

to stratigraphic position and relation to paleosols.

In the central United States, two tills stratigraphically below the Sangamon paleosol and separated by another well developed paleosol (Afton soil), were assigned a Nebraskan (lower till) and Kansan (upper till) age. The older Nebraskan till sheet was thought to be less extensive and covered by a more extensive Kansan till (Figure 4).

Subsequent work during the 1960's indicated that early Pleistocene deposits were as complex as late Pleistocene deposits. In Nebraska, two "Nebraskan" and three "Kansan" substages were recognized (Reed and Dreezan, 1965). Complexity became apparent in Kansas at about the same time (Dort, 1966; Bayne, 1968; Bayne and others, 1971) and the Kansas Geological Survey adopted much of Reed and Dreezan's classification (Zeller, 1968). In Missouri, Davis and Howe (in Bayne and others, 1971) modified Howe's (1961) classification to reflect these changes. Work in the 1970's continued to show that the four-fold stage classification was inadequate, but its use continued mainly because nothing was proposed to replace it.

A major confirmation of the complexity of early Pleistocene deposits came when Boellstorff (1973) provided lithologic and geochronologic evidence for five "pre-Illinoian" tills in Nebraska and Iowa. He demonstrated that what was once thought to be a single widespread volcanic ash of late Kansan age was several ashes of significantly different ages. Previous and contemporaneous work with the marine oxygen isotope record (Emiliani, 1955; Shackleton and Opdyke, 1973) also supported multiple early Pleistocene glaciations. Hallberg and Boellstorff (1978) argued that the stage terms Nebraskan and Kansan should be abandoned because of poor definition in their time stratigraphic meanings. In place of the four-fold classification, Boellstorff (1978) proposed an informal chronozone classification. This chronology is not widely accepted by continental stratigraphers. Instead, most workers informally designate early Pleistocene deposits as pre-Illinoian (Hallberg, 1980, 1986) or early to middle Pleistocene (Richmond and Fullerton, 1986).

Since then, studies in Nebraska (Easterbrook and Boellstorff, 1984) and Iowa (Hallberg, 1980)



Figure 4. Extent of Pleistocene glaciations in the central lowlands and plains states of North America. Location of study area is also noted. Glacial boundaries are after Flint (1971). Boundary for pre-Illinoian in Kansas is from Aber (1991).

establish a provisional stratigraphic scheme (Hallberg, 1986) for the pre-Illinoian of the Central Plains (Figure 5). The application of fission track dating techniques for the Pearlette family of ashes (Boellstorff, 1973) and the use of paleomagnetic methods (Easterbrook and Boellstorff, 1984) greatly improves this stratigraphic scheme.

With the new stratigraphic scheme, a major change in the perception of early Pleistocene deposits occurred. During this period of transition workers divided and subdivided the Pleistocene record into numerous lithostratigraphic units. This is probably the result of more careful study, but may also reflect a tendency towards subdivision. It has been recognized for some time that complex glacial sequences can be created by simple depositional processes such as glacial advance and retreat (Boulton, 1967; Sugden and John, 1979), but only recently have sedimentologic models been proposed to explain such sequences (Johnson and Hansel, 1990; Hart and Boulton, 1991). In some areas, multiple tills that have been interpreted as representing several glacial advances and retreats may represent characteristic facies changes produced by a single glacial advance and retreat (Johnson and Hansel, 1990). It is justified to test the subdivision of Pleistocene stratigraphic units, and search for criteria useful in distinguishing glacial depositional sequences.

Present knowledge indicates that periods of ice advance and retreat separated by periods of landscape stability and soil formation have occurred in North America for at least the past one million years and possibly during as much as two million years (Boellstorff, 1973). If the 1.65 Ma Plio-Pleistocene boundary is accepted then the existence of pre-Pleistocene glaciations at higher latitudes seems certain (Richmond and Fullerton, 1986). Evidence for pre-Pleistocene glaciation of the Central Lowlands and Central Plains is present (Boellstorff, 1973) but less certain (Wright, 1989). As many as two dozen distinct glacial episodes separated by significant periods of warmer climate may have occurred (Richmond and Fullerton, 1986). However, little is really known about pre-Illinoian glaciations. How many of these glaciations are recorded in the Central Plains is

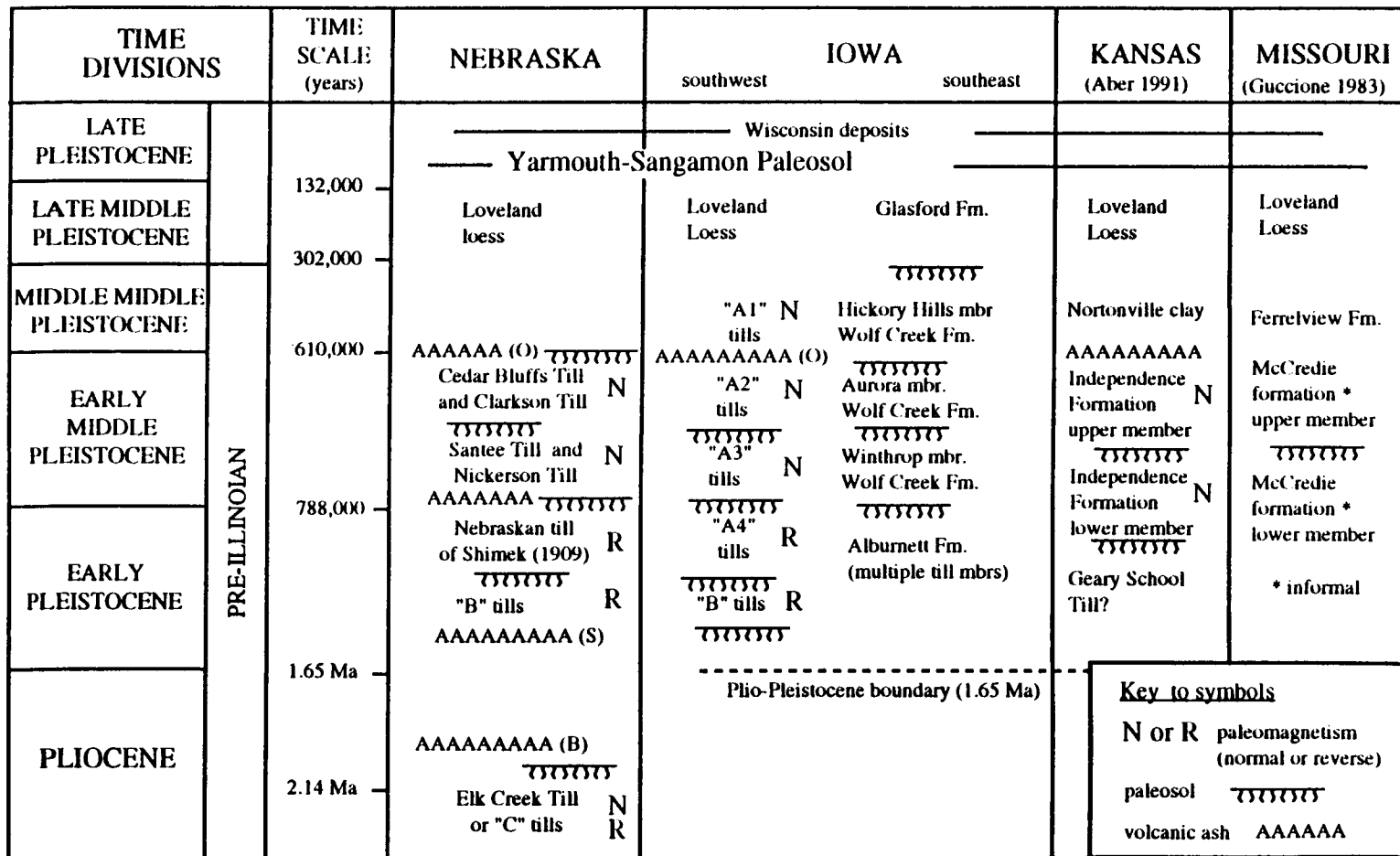


Figure 5. Present pre-Illinoian stratigraphy of Nebraska, Iowa, Kansas, and Missouri. Correlations for Nebraska and Iowa are from Hallberg (1986), correlations for Kansas and Missouri are from Aber (1991) and Guccione (1983).

uncertain, but reasonable evidence suggests at least six major pre-Illinoian events (Hallberg, 1986).

Glacial sedimentology

Sedimentologic facies analysis of glacial sequences has been proposed by Eyles and others (1983) as a replacement for traditional stratigraphic, lithologic, and mineralogic studies of till sequences. This is an extreme position, which ignores both the accomplishments of past glacial stratigraphers and the fact that basic lithologic data is a requirement for rock stratigraphic correlation (American Commission on Stratigraphic Nomenclature, 1983). Nevertheless, criticism of past methods is warranted. Often, sedimentologic analysis is not used by glacial stratigraphers generally concerned with correlation. While the correlation of glacial deposits over large areas is possible and has been accomplished by thorough study in Illinois, Iowa, and Wisconsin (Willman and Frye, 1970; Hallberg, 1980; Attig and Mickelson, 1985), it is obvious that a simple approach that ignores identification of depositional environments is not applicable to continental deposits of considerable variability.

Individual till sheets, assumed to represent distinct glacial advances, have been differentiated and correlated by lithologic and relative age criteria in Nebraska (Reed and Dreezan, 1965), Illinois (Willman and Frye, 1970), and Iowa (Hallberg, 1980). Where glacial landforms are still present, differentiation and correlation has been accomplished reasonably well. In older deposits where glacial landforms are absent, most work has focused on correlation, with only a small amount of study focused on depositional processes and environments. Basic field descriptions are needed to provide data as interpretations and correlations change in the future. Unfortunately, in the past few descriptive data have been published with interpretations. Without such data, much of the older literature is of little practical use.

Additionally, sedimentologic data are needed to test and modify theoretical models of glacial depositional processes. Currently, workers do not agree as to how subglacial sediments accumulate. Glaciologists working on the modern Antarctic ice sheet commonly disagree with glacial geologists

studying modern and ancient sedimentary sequences (e.g., Mickelson and Ham, 1992; Clarke, 1991; Hicock, 1991).

Pleistocene geology of Kansas and Missouri

Large northern erratic boulders of granite and pink quartzite were the first physical evidence widely accepted as proof of glaciation in Kansas and Missouri. From the distribution of erratics and drift the glacial margin in Kansas and Missouri was mapped in the late nineteenth century by Mudge (1866), Hay (1893), Smyth (1897), and Todd (1896), then expanded upon and refined in the twentieth century by Todd (1918), Schoewe (1924, 1927, 1930, 1941), Holmes (1942), Howe (1961), Johnson and Adkinson (1967), Johnson and Wagner (1967), O'Connor (1960, 1971), Dort (1987a), and Aber (1988a).

Study of glacial deposits has been carried out in Kansas by geologists associated with the University of Kansas and the Kansas Geological Survey (see Frye and Leonard, 1952). In Missouri studies by Todd (1896), Holmes (1942), Davis (1955), Schmaltz (1959), Howe and Heim (1968), Bayne and others (1971), and Guccione (1982, 1983) have established the basic stratigraphy and extent of glacial deposits. Dort (1987a) and Aber (1984, 1991) provide the most recent summaries of current knowledge, and history of glacial geology in Kansas. In Missouri, no such recent summary exists.

Knowledge of pre-Illinoian sediments has accumulated much more slowly than that of late Pleistocene deposits, because the pre-Illinoian land surface has been destroyed in most areas by subsequent glacial and interglacial erosion. Such is certainly the case in Kansas and Missouri where few if any glacial landforms are present (Todd, 1896; Dort, 1987a). In most areas, the extensively eroded pre-Illinoian landscape is covered by thick deposits of late Pleistocene loess, colluvium, and alluvium. In Kansas and Missouri, glacial deposits cover most of the upland areas north of the Kansas and Missouri River valleys. In most places between Topeka, Kansas and east of Kansas City, in central Missouri, drift extends a few kilometers south of Kansas and Missouri River valleys (see Figure 1).

Recently, there has been renewed interest in the pre-Illinoian of Kansas. Dort (1985) provided outcrop descriptions of differences in multiple tills along the southern glacial margin, but these deposits are so badly weathered that little can be determined about their original lithology (Davis, 1951; Aber, 1988a). Aber (1991) provides data for drift found in northeastern Kansas and for a single outcrop, which he designates as the type section of the Independence Formation. To date no lithologic difference has been found between informal upper and lower members of the Independence Formation (Nutter, 1988; Aber, 1991)

The two-lobe model (Aber, 1982, 1985a, 1988a, 1991) indicates that interaction between the Dakota and Minnesota Lobes occurred along the present course of the Missouri River north of Kansas City, Missouri. Whether interaction occurred south of Atchison, and northern Leavenworth Counties, Kansas is uncertain. Both Todd (1896) and Davis (1955) concluded that Platte County, Missouri was glaciated only once. Davis (1955) additionally provided evidence of minor interstadial retreat and readvance. Todd (1896) states that ice probably came from the northeast through Iowa, but provides only a few striations as evidence. Davis (1955) provides no data for the direction of ice movement, but states that ice movement may have been parallel to the strike direction of Pennsylvanian bedrock. This is roughly northeast to southwest, suggesting the Minnesota Lobe was responsible for sediments in the area.

If the drift in the Kansas City area was deposited by either the Dakota Lobe or by the Minnesota Lobe (Todd, 1896, Davis, 1955; Aber, 1991), it should be possible to test these alternatives by studying ice movement data, stratigraphy, and drift composition. Ice movement data should show a dominant trend in ice flow if a single lobe was dominant. If both the Dakota and Minnesota lobes were present, there may be lithologic differences in multiple tills, and ice movement data may show two trends.

This study presents data indicating that glacial deposits in the study area are similar to those of northeastern Kansas and can be reconciled to a two-lobe model, with Dakota Lobe depositing drift in

the area. It also suggests that there are problems with a two-lobe model just as there were with the four-fold North American stage classification.

Presentation of Data

This thesis includes three parts. The first details the stratigraphy and sedimentology of pre-Illinoian drift in the area and discusses its relationship to a two-lobe model. The second presents paleomagnetic data gathered to determine the remanent magnetism of tills within the study area. The third presents laboratory data characterizing diamicton within the study area. This data is compared to that for the Independence Formation (Aber, 1991) in northeastern Kansas and McCredie formation (informal) in central Missouri (Guccione, 1982, 1983).

PART I - STRATIGRAPHY AND SEDIMENTOLOGY

Methods and definitions

Stratigraphic sections were measured during field work for this thesis (Figure 6, Table 1). Additionally, numerous other exposures were examined in less detail, mainly to determine the extent and lateral variability of deposits. The color of exposed units was described using the Munsell soil color chart. Texture, sedimentary structures, facies, bed geometry, contacts, pedogenic alteration, and carbonate content were also noted.

Because of the lateral variability of glacial deposits in general, it was appropriate in several cases to construct photomosaics as suggested by Miall (1978) to better illustrate and understand lateral facies relationships. Sedimentary structures and facies were either marked onto overlays of the photomosaics or sketched in the field. This technique was applied to several of the more important exposures.

The term diamicton, as defined by Flint and others (1960), is adopted to describe poorly sorted, matrix-supported, unlithified, deposits. This term is not used as a substitute for the more familiar word "till", but only as a descriptive term, when it is not possible to provide evidence of deposition by a specific glacial process recognizable from sedimentary structures. The term "till" is used only when the definition of Boulton (1972) can be applied through the interpretation of sedimentary structures as:

"A sediment whose component particles are brought together by the direct agency of glacier ice, and which, although it may suffer subsequent glacially-induced flow, is not subsequently disaggregated."

In northeastern Kansas and northern Missouri many deposits that are of a likely glacial origin are extremely weathered and their precise origin is uncertain. For this reason it is appropriate to

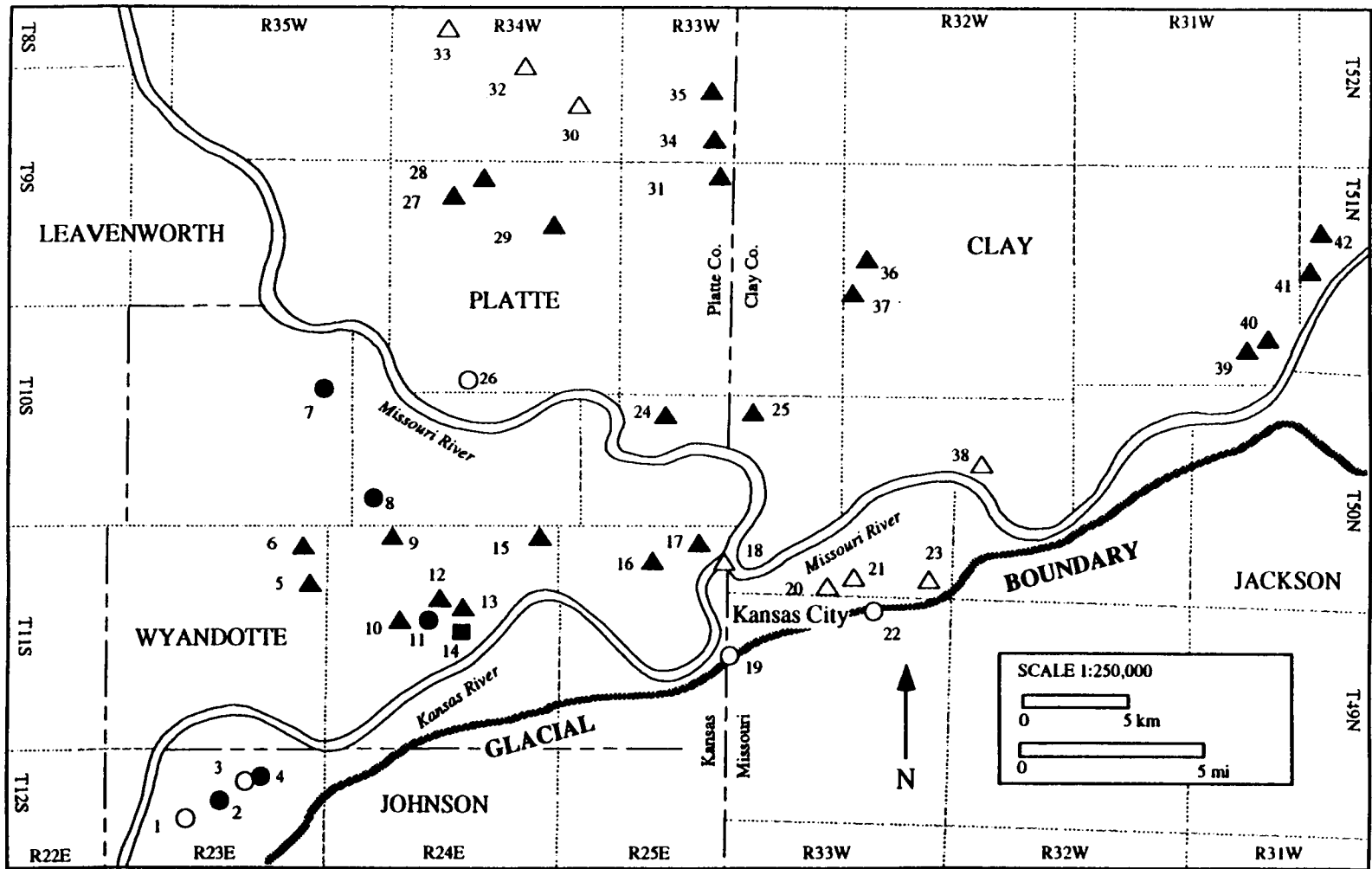


Figure 6. Locations of exposures described in text. Sections measured in this study are noted as black triangles (diamicton), black circles (sand and gravel), and black squares (other deposits); exposures described previously by other authors are noted by plain triangles (diamicton) or plain circles (sand and gravel). Numbers refer to Table 1 for list of localities.

Table 1. Measured sections and locations described in the text. Numbers are from Figure 6. See end of table for sample data symbols.

Number	Location (Location name)	Author (date)	Sample data*
1	SE1/4, SW1/4, sec. 16, T12S, R23E Johnson County, Kansas (west of Monticello)	O'Connor (1971)	none
2	SW1/4, SE1/4, SE1/4, sec. 10, T12S, R23E Johnson County, Kansas (Clear Creek Area).	this study	none
3	NE1/4, NW1/4, sec. 11, T12S, R23E Johnson County, Kansas (Askhog Gravel Pit).	O'Connor (1971)	none
4	SW1/4, SE1/4, sec. 2, T12S, R23E Johnson County, Kansas (Recreation area).	this study	none
5	NW1/4, SW1/4, sec. 1, T11S, R23E Wyandotte County, Kansas (New Jersey Avenue)	" "	T, C, S
6	center of sec. 35, T10S, R23E Wyandotte County, Kansas (Georgia Avenue)	" "	T, C, S
7	NE1/4, SW1/4, sec. 13, T10S, R23E Wyandotte County, Kansas (I-435 & Wolcott Road)	" "	none
8	SW1/4, SW1/4, SW1/4, sec. 30, T10S, R24E Wyandotte County, Kansas (Leavenworth Road)	" "	C
9	NW1/4, NE1/4, sec. 31, T10S, R24E Wyandotte County, Kansas	" "	none
10	SE1/4, SE1/4, sec. 8, T11S, R24E Wyandotte County, Kansas (south of I-70)	" "	T, C, S,
11	NW1/4, SW1/4, SW1/4, sec. 10, T11S, R24E Wyandotte County, Kansas (stream cut Mill Creek)	" "	C
12	SE1/4, NE1/4, SW1/4, sec. 10, T11S, R24E Wyandotte County, Kansas (I-70 and K-132)	" "	T, C, S
13	NE1/4, SW1/4, SE1/4, sec. 10, T11S, R24E Wyandotte County, Kansas (I-70 and K-132)	" "	P, T, C, S, H
14	NE1/4, NW1/4, NW1/4, sec. 14, T11S, R24E Wyandotte County, Kansas (Ash section)	" "	none
15	NE1/4, NE1/4, NE1/4, sec. 1, T50N, R24E Wyandotte County, Kansas (47th and Parallel Avenue)	" "	P, T, S
16	NE1/4, NW1/4, NW1/4, sec. 9, T11S, R25E Wyandotte County, Kansas (16th and State Avenue)	" "	T, S, H
17	SE1/4, SW1/4, sec. 3, T11S, R25E Wyandotte County, Kansas (6th and Nebraska)	" "	none
18	SE1/4, NE1/4, NE1/4, sec. 10, T11S, R25E Wyandotte County, Kansas (Kansas River Valley)	O'Connor and Fowler (1963)	none

Table 1. (Continued)

19	S1/2, sec. 23, T11S, R25E Jackson County, Missouri (Graystone Heights)	McCourt and others (1917)	none
20	SE1/4, SE1/4, SE1/4, sec. 32, T50N, R33W Jackson County, Missouri (Campell street)	McCourt and others (1917)	none
21	SE1/4, NW1/4, SW1/4, sec. 33, T50N, R33W Jackson County, Missouri (Lydia street)	McCourt and others (1917)	none
22	SE1/4, SW1/4, sec. 3, T49N, R33W Jackson County, Missouri (Galva Creamery)	McCourt and others (1917)	none
23	NW1/4, NE1/4, NW1/4, sec. 36, T50N, R33W Jackson County, Missouri (North Terrace Park)	Davis (1955)	none
24	NE1/4, NE1/4, SE1/4, sec. 5, T50N, R33E Platte County, Missouri (Riverside area)	this study	P, T, C, H, S
25	SE1/4, NE1/4, SW1/4, sec. 3, T50N, R33W Clay County, Missouri (Riverside area)	" "	T, S
26	SW1/4, NE1/4, sec. 34, T51N, R34W Platte County, Missouri (1 mi. west of Parkville)	Davis (1955)	none
27	NE1/4, NE1/4, sec. 9, T51N, R34W Platte County, Missouri (New Hwy 152)	this study	T, C, H, S
28	NE1/4, NE1/4, sec. 9, T51N, R34W Platte County, Missouri (New Hwy 152)	" "	T, C, H, S
29	SW1/4, SW1/4, NE1/4, sec. 10, T51N, R34W Platte County, Missouri (Utica Avenue)	" "	T
30	SW1/4, SW1/4, sec. 36, T52N, R34W Platte County, Missouri (Beatz well)	Davis (1955)	none
31	SW1/4, NE1/4, sec. 10, T51N, R33W Platte County, Missouri (169 Hwy)	this study	T, C, S
32	SE1/4, SE1/4, SW1/4, sec. 16, T52N, R34W Platte County, Missouri	Howe and Heim (1968)	none
33	SE1/4, SE1/4, NE1/4, sec. 5, T52N, R34W Platte County, Missouri (type section for Ferrelview Fm.)	Howe and Heim (1968)	none
34	SW1/4, SE1/4, sec. 3, T52N, R33W Platte County, Missouri (169 Hwy)	this study	T, S
35	NW1/4, sec. 35, T52N, R33W Platte County, Missouri (169 Hwy)	" "	none
36	NW1/4, SW1/4, SW1/4, sec. 18, T51N, R32W Clay County, Missouri (N. Antioch Road)	" "	none
37	SE1/4, SE1/4, SW1/4, sec. 7, T51N, R32W Clay County, Missouri (N. Antioch Road)	" "	T, C, S, H

Table 1. (Continued)

38	SE1/4, SW1/4, NE1/4, sec. 9, T50N, R32W Clay County, Missouri (Randolph Section)	Bayne and others 1971)	none
39	NW1/4, SE1/4, sec. 23, T51N, R31W Clay County, Missouri (Nebo Hill)	" "	P, T, C, S, H
40	NW1/4, SE1/4, sec. 23, T51N, R31W Clay County, Missouri (Nebo Hill)	" "	P, T, C, S, H
41	SE1/4, SW1/4, sec. 13, T51N, R31W Clay county, Missouri (Missouri Rock Quarry)	" "	none
42	NW1/4, NE1/4 sec. 18, T51N, R30W Clay County, Missouri (Highway EE)	" "	T, C, S, H

* Symbols for sample data: paleomagnetism sample (P), grain size analysis of till matrix (T), pebble count of 4-8mm fraction (C), susceptibility analysis (S), heavy mineral analysis (H).

use a nongenetic term until depositional processes can be more specifically identified. In the past, reports have described "boulder clays" or "tills" without citing any evidence for this interpretation. The result is that later researchers must either trust the interpretation on the reputation of the observer, or discount the information entirely. Most of these deposits probably are true tills, but there is the possibility that colluvium, debris flow material, or highly weathered outwash has been described as "till" thereby leading subsequent workers to erroneous conclusions.

The term pre-Illinoian is used to describe deposits older than late middle Pleistocene (Hallberg, 1986; Richmond and Fullerton, 1986). According to Richmond and Fullerton (1986), Illinoian glacial deposits in their type region were deposited during the late middle Pleistocene, an arbitrary time division defined as 302 ka to 132 ka. Upper and lower boundaries of this time division are based on oxygen isotope stage boundaries.

The descriptive lithofacies code adopted to describe deposits is based on that of Eyles and others (1983) and Miall (1978). Each facies is designated by three letters that describe aspects of the sediment body (Table 2). The first letter is capitalized and represents the predominant texture of the deposit as gravel (G), diamicton (D), sand (S), or fines (F). The second letter in the code refers to internal sedimentary structures, such as massive bedding (m), crossbedding (x), laminations (l), or graded bedding (g). The last letter indicates an interpretation of the processes involved in deposition or subsequent alteration. Examples include sheared (s), resedimented (r), or pedogenically altered (p) sediments. The last letter in the code is indicated as an interpretation by being set in parentheses. For example, a matrix supported, massive and sheared diamicton with oriented wedge-shaped and striated clasts would be indicated as Dm (s). Subsequently this facies, together with other supporting information such as bed contacts and facies association could be interpreted as basal till. Figure 7 lists the symbols used in stratigraphic sections.

Table 2. Lithofacies codes and description of sedimentary characteristics.

Code	Lithofacies	Description
Dm	Diamicton, massive	Homogenous, matrix-supported; very poorly sorted mixture of sand, silt, clay, and gravel. Striated and wedge-shaped clasts and boulder pavements. Lower contact usually erosive.
Dm (s)	Diamicton, massive sheared	Dm with evidence of glacial shear; bedding plane shears, rafting and deformation of underlying material. S-shaped sand wedges, smudged out clasts.
Dm (r)	Diamicton, massive resedimented	Dm with evidence of resedimentation; interbedded diamicton with sorted sand and gravel. Inverse graded beds, subhorizontal to inclined beds. Fine scale textural variability such as silt and clay stringers, and flow noses.
Dm (d)	Diamicton, massive deformed	Dm with evidence of soft-sediment deformation, loaded contacts, and diapiric structures.
Dm (p)	Diamicton, massive pedogenetically altered	Dm with evidence of pedogenesis, e.g., soil horizons and mineral alteration.
Ds	Diamicton, stratified	Matrix supported with pronounced stratification. textural differentiation or structure within diamicton.
Dg	Diamicton, graded	Diamicton with clasts normally graded
Fm	Clay and silt massive	Clast poor fines
Fmd	Clay and silt massive, diamictic	Fm with dispersed clasts
Fmo	Clay and silt massive, organic	Fm with organic matter
F1	Clay and silt laminated	Alternating fine sand, silt, and clay
F1 (d)	Clay and silt stratified and deformed	F1 with evidence of deformation
Fm (p)	Clay and silt pedogenesis	Fm pedogenetically altered.

Table 2. continued

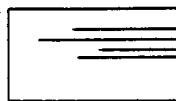
Code	Lithofacies	Description
Sh	Sand, horizontal laminations	Stratified normally bedded
Sx	Sand, crossbedded	Planar and trough cross bedded medium to coarse sand
Sr	Sand, rippled	Ripple drift cross-lamination
Sm	Sand, massive	Silty fine massive sand may have occasional oversized clasts.
S (s)	Sand, sheared	S with evidence of shearing
Sm (p)	Sand, pedogenesis	Massive silty fine sand pedogenetically altered.
Gc	Gravel, massive	Massive clast supported gravel
Gm	Gravel, massive	Massive matrix supported gravel
Gh	Gravel, crudely bedded	Crude horizontal bedding
Gg	Gravel, graded	Both normally and inversely graded gravels.
Gp	Gravel, planar bedded	Planar bedded gravel.

Figure 7. Graphic symbols used in measured sections.

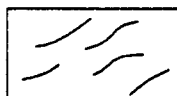
Diamicton:



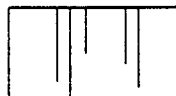
size of symbol is proportional to clast size



sheared

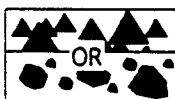


stratified

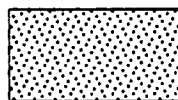


jointed

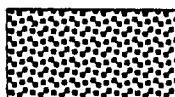
Gravel, sand, and fines:



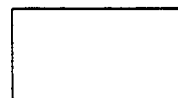
cobble and boulder gravel (size of symbol is proportional to clast size)



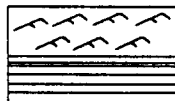
sand



pebble gravel



fines or massive

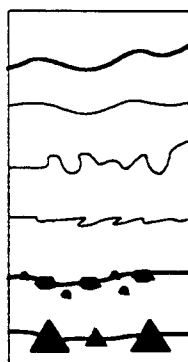


ripples
planar beds



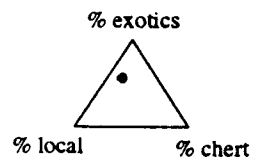
trough crossbeds
planar crossbeds

Contacts:



erosional
conformable (gradational)
loaded
interbedded
residual stone line
boulder pavement

Pebble lithology:



Directional data:



Bedrock stratigraphy

Bedrock underlying the study area consists of Upper Pennsylvanian cyclic carbonates and interbedded siliciclastics of Missourian and Virgilian Age. Units of the Pleasanton, Kansas City, Lansing, and Douglas Groups are present (Figure 8). Units are generally flat lying with gentle dips to the northwest of 10 to 20 feet per mile. The strike of beds is approximately northeast. Gentle folding as well as minor faulting is present locally.

The oldest rocks exposed in the study area are part of the Pleasanton Group. Micaceous sandstones, siltstones, and shales make up the bulk of these rocks. Pleasanton Group rocks crop out in the extreme eastern portion of the study area. Thick limestones of the Kansas City Group form prominent eastward facing escarpments in the central portion of the area. In east Kansas City, Missouri the Swope and Dennis Formations cap most of the higher elevations. In downtown Kansas City, Missouri and Kansas City, Kansas the Wyandotte Formation forms a resistant bedrock cap of the higher hills. North and west of Kansas City, Missouri a southwest trending channel fill sandstone, the Tonganoxie member of the Stranger Formation, unconformably overlies Lansing Group units and caps most of the higher uplands.

Bedrock topography

Interpretive maps of the bedrock topography of northeastern Kansas and northwestern Missouri have been created from drilling and outcrop data by several authors (Hinds and Greene, 1917; Davis, 1955; Heim and Howe, 1962, 1963; O'Connor and Fowler, 1963; Dreezan and Burchett, 1971; Sims, 1975). Dreezan and Burchett's map is the most recent compilation of data. They interpreted their map as a composite of Tertiary and Pleistocene drainage systems. Bedrock valleys in general trend to the east (Figure 9) and commonly are filled with preglacial chert gravels and glacial drift (Hinds and Greene, 1917; Frye and Leonard, 1952; Heim and Howe, 1962; Dreezan and Burchett, 1971). The modern

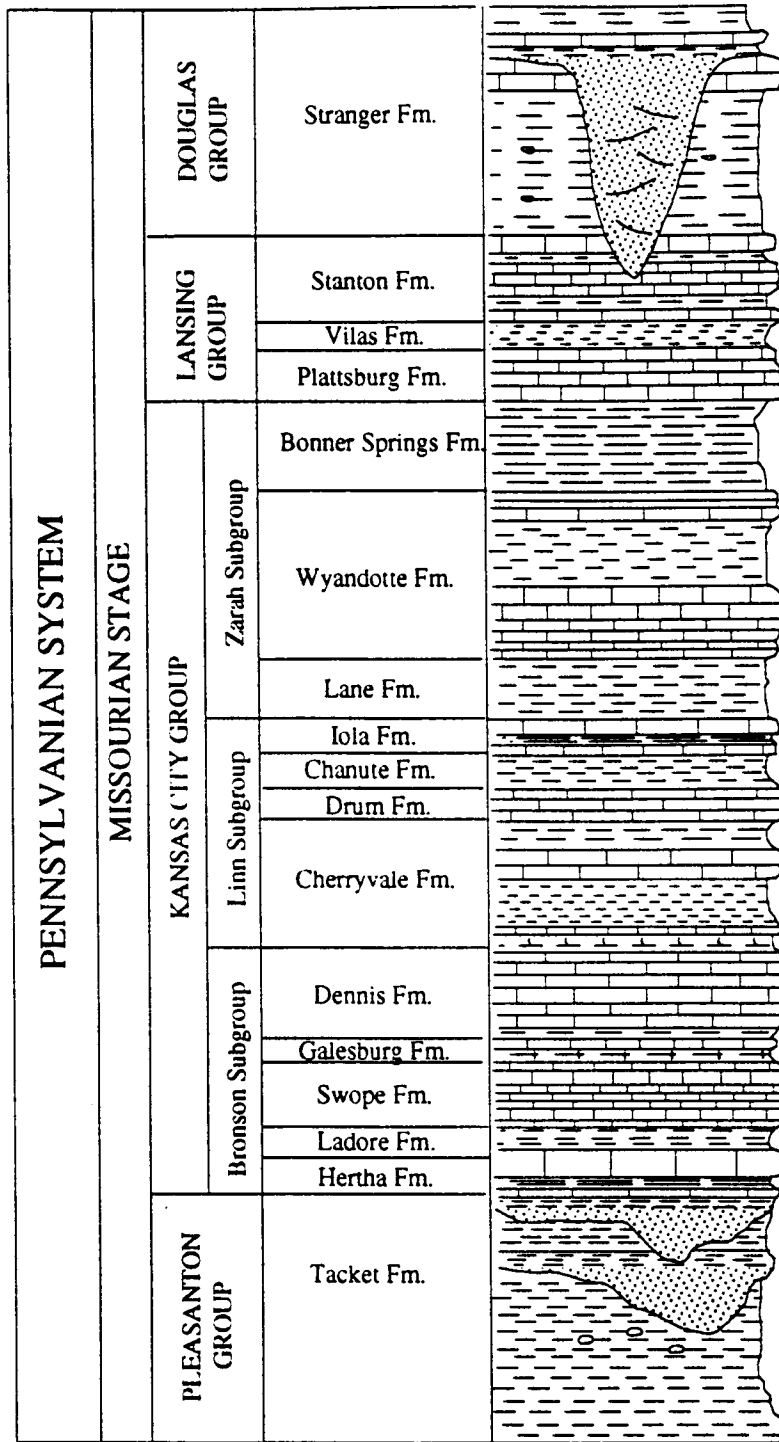


Figure 8. Geologic column of bedrock exposed in Kansas City Area
 Modified after Howe (1961) and Zeller (1968).

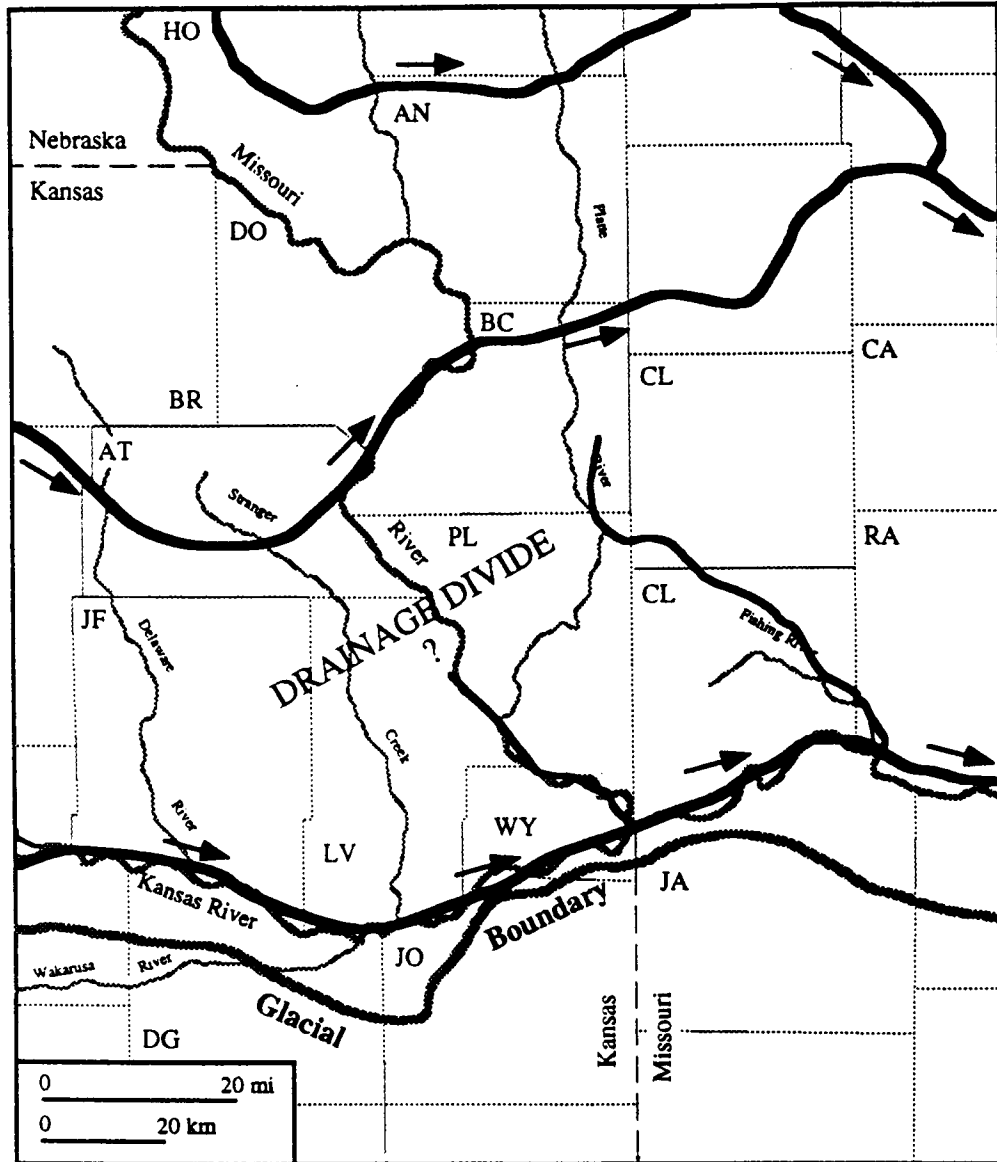


Figure 9. Major preglacial drainage (dark heavy lines) in northeastern Kansas and northwestern Missouri. (after Dreezan and Burchett, 1971).

Missouri River segment between Atchison, Kansas and Kansas City is interpreted as a tributary to the ancient Kansas River Valley.

Bedrock topography within the study area is highly irregular and made up of buried and partially exhumed valleys. Drilling data provided by the Kansas Department of Transportation indicates that depth to bedrock along Interstate Highway 70 from Kansas City, Kansas west to the Wyandotte County line is highly variable. In downtown Kansas City, Kansas and Kansas City, Missouri buried bedrock valleys are also present. Drift thickness filling the Turkey Creek valley south of downtown Kansas City, Missouri is reported as 73 meters (242 feet) thick (McCourt and others, 1917). O'Connor and Fowler also (1963) report 46 meters (150 feet) of "Kansan till" below the Kansas River in a buried bedrock valley (Figure 6, # 18). The majority of overburden covering the area is Illinoian and Wisconsin loess, colluvium and alluvium, but an appreciable thickness of drift is present in buried valleys and on undissected upland divides. The thickest exposures of drift within the study area were found in partially exhumed buried valleys.

Preglacial chert gravels

Previous workers have described chert gravels found in upland locations of eastern Kansas (Frye and Leonard, 1952; O'Connor, 1960; 1971; Aber, 1985b). These gravels are thought to be remnants of stream terraces deposited during Tertiary to early Pleistocene time. The chert is thought to be derived from Pennsylvanian and Permian limestones in the Flint Hills region. Most of this gravel is a brown to reddish brown chert (>95%). Sandstone clasts and a few resistant pebbles of quartzite, which may have a western source (Aber, 1985b) are also present.

Gravels similar to those previously described as upland gravels were not found in the study area. Drift does contain a significant and always present, percentage of brown chert. It is thought that this chert was incorporated into drift as glacier ice entered the area, destroying the pre-existing drainage pattern. Some chert may also be derived from local limestones.

Lithofacies associations

Pleistocene deposits in the study area are described using a lithofacies approach. The lithofacies are grouped into distinctive lithofacies associations (Table 3). These associations are thought to be the product of specific depositional processes that have been observed in modern glacial depositional environments (Boulton and Deynoux, 1981; Eyles et al., 1983). Facies associations are designated by a capital letter. Facies associations observed in the study area will be briefly described and an interpretation of their origin discussed. Later field descriptions will refer to these associations. Facies associations were modified from those used by Johnson and Hansel (1990) to describe similar glacial sequences in central Illinois.

Association A: Massive and bedded gravel

Gravel lithofacies of dominantly cobbles and small boulders, interbedded with pebbly sands make up this association (Figure 10, Gc, Gh, Gp, Sx). Generally beds are crudely bedded (Gh) to massively bedded (Gc). Well developed pebble foreset beds (Gp) and crossbedded sands (Sx) occur as minor elements. Most lower contacts are erosional with Association A overlying bedrock or unconsolidated deposits. Sediment often fills deep, narrow channels. Upper contacts may be sharp when overlain by diamicton or gradational if overlain by bedded sand (Association B) and diamicton facies (Associations C, D, E). Most of the pebble size and larger material consists of locally derived clasts of limestone, shale, sandstone, and chert, but a significant percentage is of non-local origin.

Association A is interpreted as the product of high energy, unsteady, streamflow processes in a glaciofluvial environment. Overall coarse grain size, poor sorting, lack of fines, and rapid lithofacies transitions indicate deposition in an high energy, environment of rapidly changing flow conditions. These processes and lithofacies are common in glaciofluvial environments (Church and Gilbert, 1975; Banerjee and McDonald, 1975; Rust and Romanelli, 1975). A proglacial outwash plain, subglacial tunnel valley, or proglacial lake flood spillway are possible depositional environments.

Table 3. Lithofacies associations and interpretation of dominant processes and depositional environments.

Facies Association	Lithofacies	Dominant Processes	Interpretation of Glacial Environment
A	major: Gc, Gh, Gp minor: Sx	high discharge rapidly fluctuating streamflow	proglacial braided streams, catastrophic lake flood, or subglacial tunnel valley
B	major: Sx, Sm, Sr, Sh minor: Gp, Gg	steady unidirectional streamflow	proglacial braided streams and lacustrine environments
C	major: Dm, Dm (s), Dm (d) minor: Sm, S (s),	high basal shear with incorporation of frozen unconsolidated sediments, ductile and brittle deformation	glacially deformed lodgment till, proglacial sediments and bedrock
D	major: Dm, Dm (s), Dm (p) minor: Sm, Sx, Sr	High basal shear ductile and brittle deformation	subglacial lodgment till with minor subglacial channel fills
E	major: Dm, Dm (s), Dm (r), Dm (p) minor: Sx, Sm, Gp	soft sediment deformation reworking and sorting of sediment	meltout till and reworked, resedimented till (flow till)
F	major: Fm, Fl, Fm (p), Fmd minor: Sm, Sh	rainout in standing water	proglacial lakes and shallow till plain depressions
G	major: Fm, Fl, Fm (p) minor: Sh, Fmo	eolian fallout and sheetwash	loess and reworked loess in valley fills



Figure 10. Example of massive and bedded gravel lithofacies and interbedded crossbedded sand lithofacies (Gc, Gh, Gp, Sx). From Leavenworth Road exposure (Figure 6, # 8).

Association B: Massive and bedded sand

This facies association contains coarse to fine, sometimes pebbly, quartzose sand (Sx, Sr, and Sh) with erratic pebbles (Figure 11). Small lenticular bodies of pebble gravel (Gp) may also be present in channel scours within this facies. This facies association usually forms tabular or lenticular bodies, one to three meters thick and tens to hundreds of meters long. Individual sets of planar and trough crossbeds in medium to coarse sand (Sx) are tens of centimeters in thickness. Fine sand ripple-drift cross laminations (Sr) and horizontal laminations (Sh) are centimeter-scale features in beds tens of centimeters thick. Weathering and oxidation have altered this facies with hematite and goethite cements commonly present. Most basal contacts are erosional but may be loaded if they overlie diamicton. Association B is commonly found underlying or interbedded with diamicton facies (Association C, D, and E). Upper contacts with diamicton or silt may be erosional, or loaded.

Association B is interpreted to be the result of fluvial processes. Crossbedding, ripples, and good sorting indicate that these sediments were deposited by steady, unidirectional currents as bedload. Trough and planar crossbeds in shallow wide channels, in association with basal till suggest an ice contact, proglacial braided stream, or proglacial lacustrine delta environment (Church and Gilbert, 1975; Boulton and Deynoux, 1981).

Association C: Deformed diamicton

Association C contains massive (Dm) and sheared (Dm (s)) diamicton containing large (meter scale) bedrock rafts and incorporated blocks of sand, silt, and clay mixed in a sometimes complex, seemingly chaotic arrangement (Figure 12). Most bedrock rafts are somewhat rounded and float in diamicton. Blocks of sorted sediment have sharp outlines and appear to have been competent clasts when incorporated. Some inclusions of sand and silt are fractured indicating brittle failure. Shear planes are often present in enclosing diamicton. This association where observed rests unconformably on bedrock or has gradational upper contacts with Association D.



Figure 11. Bedded sand lithofacies (Sx) exposed during construction of a retaining wall along State Avenue in Kansas City, Kansas (Figure 6, # 16).

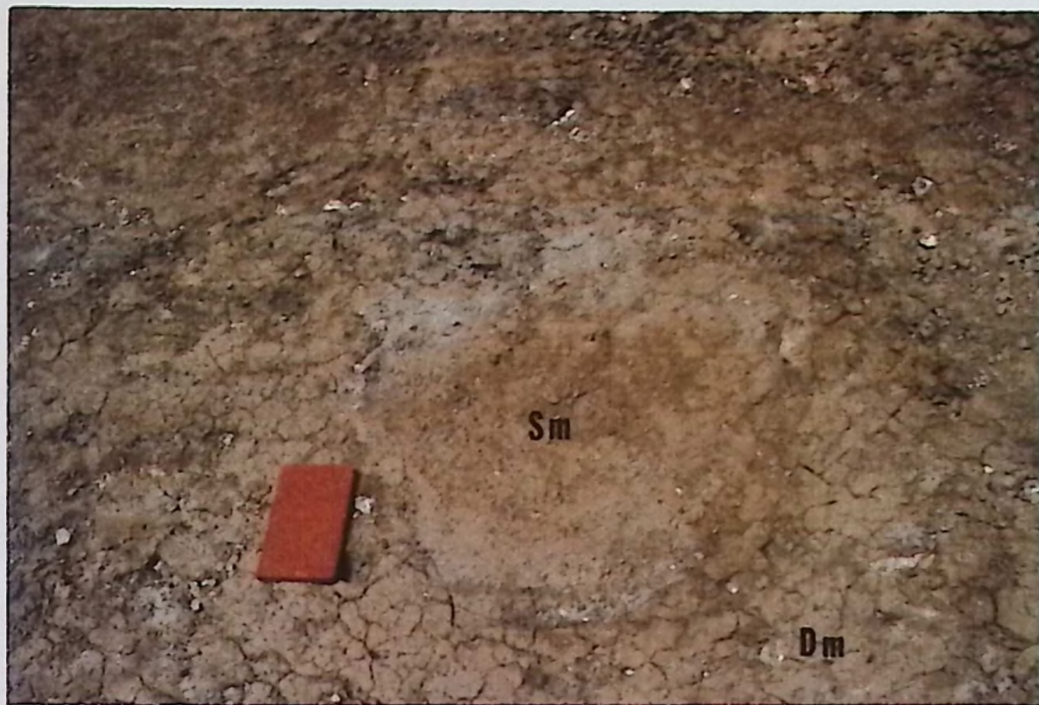


Figure 12. Deformed diamictite facies (Facies C). (A). Example of a large inclusion of pebbly sand (possibly proglacial outwash). Large blocks (> 1 m) of outwash and bedrock were observed in diamictite overlying Tonganoxie sandstone along Highway 169 in Platte County, Missouri (Figure 6, # 34). (B). Chaotically deformed diamictite, silt, and sand exposed in excavation along Highway 152. Note light colored clasts are fine silty sand, light reddish brown is diamictite with contorted small sand lenses.

Association C is interpreted to be glacially deformed outwash mixed with basal till. Shear structures and large clasts of unconsolidated sediment suggest that much of this material was redeposited as frozen blocks. Sheared and folded sediment suggests that a combination of ductile and brittle deformation occurred during deposition. This facies association may represent proglacially thrust sediments subsequently overridden by glacier ice in the marginal zone (Boulton and Deynoux, 1981).

Association D: Massive diamicton

Association D consists of primarily massive (Dm) and sheared (Dm (s)) diamicton (Figure 13). Few sedimentary structures are present except subhorizontal fractures, smudged out clasts, and a well oriented, parallel clast fabric. Wedge-shaped and striated clasts are also commonly present. Diamicton in this association is rich in fine matrix (<60%), contains less than 10% clasts larger than pebble size, and is usually dense and overconsolidated. Vertical to subvertical joints are always present extending down from the upper surface (Figure 13). Lower contacts are usually sharp and may show signs of incorporation of underlying bedrock and unconsolidated deposits. Streamlined boulders and boulder pavements are also present. This association may rest on striated bedrock or on a boulder pavement surface. Close examination of this facies sometimes reveals faint, millimeter scale, subhorizontal stratification and banding unrelated to textural differences. Association D usually overlies Association A, B, or C. It usually underlies Associations B, F or G.

Association D is interpreted as subglacial till deposited at the base of a continental glacier. Orientated fabric, wedge-shaped striated clasts, shear structures and overconsolidation are common features of subglacial till (Boulton and Deynoux, 1981; Eyles et al., 1983).

Association E: Diamicton and intercalated sorted sediment

Association E consists of well sorted sand (Sm) and silt (Fm) in centimeter-scale lenses intercalated with diamicton (Figure 14, Dm, Dm(s), Dm (p)). Sorted sediments occur in subhorizontal



Figure 13. Massive diamicton. (A). Vertical, calcite filled joints exposed along Highway 1-69 in Platte County, Missouri. (B). Closeup of joints exposed along Smithville Lake in Clay County, Missouri. Note distinctive coloration of oxidized zones bordering joints. Penknife for scale is 5 cm long.

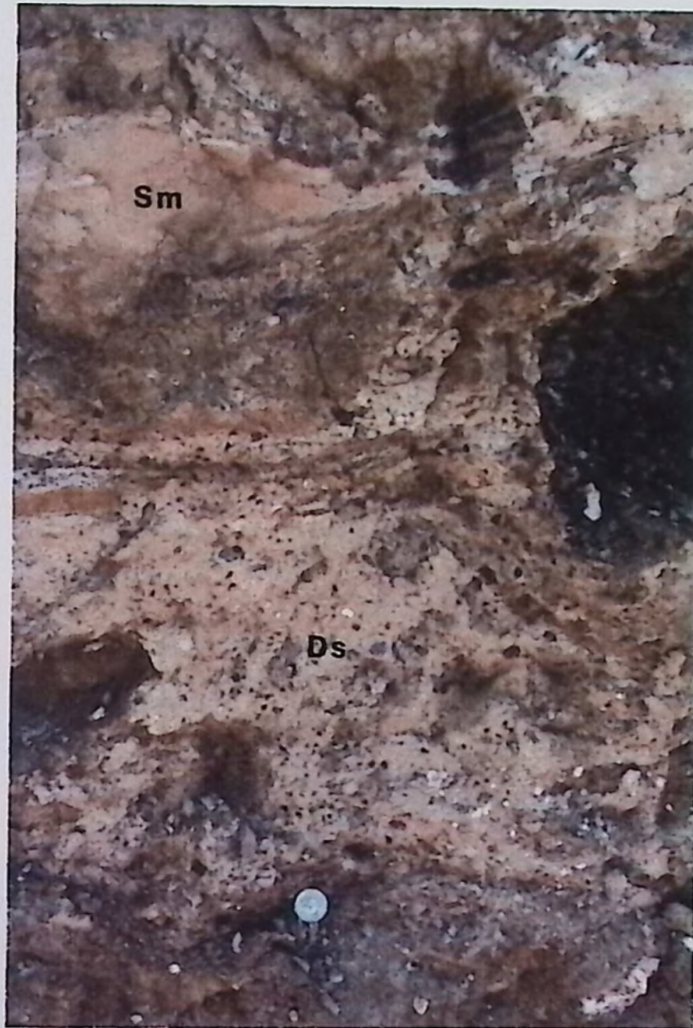


Figure 14. Diamicton and interbedded sorted sediment (Association E). Note how stratification is displaced by weathered boulder.

lenses and beds, centimeters to meters long. Contacts between sorted sediment and diamicton are sharp, but commonly show loading with clay intruded into sand. Sorted sediments show crossbedding only rarely. Diamicton may or may not show signs of shearing. Diamicton commonly has few cobble and pebble sized clasts, or has a greater concentration of pebbles than is normal for till facies. Upper and lower contacts of this facies are commonly sharp. Association E is usually found underlying Association B, F, or G and overlying Association D.

Association E is interpreted as a combination of both meltout till and resedimented till (Boulton and Deynoux, 1981). The interbedding of diamicton with sorted sediments and load structures indicates that sediments had a high water content and low shear strength when deposited. Basal till usually is overconsolidated and has a well defined clast fabric. Lack of larger cobbles and boulders, or anomalously high pebble content, indicate that facies in this association have been partially reworked by water and resedimented (Boulton and Deynoux, 1981). Facies in this association probably represent a gradation between meltout till and resedimented till. The depositional environment was probably the ice marginal zone where meltwater was abundant and water saturated, meltout till could be deposited and reworked in sediment gravity flows and slumps.

Association F: Massive clay

Association F is a massive, slightly pebbly, light gray, sandy silt to silty clay (Fm, Fmd, Fm (p)). Clayey silt facies are extremely plastic when wet and upon drying, extremely hard. Small well rounded pebbles of resistant rock types such as quartz, quartzite, and chert are found widely dispersed in this facies. Rarely, cobbles and even small boulders are found in this facies. Association F is only found overlying diamicton (Association C, D, or E). Lower contacts are usually gradational, but may also be erosional. Few sedimentary structures besides faint millimeter scale laminations are present (Fml). Fine silt and sand layers are present but uncommon. The upper contact is usually gradational into massive or laminated silt facies (Association G), or truncated by a paleosol. Pedogenic alteration is common in most exposures. Well developed blocky peds, clay skins, mangans,

slickenside surfaces, iron and manganese glauconites, and carbonate nodules are present in these pedogenically altered facies (Fm (p)). Additionally, this association is found in upland sites at elevations of 980 feet or greater.

Association F deposits settled out of suspended load in a body of water. The generally fine silt and clay size and lack of pebbles and cobbles requires quiet water for deposition perhaps in small lakes or low lying areas. Slope wash and perhaps ice rafting may have introduced coarser material into facies in this association. The great local thickness (> 3 meters), sharp basal contacts, and general lack of cobbles and boulders argues against it being a pedogenic alteration of diamicton in place. Because of the generally massive nature of facies in this association, interpretation of depositional environment is difficult, but probably includes lacustrine, and colluvial environments (see Howe and Heim, 1963)

Association G Massive and laminated silt

This facies association consists of massive, laminated, or diamictic silts (Fm, Fl, Fmd), normally resting unconformably over all other facies. Massive exposures are well sorted coarse silt that has well developed vertical joints. Various degrees of pedogenic alteration have occurred.

This facies is interpreted as loess or reworked loess. Excellent sorting, massive structure, and areal extent blanketing the topography indicate an eolian origin for most of these sediments. Lamination and interbedded, sorted fine sand suggest that some of this silt is reworked loess deposited as valley filling sediment or colluvium.

Proglacial chert and limestone gravel

In several exposures a predominantly limestone, shale, and chert gravel (Association A) was observed. This type of gravel has also been described by Todd (1896), Hinds and Greene (1917), McCourt and others (1917), Davis (1955), and O'Connor (1971) as being present in the Kansas City area. Bayne (1968), Conrad (1964), Dort (1965), and Aber (1991) have also reported similar gravels in northeastern Kansas.

Previous reports have interpreted this material as proglacial outwash (McCourt and others, 1917; Frye and Leonard, 1952; Davis 1955), buried valley fills (Hinds and Greene, 1917), ice contact deposits (O'Connor, 1971), catastrophic lake flood deposits (Aber, 1991) and separate glacial advances (Dort, 1965). The gravel observed by the writer is interpreted as a combination of proglacial outwash, ice contact deposits and catastrophic lake flood gravels deposited during ice advance. This interpretation is supported by stratigraphic position, grain size, abrupt lithofacies transitions, lithology, and channel geometry.

Road improvements made in the summer of 1990 uncovered an excellent exposure of this type of gravel (Association A), bedded sands (Association B) and weathered diamicton in north-central Wyandotte County, Kansas. The exposure is located on the northeast corner of Leavenworth Road and 91st Street (Figure 6, # 8).

The most common lithofacies present in the exposure (Figures 15, 16 and 17) is massive (Gc) to crudely stratified (Gh) clast supported gravel. There is a small percentage of sand in the matrix and some finer material that may be authigenic clay formed from the breakdown of clasts and weathering of the overlying diamicton (Dm (p)). In many places, especially around large boulders, cobbles and pebbles are well cemented with calcite and iron.

The largest boulders in the exposure are up to 2 meters in longest dimension with most between 1 and 2 meters. One sandstone boulder is approximately 3 meters in longest dimension. Most boulders are subrounded to well rounded. All of the largest boulders are of local rock types. Lithology, fossils, and sedimentary structures observed within the boulders indicate they are derived from Stanton, Vilas, and Stranger Formations, which crop out nearby. Northern erratics of boulder size are not present. Cobbles are also of mostly local lithologies, but northern erratics are present in a small percentage (<5%). Cobbles are mainly subrounded to well rounded, generally more rounded than boulders. Most erratic cobbles are granite, metagraywacke, and other metamorphic rocks. White, pink, and red granite varieties are the most common erratics, but no cobbles of Sioux Quartzite are present within this facies.



Figure 15. (A) Photo of central part of Leavenworth Road exposure. Note large channel form and foreset beds developed in center of exposure. (B). Closeup of limestone, shale, and chert dominated, clast supported gravel. Large shale clast (lower left) is 6 cm long.

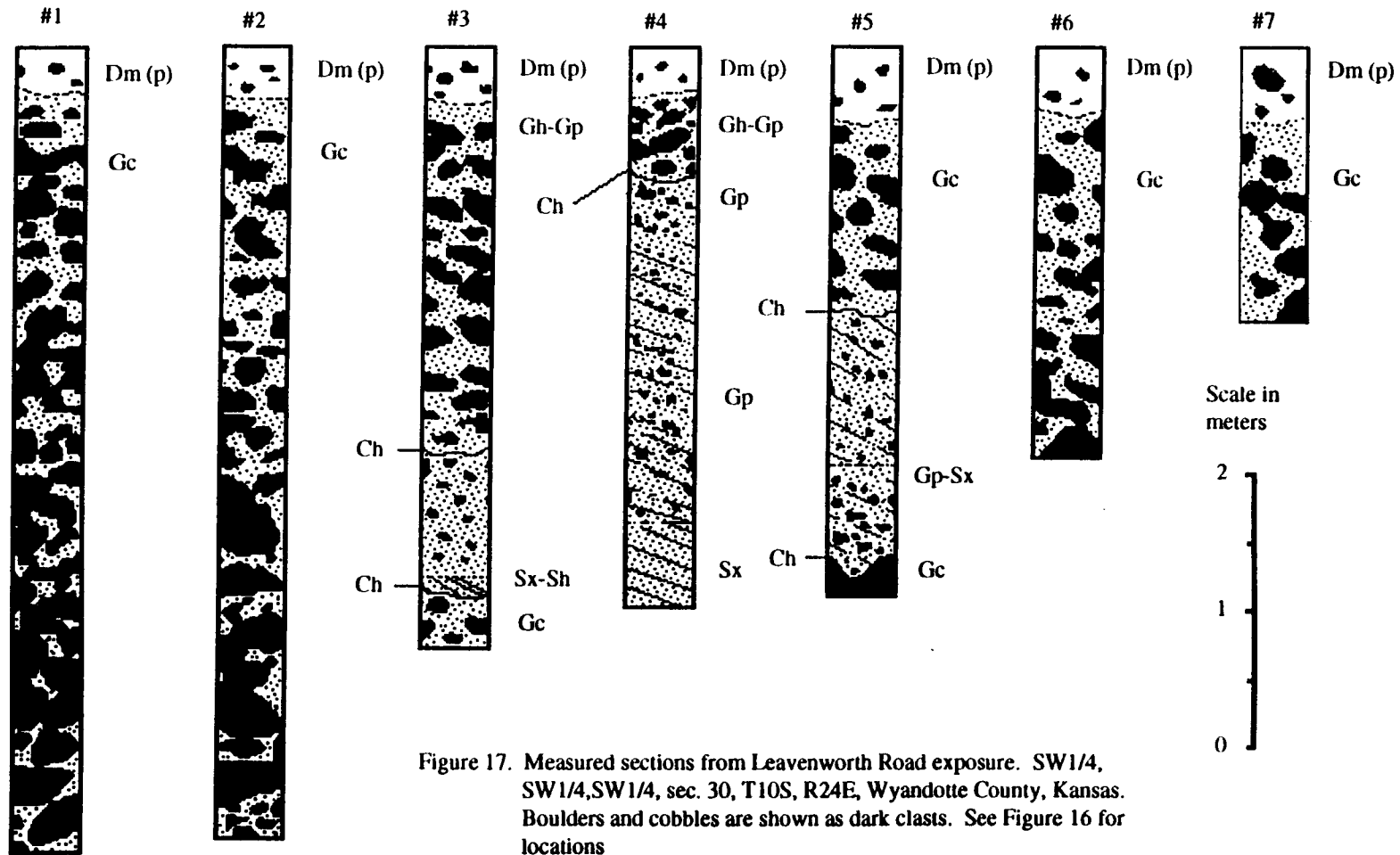


Figure 17. Measured sections from Leavenworth Road exposure. SW1/4, SW1/4, SW1/4, sec. 30, T10S, R24E, Wyandotte County, Kansas. Boulders and cobbles are shown as dark clasts. See Figure 16 for locations

Few sedimentary structures are visible in the Gc facies except for the imbrication of larger clasts. Only in thinner cobble-dominated beds (sections 3, 4, 5), is crude stratification present. Some boulders and cobbles show percussion marks and a few are broken in place, having fractures filled in with a pebbly and granular matrix.

A stratified planar crossbedded gravel (Gp) facies occurs within a channel form above a sharp scoured contact in sections 3, 4, and 5 (Figure 17). Clasts are largely (50-95%) pebble sized. The main lithologies present are limestone, shale, sandstone, (71.7%), and chert (13.0%). Erratics make up 15.3% of the small pebble fraction. Planar crossbedding with dips of between 10-30 degrees in a generally east to southeast direction is present. Set thickness is 1-2 meters. Pebble banding in crossbeds is also present. This facies is truncated by Gc and Gh facies in sections 3, 4, and 5.

Light yellow brown to dark reddish brown, planar crossbedded, medium to coarse pebbly sands (Sx and Gp) lying above a sharp scoured contact are present near the middle of the exposure. Foreset crossbed thickness is between 0.5 and 1 meter and dip to the south and southeast. Pebble lithologies are the same as in the Gp facies. Most of the sand size material is angular to subrounded quartz and feldspar. Rock fragments of limestone, shale, sandstone, and chert in sand, granule and pebble size also make up a large percentage of the material. Iron cement coats most grains.

In sections 3 and 4, light yellowish brown to dark reddish brown, fine silty massive to laminated sand (Sm to Sh) with a few pebbles is present. The fine sand is well sorted and mostly quartz. Quartz grains are mainly angular to subrounded with a large percentage of silt. In a few places it is well cemented with iron, forming dark brown and light yellow bands. The only sedimentary structures in this facies are laminations and a few small scale ripples. The relation of this facies to others could not be determined precisely because of poor exposure, but it lies below Sp and Gp facies and above or resting upon a scoured contact. In a few places this facies is found included within Gc facies with laminations at odd or vertical angles.

Lying above and truncating gravel facies Gp and Gc is a poorly sorted, dark reddish brown matrix-supported diamicton (Dm). Most cobbles and pebbles included are of resistant rock types such

as quartzite, chert, granite, dark igneous and metamorphic rocks. Some boulders of limestone, sandstone, and shale are present but are weathered.

The only vertical sequence trend in the exposure is a generally coarsening upward sequence. At the sequence base a scoured contact is cut into Gc facies. Filling this is a fine sand (Sh), (Sm) or (Sx) or well cemented gravel lag (Gc) followed by medium to coarse, planar crossbedded sand (Sx) grading into planar crossbedded gravels (Gp) and unstratified gravel (Gc) commonly truncated by another scour surface with Gc facies filling a channel. Above all facies and with an abrupt contact is the diamicton facies (Dm (p)). Lateral relationships show a major channel form (Ch) and fill sequence (Sm, Sh, Sx, Gp) in the center of the exposure bounded on either side by crudely stratified or massive gravels (Gh, Gc).

Drilling records show that gravel and sand fill a narrow channel approximately 100 meters wide and 10 or more meters deep (Figure 18). At the western end of the outcrop, bedrock of Stanton Limestone and Vilas Shale are in place. To the east borings show that removal of the Stanton Limestone has occurred and a channel is filled with many large boulders, cobbles, and sand. South of the exposure cobbles and boulders crop out. Additionally limestone cobbles mixed with erratics are found a half a mile north of the exposure near the entrance of Wyandotte County Park and near the intersection of Wolcott road and I-435 about 2 miles to the north (Figure 6, # 7).

The sedimentary structures and facies in this exposure indicate that it was deposited in an environment of high energy and rapidly fluctuating flow. Massive to crudely stratified gravel facies Gc and Gh were probably deposited as bed load in peak to waning flow discharge caused perhaps by a catastrophic proglacial lake flood cutting a channel through a drainage divide or previously deposited outwash. Facies of stratified gravel Gp and sand Sx are the product of waning flow, reworking and deposition between coarse interchannel bars. The gravel facies are covered by a weathered and leached diamicton (Dm (p)) containing a large proportion of Sioux Quartzite and other erratics. This may be the weathered residue of drift that is present in outcrops nearby (Figure 6, # 9).

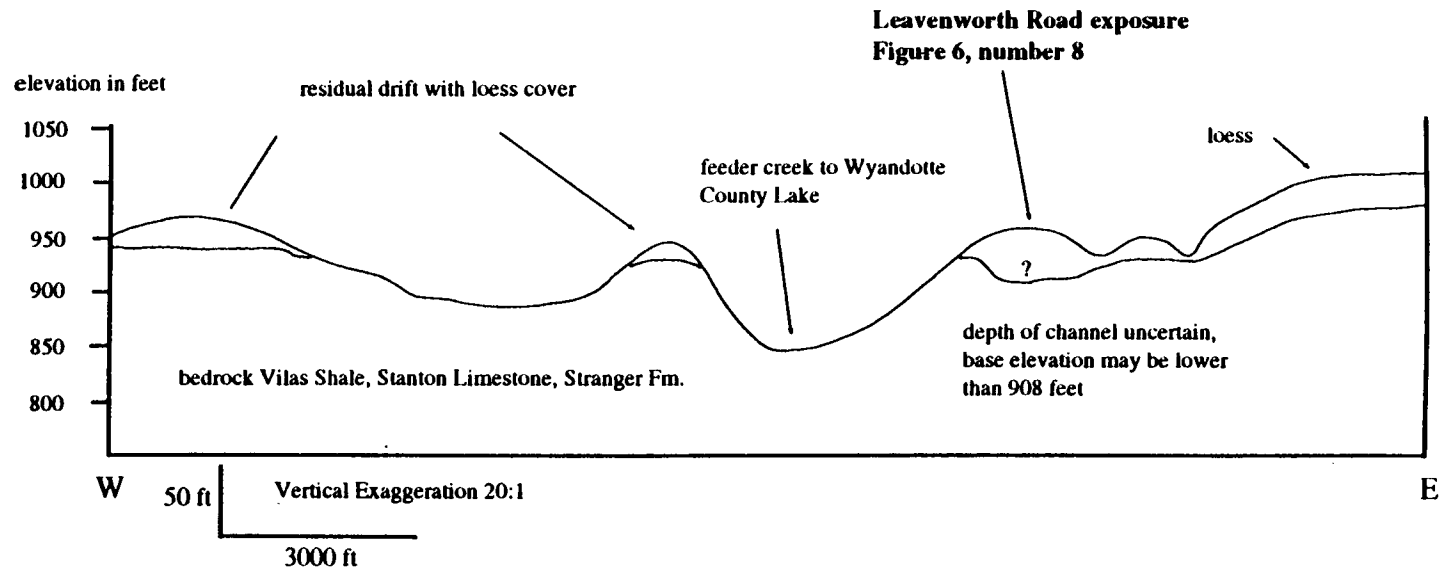


Figure 18. East-west cross section of along Leavenworth Road between Interstate I-435 and 87th Street. Cross section follows southern boundaries of T10S, R23E and T10S R24E (see Figure 6).

Gravel in this exposure is similar to sands and gravels previously described by O'Connor (1960, 1971) in Douglas County and northern Johnson County, Kansas. The writer visited the sections exposed near Askhog gravel pit (Figure 6, # 3) that O'Connor described (1971, p. 30). In this gravel pit, large foreset beds (3-5 m thick) are present. O'Connor also described a channel cut through bedrock and filled with boulders and cobbles west of Monticello (Figure 6, #1). Planar and trough crossbedded gravels and sand are exposed north of Monticello along Clear Creek (Figure 6, # 2). Sand, gravel, and overlying silt are presently exposed in an excavation near Johnson County Recreational Area (Figure 6, # 4)). In both of these exposures a sandy gravel is present containing clasts of mostly limestone and shale (80%), chert (15%), and a few erratics (5%). The main sedimentary structures are crudely to planar bedded gravels (Gc to Gp), planar and trough crossbedded sand (Sx), laminated silt (Fl) and sand (Sl).

Newell (1935) also reported valley-filling sand and gravel as thick as 24 meters near Holiday, Kansas. These deposits and those described by O'Connor (1971) are part of numerous east-west trending ice contact gravels found between Lawrence, Kansas and Kansas City, Missouri (O'Connor, 1971). The gravels seen by the writer in the Clear Creek area have the same pebble lithology and sedimentary facies as those seen in the Leavenworth Road exposure.

McCourt and Albertson (1917) also described similar deposits south of the Kansas River Valley in the Graystone Heights area of Kansas City (Figure 6, # 19) and in the buried Turkey Creek Valley south of downtown Kansas City, Missouri (Figure 6 # 22). Additionally, gravels dominated by local lithologies are found in a buried valley near Lake City east of Kansas City (Greene, 1921). In Graystone Heights the gravels fill a bedrock channel cut into the divide between Kansas River and Turkey Creek drainages. A photo included in McCourt (1917, p. 68) shows massive to crudely stratified gravel in which imbrication of boulders and vague foreset bedding are present.

All of these gravels have similar lithologies, including a low but significant percentage of northern erratics. Most gravels fill depressions or narrow channels cut into bedrock. Most channels have an east to southeast orientation. Presumably most of the material filling the channel was eroded

from the channel directly upstream. The writer has also observed this type of gravel filling a east trending bedrock channel south of Weston Missouri in an abandoned quarry (SE1/4, NW1/4, Sec. 30 T53N,R35W, Tracy, Missouri, Quadrangle). Todd (1896), and Hinds and Greene (1917) describe several exposures of this type of gravel in east-trending channels between Weston, Missouri and Smithville, Missouri. Similar gravels have been described in northeastern Kansas between St Joseph, Missouri and Atchison, Kansas (Conrad, 1964). Conrad concluded that chert gravels were conformable with "Nebraskan" till. In general, deposits in Conrad's study area contain more chert (about 50%) but probably have a similar origin.

It is likely that these gravels have multiple origins and were deposited at various times, but they all are probably related to initial ice advance because they share common stratigraphic position, lithology, lithofacies, and channel geometry. Local dominated gravels (Association A) are interpreted as a combination of ice contact gravels, proglacial outwash, and catastrophic lake flood deposits. The incorporation of significant numbers of northern erratics distinguishes these deposits from preglacial chert gravels, some of which contain a small (1-3%) percentage of quartzite pebbles derived from a western source (Aber, 1985). The great variability of lithofacies, grain sizes present, and large boulders indicate that these gravels were deposited in high discharge and variable flow environment. This precludes the possibility that they are preglacial stream deposits, because these were probably low gradient streams (Frye and Leonard, 1952), not capable of transporting massive quantities of boulders. The fact that some gravels fill deep narrow channels cut through bedrock may indicate that sediments were deposited when proglacial lakes overflowed catastrophically, cutting through local drainage divides during advance of glacier ice. In all cases where they are found in association with till, they underlie till and show no evidence of a significant time delay between deposition of gravel and till. For this reason they were probably proglacial and were deposited during glacier advance.

Till and interbedded outwash

Diamicton with variable amounts of interbedded silt, sand, and gravel is the most common type of drift in the study area. Most of the sections measured in this study were almost entirely diamicton with minor inclusions of sorted sediment (Associations C, D, and E). In several sections diamicton bodies are separated by sheets and lenses of sand (Association B). In the past tills separated by continuous sheets of stratified drift have often been interpreted as resulting from multiple glaciation (e.g., Frye and Leonard, 1952; Willman and Frye, 1970). It is now realized that sequences of proglacial, subglacial and supraglacial facies may produce complex lithofacies transitions both vertically and horizontally (e.g., Sugden and John, 1979; Boulton, 1967; Boulton, 1972; Boulton and Deynoux, 1981; Aber and others, 1989; Hart and Boulton, 1991). Unless evidence of soil formation, erosion or prolonged exposure can be demonstrated, it is more reasonable to assume that complex facies changes have occurred, reflecting migration of depositional environments or superposition of glacial facies during ice wasting. Glaciotectonism may also produce complex sequences (Aber and others, 1989; Hart and Boulton, 1991). Some of the most important exposures that display complex facies sequences will be discussed and an interpretation of their origin given. In none of the exposures is there any evidence for a major break in the pre-Illinoian sequence.

Southern Platte County, Missouri

Drift is present on nearly all of the higher divides in southern Platte County. In tributary streams of the Missouri River, pre-Illinoian drift has been completely removed. On most divides near the Missouri River only a residual lag of erratics is present. Further north in the area surrounding Kansas City International Airport drift thickens considerably.

Overlying basal gravel (Association A) in several sections, diamicton dominated by local rock types (Association C and D) is present. In the few exposures where the gravel and diamicton contact was observed it was relatively sharp, but there appears to be mixing of the lower gravel into diamicton, because both have similar small pebble lithologies. The best location where this relationship can be

seen is at the intersection of Greenhills Road and Missouri Highway 152, in southern Platte County, Missouri (Figure 6 # 27). This exposure is in an upland location with the base of the exposure approximately 950 feet in elevation

In this section a maximum of 12 meters of gravel, diamicton, sand, and silt are exposed (Figures 19, and 20). Another 3-7 meters of deformed outwash and diamicton was encountered in excavations for bridge piers below road level. The most striking aspect of this exposure is the presence of two diamicton bodies separated by sand, gravel, and silt. In the past this section may have been interpreted as containing both Nebraskan and Kansan tills or two Kansan tills, mainly because of the extent of outwash separating the tills. Because no paleosol is developed between diamicton bodies it is unlikely that this section represents two episodes of glaciation, but instead migration of proglacial and subglacial depositional environments.

Overlying Pennsylvanian bedrock, at the base of the exposure, is a bed of boulders and cobbles, mainly of limestone (Association A). Clasts are well rounded to subangular cobbles. Most pebbles are composed of local lithologies (86.9%), with minor chert (3.4%), and erratics (9.7%). The gravel is present as a lens only in the central portion of the outcrop. The contact between gravel and overlying diamicton is sharp, where well exposed, but there is no difference in lithologies of the 4-8 mm pebbles of both units. Additionally, no weathering appears to have occurred in the gravel before deposition of diamicton. The main difference between these units is that the basal gravel is clast supported (Gc) whereas the diamicton is matrix supported (Dm).

The lower diamicton is extremely dense, overconsolidated, light gray (N5) to dark gray (N3-N4), unoxidized, and unleached. Carbonized wood fragments (some appear to be twigs) and a large 10 cm diameter trunk were also found within the lower diamicton. The wood is identified as *Populus* sp. or *Salix* sp., but is too degraded to make a more detailed determination (personal communication Harry A. Alden, U.S. Forest Products Laboratory, 1992). Vertical joints are present, but little to no

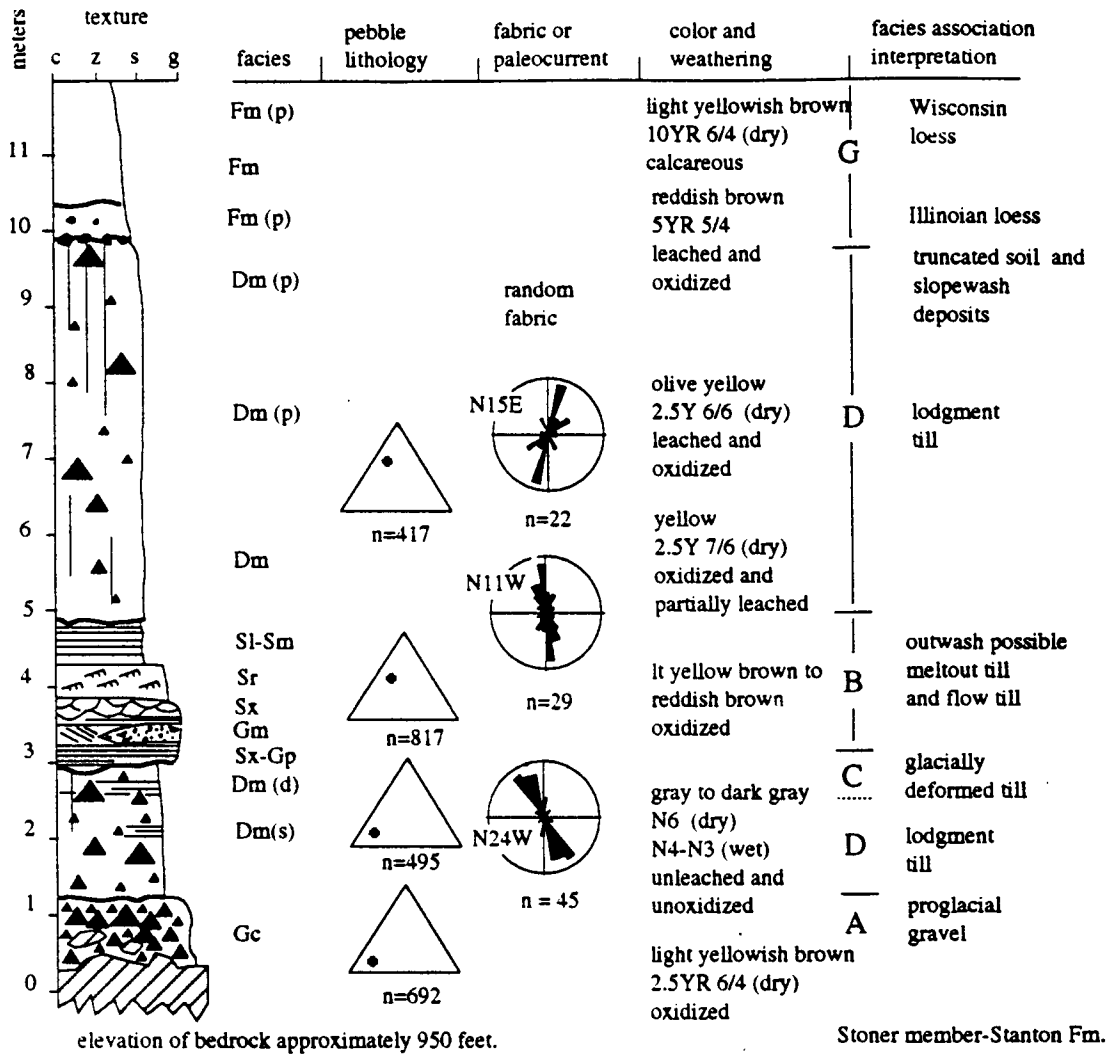


Figure 19. Measured section of roadcut along new Highway 152, Platte County, Missouri. NE1/4, NE1/4, sec. 9, T51N, R34W, Ferrelview Quadrangle. See Figure 7 for symbols. Measured 10-6-91.

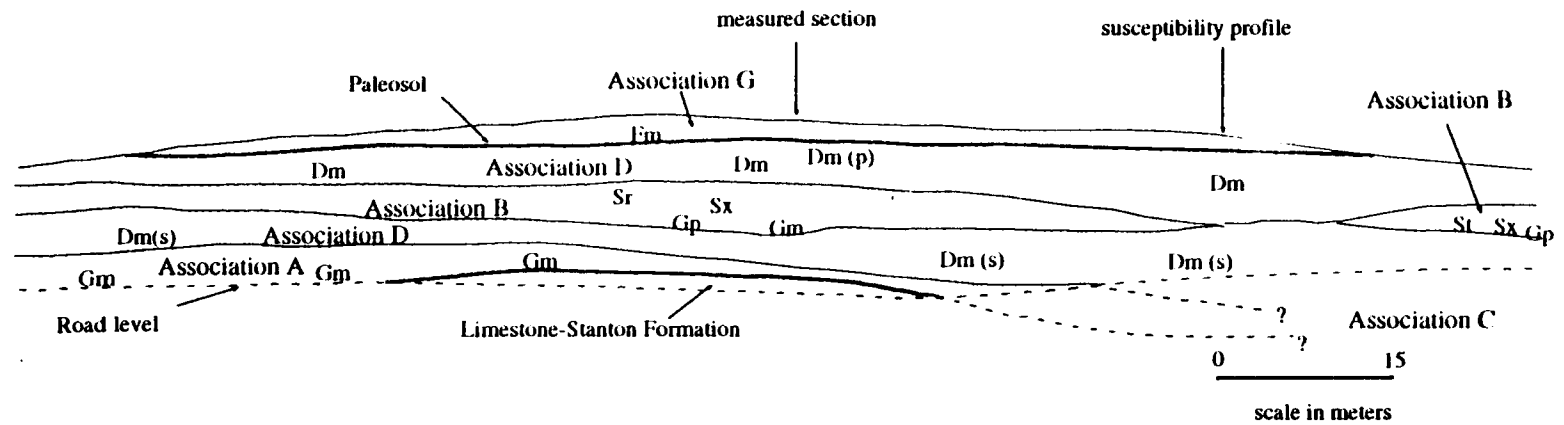


Figure 20. Line drawing of photomosaic for highway 152 exposure.

alteration (oxidation and leaching) and no soil development has taken place in this unit. Near the top of the lower diamicton is a highly irregular stratified diamicton unit (Association E). Minor sorting of sand and poorly developed stratification is present. The stratification wraps around cobbles and boulders indicating that sediment has undergone compaction and dewatering. The texture of this material is more heterogeneous than that of the underlying diamicton.

Shear fabric, wedge-shaped, striated clasts, sharp basal contact, and chaotically deformed basal facies (Association C) grading into a massive and sheared diamicton facies (Association D) suggest a subglacial origin for lower diamicton. The stratified diamicton overlying this may be meltout till or resedimented till (Association E).

The silt, sand, and gravel (Association B) separating diamictons probably has a complex origin. Planar bedded gravel (Gp), matrix supported gravel (Gm (r)), crossbedded sands (Sx), and rippled and laminated silt and sand (Sr and Sl) are present (Figure 21). All bodies appear to be generally tabular to lens shaped. Most sand bodies show signs of loading, soft sediment deformation, and intrusion, perhaps because of glaciotectonic deformation (Figure 22, 23). Most of the crossbedded sand and silt is interpreted as proglacial outwash (Association B), because of good sorting, sedimentary structures indicating unidirectional flow, and bed geometry. Interbedded matrix supported graded gravels Gg (r) may be the result of sediment gravity flows. This interpretation is supported by irregular bed geometry, unusual concentrations of matrix supported clasts, and interbedding with fluvial sediments.

Below the outwash and developed in stratified diamicton there are two sand-filled wedges. The wedges are approximately 30 cm long and 5 cm wide near the top (Figure 24). The enclosing diamicton is faintly laminated and contains thin stringers of silt and sand. This laminated diamicton may be meltout or reworked till (Association E). The wedges could be periglacial in origin or they may be related to sediment deformation caused by glacial readvance. Folding and brittle failure of semi-consolidated or frozen sediment often occurs in ice marginal areas as glacier advance plows over pre-existing sediments (Aber, 1989; Hart and Boulton, 1991).



Figure 22. Load structures in pebbly-sand and silty sand facies. Stratified diamicton is visible in lower portion of photo below silty sand. Overlying pebbly sand is massive diamicton, visible at top of photograph.



Figure 23. Soft sediment deformation structures in outwash facies in Highway 152 exposure. (A). flame structure of fine silty sand intruded into coarse sand. (B). Silty sand diapir intruded into coarse sand. These structures may be due to loading or glacial deformation.

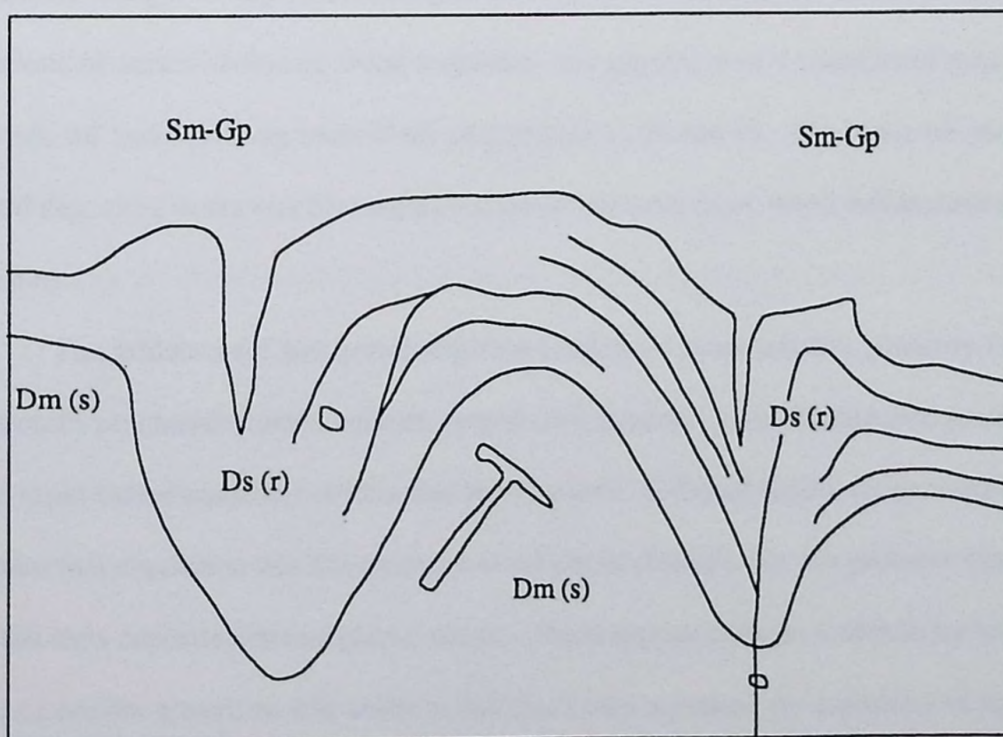


Figure 24. Sand wedge structures developed in massive and laminated diamicton, Highway 152 road cut, NE1/4, NE1/4, sec. 9, T51N, R34W, Platte County, Missouri. These structures could be periglacial features, but it is more likely they are related to soft sediment deformation or glaciotectonism.

The upper diamicton is also dense and overconsolidated, but it is oxidized and partially to completely leached of carbonate. The color of the upper diamicton is olive yellow (2.5Y 6/6) to yellow (2.5Y 7/6). No sedimentary structures are visible in the upper diamicton which appears massive and homogenous. Striated and wedge shaped clasts and oriented fabric are present in the lower part of this diamicton. The upper 3-4 meters is altered pedogenically and leached of all carbonates. This diamicton has fewer pebbles than the lower diamicton. Vertical joints are present in this unit and extend from the overlying paleosol surface to the base of the unit. Joints near the middle of the unit are filled with calcite. The lower portion of this diamicton is also interpreted as basal till mainly because of overconsolidation, oriented fabric, wedge shaped striated clasts, sharp basal contact and underlying deformed sediment. The upper part is so badly weathered that interpretation of its origin is not possible.

Tills in this exposure are interpreted as resulting from at least two advances along the fluctuating margin of a pre-Illinoian glacier. The lower till contains mostly local material, large inclusions of sorted sediment, wood fragments, and appears to be a complex of glacially deformed outwash, till and overlying meltout till (Association C, D, and E). The lower till probably was the first till deposited in the area because it contains mostly local clasts, wood, and inclusions of proglacial sediments.

The middle sand and gravel sequence consists of facies and bed geometry (Association B) common in proglacial braided outwash stream environments. Large fluctuations in stream discharge cause rapid facies transitions within this environment. Sediment bodies are generally tabular. This indicates that deposition was not restricted to subglacial channels, but was probably subaerial as broad outwash fans deposited during glacial retreat. There appears to be no evidence for soil formation in lower or middle gravel, so it is unlikely that much time separated the deposition of upper and lower tills. The sand-filled wedges could be small frost contraction cracks that formed in till before deposition of outwash, but it is more likely that they are related to the overlying glacially deformed sediment and are a product of the same deformation. The shearing and loading structures present in the

outwash sequence and in the upper part of the basal till suggest that these features have a ice contact or glaciotectonic origin. The sand filling the wedges is massive and shows none of the lamination that would be expected if contraction cracks were filled periodically over time. Also ice wedge features often show an upfolding of originally horizontal layering displaced by ice growth. Upfolding of layering is not present in these wedges.

Wyandotte County, Kansas

The distribution of drift in Wyandotte County is similar to that in southern Platte County. One difference is that several buried valleys are present along the course of the present Kansas River valley. Deposits filling these valleys consists of interbedded sand, gravel, and diamicton.

An exposure of diamicton, interbedded with silt and sand is located due east of the intersection of Interstate Highway 70 and K-132 in Wyandotte County, Kansas (Figure 6, # 13). This area is the location of a major buried valley segment. Cross sections and bridge-pier records obtained from the Kansas Department of Transportation provide evidence of a south trending, buried valley approximately 1 mile in width and as much as 120 feet deep. The lowest part of the valley floor is in Dennis Formation at an elevation of 785 feet near the intersection of I-70 and K-132. To the west, less than a kilometer from the deepest part of the buried valley, the bedrock rises abruptly to an elevation greater than 950 feet. It is not known whether this is a buried tributary of the Kansas River or a buried segment of the main stream. In the past, deposits such as these have been described as Menokan Terrace remnants (Frye and Leonard, 1952), but the amount of diamicton present makes an alluvial origin unlikely (see Dort, 1987b for Kansas River terrace stratigraphy). The cross sectional profile and slope of the bedrock suggests that it is a south trending, buried tributary valley connecting to a buried segment of the main stream. The modern Mill Creek is presently re-excavating this buried valley and probably follows the general trend of the buried tributary and margin of the main stream.

The lowest exposure of diamicton in the area is near the overpass of 65th street over I-70 (Figure 25). Highway Department records show that till extends about 5 m below the road at this

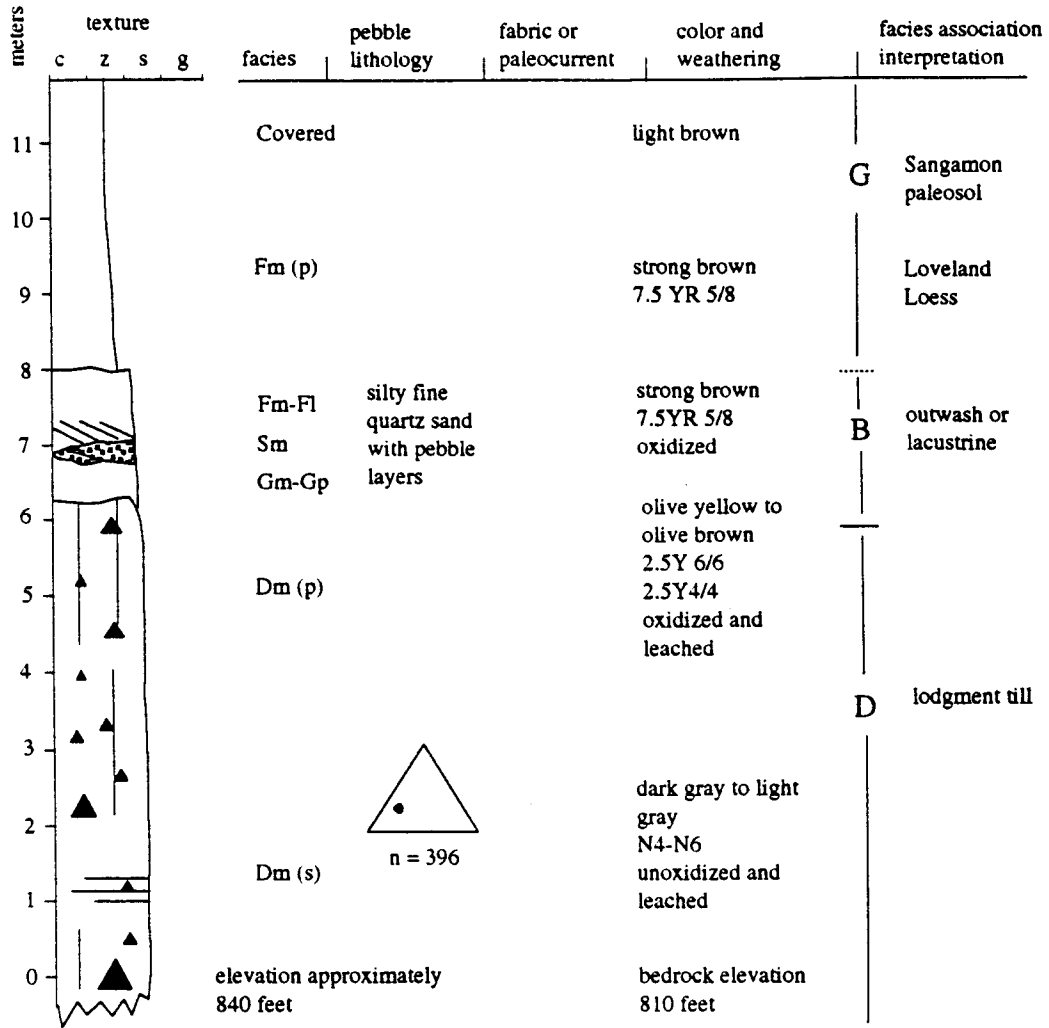


Figure 25. Section exposed along south side of I-70 1/2 mile east of K-132 NW1/4, SE1/4, SW1/4, Sec. 10, T11S, R24E, Wyandotte County, Kansas. Measured 2-22-91.

point to bedrock of Drum Formation at an elevation of 810 feet. The diamicton exposed is dark gray (N4), unoxidized and unleached, dense, and overconsolidated. It contains numerous striated and wedge-shaped clasts. Most of the clasts are of local lithologies (60.4%) but erratics (32.8%) and chert (7.0%) are also present. The diamicton displays fissility when broken apart. Because of overconsolidation, shear structure, and striated wedge-shaped clasts, this diamicton is interpreted as subglacial till (Association D).

The dark gray basal till grades up into a oxidized and leached olive yellow to olive brown (2.5Y 6/6 to 4/4) diamicton. Extending down from this unit are large joints 3-10 cm in width. Areas around the joints are oxidized and cemented with iron oxides.

Overlying weathered and leached till is a reddish brown (7.5YR 5/8), fine silty sand (Sm, S1 and Fm). This sand is weathered and oxidized. In much of the exposure the silty sand is enriched with clay and may be the B horizon of a paleosol which is developed over the exposure. Overlying silty fine sand is a reddish brown silt.

To the west of this exposure, overlying silty sand facies (Sm, Sh), is a small lens of diamicton (Dm (p)) (Figure 26). This diamicton is leached and oxidized. It is dense and contains erratic pebbles, but very few cobble sized clasts. No fissility is present in this diamicton, but planar horizontal joints are present. Near the base, the diamicton is faintly laminated with a sharp erosional base. Overlying this is a coarse, massive to planar, vaguely crossbedded, pebbly sand (Association B). Developed within this facies is a paleosol. Clay enrichment has taken place as well as complete leaching of all carbonate, and limestone clasts. This material is fairly widespread over the area. Crossbedded sands and gravels of similar lithology occur in a stream cut to the west of this exposure. These sands overlie silty fine sand and clay. This unit could not be traced to crossbedded sands capping the I-70 exposure so they may or may not be stratigraphically equivalent.

The exposures in this area are interpreted as a valley filling sequence. Glacial advance over a pre-existing valley first deposited sand and gravel (Association A and B). These facies were not observed directly, but Highway Department records indicate that boulder gravel and sand overlie bedrock

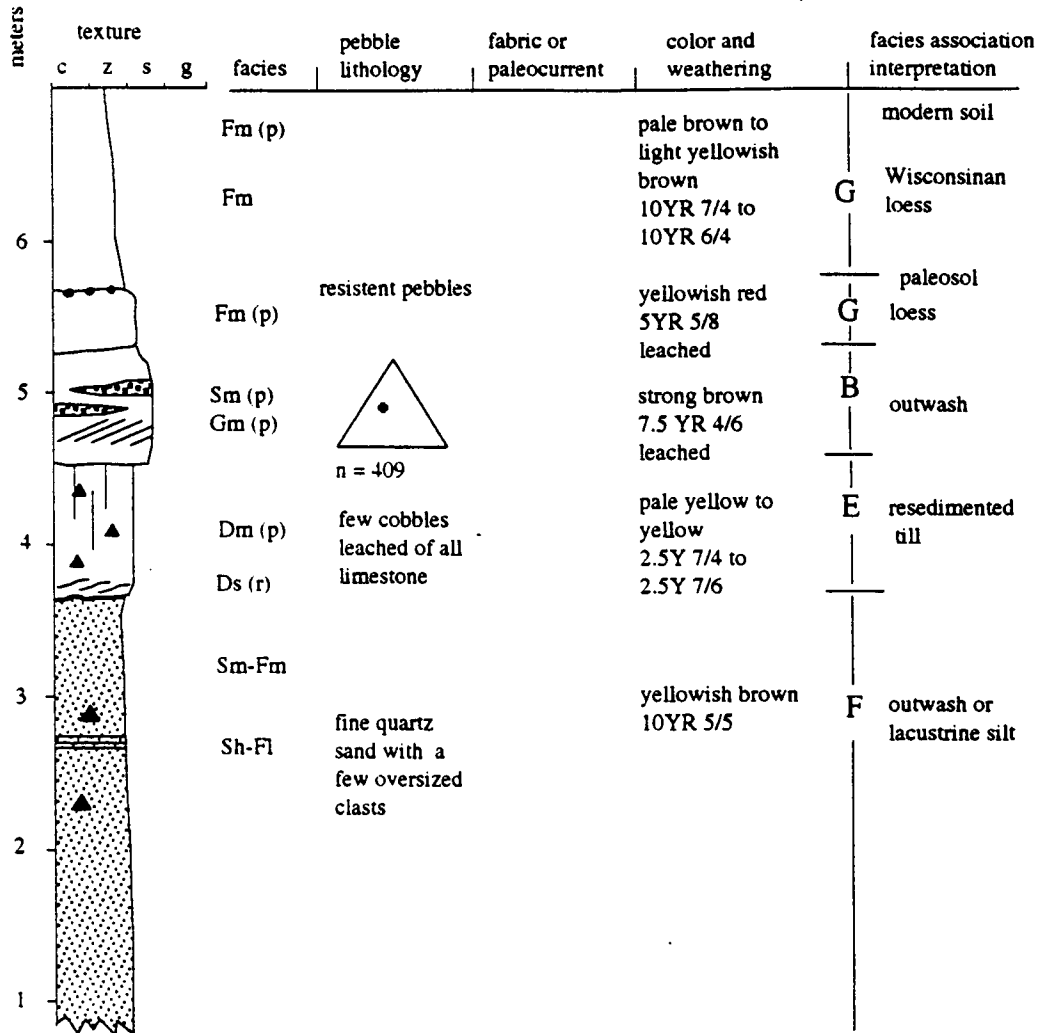


Figure 26. Measured section of roadcut on NE corner of K-132 and I-70 interchange, Wyandotte County, Kansas (NE1/4, SE1/4, SW1/4, sec. 10, T11S, R24E). Measured 2-15-91.

at the base of the valley. Basal till (Association C, D) was then deposited, filling most of the valley. Blockage of the ancestral Kansas River near Kansas City, may have caused a proglacial lake to form. Fine sands and sandy silts (Association F) overlying basal till may have been deposited in a lacustrine environment. The upper diamicton may indicate a minor readvance over lake sediments. Alternatively, the laterally restricted geometry of the upper till, as well as laminations and lack of cobble sized clasts, may suggest that this diamicton is flow till or diamictic lacustrine clay (Association E or F). Overlying this diamicton is pedogenically altered diamicton that is probably weathered outwash sand and gravel (Association B).

Another buried valley is located in eastern Wyandotte County. Exploratory drilling completed during a geotechnical site investigation prior to construction of a new federal courthouse in downtown Kansas City, Kansas, located the buried valley. The area investigated was an approximately four-square block area north of State Avenue and west of 5th Street (Figure 6, # 17). The writer examined most of the samples recovered and logged two of the borings during drilling. Six borings were made to a maximum depth of 22 meters, which was the maximum depth possible for the drill rig used (see Appendix I for drill logs). In only one of the borings was evidence present that bedrock had been reached. All borings terminated in dark gray diamicton, interpreted as basal till. The minimum elevation reached in the borings was 723 feet, or about 8 meters below the present floodplain of the Missouri and Kansas Rivers at Kansas City. The orientation of the valley was not determined, but bedrock is found at higher elevations to the west, north and south of this area. The trend of the buried valley is probably that of present Jersey Creek, which runs west to east through Kansas City, Kansas.

The sequence revealed is similar to that exposed in the buried valley east of I-70 and K-132. In all of the borings a variable amount of reddish brown silt was encountered below light brown silt interpreted as Wisconsin loess. This dark reddish brown silt is interpreted as Illinoian loess and alluvium with a thick Sangamon paleosol complex developed in it. Underlying this is alternating silt and sand interpreted as alluvial fill of Illinoian or pre-Illinoian age. Underlying this is diamicton. The maximum thickness of diamicton is greater than 11 meters. The lowest elevation reached was 723 feet.

In this boring two diamicton units separated by sand were penetrated. The lower till had a weathered zone developed in its upper 2 meters. It could not be determined from the samples available if this was a paleosol or an altered zone bordering permeable oxidized sand.

Diamicton and sand were also exposed for a short time in a vertical cut made during construction of retaining walls along State Avenue near 16th Street in Kansas City, Kansas (Figure 6, # 16). This exposure (Figure 27) consists of two massive diamictons (Association D) separated by a tabular bed of crossbedded sand (Association B) grading laterally into a boulder pavement (Figure 28). The contact between diamictons where not separated by outwash is sharp and distinct over the entire exposure. The lower diamicton is overconsolidated, partially leached, and dark olive gray (5Y 4/2). Shear fabric, and striated and wedge shaped clasts are present. The upper diamicton is light gray to light olive gray (5Y 7/2 to 5Y 6/2) and is leached. The upper diamicton contains poorly developed shear planes and well developed vertical joints.

Overlying the lower diamicton and filling a shallow channel form is medium to coarse trough and planar crossbedded sand (Sx). The sand is partially cemented with iron oxides. The sand is moderately well sorted and contains only a few pebble and cobble sized clasts. Near the base of the channel, a cobble sized (12 cm) block of diamicton is included in sand. Crossbed sets indicate a southeast paleocurrent direction. The sand wedges out between the two diamictons and grades into a boulder pavement on either side.

The boulder pavement separating the two diamictons is made up of cobble size clasts which are oriented with their long axes and striated upper surfaces in a generally northeast to southwest direction. The overlying diamicton is distinctly different in color and texture than the underlying diamicton. The upper diamicton contains fewer cobbles. Where there is a contact between upper diamicton and sand the contact is sharp with little soft sediment deformation. The upper diamicton grades into a very fine grained slightly pebbly clay (Fmd) and then into reddish brown fine sand and silt (Sm and Fm). Overlying this is reddish brown sand and sandy silt. (Sm, Fm). Developed within this is a paleosol with a sharp upper contact and reddish brown, clay rich B horizon. Light brown

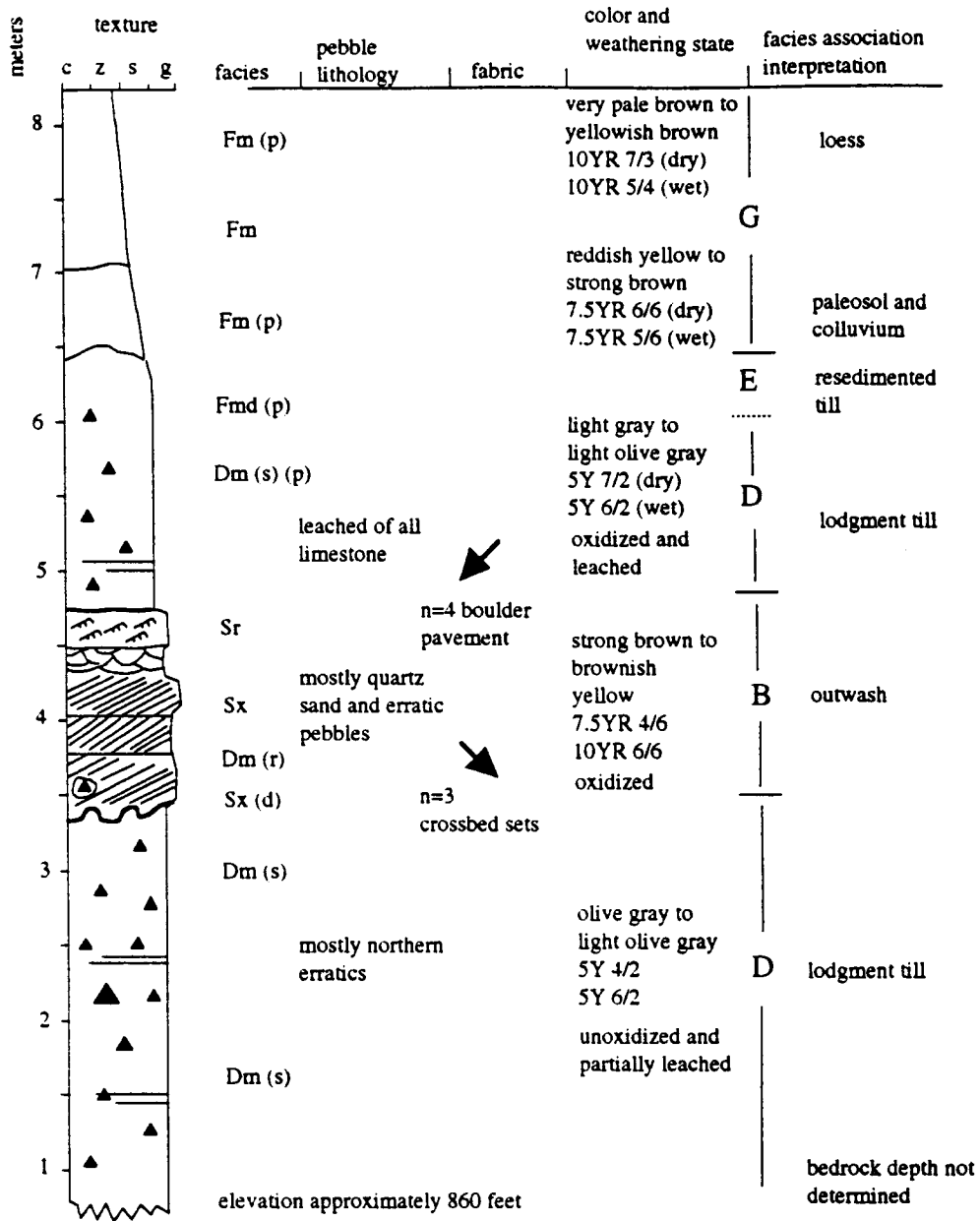


Figure 27. Measured section exposed during construction of retaining wall along 1600 State Ave., Wyandotte County, Kansas, SE1/4, SW1/4, SW1/4, T11S, R25E, Shawnee Kansas Quadrangle. Measured 7-15-90.

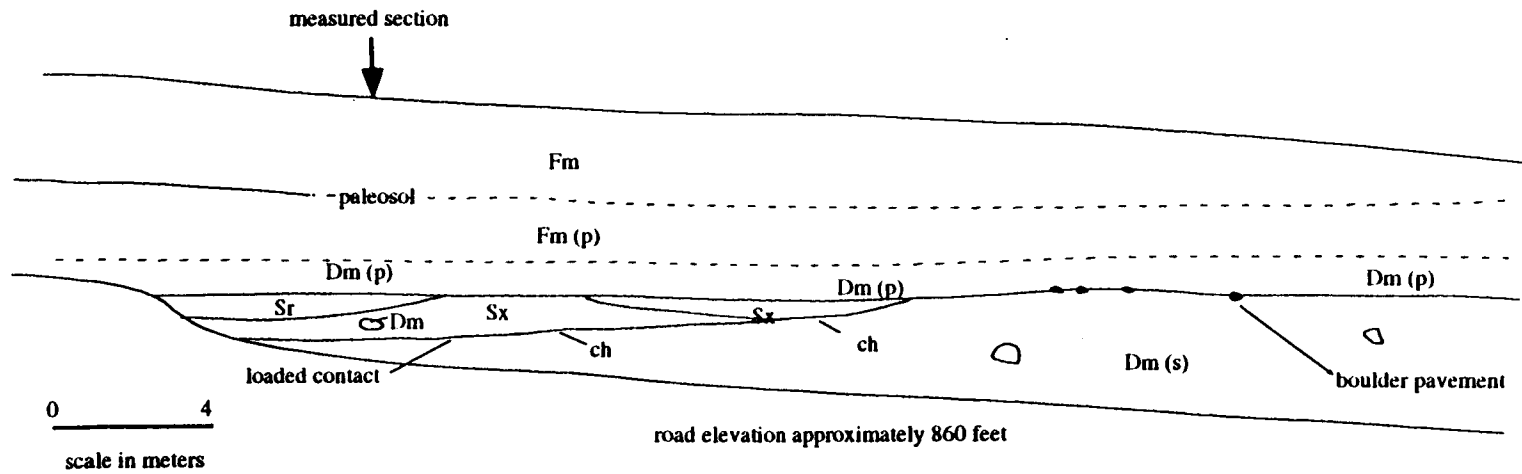


Figure 28. Field sketch of exposure along south side of State Avenue one block east of 18th Street, SE1/4, SW1/4, SW1/4, sec. 4, T11S, R25E, Wyandotte County, Kansas.

calcareous silt unconformably overlies the entire exposure.

This section is interpreted as being the result of a retreat and readvance along the glacial margin. The lower diamicton (Association D) is basal till. The base of the sequence is not exposed at this location so it is uncertain what the depth to bedrock is. The lower till (Association D) displays shear structures, wedge shaped and striated clasts, and overconsolidation. The overlying sands (Association B) are interpreted as channel filling outwash deposits. The upper diamicton (Association D) was probably deposited by a later readvance over outwash deposits. The sharp contact with the outwash may indicate truncation during readvance. The boulder pavement and sharp contact with the lower till also indicate a subglacial origin for the upper diamicton. Overlying massive, fine sand and silt (Association F and G) may be the result of lacustrine and eolian sedimentation after glacier retreat. There is no evidence for soil formation within the sequence underlying the paleosol developed in silty sand and silt so probably only a short period elapsed between deposition of tills.

Clay County, Missouri

In Clay County the distribution of drift is the same as in southern Platte County. In general drift thickens to the north in upland areas. In southern Clay County thick exposures of loess cover most of the area making it difficult to observe older deposits. It is likely several buried valleys are present along the north bank of the Missouri River. Near Nebo Hill and Missouri City thick drift sequences are present.

Bedrock and Pleistocene sediments are exposed in a road cut one mile west of Missouri City, Missouri and in areas immediately northeast and east of Nebo Hill. Exposed sections are located 1/4 mile north of the junction of Missouri Highway 210 and Missouri Highway EE (Figure 6, #42), along an access road to the Missouri Rock Company Quarry (Figure 6, #41), and just south of Highway 210 just east of Nebo Hill (Figure 6, #39 and #40).

In the exposure along Highway EE unoxidized and unleached diamicton (Association D) is exposed overlying striated and smoothed Pennsylvanian sandstone of the Pleasanton Group. The

diamicton appears to be filling a depression in the bedrock surface because bedrock rises abruptly nearby. Striated bedrock was exposed along both sides of the road after construction was completed, but soon afterward it was covered with gravel to slow erosion. Only a small patch of striated bedrock is presently visible on the west side of the road. Bedrock striations trend generally N20W.

The elevation of the striated bedrock is approximately 10 meters higher than the present Missouri floodplain. In several places a thin basal gravel (Association A) is present directly overlying bedrock. Limestone and northern erratics are common in this gravel. Overlying this is a dark gray (N4), massive diamicton (Association D). The contact between this and underlying gravel is gradational. Where gravel is not present, diamicton overlies striated bedrock. Higher up in the section numerous small (5 to 10 cm thick) wedges of sorted sand are present interbedded with diamicton (Association C). These wedges are bounded by planar surfaces interpreted as shear planes. The strike of these planar surfaces is approximately east-west, and dip is to the north. These surfaces extend into the diamicton. Similar sand bodies and planar surfaces were seen in exposures near Nebo Hill. Many tabular and lenticular shaped sand bodies were also observed included within till in this area.

Grading upward from unleached and unoxidized dark gray diamicton is a light yellow brown (2.5Y 6/4) diamicton (Association D). This leached and weathered diamicton shows many of the same features as the lower dark gray diamicton. No stratigraphic break or unconformity was noted between this facies and underlying diamicton in any of the sections in this area. A fabric sample taken from the lower dark gray till northeast of Nebo Hill shows a strong parallel fabric of N10W.

Overlying diamicton is reddish brown sand and silt in which a paleosol is developed (Association B and G). The paleosol is recognized because of its reddish color, sharp top and thick clay enriched B horizon. Overlying this is light brown calcareous loess (Association G).

The exposures in the Nebo Hill area are interpreted as a complex of subglacial till facies (Association C and D) in which glacially deformed proglacial sediments are incorporated. The planar surfaces and wedge-shaped sands are probably shear plane surfaces and sheared outwash sediment. The

strike and dip of shear surfaces, till fabric, and bedrock striations suggest a southeast trending ice advance for the area.

Exposures uncovered during construction of a new north extension of Antioch Road in Clay County, Missouri provided another good example of diamicton and interbedded outwash deposits (Figure 6, #s 36 and 37).

In this exposure unoxidized and leached diamicton rests on top of Bonner Springs Shale (Figure 29). The diamicton fills a shallow <10 m depression in the bedrock surface. The diamicton is dark gray (N4), unleached, and contains numerous erratic and local pebbles. Erratic content of this diamicton is higher (55.7%) than other unoxidized and unleached diamictons (10-35%) in the study area. A fabric sample taken from this till indicates a parallel fabric trending N10W. Interbedded with diamicton are two lens shaped sand bodies. Sand bodies are approximately 2 to 3 meters wide and 1 meter thick. Cross bedding and soft sediment deformation is apparent within these sand bodies. Overlying unweathered diamicton with a gradational contact is a oxidized and leached yellow brown (2.5Y 6/4) diamicton. Overlying this is weathered and oxidized reddish brown sand and silt.

The diamicton in this exposure is interpreted as basal till mainly because of striated and wedge-shaped clasts, fabric, shear structure, and overconsolidation. The interbedded sand bodies may be subglacial outwash channels or incorporated proglacial deposits.

Upper proglacial outwash

In several exposures a highly weathered sandy diamicton (Association B) overlies till. This type of weathered drift is exposed in road cuts along I-70 between interstate I-635 and I-435 (Figure 6, # 10) and in areas near Nebo Hill. This sandy diamicton is usually yellowish red to strong brown (5YR 5/8 to 7.5YR 4/6) in color (Figure 30). Pebble counts and grain size analysis of the material show that it has a higher percentage of chert and resistant erratics than does weathered till. In a few places it also shows original crossbedding. Davis (1951) and Aber (1988a) found that outwash deposits in Kansas usually have a high percentage of chert and resistant lithologies. This, together with observed

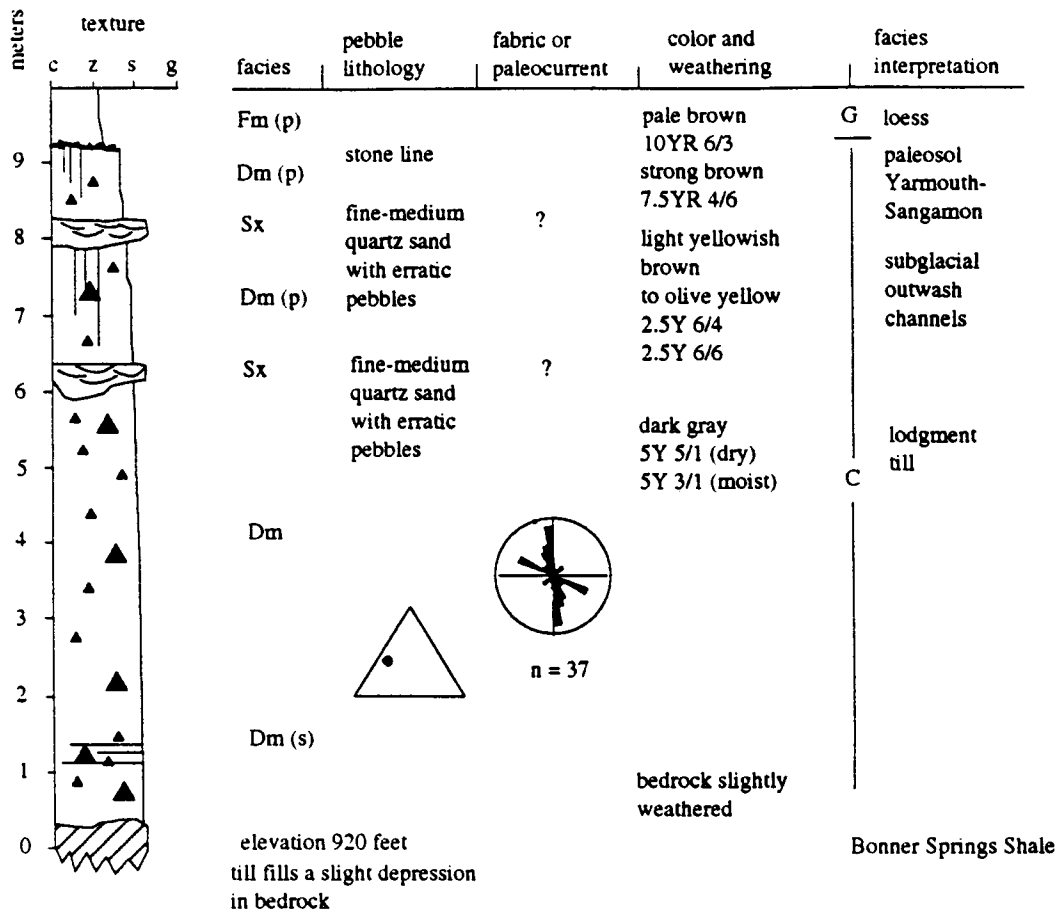


Figure 29. Measured section exposed along west side of N. Antioch Road SW1/4, SE1/4, sec. 7, T51N, R32E, Clay County, Missouri Measured 9-1-91.



Figure 30. Sandy diamicton and stone line exposed in Platte County west of Platte City. Most clasts are Sioux Quartzite and other resistant erratics.

crossbedding and overall sandy texture, indicate that these weathered diamictons were originally outwash. In the sections in which this type of material was observed it was overlying till. For these reasons it is interpreted as outwash deposited during glacial retreat.

Ice movement data

Ice movement and paleocurrent data were gathered during this study. Striations, glaciotectionic structures, crossbedding sets, boulder pavements, and till fabric measurements were used to indicate ice movement and paleocurrents. Of this data, striations, boulder pavements, and crossbedding sets are probably the most accurate data for indicating the movement of ice and water, at least in a small area. Glaciotectionic structures and till fabric measurements are probably less accurate due to measurement errors, but can also indicate the trend of ice movement. The data collected is tabulated in Table 4.

Figure 31 shows ice movement and paleocurrent data collected in the study area. In several locations where striated bedrock was observed two directions of ice movement were present. The variation in ice direction indicated from a single bedrock surface was as much as 55 degrees (Table 4, # 18). In three locations two sets of striae were apparent with one crossing over another. Fabric samples in unaltered basal till had a well orientated, presumably parallel fabric. Other samples from weathered and leached tills had a random orientation, probably caused by destruction of fabric during decalcification.

Paleocurrent measurements in facies interpreted as braided stream outwash deposits are probably not an accurate indicator of paleochannel trend. This is because paleocurrent measurements in braided stream environments may vary by as much as 180 degrees within a single channel (Potter and Pettijohn, 1963). In most sections only a few paleocurrent measurements were made, so local flow directions much different from the general channel orientation may be represented. This same argument can be made against the reliability of ice movement data. Paleocurrent arrows plotted on the map are from a combination of large scale features such as trend and slope of bedrock valleys, and small scale features such as crossbedding sets and clast imbrication.

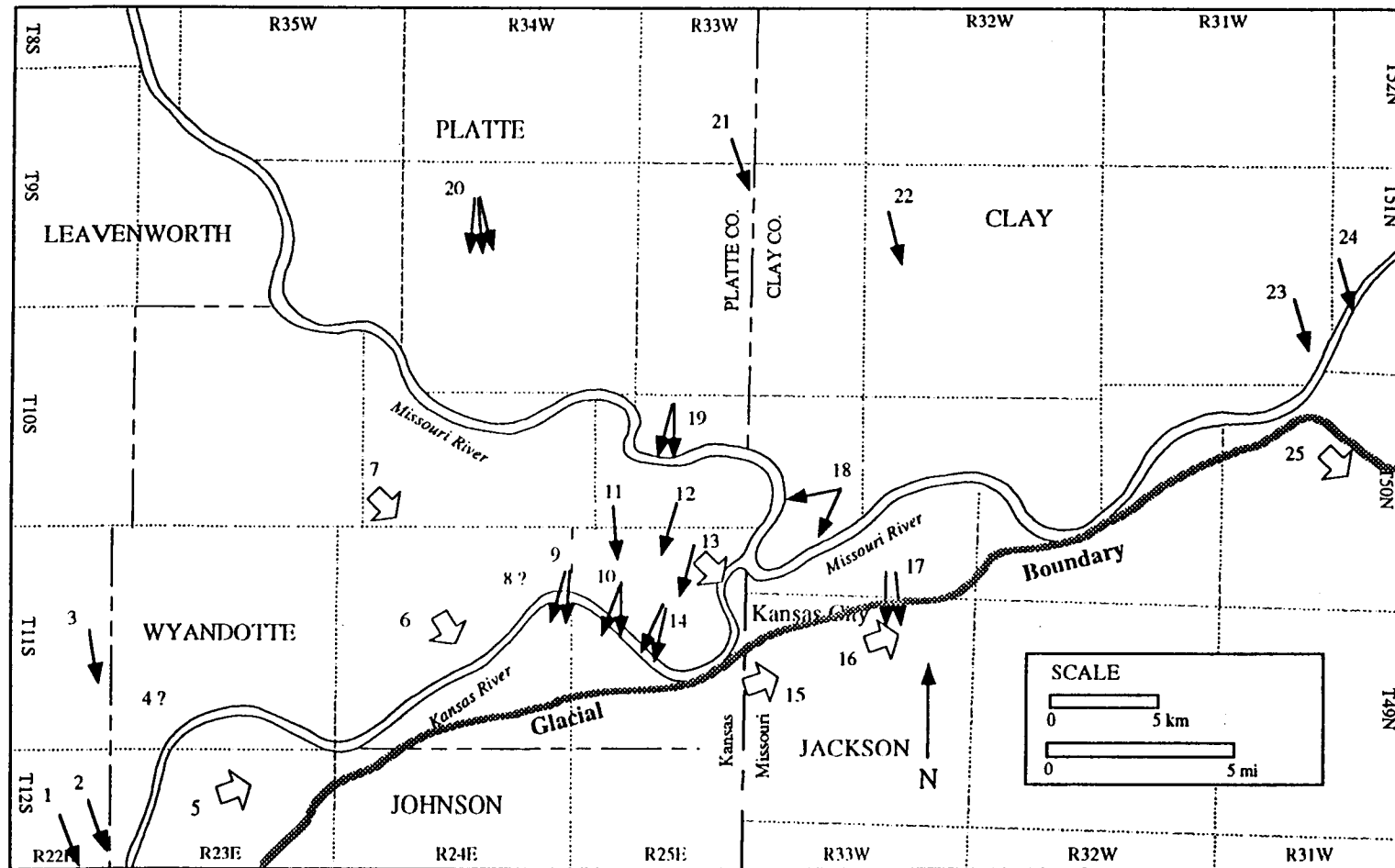


Figure 31. Ice movement data for the study area. Dark arrows are ice movement trend, white arrows are paleocurrent trends. See Table 4 for descriptions of numbered data points.

Table 4. Ice movement and paleocurrent data for study area

No.	Location, stratigraphy, and author	type	trend
(1)	2 miles east of Lenape, Leavenworth County, Kansas. Stratigraphy unknown Todd (1918)	striations	S21E
(2)	Quarry near Loring, Wyandotte County, Kansas Stratigraphy unknown, Darton (1916)	striations	S20E
(3)	NW1/4, sec. 13, T11S, R22E, Leavenworth County, Kansas. Stratigraphy unknown Jewitt and Newell (1935)	striations	S10E S34-42E
(4)	SW corner, sec. 30, T11S, R23E, Wyandotte County, Kansas Stratigraphy unknown Jewitt and Newell (1935).	striations	not recorded
(5)	Clear Creek Area, T12S, R23E Johnson County, Kansas see O'Connor, (1971) for description of area	trend of Clear Creek	ENE
(6)	Mill Creek Area, T11S, R24E Wyandotte County, Kansas (this study)	trend of buried valley and outwash crossbeds	S-SE
(7)	SW1/4, SW1/4, SW1/4, sec. 30, T10S, R23E Wyandotte County, Kansas (this study)	outwash crossbeds	S-SE
(8)	SW corner, sec. 12, T11S, R24E, Wyandotte County, Kansas. Stratigraphy unknown Jewett and Newell (1935).	striations	not recorded
(9)	center of SE1/4, sec. 12, T11S, R25E Wyandotte County Kansas below gray till and outwash on Iola Fm. (this study)	striations	S6E-S6W S20W-S50W
(10)	SW1/4, sec. 12, T11S, R24E along north side of K-132, Wyandotte County, Kansas, developed on Iola Fm. below weathered till and outwash. (this study)	striations	N4E N16E
(11)	NE1/4, sec. 30, T10S, R25E, Wyandotte County, Kansas. Stratigraphy unknown Jewett and Newell (1935).	striations	S5E
(12)	T10S, R25E, Kansas City, Kansas, Wyandotte County, Kansas. Stratigraphy unknown Todd (1918).	striations	S16W

(13)	SE1/4, SW1/4, SW1/4, sec. 4, T11S, R25E Wyandotte County, Kansas (this study)	striations on boulder pavement	SW
(14)	T11S, R25E, Kansas City, Kansas, Wyandotte County, Kansas. Stratigraphy unknown Todd (1916).	striations	S12-24W
(15)	S1/2, sec. 23, T49N, R33W, Jackson County, Kansas. Gravel (McCourt et al., 1918)	trend of buried valley	East
(16)	Turkey Creek Valley, T49N, R33W Jackson County, Missouri (Sims, 1975)	trend of buried valley	E-ENE
(17)	east side of Kansas City Missouri, Jackson County, Stratigraphy unknown Todd (1918)	striations	S-S6E
(18)	one mile north of Kansas City, Missouri Stratigraphy unknown Todd (1918)	striations	S79W and S24W
(19)	NE1/4, SE1/4, sec. 5, T50N, 33W Platte County, Missouri NE corner of I-635 and Hwy 9 (this study)	striations	S30E-S25E
(20)	NE1/4, NE1/4, sec. 9, T51N, R34W Platte County, Missouri Highway 152 (see Figure 20 for stratigraphy) (this study)	till fabric	S24E S11E S15W
(21)	SW1/4, NE1/4, sec. 10, T51N, R33W NW corner of Hwy 169 and Barry Road on Tonganoxie Sandstone below weathered till (this study)	striations	S5E
(22)	SW1/4, SE1/4, sec. 7, T51N, R32W N. Antioch Road (see Figure 31) dark gray basal till	till fabric	S19E
(23)	SE1/4, sec. 13, T51N, R30W Hwy EE on Pleasanton Group below dark gray basal till (this study)	striations	S17E
(24)	NW1/4, SE1/4, sec. 23, T51N, R31W Nebo Hill (see text for description) from dark gray basal till	till fabric	S3E
(25)	Lake City Valley, T50N, R31W Jackson County, Missouri (Greene, 1921)	trend of buried valley	E-SE

In most of the sites (13) a generally south to southeastern trend is present. In several sites (7) a southwest trend is also present. In three exposures where two sets of striae were measured, the southwest trending striations cut across those trending southeast. In several locations striated bedrock is found on high ledges bordering the northern side of Kansas and Missouri River valleys (Figure 32).

Ferrelview Formation and Nortonville clay

Howe and Heim (1968) describe thick gray, clay containing few sedimentary structures and overlying oxidized and leached till, in the upland areas of Platte, Clay, Clinton, and Caldwell Counties, Missouri. A similar clay is also reported by Frye and Leonard (1952, p. 83) in upland locations of Leavenworth County, Kansas. In Missouri it is designated as the Ferrelview Formation, after deposits exposed near Ferrelview, Missouri, just south of Kansas City International Airport. Howe and Heim (1968) provide a drill core and measured section to serve as stratotypes for the Formation (Figure 6, # 33 and 32). In Kansas, Frye and Leonard (1952) named the deposit Nortonville clay from deposits exposed near Nortonville, Kansas.

In several exposures the writer observed thick deposits of light gray massive clay (Association F) overlying weathered till in Platte (Figure 6, #s 34 and 35) and Wyandotte Counties (Figure 6, # 7 and 6). In all instances the clay is at elevations of approximately 980 feet or higher. In one exposure the clay was resting on a sharp contact with leached and oxidized glacial till below (Association D). In other exposures the contact with underlying oxidized till was poorly exposed or covered.

Overlying the clay in most exposures is either light brown silt (Association F) or reddish brown silt. In a series of excellent exposures along Highway 169 in Platte County, Missouri reddish brown silt is found overlying the Ferrelview Formation. In this silt a paleosol is well developed (Figures 33 and 34). This is interpreted to be part of the Sangamon Geosol because of thickness of leached zone, thick B horizon, color, and stratigraphic position. The maximum thickness of the



Figure 32. Striations on Raytown Limestone north of Kansas City (Table 5, number 19).



Figure 33. Road cut along Highway 169 showing relationship between Diamicton, Ferrelview Fm, and Loveland Loess. (A) At base of exposure is 1-2 meters of oxidized and leached diamicton. (B). Overlying this is 1 m of gray, clayey silt to fine sand (Ferrelview Fm.). (C). Overlying this is 0.5 meter of reddish brown silt (Loveland Loess with Sangamon paleosol developed in it).



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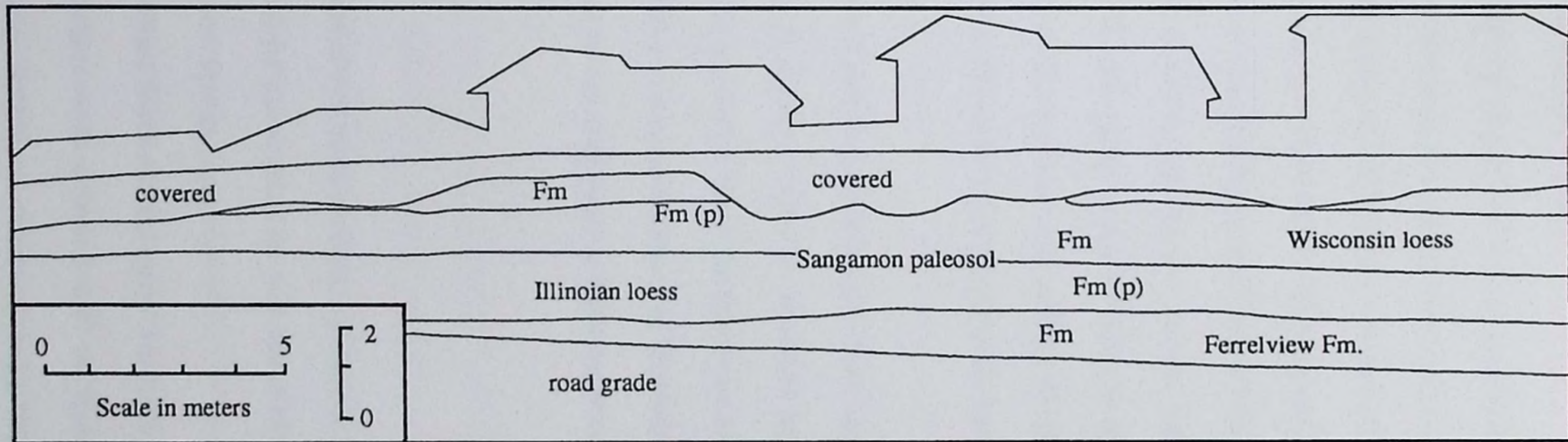


Figure 34. Line drawing from photomosaic of exposure along highway 169 North, SW1/4, NE1/4, sec. 10, T52N, R33W, Platte County, Missouri. In exposures along Missouri Highway 169 Ferrelview Formation overlies oxidized and leached till. Overlying Ferrelview is loess with a well developed (Sangamon) paleosol in upper part.

Ferrelview observed in Platte County Missouri is approximately 8 meters (Howe and Heim, 1968). The maximum thickness observed by the writer was about 3 meters.

Howe and Heim (1968) interpreted the depositional environment of the Ferrelview as being a complex of sedimentary environments. They speculated that both lacustrine and accretion-gley (Frye and others, 1960) origins were possible. The depositional environment was thought to have been an upland till plain characterized by poor drainage and small lakes. These deposits have been also recognized in several counties of northeastern Missouri (Howe and Heim, 1968). In only a few instances have original laminations or bedding structures been reported. Because of similar elevations of the deposits in Wyandotte, Leavenworth, and Platte Counties it may be possible that the depositional environment was once continuous across upland areas north of the ancestral Kansas-Missouri River Valley. If this surface was once continuous it would predate the Kansas City to Saint Joseph segment of the Missouri River Valley.

All observations made by the writer during field work support Howe and Heim's (1968) interpretation of the Ferrelview as being of multiple origins in lacustrine and accretion-gley environments. The presence of oxidized and leached till below the Ferrelview does indicate that Ferrelview is not conformable everywhere with pre-Illinoian deposits. The Ferrelview may include a variety of gleyed sediments deposited between the end of glaciation and Illinoian time when overlying Loveland Loess was deposited.

Terrace deposits and volcanic ash

One exposure of volcanic ash interbedded with fluvial overbank deposits was observed during field work. This section is found in an abandoned borrow pit on the west side of 61st street 1/8 of a mile north of Kansas Highway 32, east of Bonner Springs (Figure 6, # 14).

The ash bed lies in a sequence of overbank fluvial silts and sands. The sands consist of small scale trough crossbeds and ripple cross laminated sands, in beds 5 to 10 cm thick. The silts are massive to laminated beds from 5 to 30 cm thick. Several thin carbonaceous clay beds and lenses are

present overlying silt beds. The ash overlies silt and has an erosive base. The ash is approximately 20 cm thick and shows a fining upwards trend. The ash is highly altered, but a few glass shards were found in a sample of fine sand washed from the ash. The shards are similar to those described by Geil (1987) from a similar terrace deposit near Desoto, Kansas. Overlying the ash is finely laminated silt. This sequence is erosionally truncated and overlain by light brown silt. The silt grades up into light brown calcareous loess. The contact between the fluvial sequence and ash is at approximately 810 feet in elevation. Sand in this exposure does not contain glacial erratics and is almost entirely fine quartz sand and silt. No paleosols were found in this exposure.

The silts overlying ash are interpreted as Wisconsin to Holocene age loess and reworked loess, mainly because of massive structure and great thickness, which blankets the area. Some silts may be reworked because fine lamination is present and sandy lenses are found interbedded with silts. The fluvial sequence is interpreted as correlative to the Buck Creek Terrace deposits described by Geil (1987) (see Dort, 1987b). This interpretation is supported by topographic elevation and the lithology of the deposit. The deposits exposed near 61st Street are inset into glacial deposits observed in streamcuts along Mill Creek. The ash probably correlates to ash that Geil (1987) identified as .61 Ma Pearlette O Ash, because both sections have similar topographic elevations, and lithology.

Illinoian loess

An oxidized and leached light brown to dark reddish brown silt (7.5 YR) is found overlying glacial deposits in many sections. The thicknesses observed are between 0.5 and 5 meters. Good exposures of this loess have been described by Davis (1955) near Randolph in Clay County, Missouri (Figure 6, # 38). The best exposures observed by the writer were in upland areas of Platte County (Figure 6, # 35) and near the Kansas and Missouri Rivers (Figure 6, #'s 5, 12, 13, 17, 39-42). This silt has been interpreted as Illinoian age loess correlative to the Loveland Loess of southwest Iowa (Ruhe, 1969). This interpretation is supported by texture, massiveness, and areal extent which blankets the existing topography. The age determination is supported mainly because of stratigraphic

position above glacial deposits and below loess of Wisconsin age. In many places Loveland Loess is capped by a well developed paleosol. This paleosol has been identified as Sangamon in age (Frye and Leonard, 1952; Davis 1955). Since no means exists for assigning an absolute age to the silt in the study area, one can only determine that it postdates glacial drift and predates formation of the Sangamon paleosol.

Pre-Illinoian to Sangamon paleosols

In many of the sections observed, a paleosol, a complex of paleosols, or an erosion surface is well developed on glacial sediments and silts of pre-Illinoian and possible Illinoian age (Figure 35). The paleosol complex is best exposed in upland areas (Figure 6, numbers 29, 31, 34, 35). This paleosol and erosion surface probably correlates to a regionally significant erosion and soil forming surface (Ruhe, 1969) that developed on pre-Illinoian sediments from the end of glaciation through Sangamon time. This paleosol complex has been termed the Sangamon Geosol by Follmer (1978). The term geosol was proposed to describe a soilscape that can be recognized as a laterally extensive stratigraphic horizon (Morrison, 1967; American Commission on Stratigraphic Nomenclature, 1982). In places where Illinoian sediments are not present or are thin, paleosols likely form a welded paleosol developed from pre-Illinoian to Sangamon time (Ruhe, 1969; Hallberg, 1986). In places where Illinoian loess overlies glacial deposits, drift is leached and oxidized to a depth of a few meters, indicating pedogenesis before and during deposition of loess.

The Sangamon Geosol in the area is identified by its distinctive yellow brown to reddish brown color (7.5 YR 4/4, 4/6), thick argillic B horizon, great depth of carbonate leaching (2-10m), zones of iron and manganese accumulation, considerable mineral alteration and stratigraphic position. The physical characteristics, stratigraphy, and lateral variations are similar to the Sangamon paleosols described by Schaetzl (1986) in Brown County, Kansas and Guccione (1982, 1983) in central Missouri. In some upland areas and along divides near the Kansas and Missouri River valleys, this paleosol is thin and possibly truncated by erosion that occurred during late Pleistocene time. This interpretation is



Figure 35. Stone line and truncated paleosol overlying oxidized and leached diamicton. This type of surface is found truncating drift everywhere in the study area.

supported by the widespread presence of stone lines, which mark erosion surfaces because minor topographic features such as gullies are present along this surface. Where stone lines are present they overlie a thin B horizon of the Sangamon soil or lie directly on the C horizon developed in till. Overlying this is light brown calcareous silt interpreted as late Pleistocene loess. The presence of stone lines in a truncated Sangamon soil probably indicates that erosion occurred just prior to deposition of late Pleistocene loess.

Late Pleistocene deposits

Late Pleistocene deposits were not examined in detail. Other workers have described loess and alluvial materials found in the Kansas City area (Davis, 1955; Bayne et al., 1971, Dean and Davis, 1973). Deposits overlying the Sangamon paleosol complex are considered Wisconsin to Holocene in age by these workers. In the Kansas City area, Wisconsin deposits, especially loess, may be up to 30 meters thick (Dean and Davis, 1973). Numerous paleosols and leached zones were observed by the writer indicating that these deposits represent multiple depositional episodes. Excellent exposures of late Pleistocene loess with multiple paleosols are found near interstate I-70 and 61st Street in Kansas City, Kansas, and in numerous borrow pits north of the Missouri River along Highway 9 in Platte County, Missouri and Highway 210 in Clay County, Missouri.

Summary of stratigraphy and sedimentology

One of the major goals of this study was to determine if multiple glacial sequences are present in the greater Kansas City area. The exposures observed indicate that pre-Illinoian drift in the area was deposited during a single episode of glaciation, with minor local fluctuations along the ice margin. This interpretation is supported by the absence of significant unconformities such as paleosols and erosional surfaces within the drift sequence.

Developed in and truncating drift everywhere is a major erosional unconformity and paleosol. This surface is probably correlative to the regionally widespread erosion surface and paleosol (Ruhe,

1969; Hallberg, 1986). In several sections weathered till was observed beneath pedogenically altered silt. This silt is probably Illinoian age loess (Bayne and others, 1971; Guccione, 1982, 1983), but no criteria besides stratigraphic position are available to assign an age.

In several sections basal tills (Association D) are found separated by outwash deposits (Association B). Bed contacts are conformable and probably represent lateral migration of depositional environments and exposure of lower till and outwash for only a short time before deposition of upper till. In most other exposures a single till is present. Fragments in the lowermost glacial till, overlying bedrock, are dominantly local rock types and include some wood fragments. This indicates that the lower till was the first to be deposited in the area and that the entire sequence has been observed.

A possibility exists that the last advance to deposit sediment in the area may have removed a previously formed paleosol developed in older drift. This seems unlikely because in general ice marginal areas are dominated by deposition not erosion (Flint, 1971). If a paleosol had developed in older glacial deposits it should be preserved in at least a few locations, perhaps in buried valleys. Davis (1955) identified a poorly developed paleosol within glacial till several miles north of the study area (NE1/4, Sec. 30, T54N, R33W, Platte County, Missouri). He interpreted this thin, leached, and oxidized zone as a minor interstadial soil. This weathered zone may have formed during minor retreat and readvance along the ice margin. There really is no basis for correlating such widely separated, poorly developed paleosols, and weathering zones, which many times cannot be traced laterally even over outcrop distances (Dort, 1985). Evidence from this study indicates that the glacial margin was fluctuating locally. In this environment, minor soils may have developed in localized areas during periods of ice retreat. Because the ice margin fluctuated, soils and weathering zones may be discontinuous and time transgressive.

The major depositional environments present were proglacial, subglacial, and possibly lacustrine. The vertical facies sequence in most exposures is proglacial (Association A, B), subglacial (Association C, D, and E) overlain by proglacial, and possible lacustrine sand and clay (Association B

and F). Meltout till and reworked till facies are notably rare (Association E). In only a few locations were diamictons present that displayed sedimentary structures consistent with a supraglacial origin. This may be because these facies were initially uncommon, because they are difficult to recognize, or because they have been preferentially destroyed during subsequent erosion. The predominant till facies present is interpreted as basal till.

Coarse gravel lithofacies (Association A) found at the base of some exposures and in buried valleys are interpreted as sediments deposited during initial glacial advance, development of proglacial lakes, and derangement of the preglacial drainage. Basal till lithofacies (Association C and D) of mostly local material and incorporated sand and gravel were deposited as initial advance proceeded to maximum glaciation. Minor retreat, at least locally, is evident because of outwash (Association B) deposited between tills. During and after deglaciation, minor outwash and lacustrine sediments were deposited (Association B and F).

Ice movement data in the area show a consistent south to southeast trend. Locally, a south-southwest trend is seen near the confluence of the Kansas and Missouri Rivers. The southwest trend was found mainly in this area, so it may be a local phenomenon related perhaps to sublobe development or deflection of ice flow around the prominent Wyandotte and Swope-Dennis bedrock upland near the confluence of the Kansas and Missouri Rivers. It may also indicate that local topographic features complicate ice movement data and give a misleading impression of regional ice flow when only a few data points are available. Ice movement followed a course parallel to the modern Missouri River north of Kansas City and perpendicular to the glacial border. The south-southeast trend may indicate that the Dakota Lobe was responsible for depositing sediment within the study area, but more data are needed to support this interpretation of regional ice flow.

Massive clay, silt, and fine sand overlying till (Association F) probably were deposited in lakes and small depressions that developed on the deglaciated surface (Frye and Leonard, 1952; Howe and Heim, 1968). The fact that clay overlies oxidized and leached till indicate that a significant period of time elapsed between deglaciation and deposition of at least some clays, or that weathering occurred

along with deposition. Clay at similar elevations in Wyandotte and Platte Counties presents the possibility that the lacustrine environment was once continuous across the present Missouri River Valley segment north of Kansas City. This would support the idea that the modern Missouri river segment between Kansas City, Missouri and Atchison, Kansas is a postglacial feature (Frye and Leonard, 1952, Heim and Howe, 1968; Bayne and others, 1971).

Following deglaciation, soil formation and erosion were the dominant processes acting upon the landscape. This postglacial erosion probably removed most surface outwash, supraglacial facies, and lacustrine facies deposited during deglaciation, except in a few restricted topographic settings. The removal of a large amount of the glacial record is supported by several observations. There is a significant lack of meltout till, outwash, and reworked till in the study area. In areas effected by late Pleistocene glaciation these deposits, along with recognizable glacial landforms, are common. The thickness of drift is highly variable north of the glacial terminus, with many areas entirely devoid of drift. Additionally, pebble lag concentrations and concentrations of granite and Sioux Quartzite boulders indicate that large amounts of drift may have been removed from the area sometime after deglaciation. It is probable that most of the drift was removed during the middle Pleistocene because the Sangamon paleosol in general follows the present upland topography and is only truncated along lower valley slopes (Heim and Howe, 1963; Davis, 1955).

The next major depositional periods after glaciation were during the middle and late Pleistocene when large quantities of Illinoian and Wisconsin loess, and alluvium were deposited. This occurred during subsequent glaciations when ice advanced only as far as Des Moines, Iowa, and Yankton, South Dakota.

In summary, no evidence suggests that more than one major glaciation occurred within the study area. Fluctuations along the ice margin did occur, complicating the glacial sequence somewhat, but there are no significant unconformities present to justify a subdivision of the drift sequence. Ice movement data suggest that the Dakota Lobe deposited drift within the study area.

PART II- PALEOMAGNETISM

The present stratigraphic framework for pre-Illinoian deposits in the Central Plains (Figure 5) is based on volcanic ash chronology and paleomagnetism. Drift stratigraphically below the Pearlette O ash has been found to be of both normal and reverse polarity. The last major reversal in the earth's magnetic field occurred approximately 750,000 years ago (Mankinen and Dalrymple, 1979; Baksi et al., 1992). This reversal boundary has been used as a major stratigraphic marker in assigning an age to glacial drift in North America.

Abdelsaheb (1988) reported normal polarity for lower Kansan tills in northeastern Kansas. Because of this he inferred that the drift sequence in northeastern Kansas is younger than approximately 750,000 years. Tills studied by Abdelsaheb are probably equivalent or older in age than tills within the study area. Unfortunately, Abdelsaheb failed to identify the mineralogic carrier of stable remanence and discuss what the acquisition mechanism of remanence is. To better understand the paleomagnetism of tills similar to those examined by Abdelsaheb (1988), a small number of samples was analyzed to determine remanent magnetism, identify the magnetic carriers responsible for stable remanence, and discuss the mechanism of acquisition of remanence.

Paleomagnetic analysis

Samples for determination of remanent magnetism were taken from four sections within the study area (see Table 1 for locations). Between 3 and 12 samples were taken from each section. Seventeen samples were completely analyzed. Before data is presented, a brief discussion of the principles and problems associated with paleomagnetic techniques is presented.

One of the most important aspects of a paleomagnetic investigation is an understanding of the process of acquisition of remanent magnetism in the sediments being studied. Detrital remanent magnetization (DRM) is a well known empirically based mechanism for the acquisition of remanent magnetism in water-laid sediments (Sharma, 1986). DRM theory has been modified to explain the

remanent magnetism of glacial tills as postdepositional remanent magnetism (pDRM) (Easterbrook, 1983).

In the pDRM model, detrital magnetite grains align themselves to the ambient magnetic field in water-filled pore spaces within the sediment (Figure 36). As sediment becomes compacted, magnetite grains are locked into place after critical porosity and moisture content values are reached. Any shear stresses present in the basal zone during deposition and dewatering affect only larger, low coercivity magnetite grains, which do not contribute to stable remanence. The smaller, silt grains of magnetite, are not affected by basal shear, become energized by brownian motion, and are biased by the earth's magnetic field. Silt sized magnetite grains are the primary carrier of stable remanent magnetism.

The important parameters controlling the acquisition pDRM in glacial tills are: (1) presence of ambient magnetic field, (2) magnetic mineralogy, (3) hydrodynamic and compactional forces, (4) particle size distribution, and (5) brownian motion (Easterbrook, 1983). Of these parameters, 1 is assumed to be relatively stable over time periods longer than the time necessary to acquire pDRM, and 2 through 4 are variable in sediments.

Glacial sediments in general contain substantial amounts of detrital magnetite, principally derived from crystalline igneous source rocks. The presence of magnetite in glacial diamictons in the study area is demonstrated by several methods. Heavy mineral analysis indicates that unaltered magnetite grains are present in the fine sand fraction (.0625-.125 mm). Although this magnetite is too large to contribute to the remanent magnetism, it does indicate that unaltered detrital magnetite is present. Magnetic susceptibility values are also relatively high, indicating that significant magnetite is present. Finally, isothermal remanent magnetism (IRM) acquisition curves (Figure 37) show saturation values (SIRM) by the 200 mT step. This indicates that magnetite is the primary magnetic mineral phase present in these sediments (Thompson and Oldfield, 1987). Additionally, samples quickly lose much of their original remanent magnetism during alternating field demagnetization. This

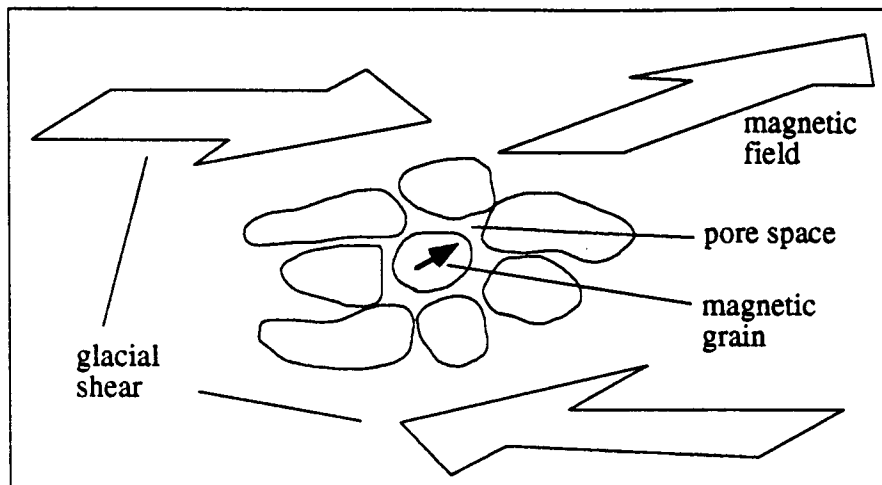


Figure 36. Diagram illustrating the process of acquisition of detrital remanent magnetism (pDRM) in glacial till (after Easterbrook, 1983).

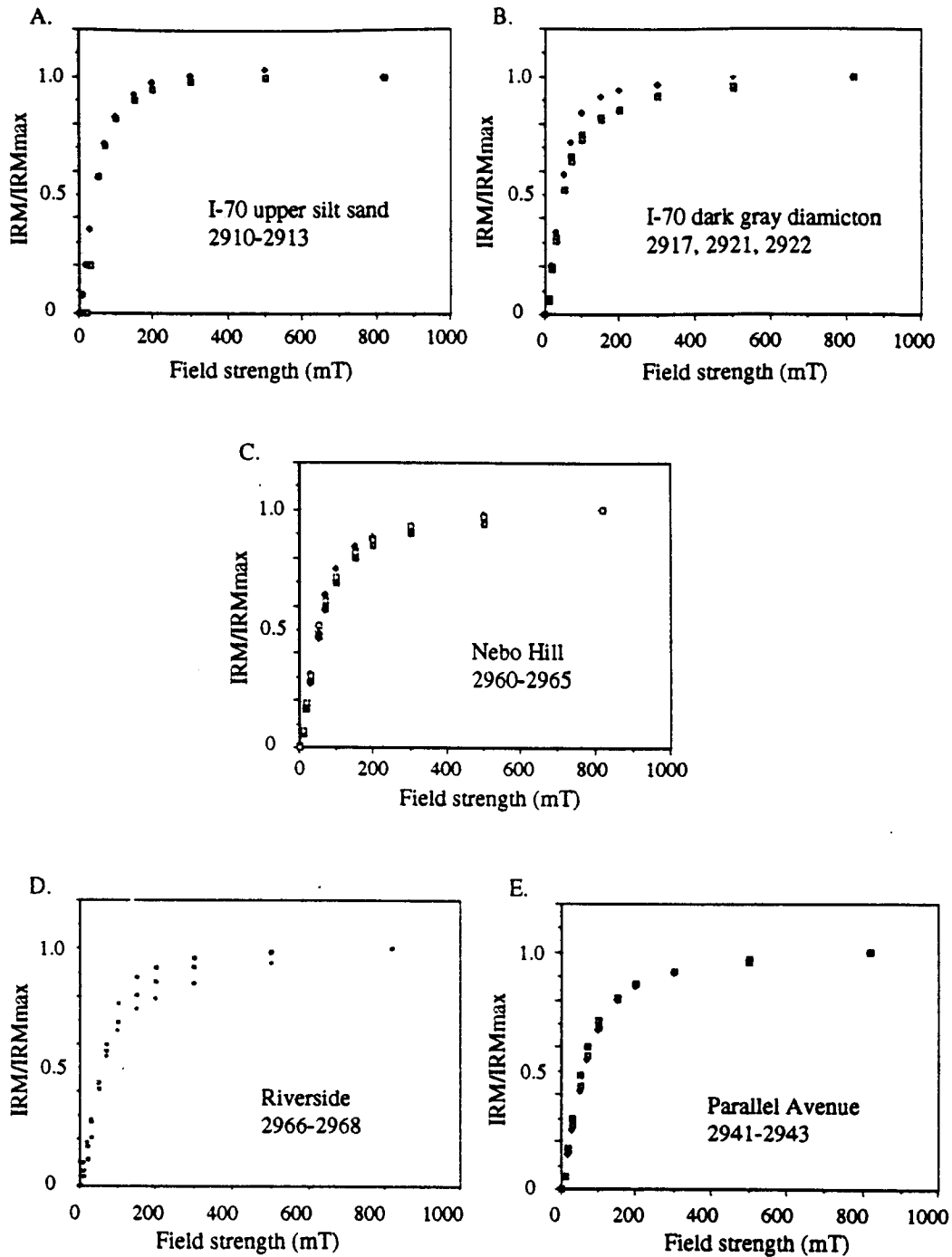


Figure 37. IRM plots for paleomagnetism samples. Maximum field strength was 820 mT. Samples all show most IRM acquired by 200 mT step, indicating that the predominant magnetic mineral is magnetite. Samples that show a slower approach to saturation probably include minor amounts of hematite.

also indicates that magnetite is the primary carrier of remanent magnetism (Thompson and Oldfield, 1986).

Grain size analysis shows that there is a high percentage of silt in till matrix (30-50%). Silt sized, single domain and pseudo-single domain magnetite grains usually are the principle carriers of stable remanence in glacial sediments (Easterbrook, 1983). For this reason, most matrix rich tills have relatively high intensities of remanent magnetism and are suitable for paleomagnetic studies.

In addition to identifying the acquisition mechanism of the original remanent magnetism, other secondary remanent magnetizations must be identified. These secondary components can have a much different remanence than the primary remanence. For example, after acquisition of DRM or pDRM many sediments may be subjected to a magnetic field different than that recorded during deposition. Sediments deposited prior to the Brunhes-Matuyama reversal boundary would acquire an original reverse polarity, but then would be subjected to a normal magnetic field for approximately 750,000 years. This may cause the sediment to acquire a north-normal, viscous remanent magnetization (VRM) component over the original remanent magnetization (DRM or pDRM). Also, a VRM may be acquired during storage and partial drying of the samples prior to measurement (Thompson and Oldfield, 1986). Subjecting a sediment to high intensity magnetic fields at a constant temperature may also induce a strong magnetism, called isothermal remanent magnetism (IRM). This occurs in nature when lightning strikes induce an IRM to surface rocks and sediments. These components of the remanent magnetism must be removed before the true remanent magnetization can be determined. Fortunately, acquired VRM and IRM are not stable and usually can be removed relatively simply by various techniques (Butler, 1992).

Another more difficult problem exists when sediments have been chemically altered in some way. Pedogenic and diagenetic ferri- and ferromagnetic minerals may be formed in a preexisting detrital sediment. As grains grow they record the ambient magnetic field present during precipitation. As a result, a chemical remanent magnetism (CRM) component may also be acquired, overprinting the original DRM, and even destroying it if original detrital magnetite is altered completely.

Finally, the most important and difficult aspect of paleomagnetic analysis is determining the component of remanent magnetism that is the original stable component and removing unstable components such as VRM, CRM, or IRM. Ideally, stepwise alternating field or thermal demagnetization should remove any unstable components of the remanent magnetization (VRM or IRM), leaving the original remanent magnetization. After a significant percentage of the remanent magnetism is removed during alternating field demagnetization, a stable principle component of the primary remanent magnetism should remain. In sediments in which magnetite and titanomagnetite are the principle carriers of remanent magnetism, alternating field demagnetization is often effective in removing secondary NRM (Butler, 1992). In these sediments, secondary NRM is usually carried by larger multidomain grains with low coercivity. Primary NRM is retained by smaller single domain and pseudo-single domain grains with higher coercivity (Butler, 1992). If sediments are unaltered this primary remanence is probably DRM or pDRM in origin, but in altered sediments CRM may be the primary form of remanent magnetism.

Methods

Samples were taken in sets of three closely spaced (within 15 cm) orientated samples to check variability between samples. At each section a fresh vertical face was cleared in matrix-rich till that appeared to be undeformed and undisturbed. All of the tills sampled, except three samples from Parallel Avenue and two samples from the I-70 exposure, were unoxidized and unleached till. Two samples from the I-70 exposure were taken from oxidized sandy silt. Three samples taken from the Parallel Avenue exposure were of leached and oxidized till. These samples were taken to compare NRM of oxidized and unoxidized deposits.

The samples were taken by pushing or gently tapping a polystyrene sample box (1" x 1" x 3/4") into the vertical face. At most sections it was possible to push the plastic sample containers into the sediment, but in a few samples, cubes were gently tapped in with a hammer while covering the sample cube with a field notebook. Easterbrook (1983) reports that shock remagnetization has never

occurred in any of 300 samples he has driven in with a hammer. Sediment distortion is possible, but clear plastic holders enable identification of distorted samples, which can be discarded. After the sample holders were pushed into the vertical face, their orientation was measured. Orientation measurements are probably only accurate to 5-10 degrees. The vertical orientation of samples was approximated by placing the sample boxes in a vertical position. Vertical orientation is probably also only accurate to 5-10 degrees. After orientation, samples were dug out of the vertical face, trimmed, and the sample boxes sealed. Some samples partially dried out in their containers before being measured, but shrinkage was minimal due to the low moisture content of the sediment.

Samples were taken to the University of Minnesota and the remanent magnetization was measured in three mutually perpendicular orientations with a three-axis ScT cryogenic magnetometer. The samples were demagnetized using a Schonstedt ASD-1 single axis alternating field demagnetizer, in steps of 2.5, 5.0, 7.5, 10, 15, 20, 30, 40, 60, 80, and 100 mT. The resulting remanent magnetism was remeasured after each step.

Declination, inclination, and intensity values were calculated from raw data using standard vector equations (Butler, 1992). Best fit vectors and maximum angular deviation (MAD) values of selected components were calculated using a program supplied by Randy Farr of the University of Kansas. MAD values calculated with this program employ a free line fit method in which the origin is not included in the best fit line. Best fit vectors for a set of samples were plotted on equal area stereonet using a program called Stereonet 4.1. Statistical analysis in this program uses Fisher distribution statistics to calculate 95% confidence cone ($\alpha 95$), and dispersion parameter (k).

Samples were then subjected to step remagnetization using an electromagnet at the University of Kansas imparting an isothermal remanent magnetism (IRM) to aid in determining magnetic mineralogy. Steps for remagnetization were 10, 20, 30, 50, 100, 150, 200, 300, 500, and 820 mT. Between each remagnetization step the imparted magnetization (IRM) was measured on a Molspin Minispin model spinner magnetometer at the University of Kansas. Induced magnetization was calculated and IRM acquisition curves plotted for each sample.

Results

Appendix II includes data for the 17 samples analyzed. Zijderveld diagrams, equal area stereonets of remanence vectors, difference vectors, and intensity versus demagnetization plots, are provided for each sample. Summary diagrams for each set of samples are shown in Figure 38. Each set of samples will be discussed briefly.

Samples 2910 and 2913 are from a light reddish brown, oxidized, sandy silt sampled approximately 8 meters from the base of the I-70 south exposure (Figure 6, # 13). Both samples show two components of remanence. One component with east declination and positive inclination, and another with north declination and positive inclination (see Appendix II for Zijderveld plots). The low coercivity east component is probably a VRM acquired during sample storage. The high coercivity component is a stable DRM, pDRM, or CRM. The stable component for sample 2910 has a best fit vector of positive inclination of 51 degrees and declination of 5 degrees after demagnetization to 40 mT. Maximum angular deviation (MAD) for this component is 6.5 degrees (values below 10 are considered good, Butler, 1992). Sample 2913 shows a similar component with best fit vector of inclination 71 degrees and declination 15 degrees. MAD value for this component is 7.2 degrees. In both of these samples half of the original intensity ($J/J_0 = 0.50$) is lost near the 20 mT step (17 mT and 20 mT respectively) and IRM plots show saturation at 100 to 200 mT. This indicates that magnetite is the primary magnetic mineral phase in these samples (Thompson and Oldfield, 1986; Butler, 1992). Since magnetite is the primary carrier of remanence probably as high coercivity single domain grains, the NRM is probably primary DRM or pDRM although pedogenic magnetite or other phases contributing as a secondary CRM are possible for these samples.

Samples 2917, 2921, and 2922 are from a dark gray unoxidized basal till below sandy silt in the I-70 south exposure (Figure 6, #13). Sample 2917 was taken 2 meters above the base of the exposure and samples 2921 and 2922 were taken at the base near road level. A single low coercivity component is present in these samples. Best fit vectors for this component has a generally NW to W declination and positive inclination. All samples lost more than half of their original intensity ($J/J_0 =$

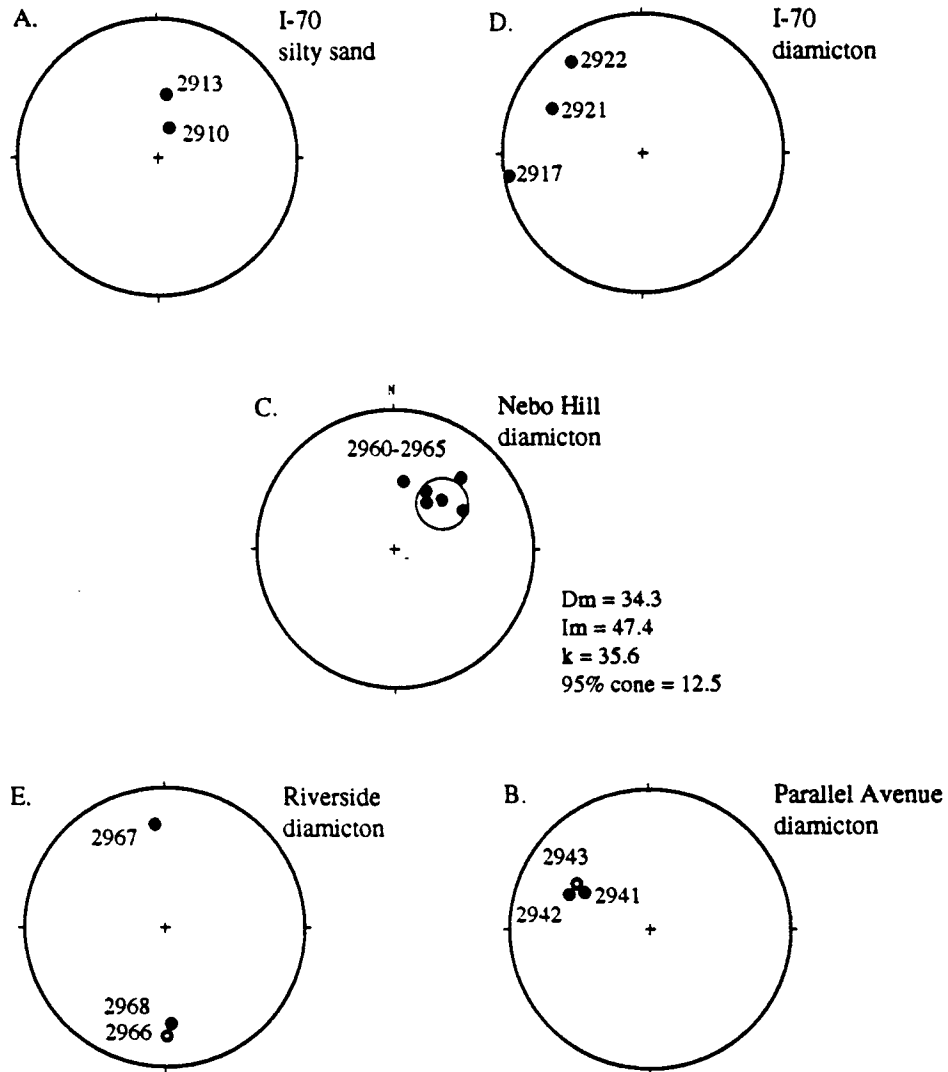


Figure 38. Equal area stereonet of best fit vectors for samples from various sites. Dark circles indicate normal polarity and open circles reversed polarity. Most samples have stable remanence components that are north and normal.

0.50) by the 10 mT step (3.2 mT, 6.3 mT, and 2.6 mT respectively) indicating that magnetite is the primary carrier of remanence. IRM curves show saturation magnetization by the 200 mT step. The slower approach to saturation by samples 2921 and 2922 may indicate that minor hematite is present in these samples (Thompson and Oldfield, 1986). Low coercivity indicates that larger single domain grains of magnetite are the primary carrier of remanence perhaps as DRM or pDRM.

Samples 2941, 2942, and 2943 are from the Parallel Avenue exposure (Figure 6, #15). All samples display a single component of remanent magnetism. Sample 2943 has inclination of negative 40 degrees and a declination of 294 degrees after the 10 mT step. Samples 2941 and 2943 have positive inclinations of 64 and 37 degrees respectively. Declinations were to the west and northwest respectively. These samples showed higher coercivity losing half of their original intensity between the 10 mT and 40 mT steps (13 mT, 16 mT, 35 mT respectively). IRM curves show that there is a slow approach towards saturation magnetization. This may indicate that another magnetic mineral phase besides magnetite is contributing to the remanent magnetism. Since these samples are oxidized and leached this is expected. Perhaps maghaemite or goethite produced by the alteration of magnetite is present giving these samples a CRM component.

Samples 2960 to 2965 are from the Nebo Hill section (Figure 6, # 40). The material sampled was a dark gray (N4) unoxidized and unleached till approximately 2 meters above the base of the exposure. All of these samples show a single component of remanent magnetism. Best fit vectors of all samples show positive inclinations and north to northeast declinations. Sample 2960 has a high original intensity and coercivity. This sample retains 71% of its original intensity after 10 mT demagnetization. This indicates that fine grained high coercivity magnetite is the primary carrier of remanent magnetism in this sample. All other samples show a 50% decrease in intensity near the 10 mT step. IRM curves show a slow approach to saturation magnetization indicating that minor hematite or maghaemite is present. The cluster of best fit vectors for this set of samples is reasonably good with a 95% cone of 12.5 degrees and a k value of 35.6 (low alpha 95 values and k values above

25 are considered good, Butler, 1992). Since magnetite is present and these samples are relatively unaltered, the NRM is probably primary DRM or pDRM

Samples 2966, 2967, and 2968 were taken from an exposure near Riverside, Missouri (Figure 6, # 24). The material was dark gray (N4) unoxidized and unleached till approximately 3 meters above bedrock. Samples 2967 and 2968 both have very high original intensities and show no decrease in intensity with stepwise alternating field demagnetization. Sample 2966 actually increased in intensity during stepwise cleaning to 10 mT. IRM curves for 2966 and 2968 show saturation magnetization at 100-200 mT, whereas sample 2967 shows a slower approach to saturation. This may indicate that these samples contain another mineral phase contributing to the remanent magnetism perhaps as a CRM. Sample 2966 shows a negative inclination and south declination. Samples 2967 and 2968 have positive inclinations.

Conclusions

The magnetic characteristics of the samples are fairly complex, indicating that the magnetic mineralogy is also fairly complex, but in both oxidized and unoxidized diamictons magnetite is the primary carrier of remanence. In most samples a small amount of a high coercivity phase is also present. Magnetite is present in oxidized and leached samples, but its origin and weathering state are less certain than in unoxidized samples. Susceptibility analysis (in Part III) indicates that two populations of different sized magnetite are present in oxidized and unoxidized diamictons. Because unoxidized diamictons usually contain large amounts of authigenic pyrite, it is possible that smaller single domain magnetite grains are being dissolved and converted to pyrite during sulfate reduction. This would explain the magnetic differences between oxidized and unoxidized diamictons. This factor together with the presence of other magnetic mineral phases such as goethite and maghaemite in oxidized drift, complicate the interpretation of the paleomagnetic results and suggest that slightly oxidized and unleached diamictons are best suited for paleomagnetic analysis.

Most of the samples analyzed exhibit a remanent magnetization of normal polarity that is relatively stable during alternating field demagnetization. Two samples possess a reverse remanent magnetism before and after alternating field demagnetization. One of the reversed samples came from leached diamicton and the other has magnetic characteristics suggesting other mineral phases besides magnetite are present. Unoxidized and unleached samples show a relatively stable normal polarity that is probably original DRM or pDRM. Partially oxidized samples also show a normal polarity, but this could be a later acquired chemical remanent magnetism (CRM).

A normal NRM acquired as DRM or pDRM in these sediments indicates that deposition occurred during a time when the earth's magnetic field was normal. The last major reversal occurred sometime between 730,000 (Mankinen and Dalrymple, 1979) and 780,000 (Baksi et al., 1992) years ago. Paleomagnetism cannot alone provide a date for sediments because the change in polarity may belong to any number of magnetostratigraphic epochs or events. The results of this study indicate that it is possible that sediments were deposited during the Brunhes normal polarity chron as Abdelsaheb (1988) concluded. The possibility also exists that they were deposited during another normal polarity subchron present between 2.1 Ma and 0.9 Ma.

PART III - LITHOLOGY OF GLACIAL DEPOSITS

In order to correlate tills in the study area with tills previously described by Aber (1991) and Guccione (1982, 1983) several parameters were chosen for comparison. Data for the Independence Formation in northeastern Kansas consist of small pebble lithology, heavy minerals (Nutter, 1988), and clay mineralogy (Aber, 1988a). Guccione's (1983) data for the McCredie formation (informal) consists primarily of texture data, heavy mineral data, and clay mineralogy data. Small-pebble counts and heavy mineral analysis were chosen as the primary lithologic means of comparing deposits. These parameters, combined with stratigraphy, paleomagnetism, and relation to paleosols, may provide enough information to make a reasonable correlation.

Clay mineralogic analysis was not attempted primarily because quantitative analysis of clay minerals using x-ray diffraction techniques is neither easily done nor highly accurate (Moore and Reynolds, 1989). Generally, comparisons made between laboratories are highly suspect. Small-pebble counts, besides being relatively simple, probably are less subjective and not highly dependent on the laboratory methods used (Gale and Hoare, 1991). Heavy mineral analysis, while being somewhat subjective and dependent on the methods used and petrologic skill of the researcher, may be accurate enough to roughly compare data sets in a semi-quantitative way. Grain size analysis and magnetic susceptibility were also investigated to provide basic lithologic data.

Color

Color of glacial sediments in the study area is mainly dependent on weathering and oxidation state. This is best seen in the differences in the color of diamictons. Most surface diamictons are leached and oxidized. This imparts a characteristic yellow brown and olive color to the sediment. Deeply buried diamictons have distinctly reducing dark grays and olive gray colors. Usually the contact between oxidized and reduced colors is gradational over several meters, but in some sections, especially where outwash is interbedded with diamicton, the color change is very abrupt. In oxidized sediments

wide (cm scale) oxidized, alteration haloes around closely spaced (cms to 1 meter) joints are present. With depth in reduced diamictons joints are widely spaced (meters to 10s of meters) and only rarely have narrow alteration haloes (mm scale).

Texture

Textural differences in the grain size distribution of tills have been used to differentiate one till from another (Dremanis and Reavely, 1953). Unfortunately, this method has not been found to be of much use in the the Central Plains because there is little variation in the texture of till matrix in the area (Hallberg, 1980). This is because the texture of till matrix is greatly influenced by the underlying sedimentary bedrock (Landim and Frakes, 1968). Areas underlain by crystalline igneous rocks generally have a sandy till matrix (matrix equals <2 mm fraction; Dremanis and Vagners, 1972). This reflects the breakdown of crystalline rock into its monomineralic, sand sized constituents. In areas underlain by carbonates, and siliciclastics, till matrix reflects the finer grained shales. Textures in these areas are usually of a sandy loam to loam texture with generally equal percentages of sand, silt, and clay sizes. Hallberg (1980) found in the analysis of over four hundred samples that there was very little difference in the till matrix texture of various tills in Iowa of widely different ages. Mooers (1990) also found, in central Minnesota, that tills known to have different source regions, had matrix textures that were indistinguishable.

For these reasons this study did not attempt to correlate tills by their texture. Grain size analysis was done instead to determine the variation within till and to determine what effect weathering had on texture. This information is needed to better evaluate magnetic susceptibility data, which is dependent on grain size variations.

Samples were taken as either 500 gram or 2000 gram bag samples or from bulk 25 kg samples. Small subsamples were split out and analyzed following the methods of Lewis (1984). A detailed description of the pipette methods used is included in Appendix III.

The results of grain size analysis for the samples analyzed are found in Appendix IV. Figure 39 shows a summary diagram of sand, silt, and clay percentages for the diamicton samples analyzed. Most of the samples analyzed were basal tills and only two samples were meltout or resedimented tills. The ternary diagram shows that there is a significant textural difference between oxidized and leached diamictons, and unoxidized and unleached diamictons. The oxidized and leached diamictons have a lower percent sand and silt, and higher percent clay than do unoxidized and unleached diamictons. This relationship is the same as that noted by Sladen and Wrigely (1983) for similar diamictons in Britain. The simplest explanation for this is that in weathered diamictons sand and silt sized particles are being broken down into clay size. It was originally thought by the writer that incomplete dispersion during analysis could be producing this effect, but there was no evidence of flocculation in the samples during analysis. Samples that did show signs of flocculation were discarded or more dispersant was added and the analysis redone. Additionally there was a general decline in sand percent in the oxidized and leached samples, so it appears that both breakdown of particles, authigenic clay formation, and pedogenic enrichment are possible explanations for the differences in diamicton matrix texture.

For unleached samples there was a relatively well defined textural range for the samples analyzed. This agrees with work of Hallberg (1980) and Stephenson and others (1988) who argue that basal tills show relatively little matrix texture variation within a given region.

Small-pebble lithology

Bulk samples of approximately 25 kg of diamicton and outwash were taken from various till units and analyzed for small pebble (4-8 mm) and >8 mm pebble lithology (see Appendix V for locations). 25 kg of till commonly yielded between 200 and 1000 4-8 mm pebbles, the same size sample of gravel and outwash included many more small pebbles. Between 400 and 500 pebbles is optimum for estimating the true frequency of a lithology in the total population with the maximum accuracy (Gale and Hoare, 1991). In some samples it was not possible to collect this many pebbles because of the large amount of bulk sample needed. The pebbles were separated from the finer fractions

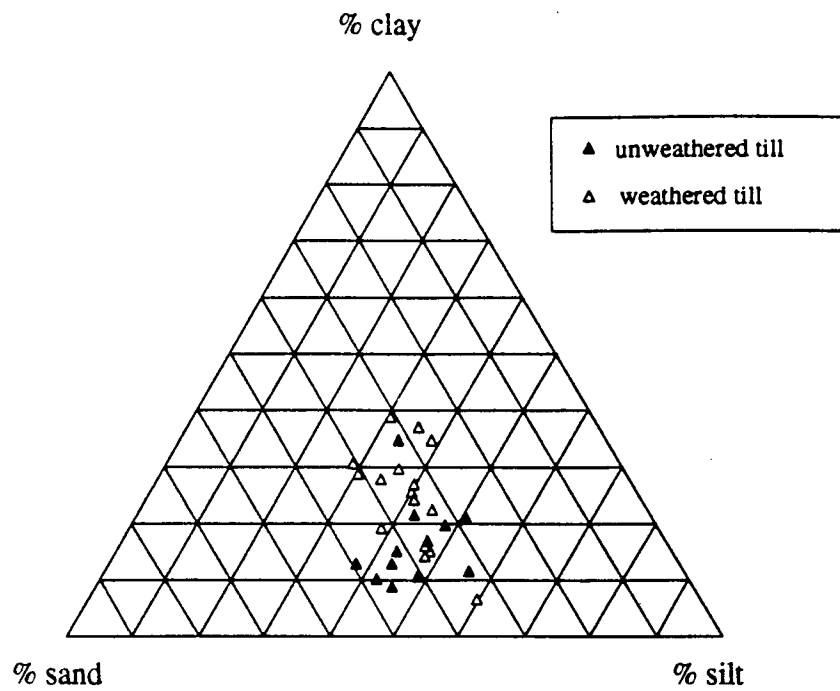


Figure 39. Summary of pipette data for till matrix. See Appendix IV for data.

by washing over a 2 mm screen. This procedure for diamictons was relatively time consuming and required soaking samples for several days before fines could be wash away. After washing, the greater than 2 mm fraction was air dried and the 4-8 mm and <8 mm fraction were separated by hand sieving.

Pebbles were classified according to lithology into one of following categories. Felsic igneous rocks were the most easily identified, they usually consisted of feldspar, quartz, and mica. In the majority of samples, granite made up most of this category. Mafic igneous rocks were identified by a finely crystalline dark matrix and high hardness (> 5.5). The most common mafic igneous rocks were basalt and gabbro. Metamorphic rocks were polycrystalline and foliated. Gneiss and schist were the most common metamorphic lithologies. Metagraywacke was distinguished by its dark greenish gray color, presence of fused detrital sand grains abundant matrix, and high hardness. Davis (1955) provides an excellent detailed description of this common erratic. Sioux Quartzite was distinguished by its distinctive pink, red and purple colors, high hardness and fused quartz grains. Chert was recognized by its high hardness, angularity, and conchoidal fracture. Limestone and dolomite were identified by reaction to acid, low hardness (<5.5), and fossil content. Sandstone, siltstone, shale, and ironstone were grouped together and were distinguished by detrital texture, fissility, and low hardness.

Pebbles were identified using an acid bottle, penknife, and hammer. Some pebbles required the use of a binocular microscope to determine lithology. Of all the categories, the mafic igneous pebbles and metamorphic pebbles were the most difficult to identify. Some pebbles classified as mafic igneous may be metagraywacke or metamorphic rocks. The identification of metagraywacke was accomplished by wetting pebbles and then identifying them under the binocular microscope. Some metamorphic rocks such as granite gneiss may have been misclassified as felsic igneous rocks.

The results of the pebble counts show that in unoxidized and unleached diamicton the largest percentage of pebbles are of local origin (Figure 40). The most abundant pebbles were of lithologies similar to bedrock underlying the till. Chert was found to be reasonably constant at 4-5% in diamicton. The percentage of erratics varies depending on weathering state of diamicton. This effect was seen in sections in which multiple samples were taken and in a single section that was sampled at

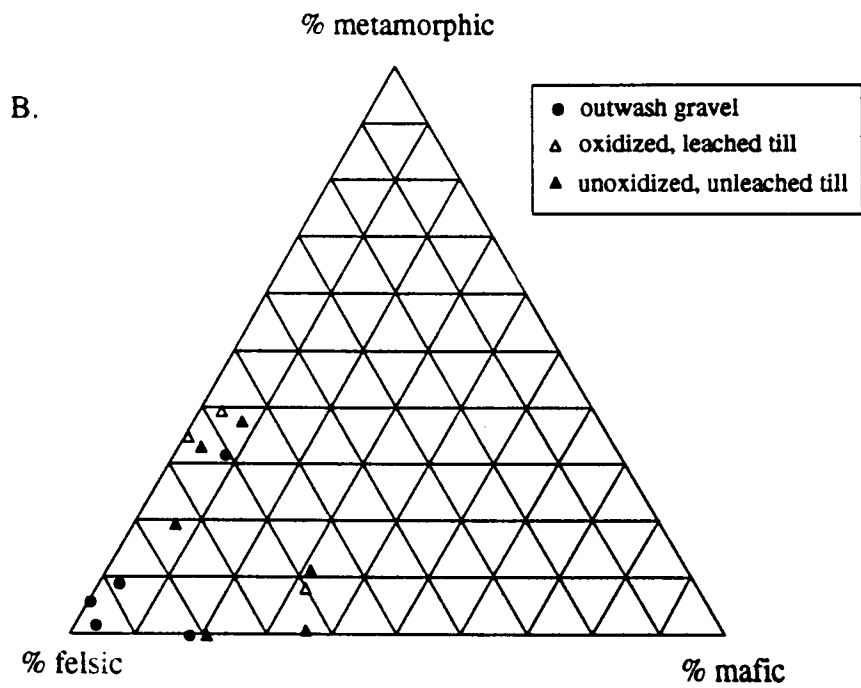
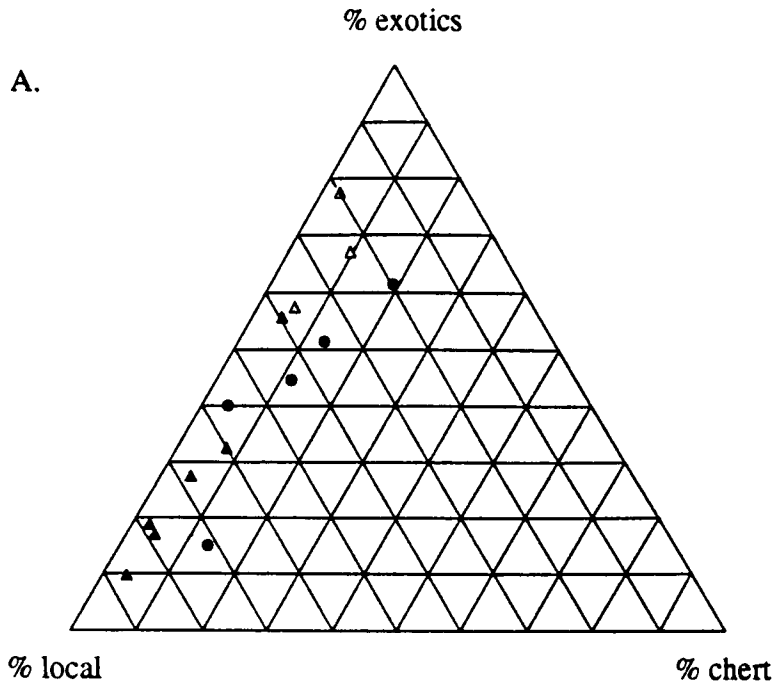


Figure 40. Summary plot showing lithology of 4-8 mm pebbles of all samples. All lithologies (A) and exocytic lithologies only (B).

half-meter intervals (Figure 41). In this section unoxidized and unleached till is dominated by local lithologies, mostly limestone. Higher in the section, as degree of leaching increases, limestone decreases, therefore increasing the percentage of erratic lithologies.

Table 5 is a summary of data from the study area, northeastern Kansas, and northwestern Missouri. Averages are calculated for data from this study, data from Platte County, Missouri Davis (1955), and data from northeastern Kansas (Nutter, 1988). The average percentages for each set of samples are similar.

In oxidized and leached samples, felsic igneous rocks and local siliciclastic rocks become the most common lithologies. This is because most and sometimes all, of the original limestone has been eliminated during weathering. The destruction of limestone accounts for almost all of the differences between weathered and unweathered tills. When the percentages of lithologies present in unweathered tills are recalculated without including limestone, the resulting percentages are similar to weathered tills.

Davis (1951) and Aber (1988a) both recognize that the pebble lithology of tills and outwash in Kansas is significantly different and can be used to distinguish outwash and till. Outwash gravels consistently have a higher percentage of resistant chert and erratics that become concentrated with increased transport energy and distance. This trend was also seen in outwash samples from the study area.

The pebble lithology of diamictons in the study area is similar to that of diamictons in northeastern Kansas. Figure 42 presents data for the Independence Formation (Nutter, 1988). One problem encountered in comparing data from the study area with that of Nutter is that no metamorphic lithologies besides Sioux Quartzite are reported in Nutter's data. Metamorphic lithologies, especially a common metagraywacke that Davis (1955) describes in detail, are absent. These were classified in the mafic category (Nutter, 1988 p.18). When data for the study area are regrouped into Nutter's categories of Sioux quartzite, felsic, and mafic lithologies, the two data sets are roughly the same (Figure 43). It was found in this study that the presence of the metagraywacke was generally common. Perhaps this

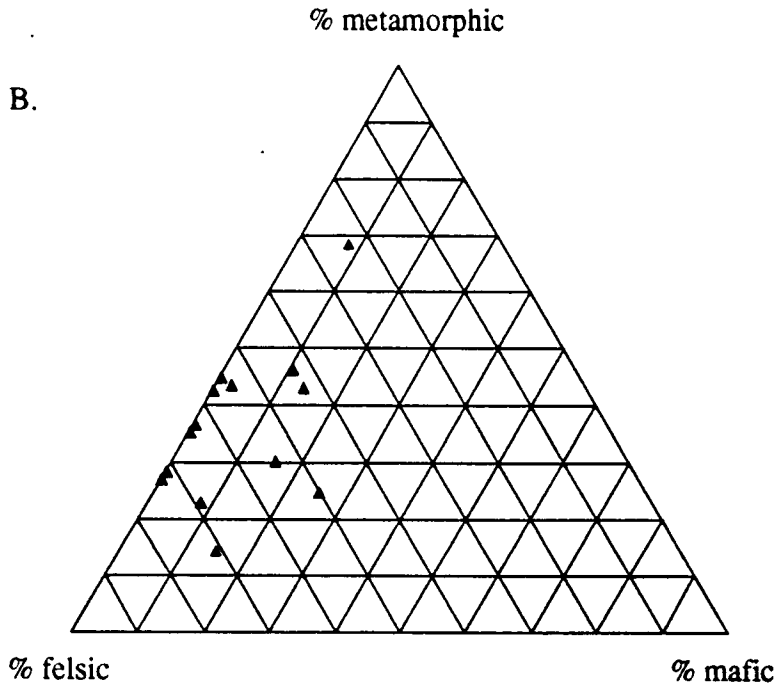
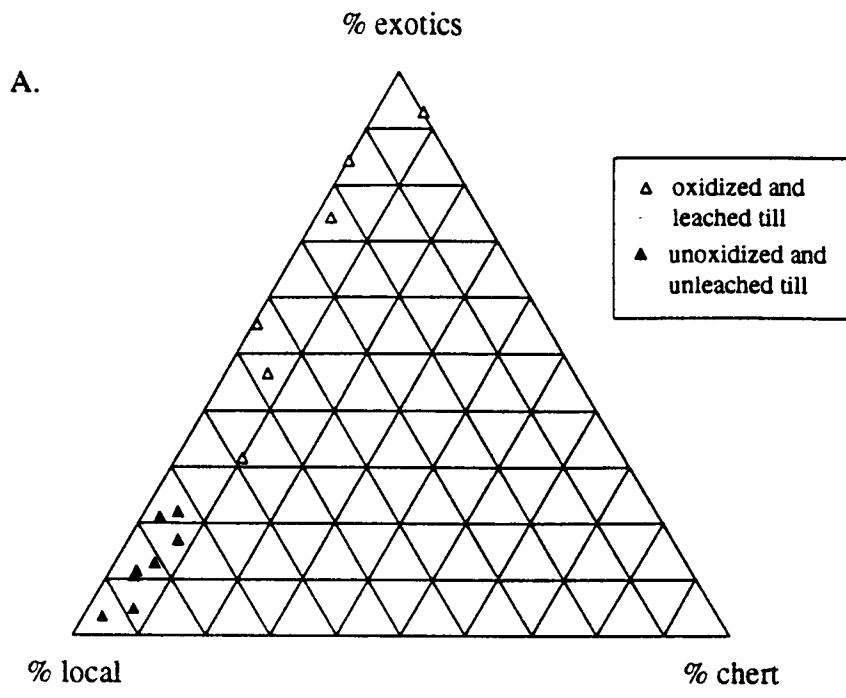


Figure 41. Results of pebble counts for highway 152 section. All lithologies (A), and exotic lithologies (B). See Appendix V for data.

Table 5. Summary of small pebble data for diamictons in northeastern Kansas and northwestern Missouri.

4-8 mm unoxidized and unleached

lithology	This Study	Platte County	NE Kansas**	
	n = 6		n = 5	n = 13
felsic	13.6	10.2	10.9	7.6
dark igneous	4.3	0.8	6.6 ¹	2.6 ¹
metamorphic	6.2	14.0	-	-
Sioux quartzite	0.04	0.4	0.9	0.7
quartz	2.8	2.6	3.0	1.2
chert	4.1	4.2	6.7	4.4
limestone	50.6	51.6	52.0	54.0
sandstone/shale	18.4	16.2	19.7	29.0

4-8 mm oxidized and leached

lithology	This Study	Platte County*	NE Kansas**	
	n = 3		no data	n = 4
felsic	34.2	-	20.1	
dark igneous	6.9	-	4.4 ¹	
metamorphic	18.1	-	-	
Sioux quartzite	1.6	-	1.3	
quartz	6.8	-	5.6	
chert	5.7	-	6.7	
limestone	5.2	-	19.4	
sandstone/shale	21.6	-	41.0	

4-8 mm unoxidized and unleached minus limestone².

lithology	This Study	Platte County*	NE Kansas**	
felsic	27.5	21.1	22.8	16.7
dark igneous	8.7	1.7	13.8 ¹	5.7 ¹
metamorphic	12.5	28.9	-	-
Sioux Quartzite	0.08	0.8	1.9	1.5
quartz	5.7	5.4	6.3	2.6
chert	8.3	8.7	14.1	9.7
limestone	-	-	-	-
sandstone/shale	37.2	33.5	41.2	63.7

* Data from Davis (1955), samples from Platte County, Missouri.

** Data from northeastern Kansas, Atchison, Doniphan, Nemaha, and Shawnee Counties (Nutter, 1988). Nutter's data includes "dark gray till" (first column) and "brown till" (second column).

¹ percentage includes dark lithologies, basalt, gabbro, greenstone, metamorphic, graywacke.

² percentages calculated from total unweathered samples without limestone class.

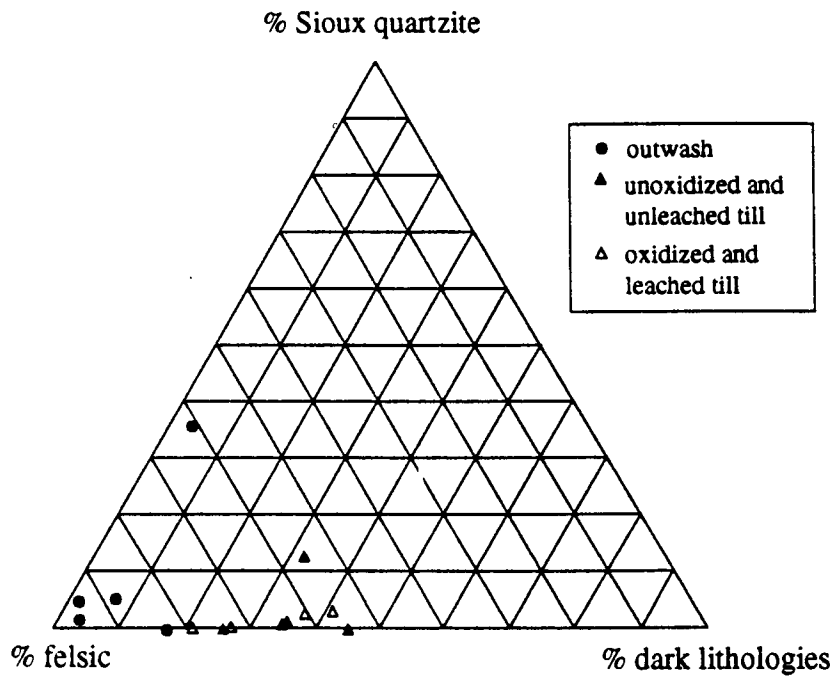


Figure 43. Data from study area grouped into categories used by Nutter (1988). Compare with Nutter's data in previous figure. Both data sets are similar in small-pebble lithology

common erratic could be a valuable indicator erratic if its source area and distribution could be delineated. Anderson (1957) reported that the metagraywacke Davis (1955) described probably came from the Animike and Knife Lake groups in western Minnesota.

Heavy mineral composition

Heavy minerals were analyzed in order to provide data for comparison with previously described glacial tills in northeastern Kansas and central Missouri. The current stratigraphic scheme for the Central Plains recognizes that A and B type tills (see Figure 5) contain high percentages of hornblende (Boellstorff, 1973). Older C type tills contain little hornblende (Boellstorff, 1973). Independence Formation and McCredie formation (informal) contain high percentages of unstable minerals such as hornblende and pyroxene and relatively low percentages of stable minerals such as tourmalene, zircon and garnet. Preglacial sediments contain high amounts of stable minerals and low amounts of unstable minerals (Guccione, 1982; Nutter, 1988; Aber, 1991).

Samples were prepared for heavy mineral analysis by first separating the sand fraction ($>.0625$ mm) from the fine fraction ($<.0625$ mm). The 3.5-4 phi and the 3.0-3.5 phi intervals were saved from sieving for heavy mineral separation. The mineral separation was done using acetylene tetrabromide (sg.= 2.96) following the methods of Lindholm (1987). The heavy mineral grains were mounted on glass slides for point count analysis under a petrographic microscope. A mechanical point count stage and medium power were used. Between 200 and 300 grains were identified from each slide with at least 100 non-opaque grains being identified. Identification of opaque minerals was made in a nonquantitative way using reflected light in order to determine the most common varieties. Identification of non-opaque minerals was completed by comparing grains with standard grain mounts and use of identification keys of Lindholm (1987). Because data was to be compared primarily with data for the Independence Formation in northeastern Kansas, only selected minerals were identified using the same procedure as Nutter (1988). Table 6 lists the minerals identified and the characteristic optical properties used in their identification.

Table 6 - Non-opaque heavy minerals and optical properties used in identification.

<u>mineral</u>	<u>optical group</u>	<u>distinguishing characteristics</u>
garnet	isotropic	high relief, (n = 1.76-1.94) colorless to red, orange or yellow, conchoidal fracture.
spinel	isotropic	high relief (n = 1.72-2.05) colorless to pale pink, also grass green or coffee brown.
kyanite	anisotropic biaxial + or -	low interference colors, parallel and inclined extinction, rectangular grains, colorless, rarely pleochroic high relief (n = 1.71-1.73)
zircon	anisotropic uniaxial +	high relief (n = 1.93-1.99), colorless parallel extinction, high birefringence
sphene	anisotropic biaxial +	high relief (n = 1.9-2.0), pale yellow or brown, incomplete extinction, high birefringence.
pyroxene	anisotropic biaxial + or -	moderate relief (n = 1.67-1.74), pale grayish green, generally nonpleochroic, inclined or parallel extinction.
epidote	anisotropic biaxial + or -	moderately high relief (1.72-1.78), colorless to pale greenish yellow, high birefringence
rutile	anisotropic uniaxial +	very high relief (n = 2.60-2.90), deep red to yellow, weakly pleochroic, parallel extinction
amphibole	anisotropic biaxial -	moderate relief (n = 1.62-1.72), brownish green to greenish blue, and reddish brown, highly pleochroic, inclined extinction (15-25 degrees)
tourmaline	anisotropic uniaxial -	moderately high relief (n = 1.62-1.69), dark brown to rare yellow, parallel extinction.

The most common heavy minerals are opaques, including pyrite and magnetite as the most common opaques. Most of the pyrite appears as spherical or cubic aggregates, but also as framboids. This indicates that some of the pyrite is authigenic in origin. Magnetite appears as both euhedral and anhedral crystals. Amphibole is the most common nonopaque mineral. Both green and blue green varieties are present. Garnet, zircon, epidote, tourmaline, and pyroxene are also common nonopaque minerals. Spinel, kyanite, spinel, and rutile are present, but uncommon. In leached and oxidized, samples mineral alteration of grains is apparent. Hornblende grains are etched and opaques are partially oxidized.

A comparison of unoxidized and unleached samples from the study area and those of the Independence Formation indicates that they are similar (Figure 44). In both, amphibole is the most common non-opaque mineral. Opaques are more common than non-opaques in both data sets. Garnet, zircon, and epidote are the next most common heavy minerals in both data sets.

Magnetic mineralogy

Previous studies have shown that magnetic susceptibility is sometimes a reliable technique for distinguishing one glacial sequence from another (Gravenor and Stupavsky, 1974; Bjork et al. 1982; Goldstein, 1989; Mooers, 1990). Since magnetite is usually the most significant magnetic mineral in glacial sediments, there is commonly a direct relationship between low field magnetic susceptibility and magnetite content (Gravenor and Stupavsky, 1974). Additionally changes in the provenance of tills may also be reflected in the quantity and grain size of detrital magnetite. Mooers (1990) in particular used rock magnetic properties to distinguish tills deposited by two lobes in central Minnesota. The tills studied by Mooers were otherwise similar in grain size and color.

A large percentage of heavy minerals in tills of northeastern Kansas and surrounding states are opaque minerals (Nutter, 1988). Magnetite makes up a large percentage of the opaque minerals (Boellstorff, 1973; Nutter, 1988; Guccione, 1983). The relative abundance of magnetite in glacial tills in the study area could be a characteristic property that in the future might distinguish various glacial

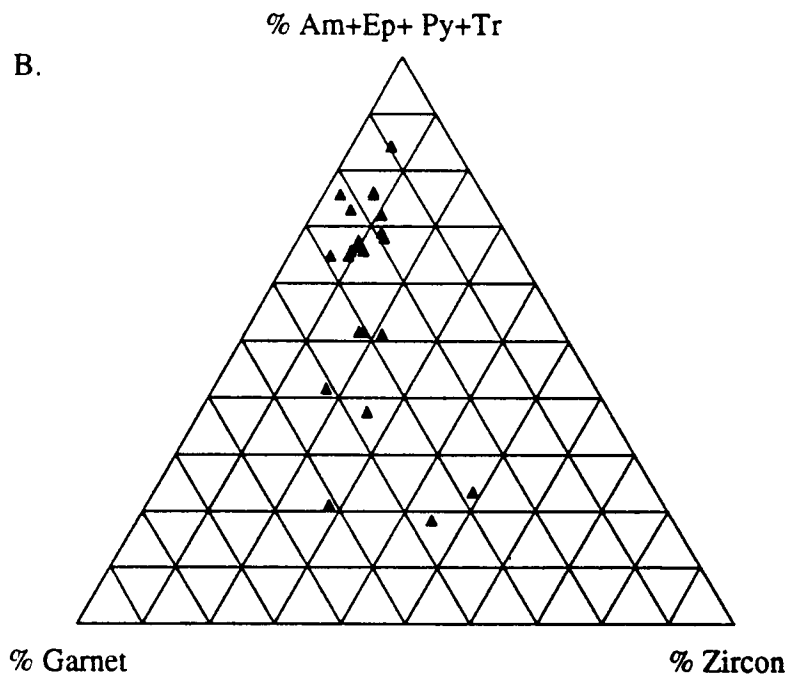
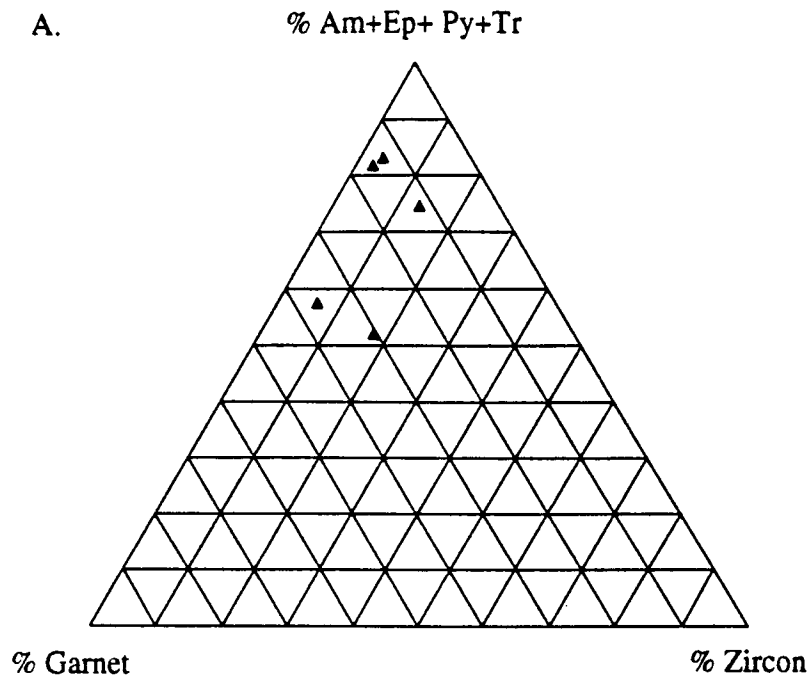


Figure 44. Comparison of heavy mineral data for study area with data for Independence Formation in northeastern Kansas (Nutter, 1988). Data for unweathered tills in the study area (A) and Independence Formation in northeastern Kansas (B).

sequences from another. For this reason the magnetic properties of till in the study area were investigated.

In the past fifteen years numerous methods have been developed to determine the magnetic mineralogy of geologic materials (Thompson and Oldfield, 1986). Three parameters were chosen to compare magnetite in glacial tills. The parameters are low field magnetic susceptibility, frequency dependent susceptibility, and anhysteretic remanent magnetism. Magnetic susceptibility can be used to determine the relative amount of magnetite in a sample. Frequency dependent susceptibility and anhysteretic remanent magnetism are used to determine the relative grain size of magnetite in a group of samples. Each parameter will be discussed briefly before the results are presented.

Magnetic susceptibility is a measure of the degree to which a substance can be magnetized. Specifically it is defined as the ratio between the magnetization induced in a material to the strength of the applied magnetic field.

$$\chi = M / H$$

where χ is the volume magnetic susceptibility (dimensionless SI units), M is the volume magnetization (Am^2m^{-3} or more simply A m^{-1}) induced in a material, and H is the strength of the applied magnetic field (A m^{-1}).

The magnetic susceptibility of a material is dependent on both intrinsic and nonintrinsic factors. Mineralogy is the primary factor, but texture of the sediment, ferromagnetic grain size, grain shape, and frequency of the applied magnetic field, also effect the absolute value of susceptibility in a material. Magnetite, titanomagnetite, and maghaemite are ferrimagnetic minerals that have relatively high mass susceptibilities, usually between $\sim 4 \times 10^{-4}$ and $6 \times 10^{-4} \text{ m}^3\text{kg}^{-1}$ (Gale and Hoare, 1991). Antiferromagnetic minerals such as hematite and most forms of goethite have relatively low susceptibilities between $\sim 3 \times 10^{-7}$ and $6 \times 10^{-6} \text{ m}^3\text{kg}^{-1}$ (Gale and Hoare, 1991). Because of this it is usually fairly easy to determine if ferrimagnetic minerals are present in a sample.

Texture of the sediment affects magnetic susceptibility mainly by diluting ferri- and ferromagnetic minerals with diamagnetic and paramagnetic minerals such as quartz, feldspar, and clay minerals. Most ferri- and ferromagnetic minerals are found in the fine sand to coarse silt range of a sediment. Therefore, coarse sediments usually have relatively low mass susceptibility while finer sediments have higher mass susceptibilities. Thompson and Morton (1979) show that the susceptibility of lake sediments is strongly correlated with particle size distribution.

Ferri- and ferromagnetic grains can be divided into three classes (multidomain, single domain, and superparamagnetic) on the basis of magnetic domain state. Factors such as grain size, shape, relaxation time, temperature, and chemistry determine the domain state of a magnetic mineral (Figure 45). Equant magnetite particles larger than 1 micron are multidomained. Particles between 0.1 and 1 micron are single domain or multidomain depending on grain shape. Particles smaller than this are superparamagnetic. The result is that the magnetic characteristics of a magnetic mineral assemblage are highly dependent on the size and shape of ferrimagnetic grains.

The relationships between grain size and applied magnetic field to susceptibility have led to the development of several techniques to determine the relative grain size of magnetite in sediments. Coercive force is the force opposing the applied magnetic field in a sample during demagnetization. If a large magnetic field is required to change the remanent magnetism of a sample, then the coercive force is high and that sample is said to have a high coercivity. Coercivity is highly dependent on the size of the applied magnetic field and the domain state of ferri- and ferromagnetic minerals in a sample. Multidomain grains exhibit a low coercivity and quickly return to their original magnetic state after the inducing field (H) is removed. Single domain and superparamagnetic grains exhibit a high coercivity and retain an induced magnetic state long after the inducing field is removed.

The generating frequency of the applied magnetic field also effects the susceptibility of ferri- and ferromagnetic minerals. Many natural materials experience a decrease in susceptibility of up to 24% with a change in frequency from 100 to 1000 Hz (Thompson and Oldfield, 1986). The likely cause of large changes in susceptibility with frequency is associated with viscous effects of ferri- and

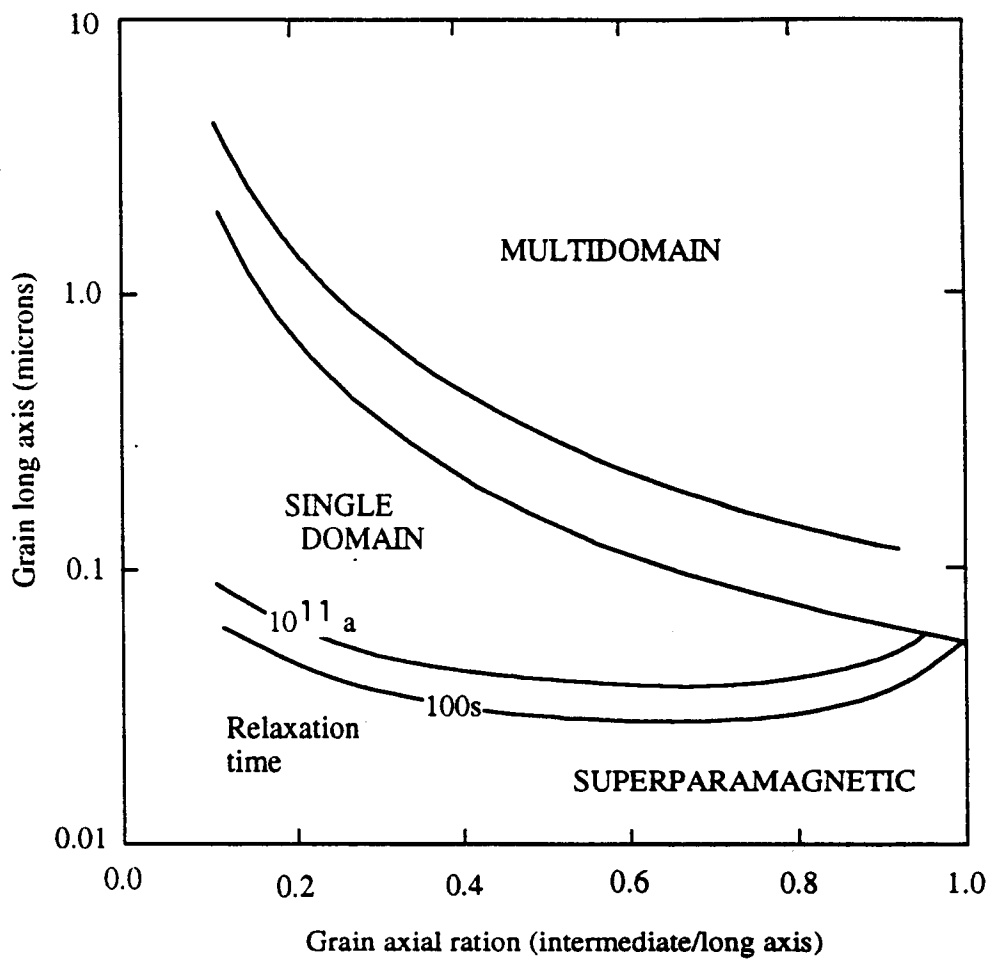


Figure 45. Plot showing the relationship between grain size and shape of ferromagnetic mineral grains and magnetic domain state (after Gale and Hoare, 1991, from Evans and McElinny, 1969). Curves delineate boundaries between various magnetic domain states as determined from experimental data.

ferromagnetic grains lying close to the superparamagnetic/single domain boundary. As the frequency of the applied field increases, the superparamagnetic/single domain boundary shifts to smaller volumes (Stephenson, 1971). Therefore at higher frequencies, a certain proportion of grains will no longer contribute to susceptibility as superparamagnetic grains but as single domain grains. Susceptibility will therefore be lower when measured in a high frequency field (Gale and Hoare, 1991). Therefore, the change in magnetic susceptibility with change in frequency can determine the relative grain size of magnetite in a sample. Sediments containing fine grained superparamagnetic magnetite usually show a decrease in magnetic susceptibility as the frequency of the applied field is changed. Sediments with coarse grained magnetite show a low frequency dependence because little of the induced magnetism remains after the inducing field is removed. This parameter may be expressed as frequency dependent susceptibility:

$$X_{fd} (\%) = 100(X_{lf} - X_{hf}) / X_{lf}$$

where X_{lf} is low field magnetic susceptibility (dimensionless SI units) and X_{hf} is high field magnetic susceptibility (dimensionless SI units) (Gale and Hoare, 1991).

Another method for determining the relative grain size variations involves plotting low field magnetic susceptibility (X_{lf}) versus anhysteretic susceptibility (ARM is the specific anhysteretic remanent magnetization acquired in a .05 mT steady field). This method, developed by King and others (1982), can be used to detect variations in magnetite grain size in a suite of samples. XARM is very sensitive to the single domain and pseudo-single domain grains of the finer magnetite fractions (King et al., 1982). X_{lf} is relatively insensitive to grain size variations. Therefore, samples with mostly fine grained magnetite show high XARM. Samples with predominantly coarse grained magnetite show low XARM (Figure 46).

Samples for susceptibility analysis were taken as part of 25 kg bulk samples or 1-2 kg bag samples from several of the exposures in the study area (see Figure 6 for locations). Large samples

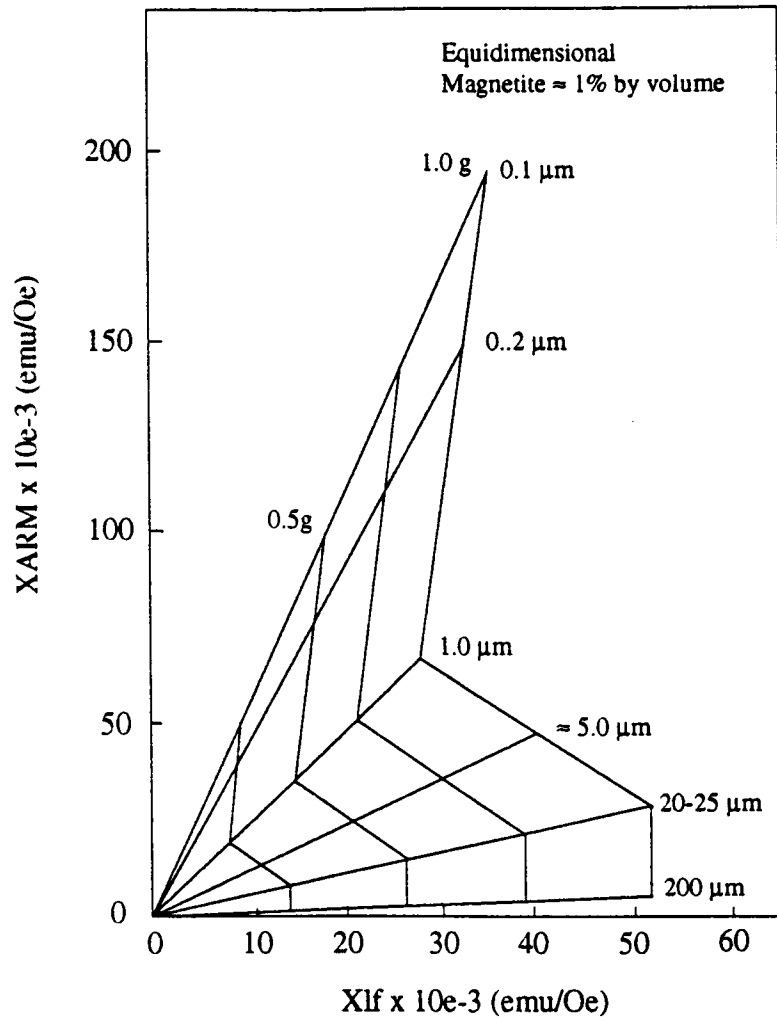


Figure 46. Variation in XARM versus Xlf with grain size for dispersed equidimensional magnetite samples. (from King et al. 1982). This diagram is constructed from empirical results of pure magnetite of known grain size. Fine magnetite has higher XARM values than does coarse magnetite. As concentration increases both Xlf and XARM increase.

were taken for pebble counts, grain size analysis and other analysis that were part of the overall study. A total of 110 samples from 14 localities were sampled and analyzed.

Additionally, two stratigraphic sections were sampled to determine the variation in magnetic susceptibility for different lithologic units. One section in a road cut along Highway 152 in Platte County (Figure 6, # 28) was sampled at 0.5 meter intervals. Two samples from each interval were prepared and a total of 36 samples were prepared from this section. Samples were also taken from two sections in a road cut along Interstate Highway I-70 (Figure 6, numbers 12 and 13). A total of 20 samples were taken from these sections.

The bulk and bag samples were taken to the lab and mixed thoroughly. From this about 500 grams of material was split out. This material was disaggregated and mixed by hand and then sieved through a 2 mm sieve. The material was air-dried and pressed into magnetically inert plastic cartridges. Some material was then wet sieved through a .0625 mm sieve and let dry until it was the consistency of paste. The paste was then inserted into plastic cartridges identical to those used for paleomagnetic samples.

Low frequency magnetic susceptibility (X_{lf}) was measured using a M.S.2 susceptibility meter with a M.S.2.B sensor. Samples were then demagnetized in a 100 mT peak alternating field using a Schonstedt ASD-1 single-axis AF demagnetizer at the University of Minnesota. An anhysteretic remanent magnetization (ARM) was imparted to the samples with a biasing field of 0.05 mT superimposed on a peak alternating field of 99 mT following the methods of King and others (1982). X_{arm} was then measured on a three-axis ScT cryogenic magnetometer.

Calculations for initial, reversible low-frequency mass susceptibility (X_{lf}) ($10^{-8} \text{ m}^3 \text{ kg}^{-1}$) were made using the following formula:

$$X_{lf} = x_{lf} / [(M_2 - M_1) / 0.01] \quad (1)$$

where x_{lf} is the measured low-frequency volume susceptibility (dimensionless SI units) of the sample container and sample, M_2 is the mass (kg) of the sample container and sample, M_1 is the mass (kg) of the sample container. In order to convert to mass susceptibility, volume susceptibility must be divided by the bulk density of the specimen. Since the sensor is calibrated against water, volume susceptibility is divided by the specific gravity of the specimen (Gale and Hoare, 1991). Therefore, the mass of the sample is divided by the mass of an equivalent volume of water (.01 kg).

The calculations for anhysteretic susceptibility (X_{ARM}) were made using the following equations:

$$x_{ARM} = J / H \quad (2)$$

where x_{ARM} is the volume anhysteretic susceptibility (dimensionless SI units), J is the measured volume magnetization induced ($A \text{ m}^{-1}$) in the material, and H is the strength of the applied biasing field (0.05 mT).

$$X_{ARM} = x_{ARM} / [(M_2 - M_1) / .01] \quad (3)$$

where units are ($10^{-8} \text{ m}^3 \text{ kg}^{-1}$) and variables have the same definitions as in equation 1.

A susceptibility profile is shown in Figure 47. Samples from the Highway 152 section show relatively little variation in low field mass susceptibility. Average values for unoxidized and unleached till and oxidized and leached till were 1.20×10^{-7} and $1.50 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$ respectively. The biggest increase in susceptibility was in a paleosol separating weathered till from late Pleistocene loess. Values in this zone were greater than $1.90 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$. Enhancement of magnetic susceptibility is commonly observed in soil horizons (Thompson and Oldfield, 1986). Basal gravel below unweathered till had average values of $1.6 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$. Both upper and lower diamictons had low X_{fd} values with identical averages of 1.1%. Weathered loess and paleosol had higher X_{fd} average value of 3.72%.

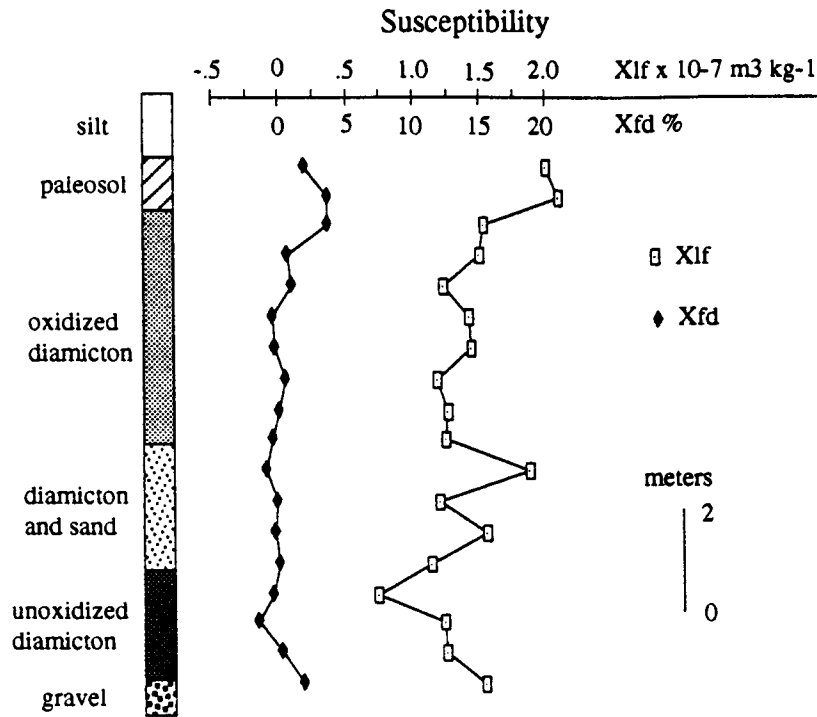


Figure 47. Susceptibility profile for Highway 152 exposure. There is little variation in the mass susceptibility (Xfd) of both oxidized and unoxidized diamicton. Most variation is in deformed diamicton and sand between upper and lower diamictons. Frequency dependent susceptibility (Xfd) is low in all units except paleosol. Paleosol near the top of exposure shows an increase in both Xlf and Xfd. Xlf is proportional to the magnetite concentration. Low Xfd values indicate that little, fine superparamagnetic magnetite is present. High Xfd values indicate that fine superparamagnetic minerals are present.

The susceptibility profile from Highway I-70 indicates a greater variability in mass susceptibility. Unoxidized till has values from 1.19 to $2.41 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$ (average = $1.81 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$). Oxidized till has values from 0.548 to $1.44 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$ (average = $0.848 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$). The argillic B horizon of a paleosol formed in outwash and loess above unweathered till had a high value of $4.38 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$.

The results of the the magnetic susceptibility analysis of bulk samples are shown in Figure 48. The plots show Xarm versus Xlf for till matrix (<2 mm) and the fine fractions of the till matrix (<.0625 mm). Both plots show that there is a consistent difference in the magnetic properties of oxidized, leached tills and unoxidized, unleached tills. The plots for both fractions are basically the same except that in the plot of the fine fractions (<.0625 mm), Xarm values are higher and the populations are better defined with respect to Xarm. These differences in the graphs indicate that most magnetite is in the <.0625 mm fraction and the coarser fractions tend to dilute susceptibility values.

The differences in the two populations can be explained by at least two possibilities. The first explanation is that two distinctive lithologic units are present. One unit contains magnetite with a low XARM indicating a relatively coarse magnetite fraction. The other unit contains magnetite with higher XARM because it contains relatively finer grained magnetite. This possibility is complicated by the great difference in the weathering states of the two populations as well as the grain size difference between oxidized and unoxidized tills.

A second possibility is that oxidized and leached tills show a finer magnetite population because authigenic ferri- or ferro magnetic minerals are present or that fine magnetite in dark gray tills has been reduced to pyrite. One set of samples from the same section in particular shows a difference in oxidized and unoxidized tills (samples from Nebo Hill and Highway EE). Since there is no evidence for a stratigraphic break in these sections it seems unlikely that two distinct units are present and the differences in magnetite are related to alteration effects.

If only unoxidized and unleached samples are compared there is little overall variation in mass

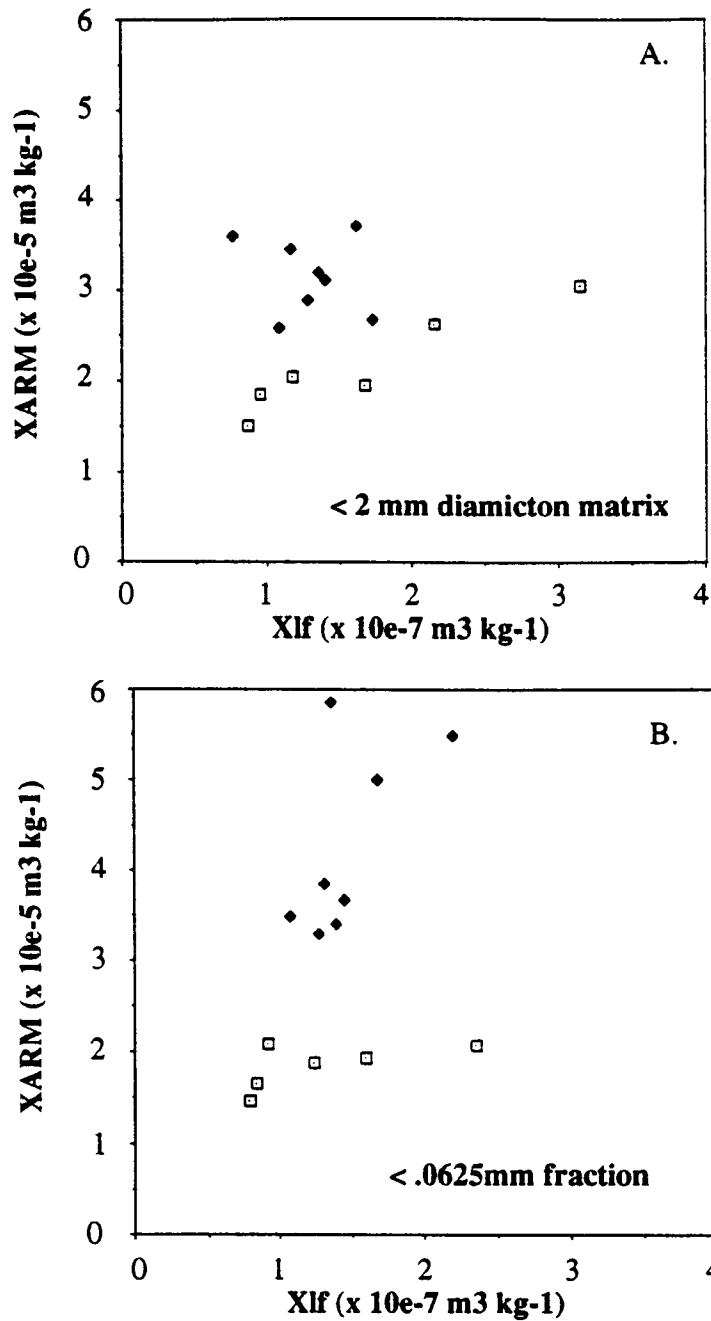


Figure 48. Xlf vs. XARM for diamicton matrix (<2mm) (A) and less than .0625 mm fraction of matrix (B). Both plots show that unoxidized and unleached samples (squares) have lower XARM values than do oxidized and leached samples (circles). All samples have a fairly restricted range of Xlf values. High XARM values indicate the presence of fine grained magnetite in oxidized and leached samples, whereas unoxidized and unleached samples contain coarser magnetite. Similar Xlf values indicate that all samples have a narrow range of magnetite content.

susceptibility (Xlf) and anhysteretic remanent susceptibility (XARM) in fine (<.0625 mm) matrix. The mass susceptibilities of unweathered samples range between 0.7 and $2.4 \times 10^{-7} \text{ m}^3 \text{ kg}^{-1}$. These are about the values seen in both profiles. Most of the variation in susceptibility for these samples is probably related to total magnetite content in the <.0625 mm fractions. In situ samples and whole matrix (<2 mm) samples display more variation than fine fraction (<.0625 mm) samples. This indicates that variations in magnetite content in the fine sand fraction may be causing susceptibility variations in these samples.

The unoxidized and unleached samples form a linear pattern on the XARM versus Xlf plots (Figure 48).. This indicates that the variation in grain size of magnetite in these samples is relatively small (King et al., 1982). Oxidized and leached samples show a narrower range of Xlf. These samples also have higher values of XARM. This indicates that in general less total and finer magnetite is present in these samples.

These results indicate that there is little variation in the grain size of magnetite in unoxidized and unleached tills. Most of the variation in Xlf in these samples is due to total magnetite content. Oxidized samples display relatively consistent values of Xlf and Xarm, indicating a narrow range of magnetite content and grain size. There is a difference in the magnetite content and grain size of the two sets of samples. Most of the difference between oxidized and unoxidized till is probably related to changes in the mineralogy of samples due to the stability of magnetite in oxidizing and unoxidizing to reducing conditions. There is a textural difference between the averages of the two populations. Oxidized and leached samples are generally finer, but the grain size differences probably are not enough to effect magnetic parameters so clearly. Oxidized and leached tills show the presence of a finer magnetic mineral fraction. This fraction may have a pedogenic or diagenetic origin because it is only found in oxidized and leached samples. It could also result from loss of fine single domain magnetite in gray reduced tills, due to conversion to pyrite. In either case changes in detrital magnetite probably have occurred in both oxidizing and unoxidized diamicton. This explains the demagnetization behavior of paleomagnetic samples analyzed (see part II). Many of the unoxidized samples displayed low

coercivity, indicating that only larger multidomained grains were present. Finer grain high coercivity magnetite may have been dissolved and converted into pyrite in these samples.

Discussion of lithology and correlation of deposits

Overall there is relatively little variation in the color, texture, small-pebble lithology, heavy minerals, and magnetic mineralogy of unoxidized and unleached basal tills in the study area. Unoxidized tills have a loam to silt loam texture, containing less than 10% gravel. Color is a dark gray to olive gray for unoxidized till. Small pebbles are of mostly local lithologies (60-95%) with a significant and always present amount of chert (4-5%) and erratics (5-40%). Opaque minerals, such as pyrite and magnetite, and unstable minerals especially hornblende and pyroxene, dominate the heavy mineral assemblage of unoxidized tills. Stable heavy minerals such as garnet, zircon, and tourmalene are also present. Magnetic susceptibility analysis shows a relatively narrow range of magnetic parameters indicating a restricted range of magnetite grain size and content.

As diamictons experience diagenesis and weathering, changes in lithology do occur. Most surface diamictons are completely oxidized to a yellow brown color and leached of carbonate and limestone clasts to depths of 3 to 4 meters. Oxidation of diamictons to depths as great as 10 meters has occurred in upland areas. The texture of diamicton becomes finer as pedogenic clay enrichment and breakdown of clasts occur. Heavy minerals are etched and resistant species are concentrated (Guccione, 1982; Nutter, 1988). Additionally changes in iron oxide mineralogy occur in oxidized and leached diamictons as well as possible diagenetic changes in reduced, pyrite rich diamictons. Because of these changes oxidized surface diamictons and some reduced valley filling diamictons are lithologically different than the original deposit. This agrees with findings of Davis (1951) and Aber (1988).

Table 7 is a summary of lithologic data for diamictons in northeastern Kansas, northcentral, and northwestern Missouri. This comparison indicates that lithologically deposits are similar in all three areas. Source area, bedrock over which the ice sheet travels, and bedrock in the area of deposition are the most important factors effecting the lithology of glacial deposits. Similar compositions

Table 7. Summary for lithologic data for tills in northeastern Kansas, northcentral Missouri, and Kansas City area.

	Independence Formation (Aber, 1991)	McCredie formation (Guccione, 1982)	Kansas City area (this study)
texture sand/silt/clay	no data	lower 29-42-29 upper 29-40-31	unweathered 40-43-17 weathered 34-40-26
color	medium dark gray N4 dark yellowish brown 10YR 5/4, 4/2	gray 2.5Y5/1 yellowish brown 10YR 6/4	gray to dark gray N6 to N3 olive yellow 2.5Y 6/6
small pebble lithology	local lithologies, chert, granite rhyolite, gneiss, greenstone, gabbro, iron formation	local lithologies, chert, granite, quartzite, dark igneous, shale, coal	local lithologies, chert, granite, metagraywacke, quartzite, basalt, gneiss, rhyolite, gabbro
heavy minerals	amphibole, epidote, tourmalene, garnet, zircon, pyroxene	amphibole, epidote, garnet	amphibole, epidote, garnet, zircon, tourmalene
clay mineralogy	illite, kaolinite, smectite in subequal amounts	illite, kaolinite	no data
magnetic susceptibility	no data	no data	Xlf = $1-2 \times 10^{-7}$ m ³ kg ⁻¹ unleached unoxidized diamicton

support the conclusion that pre-Illinoian tills in Kansas and Missouri have a common provenance and their depositing glaciers travelled over bedrock of similar composition.

Aber (1991, p. 302) defines the Independence Formation as consisting of "all diamicton and stratified sediment interbedded with diamicton in northeastern Kansas". He goes on to say that "...Independence Formation contains fragments of granite, rhyolite, gneiss, greenstone, gabbro, iron formation, amphibole, tourmaline, garnet, and other erratics derived from the Canadian Shield." Informally, he recognizes two members that are distinguished by kinetostratigraphic criteria. The lower Independence formation indicates a southwesterly ice movement trend while the upper member a southeasterly trend.

Similar small-pebble lithology, heavy minerals, and paleomagnetism of drift in the study area suggest a correlation to the Independence Formation. Paleomagnetic studies for the McCredie formation (informal) have not been carried out, but similar lithology indicates it is also correlative to till in the study area (Guccione, 1982). Because no difference has been found between upper and lower members of Independence Formation and informal McCredie formation there is no lithologic basis for correlating tills in the study area to either upper or lower members. Earlier workers faced the same problem in trying to correlate "Nebraskan" and Kansan" tills. As in the past, the presence of paleosols and stratigraphic position are still the only criteria for correlating tills. Dort (1985) discusses the numerous problems with correlations based on paleosols and stratigraphic position alone. An example of such a correlation is offered to illustrate some of the problems.

Two possible correlations of the glacial sequence observed in the study area to the Independence Formation in northeastern Kansas are given in Figure 49. Because the lower till in the study (see Figure 19) area contains inclusions of wood and glacially deformed, incorporated outwash deposits, and is overlain by outwash and another thick basal till, a correlation to the lower Independence Formation could be made. Aber (1988, p. 9) describes lower Independence Formation as "...everywhere dark gray or olive gray in color and contains abundant buried wood." The lower dark gray, wood bearing diamicton exposed in Platte County, Missouri therefore could be correlated to the lower

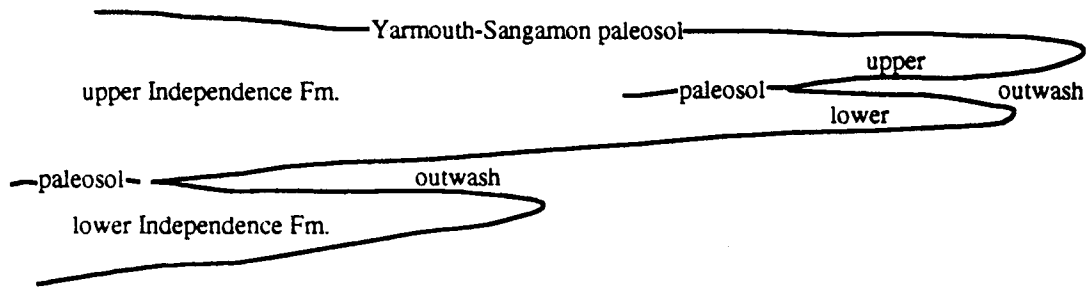
Doniphan-Atchison Counties

Platte County

Kansas City

North

South



OR

North

South

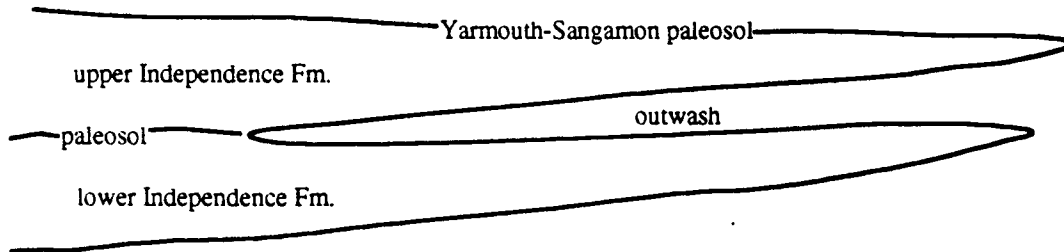


Figure 49. Two possible correlations of glacial deposits in Kansas City area with Independence Formation of northeastern Kansas.

Independence Formation, using this criteria. The main problem with this correlation is that ice movement data in the study area shows a generally south to southeast trend not a southwesterly trend. The lower till at the Highway 152 exposure also displays this southeasterly trend. If this correlation is correct, then ice movement direction does not conform to the only criteria put forth at this time to distinguish between upper and lower members.

Another possibility is that both tills in the study area correlate to the upper, southeasterly trending member of the Independence Formation. This would allow the two-lobe model but would suggest that Minnesota Lobe ice never reached the study area. The main problem with this correlation is that it fails to explain south-southwesterly ice movement in the area and it leads to a somewhat bizarre ice lobe margin seeming to detour around Platte and Clay Counties, Missouri in order to rejoin the projected ice margin of the lower McCredie Formation in north-central Missouri. A review of possible correlations with the upper and lower McCredie formation leads to similar possible correlations and problems.

The possibility also exists that ice movement data is controlled mainly by local topography and is not a reliable indicator of regional ice movement. If this is the case, the entire two-lobe model falls apart and we are left with a single glaciation of unknown ice lobe dynamics.

Considering the evidence available and accepting a two-lobe model, it seems most likely that tills in the study area correlate with the upper members of the Independence Formation and informal McCredie formation for the following reasons: (1) No evidence exists for a significant period of exposure of the lower till, such as a paleosol or erosion surface. Significant paleosols have been described separating upper and lower tills in both northeastern Kansas and central Missouri., (2) Ice movement data suggest that the dominant trend in ice movement was south-southeast. Only locally near the confluence of Kansas and Missouri Rivers is a southwest trend present and this could be explained as a local deflection of ice around the Wyandotte and Swope-Dennis bedrock uplands, (3) previous studies have indicated that till along the glacial border can be physically traced to upper tills in Doniphan and Atchison Counties (Frye and Leonard, 1952), (4) Regional bedrock topography

(Anderson and Hornberg , 1957) indicate that Minnesota Lobe ice would be deflected to the east of the study area, (5) Mapping of the Sioux Quartzite erratic train (Willard, 1980) also indicates that ice movement in general was southeasterly and ice from the Dakota Lobe would have been dominant in the area.

CONCLUSIONS

Stratigraphy and sedimentology of pre-Illinoian deposits in the Kansas City, Kansas and Kansas City, Missouri area suggests that drift was deposited by a single episode of glaciation and that retreat and readvance of the ice front occurred at least locally. The time separating retreat and readvance was not long enough for soil forming processes to greatly affect exposed drift. This confirms previous conclusions by Davis (1955) in Platte County, Missouri. After deglaciation, lacustrine and acretion-gley environments may have been present (Heim and Howe, 1968), but erosion and soil formation were the dominant processes acting before the next major periods of deposition of fluvial and eolian silt in Illinoian, Wisconsin, and Holocene times.

Ice movement data in the Kansas City area shows two trends of ice movement, but most data show a generally south to southeast trend in ice movement. This direction would suggest that till in the study area correlates to the upper member of the Independence Formation in northeastern Kansas. Pebble lithology and heavy mineral composition also suggest correlation with the Independence Formation.

Lithologic and magnetic susceptibility analysis indicate that weathering and pedogenic processes have altered the lithology and iron oxide mineralogy of surface drift in the area. Only at depths greater than 5 to 10 meters is drift unoxidized to reduced and not leached of primary carbonate. Even these deeply buried deposits may be altered somewhat because of diagenetic changes related to conversion of magnetite to pyrite. Relatively unaltered tills are usually found in buried bedrock depressions or in thick upland sequences. These results agree with those of previous workers (Davis, 1951; Aber, 1988; Nutter, 1988).

Paleomagnetic results show that a stable normal polarity is recorded in some tills of the study area. This remanent magnetism is interpreted to be primary DRM or pDRM in origin. Paleomagnetic data from this study, while not conclusive, does indicate that till in the study area was deposited during a time of normal polarity, presumably since the last magnetic reversal approximately 750,000 years

ago. Rock magnetic parameters studies indicate that there is a change in magnetic mineralogy from unoxidized and unleached till to oxidized and leached glacial tills. This change is probably related to diagenetic changes in both oxidized and unoxidized tills.

Till lithology and ice movement trends in the study area can be reconciled with a two-lobe model of pre-Illinoian glaciation in northeastern Kansas and northwest Missouri, although no evidence directly supporting a two-lobe model is found in the area. However, several problems with this model remain. The best argument for the two-lobe model is its analogy with Late Pleistocene lobes and its elegant simplicity. Unfortunately nature is rarely simple. The main arguments against the model is that it is based on only a single outcrop and widely scattered ice movement data of unknown stratigraphic significance. The assumption that widely spaced ice movement data is a reliable indicator of regional ice flow directions is also questionable. Until large data sets are gathered and ice movement data are put into a stratigraphic context, it is entirely possible that incorrect interpretations will result.

If the two-lobe model is correct, it is still unclear where the boundary between Dakota and Minnesota lobes was located and how this boundary changed with time. Its effect upon and relationship to drainage around the southern glacial margin is also unknown. If the Dakota Lobe was solely responsible for deposition of sediments near Kansas City, Missouri, then it is not possible for the Kansas City to Atchison segment of the modern Missouri River to have formed as an ice marginal stream to Minnesota Lobe ice. It also seems unlikely that it formed ice-marginally to Dakota Lobe ice because drainage would have been to the southeast, away from the ice margin.

If the Missouri River, north of Kansas City, formed as an ice marginal stream to Minnesota Lobe then subsequent advance by Dakota Lobe ice would have overrun and filled this newly created stream during maximum glacial advance into the Kansas City area. No evidence exists of buried portions of Missouri River or tributary valleys between Kansas City and Atchison. Also two tills should found fairly widespread over the area. Additionally, evidence for southwest trending ice movement, roughly perpendicular to the valley, should be found if it formed as an ice marginal stream. No such trend was found in this study.

A more likely scenario is that Minnesota Lobe ice advanced only as far as the ancestral Grand River Valley east of St. Joseph, Missouri and perhaps somewhat farther south locally (Figure 50). This is roughly the old "Nebraskan" glacial boundary in northwestern Missouri as described by Howe and Heim (1963). To the east, Minnesota Lobe ice advanced as far south as north-central Missouri, depositing a lower till recognized by Holmes (1941), Schmaltz (1959), and Guccione (1983). A later advance of the Dakota Lobe reached as far as Kansas City. Perhaps at this time Minnesota Lobe may have readvanced to northcentral Missouri again depositing upper McCredie formation. At this time Minnesota and Dakota Lobes may have been completely confluent along the glacial border. The boundary between ice lobes was east and north of Kansas City at this time. Minor readvance and retreat probably occurred locally in both lobes, complicating the record and producing the multiple tills recognized in this study and by Dort (1985) along the southern glacial border in Kansas.

The results from this study suggest that study of ice dynamics and its relation to the spatial distribution of drift could still be the most profitable avenue for future research, but until many more ice movement data are gathered, interpretations should be considered highly tentative. Detailed mapping of surface geology and sampling of drift through deep boreholes could provide a better understanding of pre-Illinoian stratigraphy in Kansas and Missouri. New techniques especially those to rapidly and accurately measure till fabric in the field, must be developed if studies of the dynamics of pre-Illinoian glaciations is to continue.

The history of the segment of the modern Missouri River segment between Kansas City and Atchison is still a major unknown in the area. If this segment developed after glaciation as previous workers have suggested (Todd, 1918; Frye and Leonard, 1952; Davis, 1955; Heim and Howe, 1963; Bayne et al., 1971), glacial drift should not be present within this valley. Another problem critical to reconstructing the glacial history of the area is locating the boundary between Minnesota and Dakota Lobes. Detailed mapping, ice movement data and stratigraphic data are necessary in northwestern Missouri before this question can be answered. At present, almost no data is published on the pre-Illinoian of northwestern Missouri. And finally, the extent and origin of Nortonville and Ferrelview



Figure 50. Reconstruction of Dakota and Minnesota Lobes. Minnesota Lobe never reached Kansas City area but may have reached as far south as Atchison, Kansas and St. Joseph Missouri. This is roughly the Nebraskan glacial boundary as defined by Howe and Heim (1963). Both lobes may or may not have been confluent at any one time, but it is likely that both lobes advanced and retreated at least locally along their southern margins.

Formations in Kansas and Missouri could provide information about the postglacial land surface and perhaps end moraine morphology. Paleomagnetic and pollen studies of these fine grained deposits could also provide data on timing and environment at the end of pre-Illinoian glaciation.

Still another problem, not completely resolved, is the age of glacial sediments in northeastern Kansas and northwestern Missouri. Paleomagnetism (Abdelsaheb, 1988 and this study) and fission track dates (Geil, 1987) tentatively indicate that drift is older than the Pearlette O ash (.61 Ma) and younger than the Bruhnes-Matayama boundary (.75 Ma). Unfortunately, this is based on only a *single* fission track date and a *few dozen* paleomagnetic measurements on glacial till. Obviously, much more work needs to be done. Until new absolute dating methods are developed and applied to older glacial sediments, paleomagnetic methods are the best existing tools for developing and testing a pre-Illinoian stratigraphy. Hopefully, more detailed paleomagnetic and stratigraphic investigations will be carried out in the future, shedding more light on the history of pre-Illinoian deposits in Kansas and Missouri.

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Appendix I-Additional Field Data

Location: 6th and Nebraska, Kansas City, Kansas, B-1, 500 ft east of 7th St., 12 meters south of Nebraska Ave., SE1/4, SW1/4, Sec. 3, T11S, R25E, Kansas City, Missouri-Kansas Quadrangle.

Description: Driller's log for site investigation for Federal Courthouse at 5th and State Avenue

Surface elevation: approximately 860 feet

Driller: R. Smith (Alpha-Omega Geotech Inc., Kansas City, Kansas)

Logger: R. Smith

Date: 5-16/23-89

depth (m)	elevation (ft)	thickness (m)	description (interpretation)
0 to 3.0	850.0	3.0 m	(fill) Clayey silt, reddish brown, rubble.
3.0 to 4.0	847.0	1.0	(Illinoian loess, colluvium, alluvium) Silty clay, light reddish brown, very stiff.
4.0 to 4.6	845.0	0.6	Silty sand, light brown.
4.6 to 5.0	843.5	0.4	Sandy clay, light reddish brown, medium.
5.0 to 6.1	840.0	1.1	Sandy clay, light brown.
6.1 to 7.6	835.0	1.5	Silty clay, light reddish brown, w/iron nodules, medium.
7.6 to 8.1	833.5	0.5	Silty clay, light reddish brown, medium.
8.1 to 9.1	830.0	1.0	Sandy silt, light brown, w/iron nodules.
9.1 to 10.7	825.0	1.6	Sandy clay, light reddish brown, medium.
10.7 to 11.1	823.5	0.4	Silty clay, dark reddish brown, w/iron nodules, medium.
11.1 to 12.2	820.0	1.1	Silty clay, dark brown.
12.2 to 12.7	818.5	0.5	Silty clay, light greenish brown, w/iron stains, medium.
12.7 to 13.7	815.0	1.0	(pre-Illinoian till > 24 feet) Sandy silt, light brown to brown, w/iron stains and fine gravel.
13.7 to 15.2	810.0	1.5	Silty clay, light greenish brown, w/iron stains, medium.
15.2 to 16.5	806.0	1.3	Silty clay, light yellowish brown, w/fine gravel and iron stains, hard.
16.5 to 18.0	801.0	1.5	Silty clay, light reddish brown, w/fine gravel, and iron stains, stiff.
18.0 to 19.5	796.0	1.5	Sandy clay, bluish gray, fine
19.5 to 19.9	795.0	0.4	Silty clay, dark grayish brown, very stiff.

boring terminated at 19.9 meters in diamicton

Appendix I-Additional Field Data (continued)

Location: 6th and Nebraska, Kansas City, Kansas, B-2, 300 ft west of 5th St., 12 meters south of Nebraska Ave., SE1/4, SW1/4, Sec. 3, T11S, R25E, Kansas City, Missouri-Kansas Quadrangle.

Description: Driller's log for site investigation for Federal Courthouse at 5th and State Avenue

Surface elevation: approximately 800 feet

Driller: R.Smith (Alpha-Omega Geotech Inc., Kansas City, Kansas)

Logger: P. Colgan

Date: 5-24-89

depth (m)	elevation (ft)	thickness (m)	description (interpretation)
0 to 0.6	798.0	0.6	(fill) Silty clay, light reddish brown, rubble.
0.6 to 3.7	788.0	3.1	(alluvial or colluvium 33 feet) Silty clay, dark reddish brown w/pebbles.
3.7 to 6.1	780.0	2.4	Silty clay, dark brown.
6.1 to 9.1	770.0	3.0	Sand, reddish brown, coarse, poorly sorted.
9.1 to 10.7	765.0	1.6	Sharp contact Clayey silt, dark reddish brown, w/iron stains.
10.7 to 12.2	760.0	1.5	(pre-Illinoian till and outwash >36.5 feet) Silty clay, dark blue gray, little sand, no larger clasts.
12.2 to 13.7	755.0	1.5	Silty clay, light blue gray, w/larger clasts.
13.7 to 16.7	745.0	3.0	Silty clay, light blue gray, w/lenses of sand and pebbles.
16.7 to 21.3	730.0	4.6	Silty clay, light blue gray, w/pebbles and granules.
21.3 to 21.8	728.5	1.5	Silty sand, light blue gray.

boring terminated at 21.8 meters, bedrock depth not determined.

Appendix I-Additional Field Data (continued)

Location: 6th and Nebraska, Kansas City, Kansas, B-3 90 meters west of 5th St., 30 meters north of Nebraska Ave., SE1/4, SW1/4, Sec. 3, T11S, R25E, Kansas City, Missouri-Kansas Quadrangle

Description: Driller's log for site investigation for Federal Courthouse at 5th and State Avenue, Kansas City Kansas.

Surface elevation: approximately 795 feet

Driller: R.Smith (Alpha-Omega Geotech Inc., Kansas City, Kansas)

Logger: R. Smith

Date: 5-26-89

depth (m)	elevation (ft)	thickness (m)	description (interpretation)
0 to 2.1	788.0	2.1 m	(fill 7 feet) Silt, dark brown, rubble.
2.1 to 3.0	785.0	0.9	(colluvium or alluvium 5 feet) Silt, clayey, brown.
3.0 to 3.7	783.0	0.7	Clayey silt, dark brown w/gravel and plant roots.
3.7 to 4.6	780.0	0.9	(glacial till 23 feet) Silty clay, dark bluish gray.
4.6 to 8.2	768.0	3.6	Silty clay, dark grayish brown, iron stains.
8.2 to 10.7	760.0	2.5	Silty clay, dark bluish gray w/gravel.
10.7 to 11.6	757.0	0.9	(weathering zone in till ? 11.5 feet) Silty clay, yellowish to reddish brown, w/fine gravel.
11.6 to 12.2	755.0	0.6	Sandy silt, light brown (outwash?).
12.2 to 14.2	748.5	2.0	Silty clay, dark grayish brown, w/iron stains.
14.2 to 15.2	745.0	1.0	(glacial till > 25.5 feet) Sandy silt, light brown.
15.2 to 15.7	743.5	0.5	Silty clay, light grayish brown w/fine gravel.
15.7 to 16.8	740.0	1.1	Sandy silt, light brown.
16.8 to 18.3	735.0	1.5	Silty clay, light grayish brown.
18.3 to 19.8	730.0	1.5	Silty clay, dark grayish brown.
19.8 to 22.0	723.0	7.0	Silty clay, dark grayish brown, w/fine gravel.

Boring terminated at 22.0 meters, out of auger

Appendix I-Additional Field Data (continued)

Location: 6th and Nebraska, Kansas City, Kansas, B-4, 90 meters east of 7th St., 20 meters north of Nebraska Ave., SE1/4, SW1/4, Sec. 3, T11S, R25E, Kansas City, Missouri-Kansas Quadrangle.

Description: Driller's log for site investigation for Federal Courthouse at 5th and State Avenue.

Surface elevation: approximately 845 feet

Driller: R. Smith (Alpha-Omega Geotech Inc., Kansas City, Kansas)

Logger: P. Colgan

Date: 5-30-89

depth (m)	elevation (ft)	thickness (m)	description (interpretation)
0 to 1.5	840.0	1.5 m	(Wisconsin loess 10 feet) Silty clay, dark brown light yellow toward bottom.
1.7 to 2.1	838.0	0.4	Clayey silt, dark grayish brown, w/fine gravel.
2.1 to 3.0	835.0	0.9	Sandy silt, dark yellow brown.
3.0 to 3.7	833.0	0.7	(Sangamon soil in Illinoian loess and alluvium 30 feet) Clayey silt, light reddish brown.
3.7 to 4.6	830.0	0.9	Sandy silt, light brown.
4.6 to 5.0	828.5	0.6	Clayey silt, light brown, w/iron stains.
5.0 to 6.1	825.0	1.1	Clayey silt, light reddish brown.
6.1 to 6.6	823.5	0.5	Silty Clay, light reddish brown, w/fine gravel and iron stains.
6.6 to 7.6	820.0	1.0	Clayey silt, light reddish brown.
7.6 to 8.1	818.5	0.5	Silty clay, light reddish brown.
8.1 to 9.1	815.0	1.0	Silty sand, light brown, medium to fine.
9.1 to 9.6	813.5	0.5	Clayey silt, light reddish brown.
9.6 to 10.7	810.0	1.1	Silty sand, light brown, fine to medium.
10.7 to 11.1	808.5	0.4	Clay, greenish to grayish brown w/iron stains.
11.1 to 12.2	805.0	0.9	Silty sand, light brown.
12.2 to 18.3	785.0	6.1	(pre-Illinoian till 32.5 feet) Clayey silt, light greenish brown, w/fine gravel and iron stains.
18.3 to 18.8	783.5	0.5	Clayey silt, grayish brown, hard.
18.8 to 19.8	780.0	1.0	Sandy silt, light brown (outwash).
19.8 to 20.4	778.0	0.6	Clayey silt, dark grayish brown w/fine gravel, hard.

boring terminated at 20.4 meters, because of auger refusal

Appendix I-Additional Field Data (continued)

Location: 6th and Nebraska, Kansas City, Kansas, B-5, 500 ft east of 7th St., 40 ft. south of Nebraska Ave., SE1/4, SW1/4, Sec. 3, T11S, R25E, Kansas City, Missouri-Kansas Quadrangle.

Description: Driller's log for site investigation for Federal Courthouse at 5th and State Avenue

Surface elevation: approximately 825 feet

Driller: R. Smith (Alpha-Omega Geotech Inc., Kansas City, Kansas)

Logger: R. Smith

Date: 6-2-89

depth (m)	elevation (ft)	thickness (m)	description (interpretation)
0 to 1.5	820.0	1.5	(fill) Clayey silt, dark brown, w/rubble.
1.5 to 2.1	818.0	0.6	(Sangamon soil Illinoian loess and colluvium-alluvium) Silty clay dark reddish brown, w/fine gravel, very stiff.
2.1 to 3.0	815.0	0.9	Silt, brown.
3.0 to 4.6	810.0	1.6	Clayey silt, light grayish brown, marbled brown w/iron stains, stiff.
4.6 to 5.2	808.0	0.6	Silty clay, dark reddish brown, w/iron stains, very stiff.
5.2 to 6.1	805.0	0.9	Clayey silt, brown
6.1 to 7.6	800.0	5.0	Silty clay, light reddish brown, stiff.
7.6 to 8.2	798.0	0.6	Silty clay, light reddish brown, w/iron stains, stiff.
8.2 to 9.1	795.0	0.9	Clayey silt, light brown to brown.
9.1 to 9.8	793.0	0.7	Silty clay, reddish brown, w/iron stains, medium.
9.8 to 10.7	790.0	0.9	Sandy silt, light brown, fine
10.7 to 11.3	788.0	0.6	(pre-Illinoian till and outwash > 25 feet) Silty clay, light grayish brown, w/fine gravel, medium.
11.3 to 12.2	785.0	0.9	Sandy clay, light brown and gray, fine.
12.2 to 13.7	780.0	0.9	Clayey silt, light yellowish brown and gray marbled, w/iron stains and fine gravel, stiff.
13.7 to 15.2	775.0	1.5	Silty clay, light reddish brown, w/fine gravel and iron stains, very stiff.
15.2 to 16.8	770.0	1.6	Silty sand, dark grayish brown and yellowish brown, w/fine gravel.
16.8 to 18.2	765.4	1.4	Silty clay, dark grayish brown, hard

boring terminated at 18.2 meters due to refusal of auger

Appendix I-Additional Field Data (continued)

Location: 6th and Nebraska, Kansas City, Kansas, B-6, 150 ft west of 5th St., 40 ft. north of State Ave., SE1/4, SW1/4, Sec. 3, T11S, R25E, Kansas City, Missouri-Kansas Quadrangle.

Description: Driller's log for site investigation for Federal Courthouse at 5th and State Avenue.

Surface elevation: approximately 825 feet

Driller: R. Smith (Alpha-Omega Geotech Inc., Kansas City, Kansas)

Logger: R. Smith

Date: 6-6-89

depth (m)	elevation (ft)	thickness (m)	description (interpretation)
0 to 3.8	812.5	3.8	(fill) Clayey silt, brown to light brown, rubble.
3.8 to 4.6	810	1.2	(colluvium and alluvium 47.5 feet) Clayey silt, dark bluish gray.
4.6 to 6.1	805	1.5	Clayey silt, light brown and gray.
6.1 to 8.1	798.5	2.0	Clayey sand and silt, light brown and gray.
8.1 to 9.6	793.5	1.5	Silty sand, light brown, fine.
9.6 to 12.2	785	1.6	Silty sand, fine.
12.2 to 13.7	780	1.5	Sandy silt, light reddish brown and gray, soft.
13.7 to 15.7	773.5	2.0	Sandy silt, light reddish brown and gray, w/clay and small iron nodules, less stiff.
15.7 to 18.3	765	0.6	No return, water.
18.3 to 18.8	763.5	0.5	(weathered drift > 5.2 feet) Sandy clay and silt, light brown, w/iron nodules, limestone, quartzite.
18.8 to 19.2	762.1	0.4	Auger refused at 62.9.
19.2 to 19.6	760.6	0.4	Sandy clay and silt, chert.
19.6 to 19.8	760	0.2	Auger hard, on boulder?
19.8 to 19.9	758.8	0.1	Sandy clay, chert and iron stains.

boring terminated at 19.9 meters due to auger refusal.

Appendix I-Additional Field Data (continued)

Location: Highway road cut thru north bluff of the Missouri River one mile east of Missouri City, Missouri. SW1/4, Sec. 7, T51N, R31E, Missouri City, Quadrangle. (Figure 6, # 42)

Description: diamicton and loess overlying Pleasanton Group through Bethany Falls Limestone.

Surface elevation: base of diamicton exposure on Pleasanton Group at approximately 780 feet.

Measured: P. Colgan 6-24-91.

from base (elevation 740 feet)

0-12 m	Pleasanton Group Shale and Sandstone, dark gray to light brown, micaceous thin bedded, calcareous.
12-13.7 m	pre-Illinoian drift Gravel, cobble and boulder size, overlying bedrock; in other places diamicton overlies striated bedrock; striations trend N20W; gravel is mostly sandstone, limestone, and erratics of pink and gray granite, Sioux quartzite, iron cemented limestone conglomerate, basalt, metagraywacke, and gneiss.
13.7-15.5 m	Diamicton, dark gray (N4) overlying striated bedrock and gravel; includes numerous erratics and lenses of outwash, overconsolidated and fissile.
15.5-18.9 m	covered, mostly diamicton
18.9-22.0 m	Diamicton, light yellow brown (2.5Y 6/4) oxidized and partially leached, contains wedge shaped bodies of well sorted sand and gravel; iron cemented gravels interbedded with diamicton; wedges are bounded by shear planes that dip to northwest.
22.0-23.8 m	Sangamon paleosol Clayey silt, light reddish brown, contains resistant pebbles, capped by pebble band with many Sioux Quartzite cobbles, thins to south; sharp upper contact with light brown silt.
23.8-34.8 m	Wisconsin loess Silt, light brown calcareous, mostly covered

Appendix I-Additional Field Data (continued)

Location: Highway road cut east of Nebo Hill north bluff of the Missouri River, NW1/4, SE1/4, Sec. 23, T51N, R31E, Missouri City, Quadrangle. (Figure 6, #s 39 and 40)

Description: diamicton and loess overlying along south side of Missouri Highway 210.

Surface elevation: base of diamicton exposure on Pleasanton Group at approximately 740 feet.

Measured: P. Colgan 6-24-91.

from base

0-3.0 m	pre-Illinoian drift Diamicton, dark gray (N4), fissile, jointed, overconsolidated; in upper five feet contains numerous subhorizontal sand wedges (5-10 cm wide and 10-30 cm long); numerous boulders of Bethany Falls Limestone; erratics of Sioux Quartzite, basalt, metagraywacke, granite. Large channel of sand near base of exposure on east side, contains well sorted planar crossbedded quartz sand.
3.0-9.1 m	Diamicton, light yellow brown (2.5Y 6/4), poorly exposed.
9.1-10.7 m	Sand, light reddish to dark reddish brown, includes numerous erratics; poorly exposed.
10.7-13.7 m	Sangamon paleosol Clayey silt, light reddish brown.
13.7-15.0 m	Wisconsin loess Silt, light brown calcareous, poorly exposed.

Appendix I-Additional Field Data (continued)

Location: Abandoned loess pit, west of 61th street, N1/2, NW1/4, Sec. 14, T11S, R24E,
Shawnee, Kansas Quadrangle. (Figure 6, # 14)

Description: Interbedded silts, clay, and sand in terrace deposit, weathered volcanic ash.

Surface elevation: Top of ash bed approximately 810-820 feet.

Measured: P. Colgan 6-1-91.

from base of exposure:

0-40 cm	Clayey silt and fine sand, light gray green, mottled orange and brown; black clay drapes on small scale ripple (1 cm); interbedded with clay lenses (2-3 cm).
40-60 cm	Sand, light yellow brown, fine to medium, scour filled trough crossbeds (2-5 cm thick 40 to 50 cm wide), bedding is iron stained, mostly quartz with some heavies.
60-70 cm	Clay, light gray, with black organic rich layers laterally persistent over outcrop.
70-72 cm	Clay, black organic rich, top and bottom contacts are sharp with gray silt.
72-102 cm	Sand, light gray green, fine to medium, interbedded with clay in small scour fills, trough cross bedded.
102-140 cm	Silty sand, yellow brown, fine, scour fills at top.
140-250 cm	Same as above except fining up to fine silty sand, some trough crossbeds in lower 50 cm.
250-300 cm	Volcanic Ash, Sandy silt, pale brown to white, sharp base, 5 mm pink alteration zone at base, fines upward.
300-400 cm	Silty sand, light brown, fine, gradational upper contact with loess.
4-10 m	Silt, light brown to pale brown, massive, some sandy layers may be reworked in lower part.

Appendix I-Additional Field Data (continued)

Location: Road cuts along Hwy 169, Clay County, Missouri, NW1/4, NE1/4, Sec. 10, T51N, R33W,
Nashua, Missouri Quadrangle. (Figure 6, # 34)

Description: on southeast corner of 169 and 152 interchange.

Surface elevation: 980 feet at base of exposure.

Measured: P. Colgan 9-1-91

from base:

0-3 m	(Tonganoxie Sandstone, Stranger Formation) Sandstone, light yellow brown, fine, micaceous, iron stained.
3-5 m	(pre-Illinoian till, Association C and D) Diamicton, light olive gray (2.5Y 5/4) mottled pale olive (5Y 6/3), joints yellowish brown (10YR 5/8); texture 34.3% sand, 49.9% silt, 15.9% clay; some joints are carbonate filled; large inclusions (meter scale) of Tonganoxie Sandstone and sorted sediments in diamicton; small lense shaped channels of fine sorted sand cut into diamicton.
5-7 m	(Ferrelview Formation, Facies F) Silty clay, light brown to gray
7-7.2 m	Silty clay, dark brown, organic rich, manganese stained.
7.2-8.2 m	(Sangamon paleosol in Loveland loess) Silty clay, dark reddish brown
8.2-9 m	Clayey silt, dark reddish brown
9-12 m	(Wisconsin loess) Silt, light brown.
12-12.5 m	Silt, light gray, w/iron stains.
12.5-14 m	Silt, light gray, w/reddish brown mottles.

Appendix I-Additional Field Data (continued)

Location: Road cuts along Hwy 169, Platte County, Missouri, NW1/4, NE1/4, Sec. 10, T51N, R33W, Nashua, Missouri Quadrangle. (Figure 6, # 35)

Description: west side of 169 on northwest corner of interchange with 152.

Surface elevation: 980 feet at base of exposure.

Measured: P. Colgan 9-1-91

from base

- | | |
|-----------|--|
| 0-6 m | (pre-Illinoian till)
Diamicton, light olive gray (2.5Y 5/4) mottled pale olive (5Y 6/3), joints yellowish brown (10YR 5/8); oxidized and leached some joints are carbonate filled, polygonal pattern, spaced 20-40 cm; large inclusions (meter scale) of sorted sediments in diamicton mostly fine silty sand and pebbly sand; rotten granite boulders; erratics include gneiss, granite, Tonganoxie sandstone, limestone, Sioux Quartzite. |
| 6-6.4 m | (stone line)
Pebbly clay, light reddish brown, contains numerous pebble and sand size clasts in clayey matrix, irregular topography on diamicton; a channel (1 meter thick and 3 meters wide) filled with pebbly sand is present. Sioux Quartzite common. |
| 6.4-7.0 m | (Sangamon soil in Loveland loess and colluvium)
Clayey silt, dark reddish brown, leached and oxidized, sharp upper contact with light brown silt. |
| 7-9 m | (Wisconsin loess)
Silt, light brown, calcareous |

Appendix I-Additional Field Data (continued)

Location: 1 block north of Barry Road and Utica Ave., SW1/4, NE1/4, Sec. 10, T50N,R34W,
Parkville, Missouri-Kansas Quadrangle. (Figure 6, # 29)

Description: 1 block north of Barry Road and Utica Ave., Platte County, Missouri.

Surface elevation: 1000 feet

Measured: P. Colgan 8-16-91

from base

- | | |
|-----------|--|
| 0-1 m | (Tonganoxie Sandstone)
Sandstone, light yellow brown, micaceous, iron stained,
crossbedded. |
| 1-3 m | (pre-Illinoian till with Yarmouth-Sangamon paleosol)
Diamicton, light yellow brown to dark greenish gray,
manganese stains on joint plains, carbonate in some joints;
texture 31.1% sand, 20.5% silt, 48.4% clay. |
| 3-3.5 m | (Loveland loess and colluvium, stone line)
Pebbly sand, dark reddish brown, with clay matrix, resistant
sandstone, weathered granite, Sioux quartzite; sharp upper
contact. |
| 3.5-4.5 m | (Wisconsin loess)
Silt, light brown, calcareous. |

Appendix I-Additional Field Data (continued)

Location: Road cut along Hwy 169, Clay County, Missouri, NW1/4, NE1/4, Sec. 10, T51N, R33W,
Nashua, Missouri Quadrangle. (figure 6, # 35)

Description: east side of 169 northeast corner 110th and 169.

Surface elevation: 1020 feet at base of exposure.

Measured: P. Colgan 10-27-91

from base

0-2 m	(Yarmouth-Sangamon Profile in Ferrelview Formation) Clay, light greenish gray, mottled reddish brown, blocky, manganese stains, iron nodules 1 to 5 mm, root traces, carbonate nodules (1 to 3 cm) near base.
2-2.6 m	(Sangamon soil in Loveland loess) Clay, dark reddish brown to brown near top, sharp top, gradational lower contact.
2.6-3.2 m	Clayey silt, light brown, with iron nodules.
3.2-3.5 m	(Wisconsin loess) Silt, reddish brown mottled gray, clay filled fractures extending from next unit down into silt.
3.5-4.5 m	Silty clay, gray mottled reddish brown, iron tubules 1 cm, some large 2 cm iron nodules.
4.5-5.5 m	Silt, light brown, mottled reddish brown, calcareous.

Appendix I-Additional Field Data (continued)

Location: Road cut west of overpass of I-435 over New Jersey Ave., NW1/4, SW1/4, Sec. 1, T11S, R23E, Edwardsville Kansas Quadrangle, (Figure 6, # 6)

Description: cut just west of overpass and in erosion gullies in field to southwest.

Surface elevation: bedrock at 990 feet

Measured: P. Colgan 6-27-91

from base

- 0-0.5 m Limestone exposed in creek southwest of exposure

(pre-Illinoian till)
.5-3 m Diamicton, pale olive (5Y 6/3), brownish yellow (10YR 6/8) along joints; oxidized and leached, manganese stains on joint planes; carbonate nodules; large Sioux quartzite erratic; capped by resistant pebble layer where overlying clay not present.
- 3-5 m (Yarmouth-Sangamon paleosol in Ferrelview Formation)
Clay, light gray (2.5Y 7/2), leached; mottled with mm splotches of olive yellow (2.5Y 6/6); mm size manganese nodules, blocky ped structure.
- 5-8 m (Wisconsin loess)
Silt, yellowish brown (10YR 5/4) to pale yellow (2.5Y 8/4), contains scattered pebbles in lower part.

Appendix I-Additional Field Data (continued)

Location: Road cut east of overpass of I-435 over Georgia Ave., center of Sec. 35, T10S, R23E,
Wolcott, Missouri-Kansas Quadrangle. (Figure 6, # 5)

Description: cut just east of overpass.

Surface elevation: base at 995 feet

Measured: P. Colgan 6-27-91

from base

- | | |
|-------|--|
| 0-2 m | (pre-Illinoian till)
Diamicton, light yellowish brown (2.5Y 6/4) mottled light gray; joints strong brown (7.5YR 5/8); manganese stains on joint planes, blocky soil structure in upper part; strong line at top. Sioux Quartzite boulder. |
| 2-4 m | (Yarmouth-Sangamon soil in Ferrelview Formation)
Clay, light gray mottled reddish brown, leached, few sand grains and erratics. |
| 4-6 m | Silt, light brown, leached modern soil developed. |

Appendix II - Paleomagnetism data

2910- Interstate I-70 exposure, 10m from base in light brown clayey silt

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	73	11.72	1.00
2	5.00	77	9.303	0.79
3	10.00	76	7.367	0.63
4	20.00	73	4.306	0.37
5	40.00	73	1.758	0.15
6	60.00	48	.9509	0.081
7	80.00	55	.7636	0.065
8	100.00	31	1.029	0.088

J/J0 50% = 17 mT

2913- Interstate I-70 exposure, 10m from base in light brown clayey silt

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	58	12.10	1.00
2	5.00	57	10.69	0.88
3	10.00	53	9.406	0.78
4	20.00	52	6.209	0.51
5	40.00	55	3.164	0.26
6	60.00	67	2.017	0.17
7	80.00	37	1.347	0.11
8	100.00	76	1.543	0.13

J/J0 50% = 20 mT

2917- Interstate I-70 exposure, 2m from base in dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	11	2.133	1.00
2	5.00	58	.4462	0.21
3	7.50	83	.3615	0.17
4	10.00	83	.2530	0.12
5	15.00	37	.4366	0.21
6	20.00	52	.4401	0.21
7	30.00	41	.5007	0.23
8	40.00	56	.5561	0.26
9	60.00	9	.0616	0.03
10	80.00	50	.3284	0.15
11	100.00	60	.5206	0.24

J/J0 50% = 3.2 mT

Appendix II - Paleomagnetism data (continued)

2921 - Interstate I-70 exposure, 2m from base in dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	25	2.445	1.00
2	2.50	24	1.803	0.74
3	5.00	18	1.378	0.56
4	7.50	17	1.088	0.44
5	10.00	17	.9717	0.40
6	15.00	20	.8624	0.35
7	20.00	13	1.017	0.42
8	30.00	7	1.186	0.48
9	40.00	16	1.288	0.53
10	60.00	8	.9612	0.39
11	80.00	-2	1.074	0.44
12	100.00	-6	1.031	0.42

J/J0 50% = 6.3 mT

2922 - Interstate I-70 exposure, 2m from base in dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	26	1.723	1.00
2	2.50	34	.8416	0.49
3	5.00	53	.5031	0.29
4	7.50	37	.5174	0.30
5	10.00	29	.5662	0.33
6	15.00	27	.6586	0.38
7	20.00	12	.5628	0.33
8	30.00	15	.3050	0.18
9	40.00	-16	.1933	0.11
10	60.00	-22	.6582	0.38
11	80.00	-16	.3005	0.17
12	100.00	34	.2658	0.15

J/J0 50% = 2.6 mT

2941 - Parallel Avenue, light olive diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	54	1.660	1.00
2	2.50	57	1.446	0.87
3	5.00	57	1.253	0.75
4	10.00	71	.9799	0.59
5	20.00	75	.4719	0.28
6	30.00	88	.5922	0.36
7	40.00	66	.4188	0.25
8	60.00	68	.6320	0.38
9	80.00	46	.6710	0.40
10	100.00	64	.5970	0.36

J/J0 50% = 13 mT

Appendix II - Paleomagnetism data (continued)

2942 - Parallel Avenue, light olive diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	49	298	1.310
2	2.50	54	293	1.143
3	5.00	58	295	.9666
4	10.00	64	297	.8000
5	20.00	68	303	.5563
6	30.00	40	270	.4373
7	40.00	19	284	.4261
8	60.00	8	244	.3337
9	80.00	49	233	.6780
10	100.00	20	239	.5771

J/J0 50% = 16 mT

2943 - Parallel Avenue, light olive diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	-16	294	1.201
2	2.50	-24	297	1.181
3	5.00	-28	295	1.258
4	10.00	-40	294	1.091
5	20.00	-54	287	.9030
6	30.00	-63	294	.6553
7	40.00	-78	303	.5304
8	60.00	-65	307	.6825
9	80.00	-54	264	.4583
10	100.00	-40	294	.6207

J/J0 50% = 35 mT

2960 - Nebo Hill dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	43	280	3.492
2	2.50	41	274	3.278
3	5.00	40	270	3.086
4	10.00	37	267	2.821
5	20.00	35	263	2.559
6	30.00	35	262	2.548
7	40.00	32	264	2.654
8	60.00	28	257	2.399
9	80.00	31	268	2.519
10	100.00	32	263	2.475

J/J0 50% = >100 mT

Appendix II - Paleomagnetism data (continued)

2961 - Nebo Hill dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	24	1.278	1.00
2	2.50	24	.8350	0.65
3	5.00	14	.5059	0.40
4	10.00	-4	.4559	0.36
5	20.00	-43	.4418	0.35
6	30.00	-48	.7062	0.55
7	40.00	-32	.6115	0.48
8	60.00	-46	1.223	0.96
9	80.00	-63	1.046	0.82
10	100.00	-64	.8931	0.70

J/J0 50% = 4.0 mT

2962 - Nebo Hill dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	47	1.554	1.00
2	2.50	45	1.111	0.71
3	5.00	45	.9818	0.63
4	10.00	42	.8375	0.54
5	20.00	40	.4483	0.29
6	30.00	63	.3380	0.22
7	40.00	45	.2631	0.17
8	60.00	65	.4354	0.28
9	80.00	57	.4811	0.31
10	100.00	51	.2921	0.19

J/J0 50% = 12 mT

2963 - Nebo Hill dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0
1	0.00	47	1.657	1.00
2	5.00	55	1.103	0.67
3	10.00	54	.7841	0.47
4	15.00	51	.6368	0.38
5	20.00	42	.4417	0.27
6	40.00	29	.4974	0.30
7	60.00	20	.1702	0.10
8	80.00	45	.3761	0.23
9	100.00	51	.3329	0.20

J/J0 50% = 9.3 mT

Appendix II - Paleomagnetism data (continued)

2964 - Nebo Hill dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0	
1	0.00	59	75	3.050	1.00
2	5.00	56	92	2.248	0.74
3	10.00	58	107	1.951	0.64
4	15.00	55	115	1.695	0.56
5	20.00	56	130	1.488	0.49
6	40.00	44	136	1.308	0.43
7	60.00	42	138	1.309	0.43
8	80.00	48	132	1.148	0.38
9	100.00	41	142	.5174	0.17

J/J0 50% = 19 mT

2965 - Nebo Hill dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0	
1	0.00	50	22	1.451	1.00
2	5.00	40	10	.6011	0.41
3	10.00	20	358	.2915	0.20
4	15.00	-36	79	.2506	0.17
5	20.00	-75	40	.2682	0.18
6	40.00	-66	349	.2062	0.14
7	60.00	-64	70	.4970	0.34
8	80.00	-75	88	.5085	0.35
9	100.00	-57	126	.4480	0.31

J/J0 50% = 4.2 mT

2966 - Riverside dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0	
1	0.00	-24	-102	1.000	1.00
2	5.00	-29	-90	1.038	1.00
3	10.00	-32	-87	1.126	1.10
4	15.00	-34	-83	1.140	1.10
5	20.00	-35	-83	1.165	1.20
6	30.00	-35	-83	1.219	1.20
7	40.00	-36	-80	1.264	1.30
8	60.00	-41	-81	1.203	1.20
9	80.00	-40	-79	1.252	1.30
10	100.00	-41	-78	1.019	1.00

J/J0 50% = > 100 mT

Appendix II - Paleomagnetism data (continued)

2967 - Riverside exposure, dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0	
1	0.00	24	353	72.77	1.00
2	5.00	24	352	72.57	1.00
3	10.00	23	352	72.41	1.00
4	15.00	23	352	72.18	0.99
5	20.00	23	352	72.17	0.99
6	30.00	23	353	72.11	0.99
7	40.00	23	353	72.28	0.99
8	60.00	22	353	71.70	0.99
9	80.00	23	353	71.12	0.98
10	100.00	23	354	70.00	0.99

J/J0 50% = >100 mT

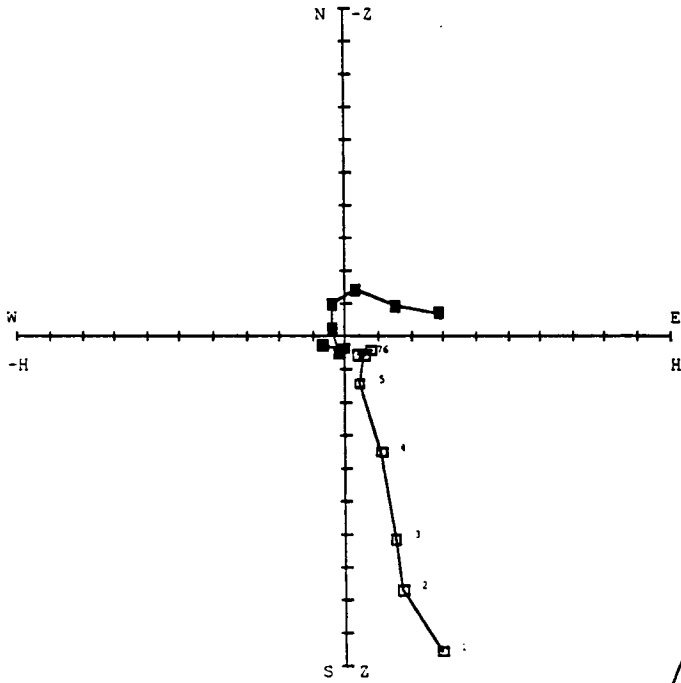
2968 - Riverside exposure, dark gray diamicton

Demag Step (mT)	Inclination	Declination	Intensity (mA/m)	J/J0	
1	0.00	33	358	1.232	1.00
2	5.00	26	357	1.280	1.00
3	10.00	20	356	1.306	1.10
4	15.00	17	356	1.342	1.00
5	20.00	15	352	1.288	1.00
6	30.00	13	355	1.278	1.20
7	40.00	8	350	1.443	1.20
8	60.00	12	349	1.445	1.20
9	80.00	11	354	1.447	1.20
10	100.00	19	1	1.465	1.20

J/J0 50% = >100 mT

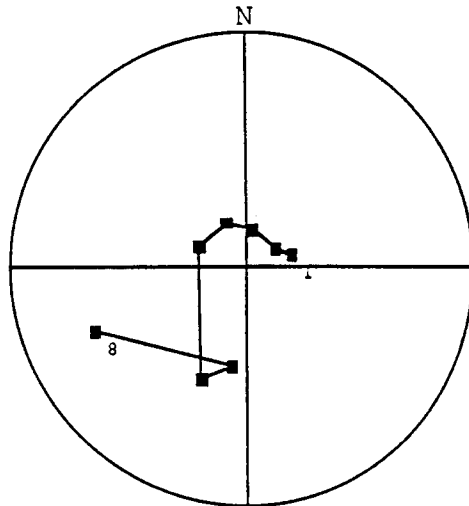
170 2910

	STEP	DECL	INCL
1	0	75.7	72.9
2	5	58.7	77.4
3	10	11.5	76.4
4	20	337.0	73.3
5	40	294.0	72.6
6	60	202.0	48.4
7	80	188.0	55.4
8	100	247.0	31.2

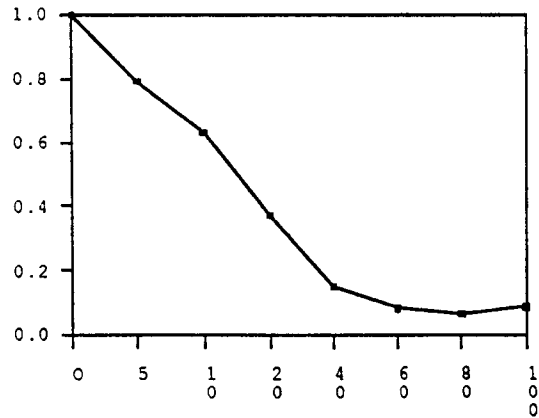
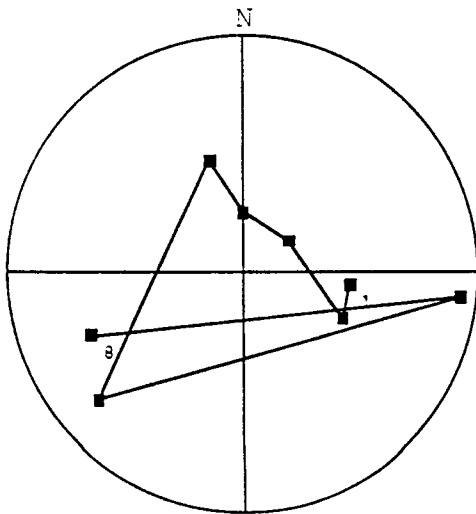


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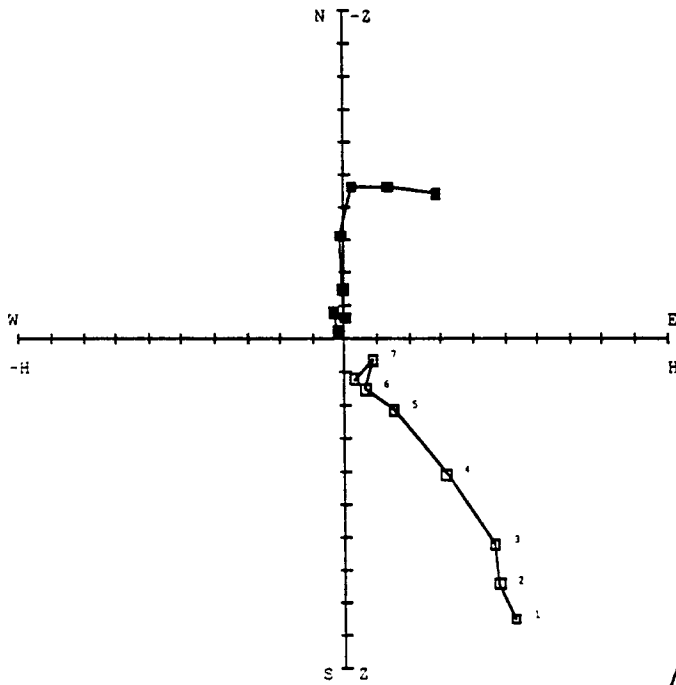


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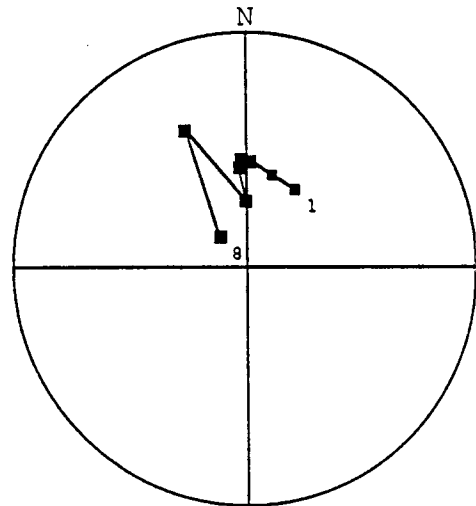
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	STEP	DECL	INCL
1	0	33.0	58.0
2	5	16.0	57.0
3	10	3.0	53.0
4	20	358.0	52.0
5	40	356.0	55.0
6	60	359.0	67.0
7	80	336.0	37.0
8	100	319.0	76.0

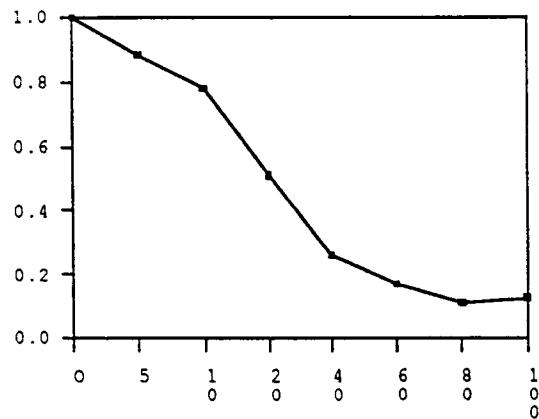
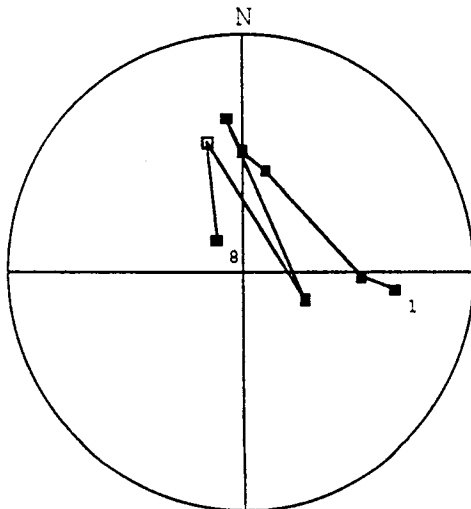


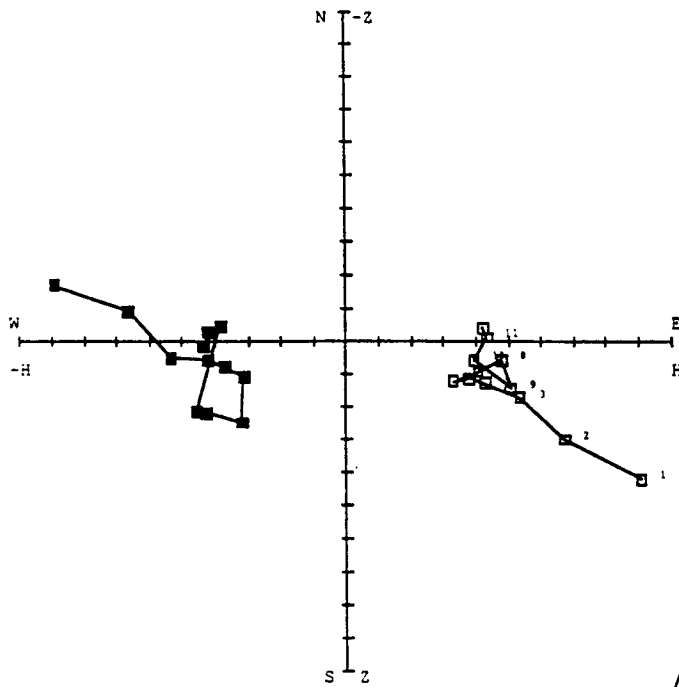
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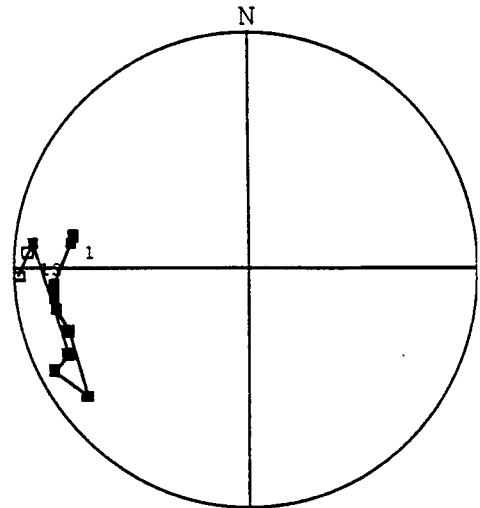


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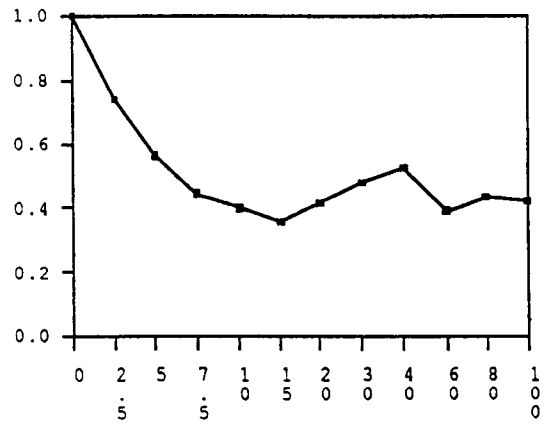
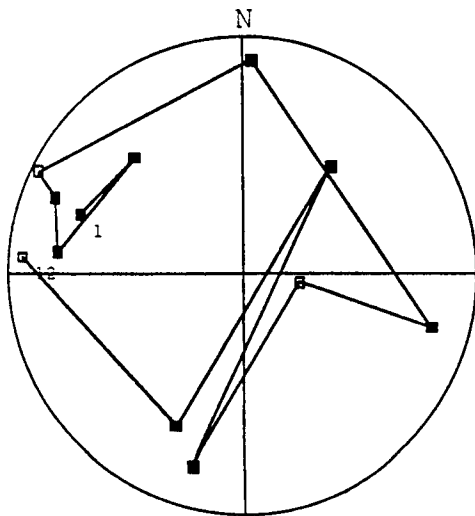
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3	5	265.0	18.0
4	7.5	262.0	17.0
5	10	258.0	17.0
6	15	251.0	20.0
7	20	232.0	13.0
8	30	243.0	7.0
9	40	245.0	16.0
10	60	277.0	8.0
11	80	268.0	-2.0
12	100	274.0	-6.0

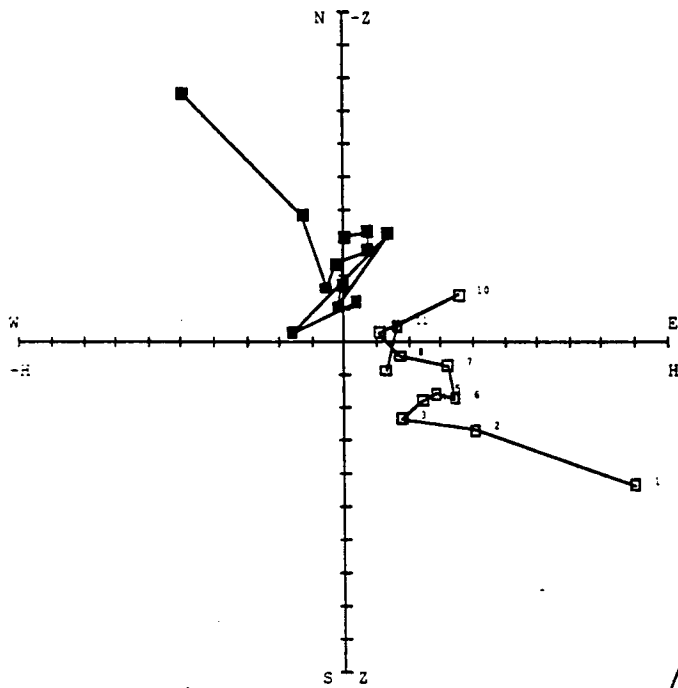
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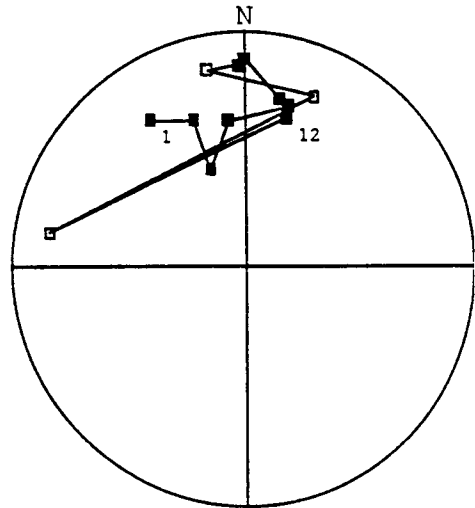


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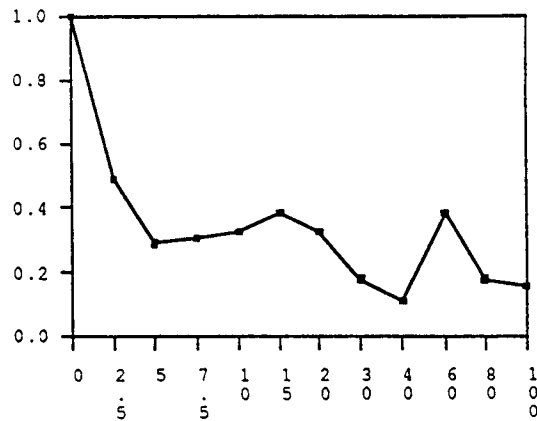
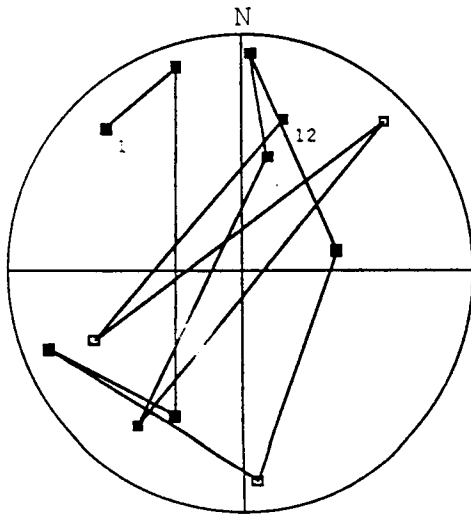
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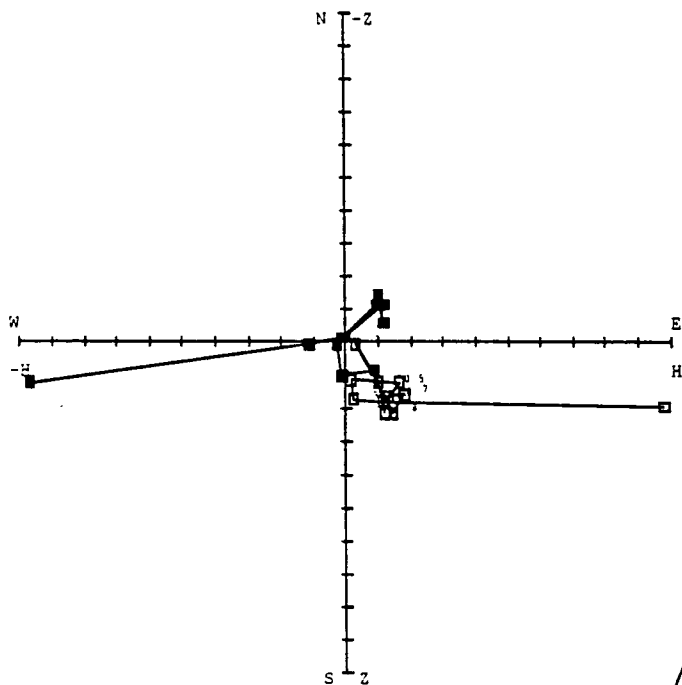
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4	7.5	354.0	37.0
5	10	15.0	29.0
6	15	12.0	27.0
7	20	360.0	12.0
8	30	358.0	15.0
9	40	349.0	-16.0
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11	80	280.0	-16.0
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REMANENCE VECTORS



DIFFERENCE VECTORS



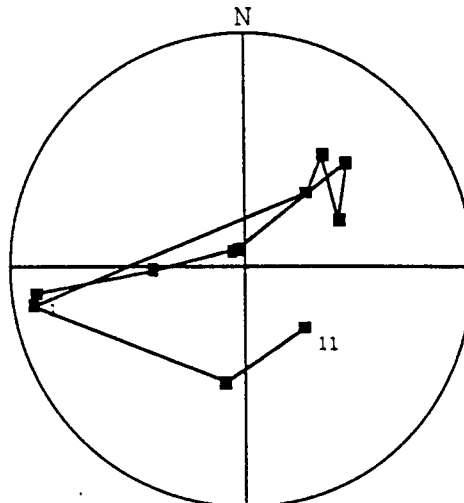


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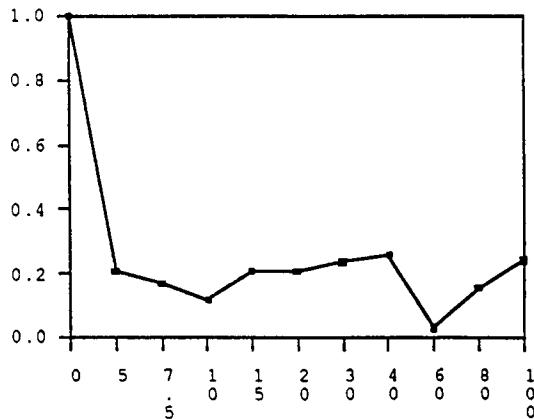
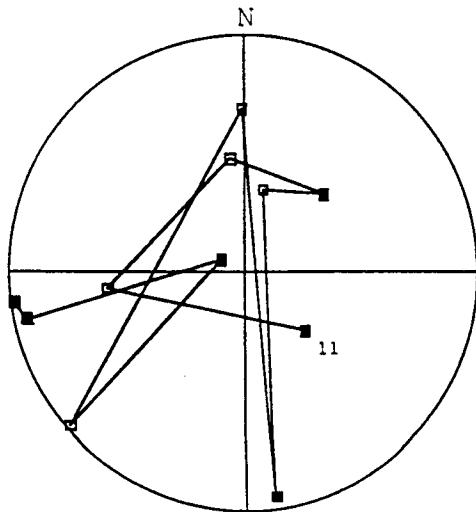
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5	15	44.0	37.0
6	20	64.0	52.0
7	30	35.0	41.0
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9	60	260.0	9.0
10	80	190.0	50.0
11	100	134.0	60.0

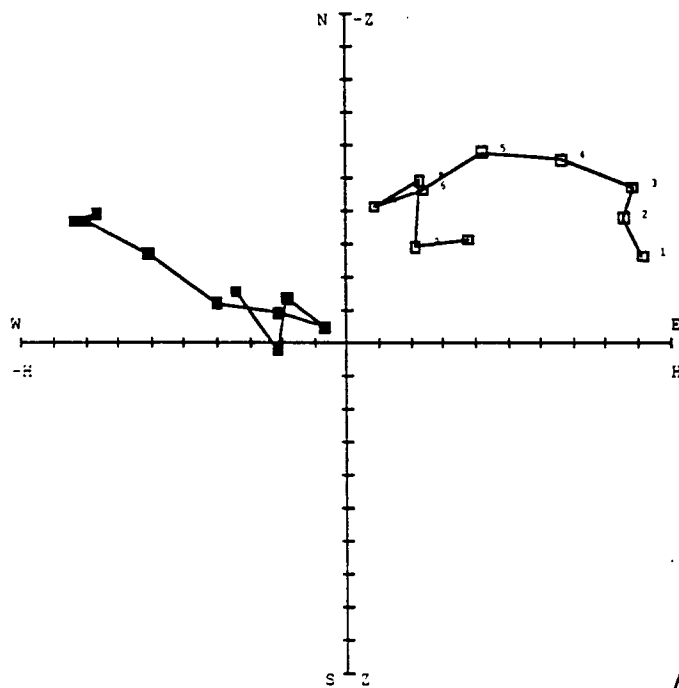
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REMANENCE VECTORS



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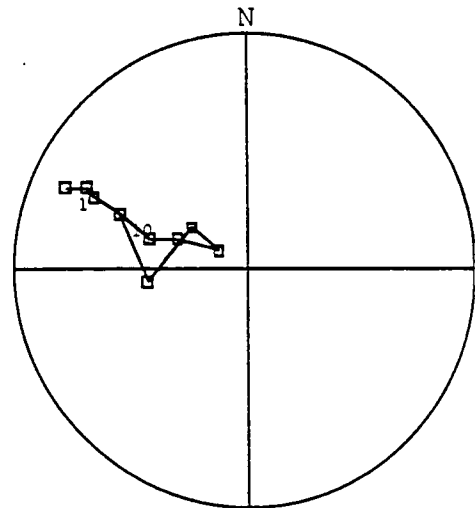


Parallel 2943

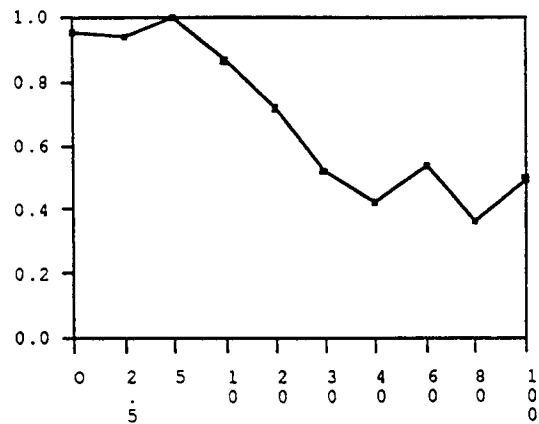
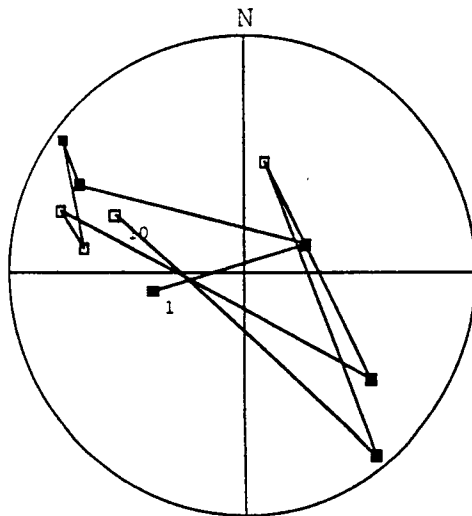
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8	60	-65.0
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10	100	-40.0

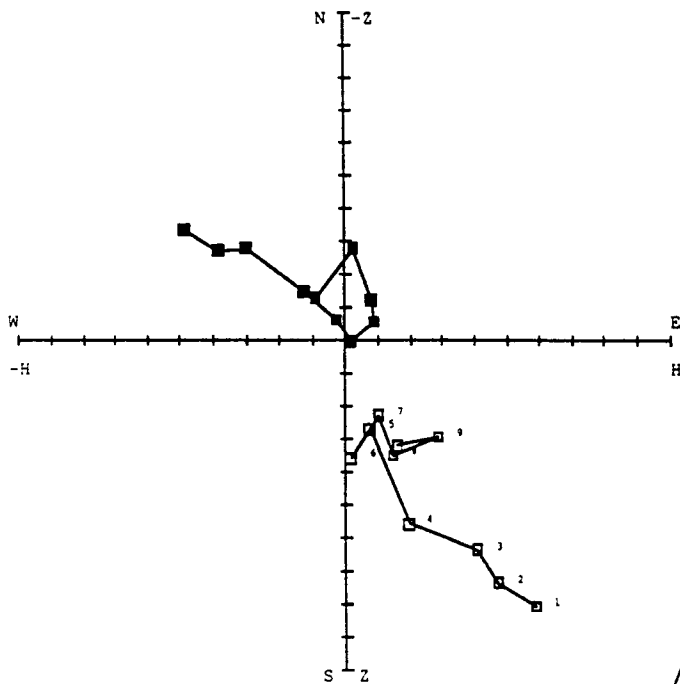
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REMANENCE VECTORS



DIFFERENCE VECTORS



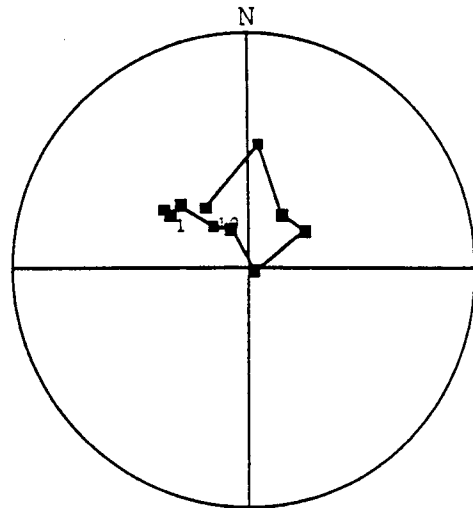


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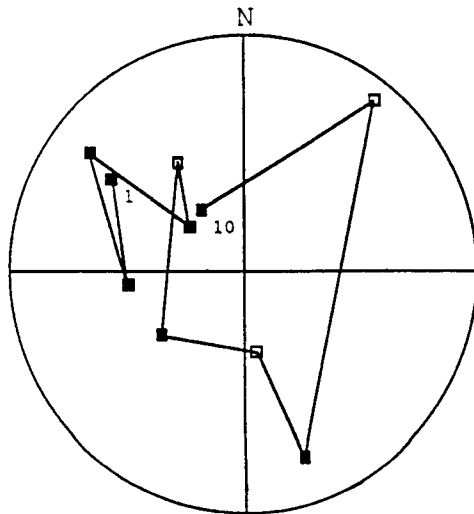
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3	5	57.2
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5	20	75.1
6	30	87.9
7	40	63.9
8	60	68.0
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10	100	63.7

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REMANENCE VECTORS

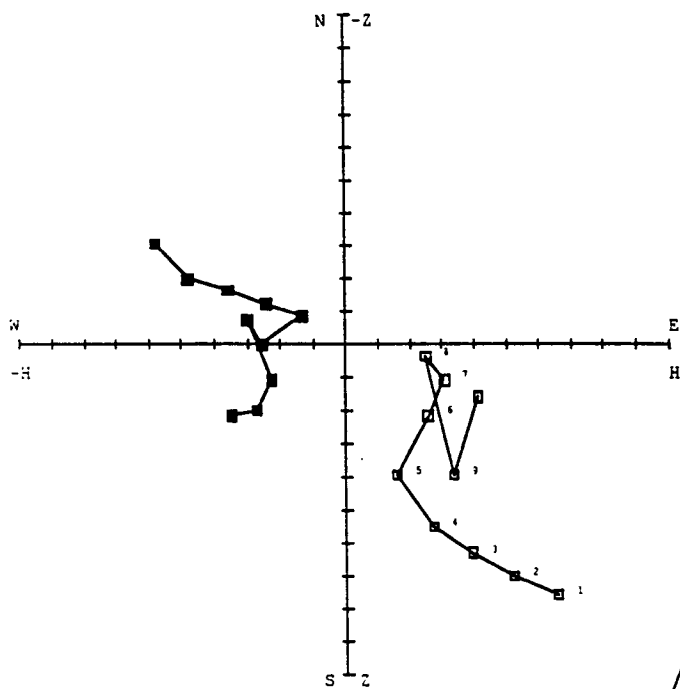


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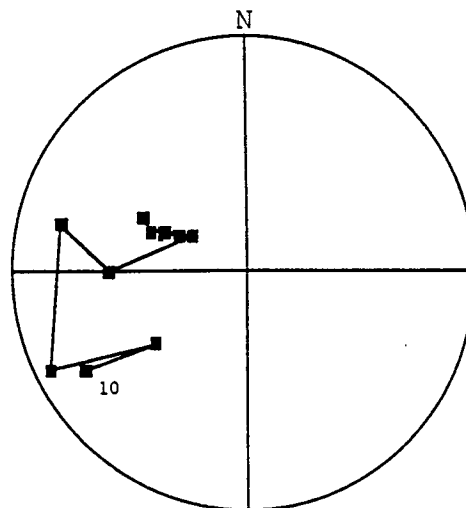
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3	5	295.0
4	10	297.0
5	20	303.0
6	30	270.0
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8	60	244.0
9	80	233.0
10	100	239.0

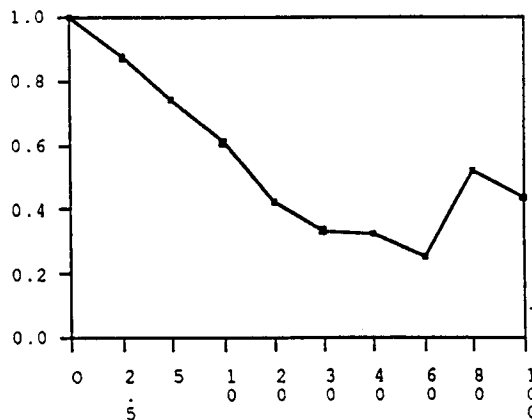
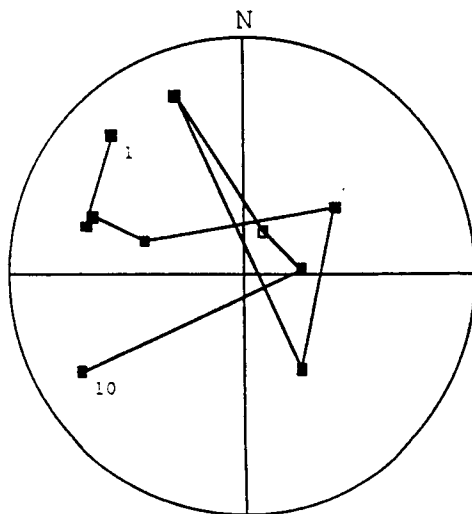


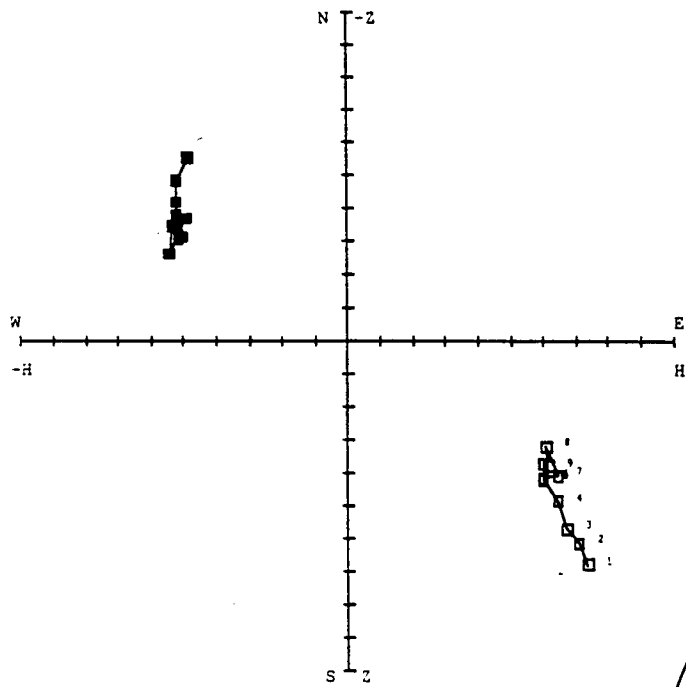
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CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS



DIFFERENCE VECTORS



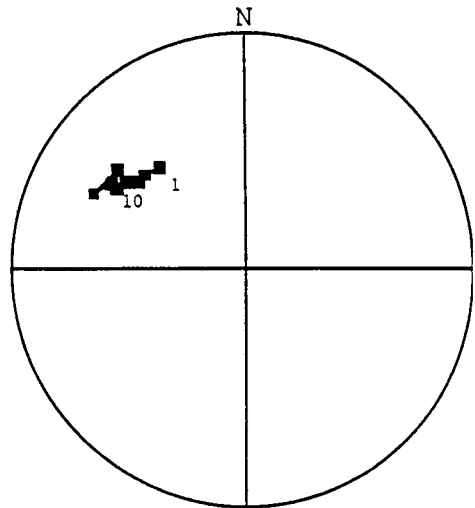


NH 2960

	STEP	DECL	INCL
1	0	319.0	42.7
2	2.5	313.0	40.8
3	5	309.0	40.4
4	10	306.0	37.2
5	20	302.0	35.2
6	30	301.0	34.9
7	40	303.0	32.4
8	60	296.0	28.1
9	80	307.0	31.4
10	100	302.0	31.7

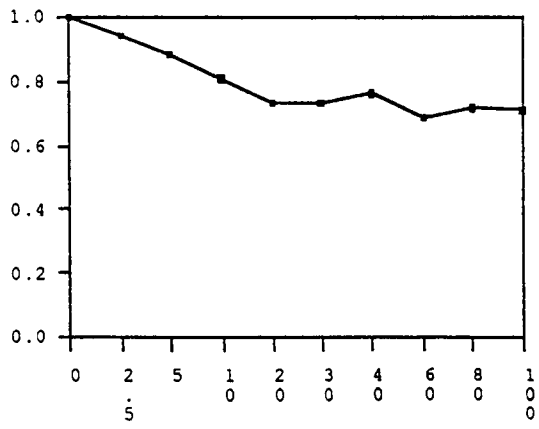
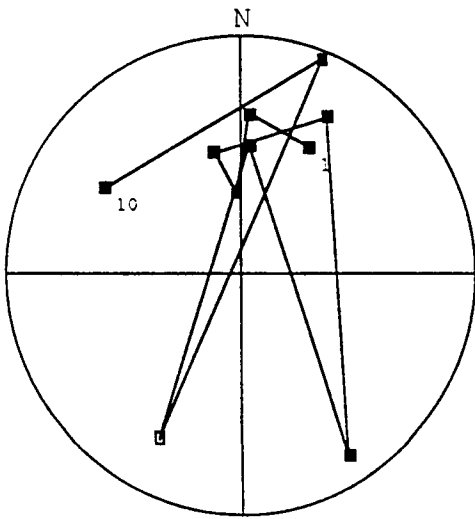


REMANENCE VECTORS



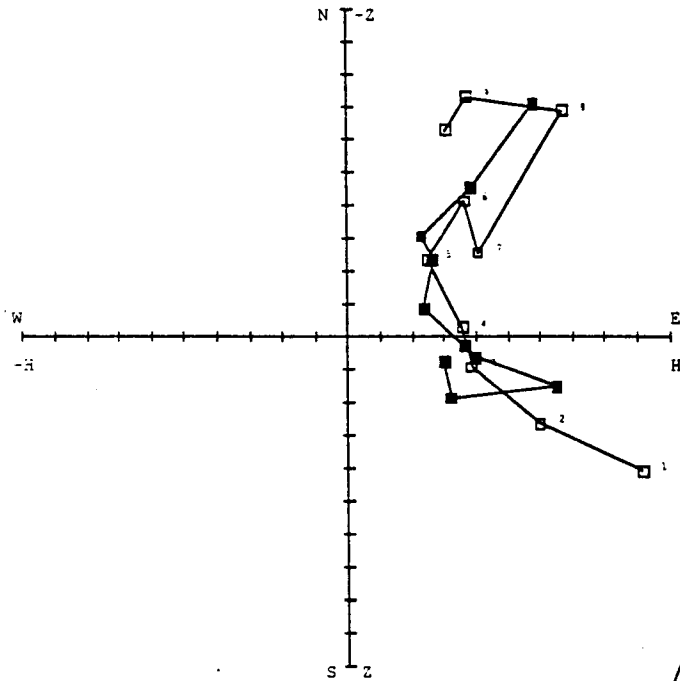
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CLOSED SYMBOLS=HORIZONTAL PLANE

DIFFERENCE VECTORS



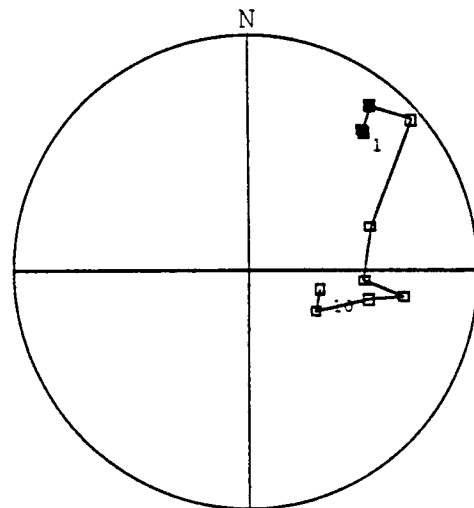
NH 2961

STEP	DECL	INCL
1	0	39.0
2	2.5	40.0
3	5	37.0
4	10	48.0
5	20	70.0
6	30	95.0
7	40	99.0
8	60	123.0
9	80	120.0
10	100	105.0

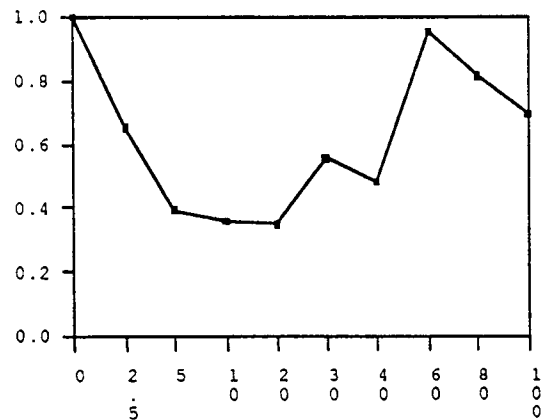
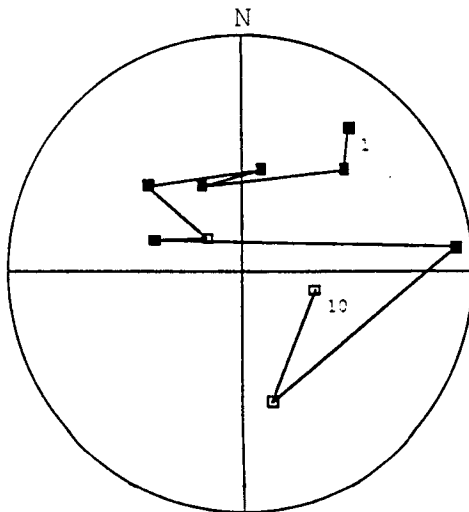


OPEN SYMBOLS=VERTICAL PLANE
CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS

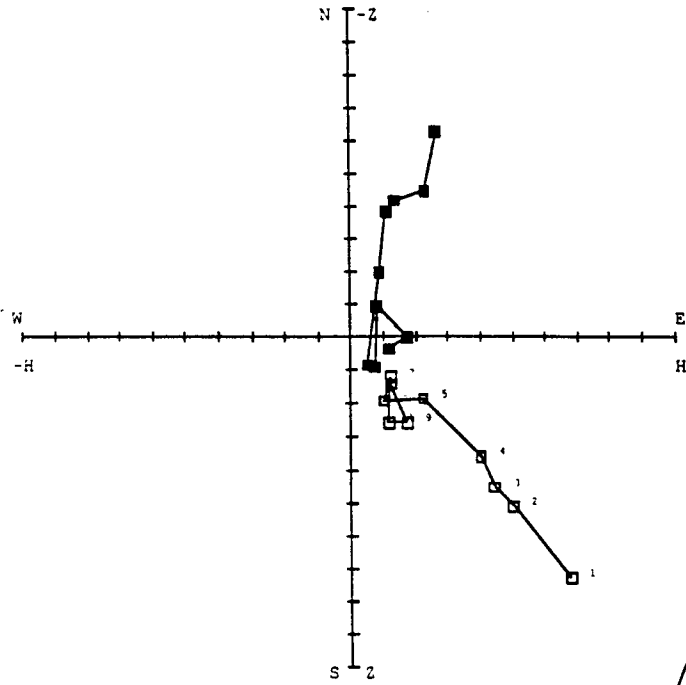


DIFFERENCE VECTORS



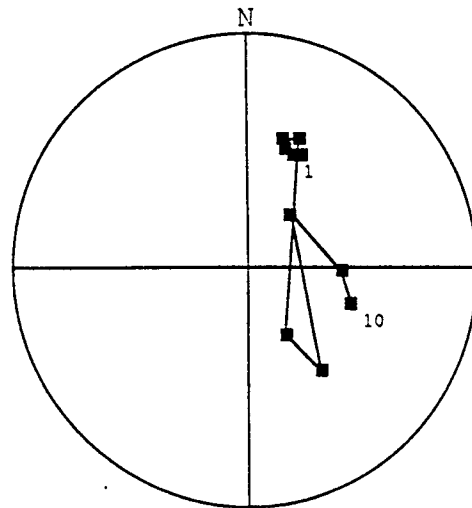
NH 2962

	STEP	DECL	INCL
1	0	23.0	47.0
2	2.5	27.0	45.4
3	5	18.0	45.3
4	10	16.0	41.9
5	20	23.0	40.3
6	30	149.0	63.3
7	40	143.0	45.1
8	60	40.0	65.3
9	80	91.0	56.6
10	100	108.0	51.1

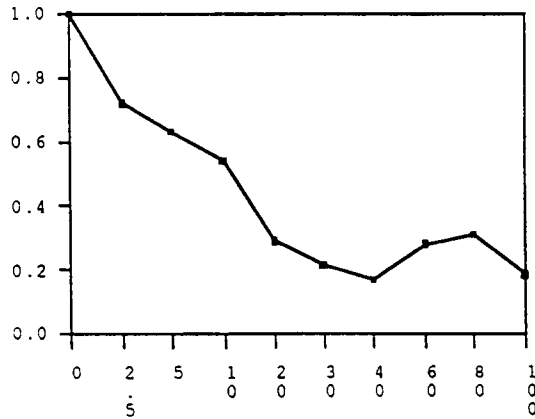
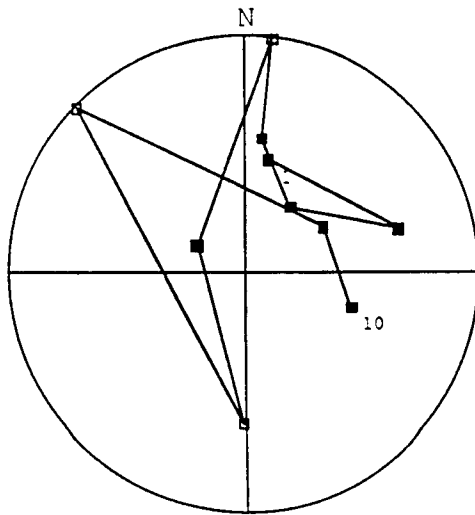


OPEN SYMBOLS=VERTICAL PLANE
CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS

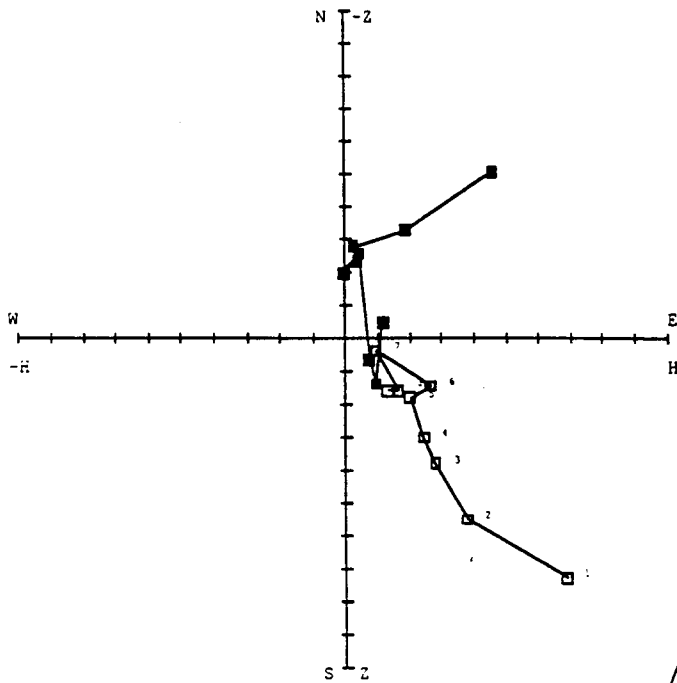


DIFFERENCE VECTORS



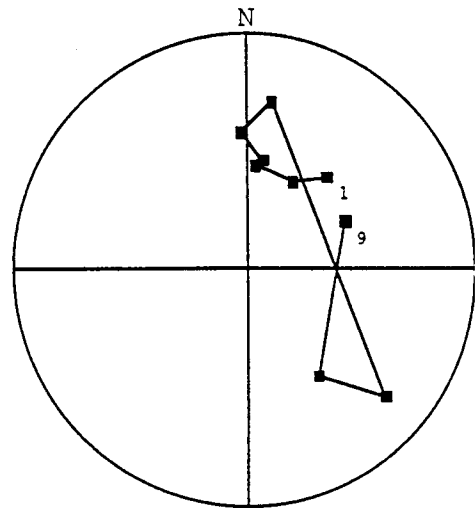
NH 2963

STEP	DECL	INCL
1	0	46.9
2	5	55.4
3	10	53.7
4	15	51.2
5	20	358.0
6	40	9.0
7	60	132.0
8	90	146.0
9	100	65.0

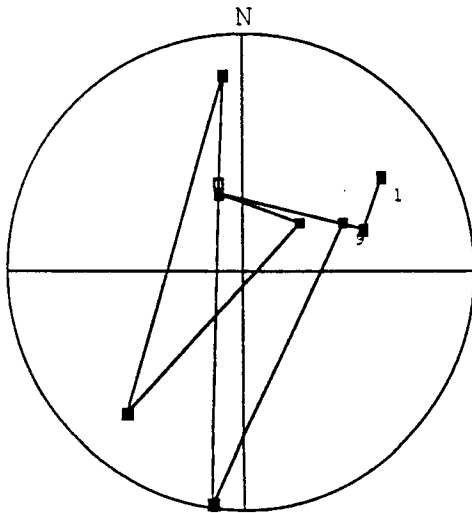


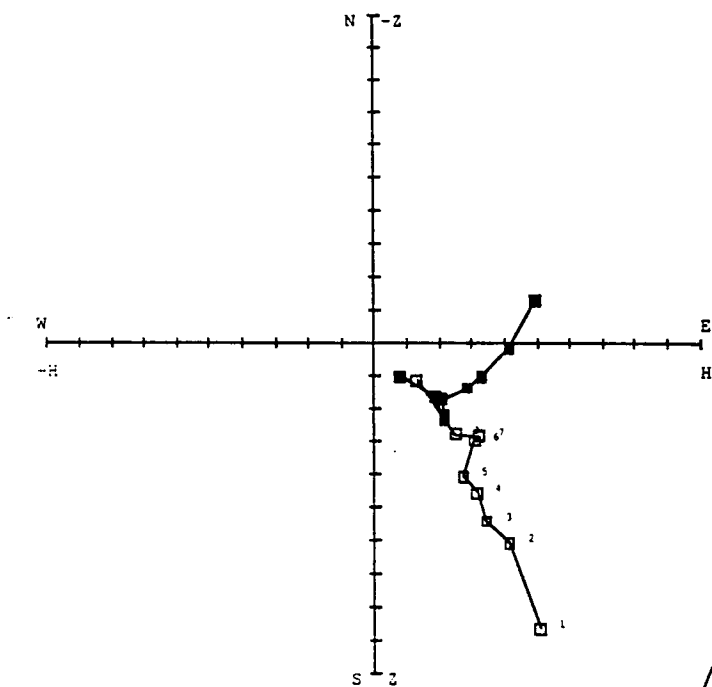
OPEN SYMBOLS=VERTICAL PLANE
CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS



DIFFERENCE VECTORS



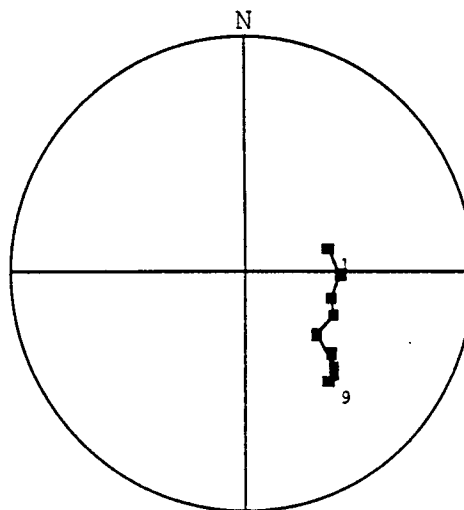


NH 2964

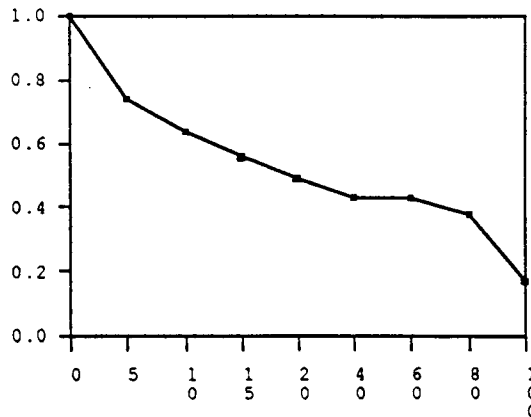
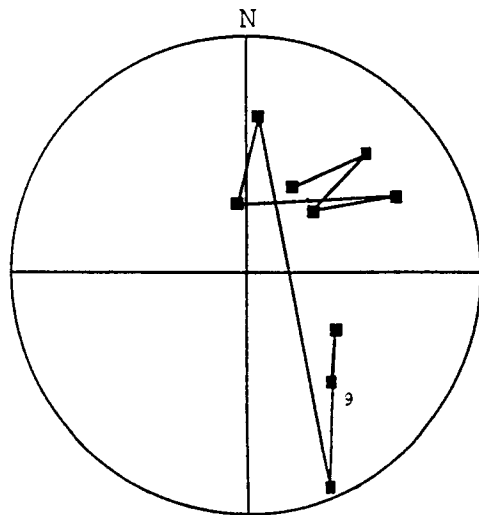
	STEP	DECL	INCL
1	0	75.0	59.5
2	5	92.0	55.9
3	10	107.0	57.9
4	15	115.0	55.2
5	20	130.0	56.3
6	40	136.0	44.0
7	60	138.0	42.1
8	80	132.0	48.3
9	100	142.0	41.4

OPEN SYMBOLS=VERTICAL PLANE
CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS

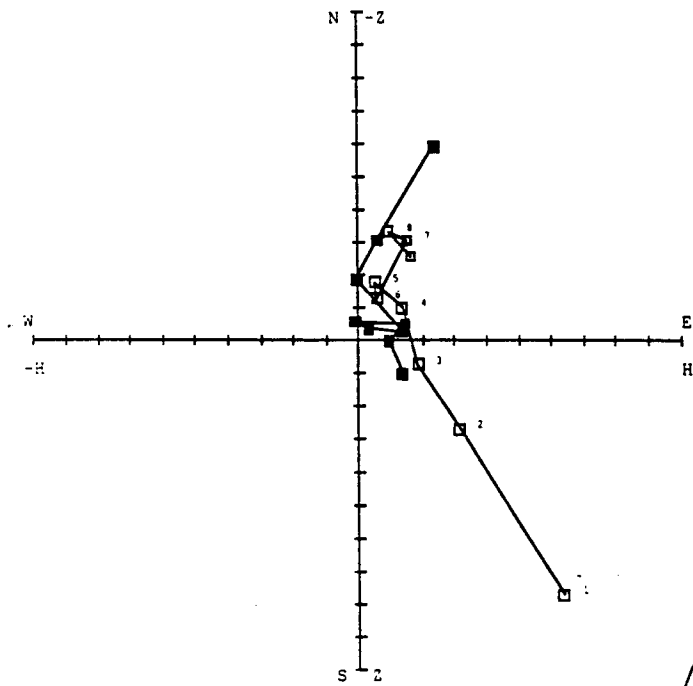


DIFFERENCE VECTORS



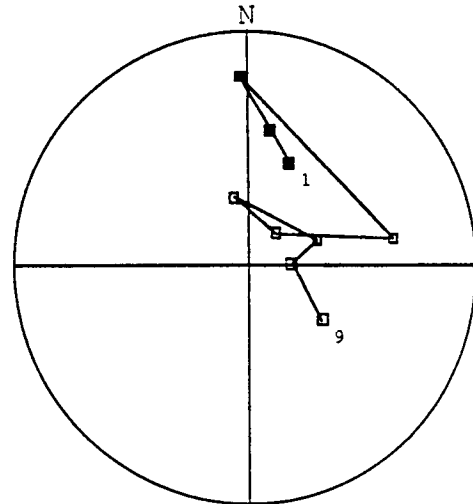
NH 2965

	STEP	DECL	INCL
1	0	22.0	50.4
2	5	10.0	40.4
3	10	358.0	20.1
4	15	79.0	-36.4
5	20	40.0	-74.8
6	40	343.0	-65.7
7	60	70.0	-64.1
8	80	88.0	-74.8
9	100	126.0	-57.4

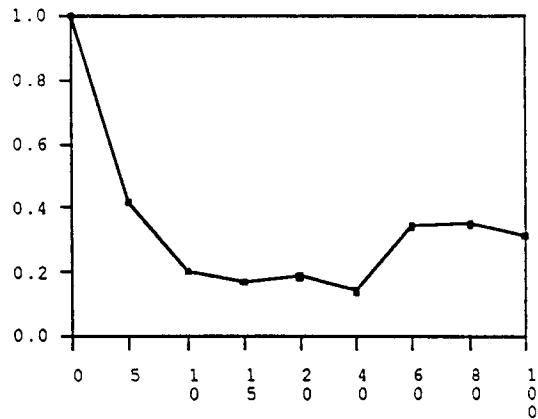
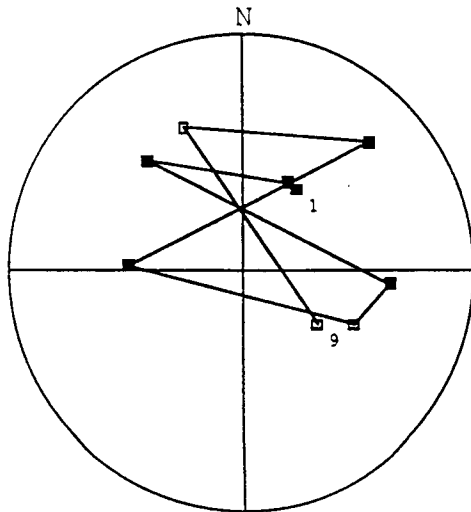


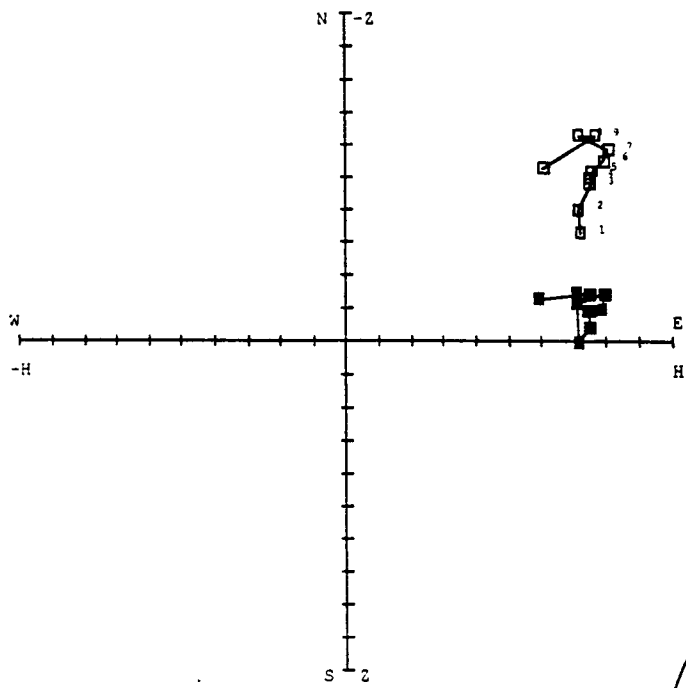
OPEN SYMBOLS=VERTICAL PLANE
CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS



DIFFERENCE VECTORS



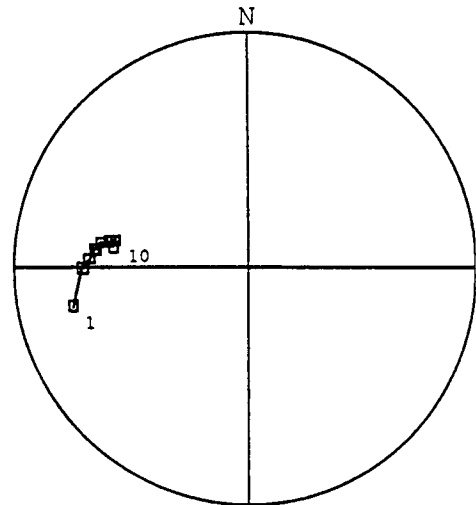


RS 2966

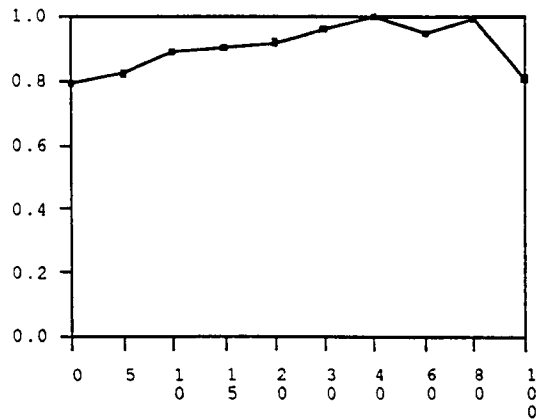
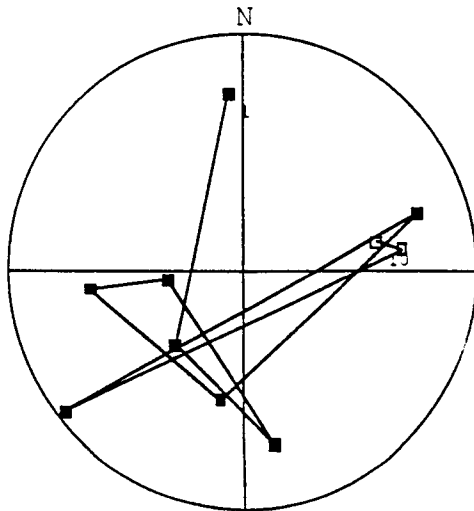
STEP	DECL	INCL
1	0	-102.0
2	5	-90.0
3	10	-87.0
4	15	-83.0
5	20	-83.0
6	30	-83.0
7	40	-80.0
8	60	-81.0
9	80	-79.0
10	100	-78.0

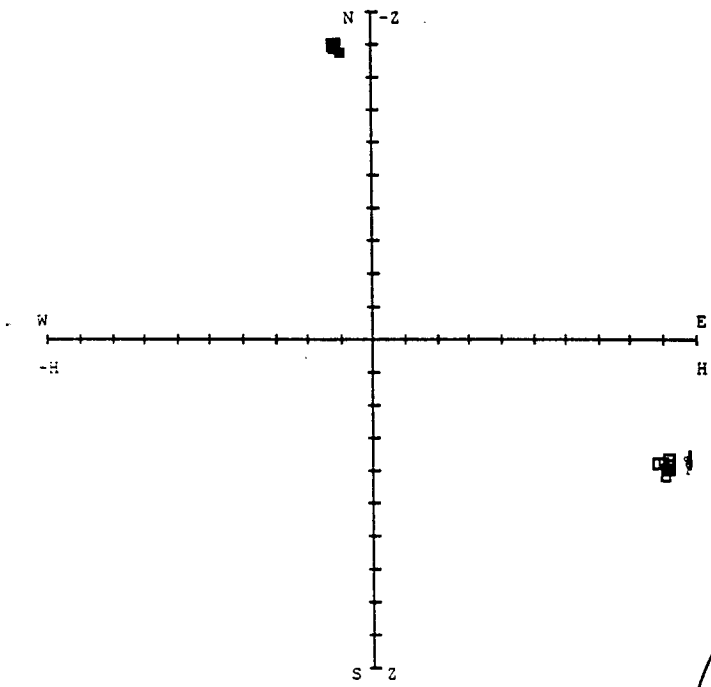
OPEN SYMBOLS=VERTICAL PLANE
CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS



DIFFERENCE VECTORS



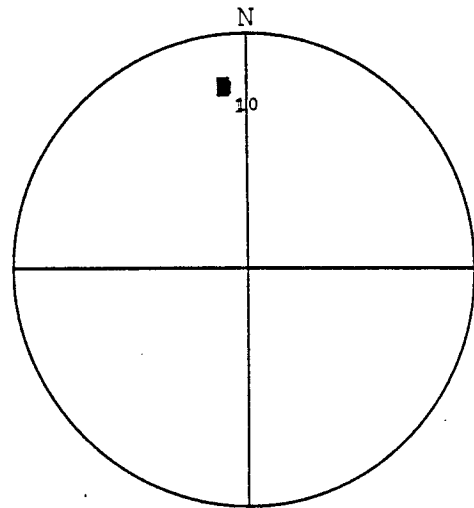


RS 2967

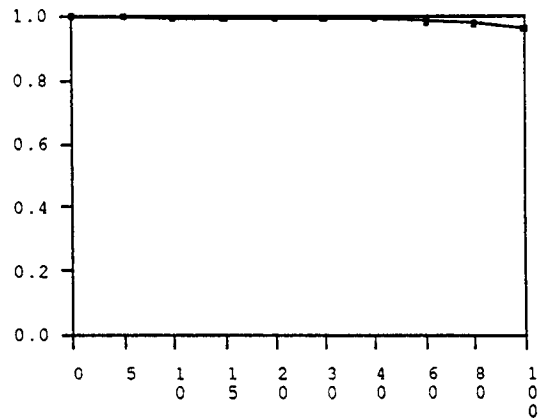
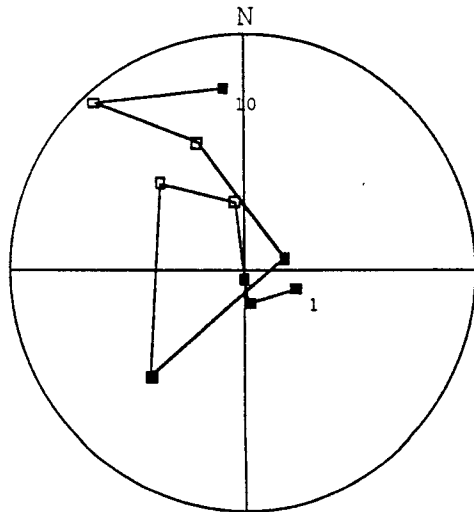
STEP	DECL	INCL
1	0	352.6
2	5	352.4
3	10	352.4
4	15	352.4
5	20	352.4
6	30	352.5
7	40	352.9
8	60	352.6
9	80	352.8
10	100	353.6

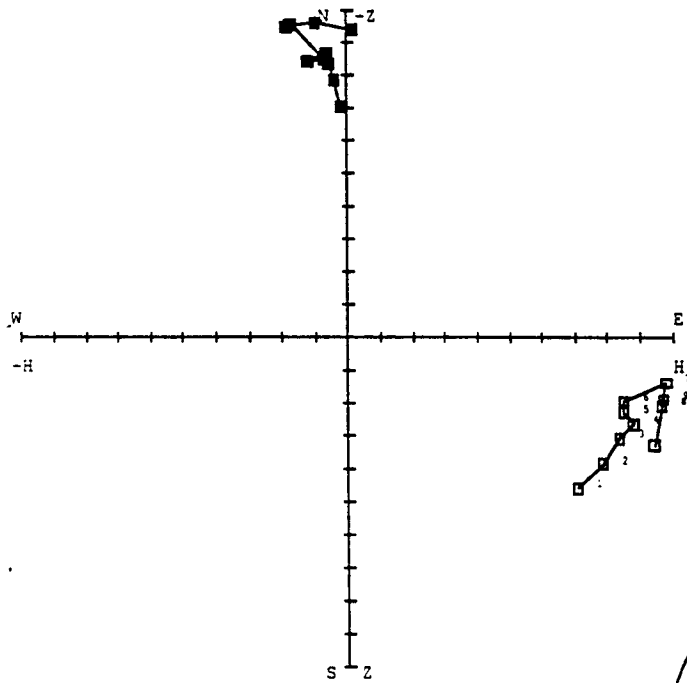
OPEN SYMBOLS=VERTICAL PLANE
CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS



DIFFERENCE VECTORS



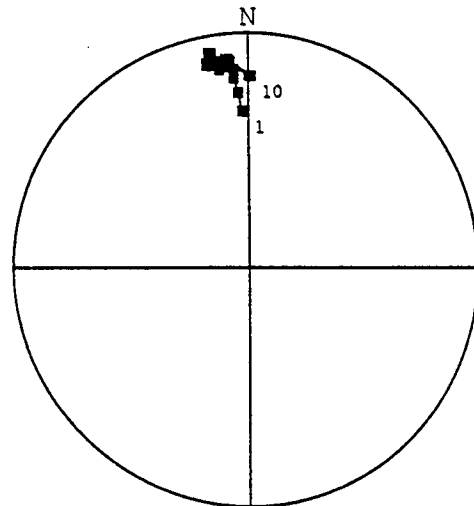


RS 2968

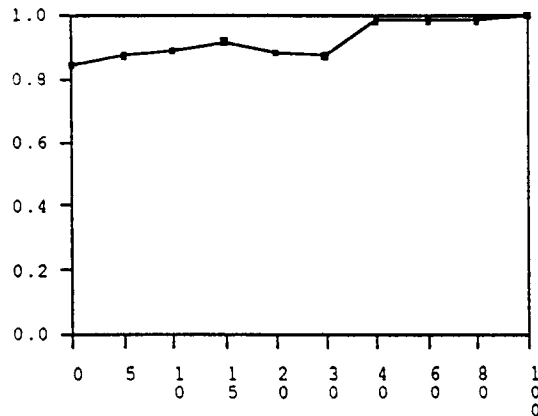
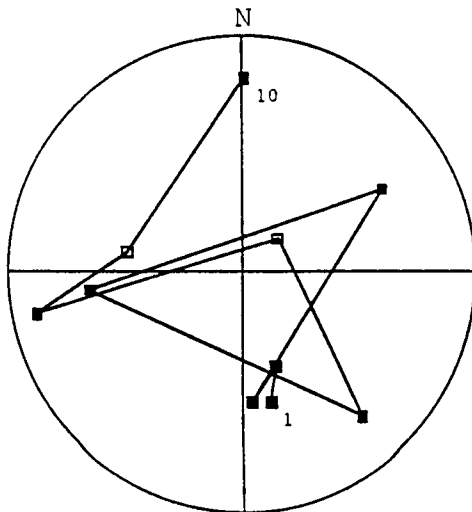
	STEP	DECL	INCL
1	0	358.0	33.0
2	5	357.0	26.0
3	10	356.0	20.0
4	15	356.0	17.0
5	20	352.0	15.0
6	30	355.0	13.0
7	40	350.0	8.0
8	60	349.0	12.0
9	80	354.0	11.0
10	100	1.0	19.0

OPEN SYMBOLS=VERTICAL PLANE
CLOSED SYMBOLS=HORIZONTAL PLANE

REMANENCE VECTORS



DIFFERENCE VECTORS



Appendix III - Pipette analysis Procedure

- 1). Obtain a representative subsample that will yield no more than 15-20 grams of mud. For most diamictons in this study between 30-40 grams of air dried sample was enough.
- 2). Sample was soaked in a 2% sodium hexametaphosphate solution for at least 24 hours.
- 3). Wet sieve sample through a #230 (.0625mm) sieve. Use 2% dispersant solution to wash and use no more than 500 ml solution.
- 4). Oven dry remaining sand fraction and weigh to nearest .01 gram.
- 5). Transfer mud collected in wet sieving into a 1000 ml cylinder. Top off cylinder to 1000 ml with dispersant solution.
- 6). Stopper cylinder with a rubber stopper and mix sample for at least 2 minutes.
- 7). Let cylinder stand over night to check for flocculation.
- 8). If flocculation is not apparent mix cylinder completely for 2 minutes.
- 9). To begin analysis stir cylinder for 1 minute using a brass stirring rod. After 1 minute remove stirring rod.
- 10). Take 20 ml aliquots from appropriate depths (calculate depth from table 10 and figure 10, from Lewis (1984) at 20s, 2min, 4 min, 8 min, 15 min, 30 min, 2hr, 8hr, 36hr). Empty pipette into previously weighed 50 ml beakers. Rinse pipette with 20 ml of distilled water after each withdrawal.
- 11). Oven dry beakers at temperature below 100 C to avoid boiling over.
- 12). Weigh oven dried beakers to the nearest .001 gram after they cool for 1 hour.
- 13). Calculate cumulative weight percent for each phi interval using the following method:
 - a). Subtract beaker weights from beaker + sediment weight to get pipette sample weight.
 - b). Multiply the weight of sediment from the 4 phi sample by 50 and subtract the weight of dispersant in the column. This gives the total weight of mud in the sample (F).
 - c). $\text{cumulative wt. \%} = 100 - \frac{([50 \times \text{pipette sample wt.}] - (\text{dispersant wt. per liter}))}{S + F}$

Appendix IV - Texture data

sample	sampling site	lithology	% sand	% silt	% clay
1	Nebo Hill (624NH)	basal till unleached	42.2	42.6	15.3
2	Nebo Hill (641NH)	basal till unleached	32.7	55.3	12.0
3	Highway EE (61EE)	basal till unleached	49.3	37.5	13.2
4	Highway EE (624EEB)	basal till unleached	31.9	33.1	35.0
5	Highway EE (624EEA)	basal till leached	32.6	44.4	22.9
6	Antioch Road (912AR)	basal till unleached	47.5	41.9	10.5
7	Antioch Rd (ARW)	basal till leached	34.7	40.7	24.5
8	Riverside (6261RS)	basal till unleached	36.2	46.7	17.1
9	152 Hwy (9301152)	basal till unleached	36.0	42.3	21.7
10	152 Hwy (9306152)	basal till leached	33.1	39.7	27.3
11	152 Hwy (9302152)	basal till leached	38.1	47.2	14.7
12	152 Hwy (1525U)	lodgment till leached	34.1	36.0	29.9
13	Hwy I-70 (711170)	lodgment till unleached	41.1	48.0	10.9
14	Hwy I-70 (13270TA)	lodgment till leached	42.1	38.5	35.0
15	Parallel Ave. (651PA)	diamicton leached	36.8	47.8	15.5
16	1-69 Hwy (91TMN)	basal till leached	34.3	39.8	26.0
17	1-69 Hwy (9301169)	diamicton leached	34.0	59.2	6.8
18	1-69 Hwy S (169)	stratified diamicton	37.2	46.7	16.2
19	State Ave. (24HI U)	basal till leached	27.3	35.4	37.4
20	State Ave. (24HI I)	basal till leached	26.5	38.5	35.0
21	Georgia Ave. (6261GA)	diamicton leached	37.9	33.7	28.4
22	New Jersey Ave. (6261NJ)	diamicton leached	40.7	28.4	30.9
23	Utica Ave. (816UT)	diamicton leached	28.1	24.5	47.3

APPENDIX V-Small-pebble data

Highway 152 exposure:

sample	n	LI	DI	MM	SQ	Q	CH	LS	SS-SH	% LS	% LI	% DI	% MM	% CH	% EX	% LO
oxidized basal gravel:																
1	256	1	1	8	1	2	17	186	40	72.66	1.17	0.39	3.52	6.64	5.08	88.28
lower unoxidized and unleached till:																
2	192	3	1	3	0	0	5	111	69	57.81	1.56	0.52	1.56	2.60	3.65	93.75
3	110	5	2	4	0	2	4	49	44	44.55	6.36	1.82	3.64	3.64	11.82	84.55
4	54	5	1	1	0	0	3	20	24	37.04	9.26	1.85	1.85	5.56	12.96	81.48
5	103	7	0	3	0	1	4	53	35	51.46	7.77	0.00	2.91	3.88	10.68	85.44
oxidized and unleached till and outwash:																
6	41	4	0	2	0	1	3	21	10	51.22	12.20	0.00	4.88	7.32	17.07	75.61
7	63	7	0	5	0	2	3	30	16	47.62	14.29	0.00	7.94	4.76	22.22	73.02
8	215	21	1	19	1	4	5	119	45	55.35	11.63	0.47	9.30	2.33	21.40	76.28
upper oxidized and leached till:																
9	54	8	3	14	0	5	0	19	5	35.19	24.07	5.56	25.93	0.00	55.56	44.44
10	64	16	0	8	3	3	4	21	9	32.81	29.69	0.00	17.19	6.25	46.88	46.88
11	45	8	1	3	0	1	4	22	2	48.89	20.00	2.22	6.67	8.89	28.89	53.33
12	45	17	0	16	1	4	0	0	0	0.00	46.67	0.00	37.78	0.00	84.44	0.00
13	47	15	0	14	1	5	1	7	2	14.89	42.55	0.00	31.91	2.13	74.47	19.15
14	6	2	1	1	0	0	1	0	0	0.00	33.33	16.67	16.67	16.67	66.67	0.00
lower	308	20	4	11	0	3	16	233	18	75.65	7.47	1.30	3.57	5.19	12.34	81.49
upper	261	66	5	56	5	18	10	69	18	26.44	32.18	1.92	23.37	3.83	57.47	33.33

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Appendix V-Pebble Count Data

Sample number: MC-3

Location: Stream cut along Mill Creek, 100 m south of where I-70 crosses creek.
NW1/4, SW1/4, SW1/4, Sec. 10, T11S, R24E, Shawnee Quadrangle.

Sampling point: in crossbedded outwash, 2 meters above stream level.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	128	54.5	felsic	-	-
dark igneous	4	1.7	dark igneous	-	-
metamorphic	5	2.1	metamorphic	-	-
Sioux Quartzite	8	3.4	Sioux Quartzite	-	-
quartz	0	0.0	quartz	-	-
chert	43	18.3	chert	-	-
limestone	0	0.0	limestone	-	-
sandstone/shale	47	20.0	sandston/shale	-	-
total	235	100	total	-	-
% erratics	61.7		% erratics	-	
% local	20.0		% local	-	
% chert	18.3		% chert	-	

Sample number: LVR-1

Location: Roadcut on north side of Leavenworth Road, SW1/4, SW1/4, SW1/4,
Sec. 30, T10S, R23E, Wolcott, Missouri-Kansas Quadrangle.

Sampling point: see figure 10 for location.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	55	12.6	felsic	3	2.5
dark igneous	0	0.0	dark igneous	0	0.0
metamorphic	11	2.5	metamorphic	0	0.0
Sioux Quartzite	1	0.2	Sioux Quartzite	1	0.8
quartz	0	0.0	quartz	5	4.2
chert	57	13.0	chert	32	27.1
limestone	132	30.1	limestone	43	36.4
sandstone/shale	182	41.6	sandston/shale	34	28.8
total	438	100	total	118	100
% erratics	15.3		% erratics	7.6	
% local	71.7		% local	65.3	
% chert	13.0		% chert	27.1	

Appendix V-Pebble Count Data (continued)

Sample number: LVR 2

Location: Roadcut on north side of Leavenworth Road, SW1/4, SW1/4, SW1/4,
Sec. 30, T10S, R23E, Wolcott, Missouri-Kansas Quadrangle.

Sampling point: see figure 10 for location.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	-	-	felsic	1	1.4
dark igneous	-	-	dark igneous	0	0.0
metamorphic	-	-	metamorphic	0	0.0
Sioux Quartzite	-	-	Sioux Quartzite	0	0.0
quartz	-	-	quartz	0	0.0
chert	-	-	chert	19	27.5
limestone	-	-	limestone	23	33.0
sandstone/shale	-	-	sandston/shale	25	35.9
total	-	-	total	69	-
% erratics	-	-	% erratics	1.4	
% local	-	-	% local	68.9	
% chert	-	-	% chert	27.5	

Sample number: LVR 4

Location: Roadcut on north side of Leavenworth Road, SW1/4, SW1/4, SW1/4,
Sec. 30, T10S, R23E, Wolcott, Missouri-Kansas Quadrangle.

Sampling point: see figure 10 for location.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	-	-	felsic	9	7.8
dark igneous	-	-	dark igneous	0	0.0
metamorphic	-	-	metamorphic	0	0.0
Sioux Quartzite	-	-	Sioux Quartzite	0	0.0
quartz	-	-	quartz	0	0.0
chert	-	-	chert	11	9.6
limestone	-	-	limestone	70	60.9
sandstone/shale	-	-	sandston/shale	24.1	21.8
total	-	-	total	115	100
% erratics	-	-	% erratics	7.8	
% local	-	-	% local	72.7	
% chert	-	-	% chert	9.6	

Appendix V-Pebble Count Data (continued)

Sample number: 610AM

Location: South of I-70, SE1/4, SE1/4, Sec. 8, T11S, R24E, Shawnee, Kansas
 Quadrangle.

Sampling point: yellowish red (5YR 4/6) diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	78	39.4	felsic	49	17.5
dark igneous	0	0.0	dark igneous	3	1.1
metamorphic	1	0.5	metamorphic	0	0.0
Sioux Quartzite	5	0.0	Sioux Quartzite	18	6.5
quartz	19	9.6	quartz	34	12.2
chert	25	12.6	chert	123	44.8
limestone	0	0.0	limestone	0	0.0
sandstone/shale	70	35.4	sandston/shale	52	18.6
total	198	100	total	279	100
% erratics	52.0		% erratics	37.3	
% local	35.4		% local	18.6	
% chert	12.6		% chert	44.8	

Sample number: 661MN

Location: Abandoned barrow site on northwest corner of 169 and Barry Road.
 SW1/4, NE1/4, Sec. 10, T51N, R33W, North Kansas, City Quadrangle.

Sampling point: 1 meter below stoneline in center of site in light olive brown (2.5Y 5/4)
 oxidized and leached diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	47	35.9	felsic	4	23.5
dark igneous	0	0.0	dark igneous	1	5.9
metamorphic	30	22.9	metamorphic	4	23.5
Sioux Quartzite	1	0.7	Sioux Quartzite	1	5.9
quartz	10	7.6	quartz	0	0.0
chert	12	9.2	chert	0	0.0
limestone	0	0.0	limestone	0	0.0
sandstone/shale	31	23.7	sandston/shale	7	41.2
total	131	100	total	17	100
% erratics	67.2		% erratics	58.8	
% local	23.7		% local	41.2	
% chert	9.1		% chert	0.0	

Appendix V-Pebble Count Data (continued)

Sample number: 641EE

Location: Hwy EE 1/8 mile north of Missouri Hwy 210, SW1/4, Sec. 7, T51N, R30W, Missouri City, Missouri Quadrangle.

Sampling point: 2meters above striated bedrock in dark gray (N4) unoxidized and unleached diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	60	9.3	felsic	15	9.5
dark igneous	44	6.8	dark igneous	16	10.1
metamorphic	1	.2	metamorphic	2	1.3
Sioux Quartzite	0	0.0	Sioux Quartzite	0	0.0
quartz	19	3.0	quartz	2	1.3
chert	15	2.3	chert	10	6.3
limestone	461	71.6	limestone	100	63.3
sandstone/shale	44	6.8	sandston/shale	13	8.2
total	644	100	total	158	100
% erratics	19.3		% erratics	22.2	
% local	78.4		% local	71.5	
% chert	2.3		% chert	6.3	

Sample number: 711170

Location: south side of I-70, NE1/4, SW1/4, SE1/4, Sec. 10, T11S, R24E, Shawnee Kansas, Kansas.

Sampling point: near base of exposure in dark gray (N4) diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	67	16.9	felsic	7	17.1
dark igneous	40	10.1	dark igneous	1	2.4
metamorphic	15	3.8	metamorphic	2	4.9
Sioux Quartzite	0	0.0	Sioux Quartzite	1	2.4
quartz	8	2.0	quartz	0	0.0
chert	28	7.1	chert	1	2.4
limestone	179	45.2	limestone	16	39.0
sandstone/shale	59	14.9	sandston/shale	13	31.7
total	396	100	total	41	100
% erratics	32.8		% erratics	26.9	
% local	60.4		% local	70.7	
% chert	7.0		% chert	2.4	

Appendix V-Pebble Count Data (continued)

Sample number: 641NH

Location: streamcut south of Missouri Hwy 210 northwest of Nebo Hill, NW1/4, SE1/4, Sec. 23, T51N, R31W, Missouri City, Missouri Quadrangle

Sampling point: 2meters above base of exposure in dark gray (N4) unoxidized and unleached diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	25	12.3	felsic	6	17.6
dark igneous	2	1.0	dark igneous	1	2.9
metamorphic	7	3.4	metamorphic	3	8.8
Sioux Quartzite	0	0.0	Sioux Quartzite	0	0.0
quartz	1	0.5	quartz	0	0.0
chert	8	3.9	chert	0	0.0
limestone	113	55.7	limestone	20	58.8
sandstone/shale	47	23.2	sandston/shale	4	11.8
total	203	100	total	34	100
% erratics	17.2		% erratics	29.3	
% local	78.9		% local	70.6	
% chert	3.9		% chert	0.0	

Sample number: 712I70

Location: south side of I-70, NE1/4, SW1/4, SE1/4, Sec. 10, T11S, R24E, Shawnee Kansas, Kansas Quadrangle.

Sampling point: 2meters above striated bedrock in dark gray (N4) unoxidized and unleached diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	152	37.2	felsic	22	16.2
dark igneous	5	1.2	dark igneous	4	2.9
metamorphic	0	0.0	metamorphic	0	0.0
Sioux Quartzite	4	1.0	Sioux Quartzite	3	2.2
quartz	24	5.9	quartz	7	5.1
chert	45	11.0	chert	35	25.7
limestone	0	0.0	limestone	0	0.0
sandstone/shale	179	43.8	sandston/shale	68	50.0
total	409	100	total	136	100
% erratics	45.2		% erratics	26.4	
% local	43.8		% local	50.0	
% chert	11.0		% chert	25.7	

Appendix V-Pebble Count Data (continued)

Sample number: 10271152

Location: northside of new Hwy 152 near overpass of Greenhills road, NE1/4, NE1/4, Sec. 9, T51N, R34W.

Sampling basal gravel below dark gray (N4) lower diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	33	6.7	felsic	1	1.9
dark igneous	10	2.0	dark igneous	2	2.2
metamorphic	0	0.0	metamorphic	0	0.0
Sioux Quartzite	0	0.0	Sioux Quartzite	0	0.0
quartz	5	1.0	quartz	0	0.0
chert	17	3.4	chert	4	4.3
limestone	237	47.9	limestone	50	54.3
sandstone/shale	193	39.0	sandston/shale	35	38.0
total	495	100	total	92	100
% erratics	9.7		% erratics	4.1	
% local	86.9		% local	92.3	
% chert	3.4		% chert	4.3	

Sample number: 10273152

Location: northside of new Hwy 152 near overpass of Greenhills road, NE1/4, NE1/4, Sec. 9, T51N, R34W.

Sampling point: in middle of upper olive yellow (2.5Y 6/6) oxidized and partially leached diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	131	31.4	felsic	6	14.3
dark igneous	76	18.2	dark igneous	5	11.9
metamorphic	13	3.1	metamorphic	1	2.4
Sioux Quartzite	7	1.7	Sioux Quartzite	0	0.0
quartz	14	3.4	quartz	2	4.8
chert	23	5.5	chert	7	16.7
limestone	65	15.6	limestone	14	33.3
sandstone/shale	88	21.1	sandston/shale	7	16.7
total	417	100	total	42	100
% erratics	57.8		% erratics	33.4	
% local	36.7		% local	50.0	
% chert	5.5		% chert	16.7	

Appendix V-Pebble Count Data (continued)

Sample number: 10274152

Location: northside of new Hwy 152 near overpass of Greenhills road, NE1/4, NE1/4, Sec. 9, T51N, R34W.

Sampling point: in outwash between upper and lower diamictons.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	196	22.7	felsic	-	-
dark igneous	26	3.0	dark igneous	-	-
metamorphic	100	11.6	metamorphic	-	-
Sioux Quartzite	10	1.2	Sioux Quartzite	-	-
quartz	17	2.0	quartz	-	-
chert	28	3.2	chert	-	-
limestone	180	20.9	limestone	-	-
sandstone/shale	306	35.5	sandston/shale	-	-
total	863	100	total	-	-
% erratics	57.8		% erratics	-	
% local	36.7		% local	-	
% chert	5.5		% chert	-	

Sample number: 10272152

Location: northside of new Hwy 152 near overpass of Greenhills road, NE1/4, NE1/4, Sec. 9, T51N, R34W.

Sampling point: in lower dark gray (N4) diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	43	6.4	felsic	1	0.9
dark igneous	20	3.0	dark igneous	1	0.9
metamorphic	0	0.0	metamorphic	0	0.0
Sioux Quartzite	0	0.0	Sioux Quartzite	0	0.0
quartz	0	0.0	quartz	0	0.0
chert	12	1.8	chert	0	0.0
limestone	477	70.5	limestone	80	75.5
sandstone/shale	125	18.5	sandston/shale	24	22.6
total	677	100	total	106	100
% erratics	9.4		% erratics	1.8	
% local	89.0		% local	98.2	
% chert	1.8		% chert	0.0	

Appendix V-Pebble Count Data (continued)

Sample number: 711ANT

Location: east side of N. Antioch Road, SW1/4, NW1/4, Sec. 18, T51N, R32W, North Kansas City, Missouri Quadrangle.

Sampling point: in dark gray (N4) diamicton 2 meters above road level

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	37	21.0	felsic	11	16.9
dark igneous	7	4.0	dark igneous	1	1.5
metamorphic	37	21.0	metamorphic	16	24.6
Sioux Quartzite	0	0.0	Sioux Quartzite	1	1.5
quartz	17	9.7	quartz	5	7.7
chert	8	4.5	chert	5	7.7
limestone	35	19.9	limestone	15	23.1
sandstone/shale	35	19.9	sandston/shale	11	16.9
total	176	100	total	65	100
% erratics	55.7		% erratics	52.2	
% local	39.8		% local	40.0	
% chert	4.5		% chert	7.7	

Sample number: 6261RS

Location: northwest corner of I-635 and Hwy 9, NE1/4, SE1/4, Sec. 5, T10S, R33W, Parkville, Missouri Quadrangle.

Sampling point: in unoxidized and unleached dark gray (N4) diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	38	15.7	felsic	5	18.5
dark igneous	2	0.8	dark igneous	2	7.4
metamorphic	21	8.7	metamorphic	3	11.1
Sioux Quartzite	1	0.4	Sioux Quartzite	1	3.7
quartz	4	1.7	quartz	0	0.0
chert	10	4.1	chert	0	0.0
limestone	98	40.5	limestone	11	40.7
sandstone/shale	65	26.9	sandston/shale	5	18.5
total	242	100	total	27	100
% erratics	27.3		% erratics	40.7	
% local	68.6		% local	59.3	
% chert	4.1		% chert	0.0	

Appendix V-Pebble Count Data (continued)

Sample number: 6261NJ

Location: west of I-435 overpass on New Jersey Ave., NW1/4, SW1/4, Sec. 1, T11S, R23E,
Edwardsville, Kansas Quadrangle.

Sampling point: in oxidized and leached pale olive (5Y 6/3) diamicton.

4-8 mm fraction:			> 8 mm fraction		
type	n	%	type	n	%
felsic	30	35.3	felsic	2	18.2
dark igneous	2	2.4	dark igneous	0	0.0
metamorphic	24	28.2	metamorphic	2	18.2
Sioux Quartzite	2	2.4	Sioux Quartzite	0	0.0
quartz	8	9.4	quartz	0	0.0
chert	2	2.4	chert	1	9.1
limestone	0	0.0	limestone	0	0.0
sandstone/shale	17	20.0	sandston/shale	5	45.5
total	85	100	total	11	100
% erratics	77.6		% erratics	36.4	
% local	20.0		% local	45.5	
% chert	2.4		% chert	9.1	

Appendix VI- Heavy Mineral Analysis Method

- 1). Separate and combine fine and very fine sand fractions (.0625-.125mm) from grain size analysis fractions.
- 2). Split out, using cone and quartering a 5-10 gram subsample. Weigh subsample to nearest .001 gram.
- 3). Pour sample into separatory funnel filled with acetylene tetrabromaform (s.g.= 2.96). Stir and let stand for 20 minutes. After 20 minutes stir again. Wait until good separation is apparent.
- 4). Open lower stopcock and collect heavies on a filter paper. Wash with acetone and let dry. Repeat with a new filter paper to collect light minerals.
- 5). Weigh heavy and light fractions and calculate the percent heavy minerals and percent light minerals.
- 6). Splint out small subsamples from heavy and light minerals to mount on a glass slide.
- 7). Count two hundred grains using a polarizing microscope classifying grains into one of the established classes (Table 6).

Appendix VII-Heavy mineral data

Sample: 624EE

Location: Highway EE 1/8 mile north of Missouri Highway 210 (Figure 6, # 42)

Sampling point: 2 meters above striated bedrock in dark gray diamicton.

<u>mineral</u>	<u>n</u>	<u>%</u>	<u>normalized</u>	
Opaques	87	42.9	Am+Ep+Py+Tr	51.8
Garnet	34	16.7	Garnet	30.4
Kyanite	0	0.0	Zircon	17.9
Zircon	20	9.9		100%
Sphene	3	1.5		
Pyroxene	7	3.4		
Epidote	8	3.9		
Rutile	1	0.5		
Amphibole	43	21.1		
Tourmaline	0	0.0		
total	266	100%		

Sample: 641NH

Location: Streamcut south of Missouri Highway 210, northwest of Nebo Hill (Figure 6, #39).

Sampling point: 3 meters above base of exposure

<u>mineral</u>	<u>n</u>	<u>%</u>	<u>normalized</u>	
Opaques	112	46.7	Am+Ep+Py+Tr	83.1
Garnet	15	6.3	Garnet	12.7
Kyanite	3	1.3	Zircon	4.2
Zircon	5	2.1		100%
Sphene	4	1.7		
Pyroxene	2	0.8		
Epidote	9	3.8		
Rutile	3	1.3		
Amphibole	84	35.0		
Tourmaline	3	1.3		
total	240	100%		

Appendix VII-Heavy mineral data

Sample: 10272152

Location: North side of Highway 152 near overpass of Greenhills Road (Figure 6, #28).

Sampling point: In lower dark gray diamicton.

<u>mineral</u>	<u>n</u>	<u>%</u>	<u>normalized</u>	
Opagues	115	43.4	Am+Ep+Py+Tr	74.8
Garnet	17	6.4	Garnet	11.6
Kyanite	2	0.7	Zircon	13.6
Zircon	20	7.5		100%
Sphene	0	0.0		
Pyroxene	14	5.3		
Epidote	3	1.1		
Rutile	1	0.3		
Amphibole	82	30.9		
Tourmaline	11	4.2		
total	265	100%		

Sample: 711170

Location: South side of I-70 east of K-132 (Figure 6, 13).

Sampling point: Near base of exposure in dark gray diamicton.

<u>mineral</u>	<u>n</u>	<u>%</u>	<u>normalized</u>	
Opagues	119	44.7	Am+Ep+Py+Tr	55.0
Garnet	50	18.8	Garnet	38.2
Kyanite	3	1.1	Zircon	6.8
Zircon	9	3.4		100%
Sphene	0	0.0		
Pyroxene	0	0.0		
Epidote	10	3.8		
Rutile	7	2.6		
Amphibole	56	21.1		
Tourmaline	6	2.3		
total	240	100%		

Appendix VII-Heavy mineral data

Sample: 711ANT

Location: Road cut along N. Antioch Road (Figure 6, #36).

Sampling point: 2 meters above base of exposure in dark gray diamicton.

<u>mineral</u>	<u>n</u>	<u>%</u>	<u>normalized</u>	
Opagues	62	37.1	Am+Ep+Py+Tr	81.4
Garnet	13	7.8	Garnet	15.1
Kyanite	0	0.0	Zircon	3.5
Zircon	3	1.8		100%
Sphene	0	0.0		
Pyroxene	1	0.6		
Epidote	8	4.8		
Rutile	19	11.4		
Amphibole	58	34.7		
Tourmaline	3	1.8		
total	167	100%		

Appendix VII-Magnetic susceptibility data

susceptibility profile 152 Highway section:

sample	freq*	Read #1	Read #2	Average	sample wt.	Xlf SI units	% Xfd
basal gravel:							
1	L	22.7	23.1	23.0	12.000	1.92E-07	
1	H	22.7	22.8	22.6	12.000	1.88E-07	1.96
unoxidized and unleached till:							
2	L	16.6	16.7	16.9	12.092	1.39E-07	
2	H	16.3	16.6	16.2	12.092	1.34E-07	4.15
3	L	18.7	18.2	18.8	11.789	1.59E-07	
3	H	18.5	18.6	18.5	11.789	1.57E-07	1.60
4	L	13.5	13.5	13.7	11.903	1.15E-07	
4	H	13.5	13.7	13.5	11.903	1.14E-07	1.11
5	L	17.1	17.1	17.3	11.990	1.44E-07	
5	H	17.4	17.3	17.3	11.990	1.44E-07	0.29
oxidized and partially leached till and outwash:							
6	L	14.2	13.9	14.2	11.522	1.23E-07	
6	H	14.5	14.5	14.4	11.522	1.25E-07	-1.06
7	L	9.4	9.3	9.5	11.138	8.57E-08	
7	H	9.6	9.6	9.6	11.138	8.57E-08	-0.01
8	L	9.5	9.4	9.7	11.386	8.48E-08	
8	H	9.5	9.5	9.5	11.386	8.34E-08	1.55
9	L	13.7	13.7	13.8	11.764	1.17E-07	
9	H	13.8	13.8	13.7	11.764	1.16E-07	0.71
10	L	15.6	15.4	15.6	11.718	1.33E-07	
10	H	15.4	15.4	15.3	11.718	1.31E-07	1.61
11	L	17.4	17.4	17.4	10.399	1.68E-07	
11	H	17.3	17.4	17.3	10.399	1.66E-07	0.86
12	L	18.9	18.6	18.9	11.253	1.68E-07	
12	H	18.7	18.7	18.7	11.253	1.66E-07	1.06
13	L	14.9	14.9	15.0	11.825	1.27E-07	
13	H	14.8	14.8	14.8	11.825	1.25E-07	1.98
14	L	15.7	15.8	16.0	11.731	1.36E-07	
14	H	16.0	16.0	16.0	11.731	1.36E-07	0.31
15	L	22.4	22.3	22.4	11.947	1.88E-07	
15	H	22.4	22.4	22.3	11.947	1.87E-07	0.67
16	L	25.0	25.1	25.1	11.812	2.12E-07	
16	H	25.2	25.2	25.1	11.812	2.12E-07	0.00
17	L	16.3	16.3	16.3	12.067	1.35E-07	
17	H	16.3	16.3	16.3	12.067	1.35E-07	0.31
18	L	17.5	17.4	17.5	12.592	1.39E-07	
18	H	17.4	17.4	17.3	12.592	1.37E-07	1.14
19	L	15.8	15.7	15.9	12.401	1.28E-07	
19	H	15.6	15.6	15.6	12.401	1.25E-07	1.89
20	L	17.5	17.4	17.5	11.829	1.48E-07	
20	H	17.4	17.4	17.4	11.829	1.47E-07	0.57
21	L	15.9	15.8	15.9	11.996	1.33E-07	
21	H	15.6	15.7	15.6	11.996	1.30E-07	1.89
22	L	16.1	16.1	16.3	12.753	1.27E-07	
22	H	16.0	16.1	16.0	12.753	1.25E-07	1.54

Appendix VII-Magnetic susceptibility data

23	L	18.9	18.9	18.9	11.934	1.58E-07	
23	H	18.8	18.8	18.8	11.934	1.57E-07	0.79
24	L	18.8	18.7	18.6	12.157	1.53E-07	
24	H	18.4	18.5	18.4	12.157	1.51E-07	1.07
25	L	20.1	20.2	20.2	11.875	1.70E-07	
25	H	20.0	20.1	20.0	11.875	1.68E-07	0.74
26	L	14.9	14.9	15.0	10.895	1.38E-07	
26	H	15.0	15.0	15.0	10.895	1.37E-07	0.65
27	L	18.0	18.0	18.0	12.889	1.39E-07	
27	H	17.9	17.9	17.9	12.889	1.39E-07	0.28
28	L	18.8	18.9	18.9	14.446	1.31E-07	
28	H	18.1	18.1	18.1	14.446	1.25E-07	4.23
29	L	20.5	20.7	20.4	13.665	1.49E-07	
29	H	19.9	20.0	19.9	13.665	1.46E-07	2.21
30	L	25.1	25.0	25.1	14.347	1.75E-07	
30	H	24.7	24.7	24.7	14.347	1.72E-07	1.60
31	L	21.7	21.6	21.8	13.498	1.62E-07	
31	H	20.8	20.8	20.8	13.498	1.54E-07	4.59
32	L	21.8	21.9	21.7	12.801	1.69E-07	
32	H	20.6	20.6	20.6	12.801	1.61E-07	5.08
oxidized and leached loess:							
33	L	29.2	29.4	29.4	13.465	2.18E-07	
33	H	27.9	28.0	28.0	13.465	2.08E-07	4.93
34	L	31.8	31.9	31.8	14.124	2.25E-07	
34	H	30.2	30.3	30.2	14.124	2.14E-07	4.88
35	L	29.4	29.4	29.2	13.669	2.13E-07	
35	H	28.0	28.2	28.1	13.669	2.06E-07	3.60
36	L	28.1	28.1	28.0	13.332	2.10E-07	
36	H	27.3	27.2	27.2	13.332	2.04E-07	2.86

* High field frequency = 1000 Hz, low frequency = 100 Hz

Appendix VII-Magnetic susceptibility data

susceptibility profile I-70 Highway section:

Sample	Read-1	Read-2	Read-3	Av.	wt. sample (g)	Xlf (m ³ kg ⁻¹)	Average
unoxidized and unleached till:							
2917	13.9	16.7	14.3	15.0	12.58	1.19E-07	1.81E-07
2918	8.9	11.1	9.6	9.9	7.8	1.27E-07	
2919	22.6	21.6	24.1	22.8	10.93	2.08E-07	
2920	24	26.3	26	25.4	12.79	1.99E-07	
2921	30.4	30.1	30.7	30.4	13.76	2.20E-07	
2922	30.3	28.1	31.1	29.8	12.39	2.41E-07	
2925	15.5	14.1	16.4	15.3	8.7	1.76E-07	
2926	16.1	16.8	19.8	17.7	9.47	1.86E-07	
2927	13.9	13.7	13.6	13.7	8.42	1.63E-07	
2928	14.6	13.2	14.6	14.1	8.09	1.75E-07	
oxidized and leached till:							
2914	6.1	5.3	5.8	5.7	10.46	5.48E-08	8.48E-08
2915	5.6	6.7	4.9	5.7	10.33	5.55E-08	
2916	16.8	14.9	16.9	16.2	11.24	1.44E-07	
oxidized silty fine sand:							
2909	48.7	51.1	50.2	50	10.96	4.56E-07	4.38E-07
2910	53.4	52.9	54.5	53.6	12.21	4.39E-07	
2911	37.6	40.3	39.8	39.2	9.64	4.07E-07	
2912	51.3	50	49.5	50.3	10.77	4.67E-07	
2913	46.6	45.6	46.1	46.1	10.92	4.22E-07	
oxidized and leached till:							
2923	7.5	8	8.8	8.1	10.28	7.88E-08	9.09E-08
2924	10.2	8.4	10	9.5	9.25	1.03E-07	

Appendix VII-Magnetic susceptibility data

< 2mm fraction

number sample sample wt read #1 read #2 read#3 average Xlf (m3 kg-1) J (A/M) Xarm (m3 kg-1) AV. XLF AV. XARM

Unoxidized and leached:

3000	641NH	10.623	26.1	25.6	26.5	26.1	2.45E-07	0.15	2.83E-05	2.13E-07	2.67E-05
3001	641NH	10.012	20.6	20.2	20.6	20.5	2.04E-07	0.16	3.11E-05		
3002	641NH	9.771	18.2	18.5	18.6	18.4	1.89E-07	0.10	2.09E-05		
3003	61EE	10.587	12.2	12.0	12.0	12.1	1.14E-07	0.11	2.02E-05	1.15E-07	2.08E-05
3004	61EE	10.644	12.5	12.3	12.4	12.4	1.16E-07	0.12	2.16E-05		
3005	61EE	10.645	12.1	12.3	12.0	12.1	1.14E-07	0.11	2.07E-05		
3015	711I70	10.116	30.5	30.3	30.5	30.4	3.01E-07	0.14	2.70E-05	3.13E-07	3.09E-05
3016	711I70	10.233	29.5	29.5	29.5	29.5	2.88E-07	0.13	2.62E-05		
3017	711I70	10.224	35.7	35.8	36.0	35.8	3.50E-07	0.20	3.95E-05		
3018	6241NH	9.557	14.6	14.5	14.5	14.5	1.52E-07	0.09	1.93E-05	1.65E-07	1.99E-05
3019	6241NH	9.608	17.3	17.6	17.6	17.5	1.82E-07	0.09	1.97E-05		
3020	6241NH	9.785	15.6	15.6	15.6	15.6	1.59E-07	0.10	2.08E-05		
3030	6261RS	9.921	8.8	8.6	8.7	8.7	8.77E-08	0.08	1.60E-05	8.40E-08	1.54E-05
3031	6261RS	10.189	7.4	7.5	7.5	7.5	7.33E-08	0.08	1.49E-05		
3032	6261RS	10.192	9.3	9.3	9.2	9.3	9.09E-08	0.08	1.53E-05		
3033	6241EE	10.11	9.4	9.4	9.4	9.4	9.30E-08	0.09	1.86E-05	9.25E-08	1.89E-05
3034	6241EE	9.905	8.9	8.8	8.8	8.8	8.92E-08	0.09	1.86E-05		
3035	6241EE	10.324	9.9	9.8	9.8	9.8	9.52E-08	0.10	1.96E-05		

Oxidized and leached:

3006	661MN	9.816	12.5	12.5	12.5	12.5	1.27E-07	0.14	2.93E-05	1.26E-07	2.92E-05
3007	661MN	10.375	13.2	13.2	13.0	13.1	1.27E-07	0.15	2.87E-05		
3008	661MN	10.102	12.6	12.6	12.5	12.6	1.24E-07	0.15	2.96E-05		
3009	653PA	9.864	14.1	14.0	14.0	14.0	1.42E-07	0.16	3.24E-05	1.38E-07	3.14E-05
3010	653PA	10.04	13.2	13.3	13.2	13.2	1.32E-07	0.15	2.91E-05		
3011	653PA	10.21	14.2	14.1	14.2	14.2	1.39E-07	0.17	3.28E-05		
3021	6261NJ	9.545	10.1	10.1	10.1	10.1	1.06E-07	0.13	2.71E-05	1.06E-07	2.62E-05
3022	6261NJ	9.764	10.7	10.8	10.6	10.7	1.10E-07	0.13	2.65E-05		
3023	6261NJ	9.897	10.1	10.1	10.2	10.1	1.02E-07	0.12	2.49E-05		
3036	759A	9.898	12.9	12.9	12.9	12.9	1.30E-07	0.16	3.21E-05	1.33E-07	3.23E-05

Appendix VII-Magnetic susceptibility data (continued)

3037	795A	10.303	14.3	14.3	14.4	14.3	1.39E-07	0.17	3.20E-05		
3038	795A	10.156	13.0	13.2	13.2	13.1	1.29E-07	0.17	3.27E-05		
3039	6261GA	10.189	16.7	16.7	16.6	16.7	1.64E-07	0.19	3.64E-05	1.60E-07	3.74E-05
3040	6261GA	10.014	17.2	17.0	17.2	17.1	1.71E-07	0.18	3.69E-05		
3041	6261GA	9.703	14.3	14.1	14.3	14.2	1.47E-07	0.19	3.89E-05		
3051	51AR	9.468	-	11	10.9	27.0	2.85E-07	0.12	2.61E-05	1.71E-07	2.70E-05
3052	51AR	10.223	11.6	11.5	11.6	11.6	1.13E-07	0.14	2.71E-05		
3053	51AR	10.015	11.4	11.5	11.4	11.4	1.14E-07	0.14	2.78E-05		
3045	831169	10.344	11.3	11.4	11.4	11.4	1.10E-07	0.18	3.46E-05	1.14E-07	3.48E-05
3046	831169	10.185	12.0	11.9	12.0	12.0	1.17E-07	0.17	3.42E-05		
3047	831169	10.189	11.7	11.7	11.7	11.7	1.15E-07	0.18	3.57E-05		
3057	6242NH	10.345	7.6	7.7	7.8	7.7	7.44E-08	0.19	3.69E-05	7.43E-08	3.63E-05
3058	6242NH	10.217	7.7	7.8	7.7	7.7	7.57E-08	0.18	3.46E-05		
3059	6242NH	10.067	7.3	7.3	7.4	7.3	7.28E-08	0.19	3.75E-05		
Ferrelview Formation:											
3024	6262GA	9.376	11.4	11.5	11.4	11.4	1.22E-07	0.13	2.74E-05	1.21E-07	2.75E-05
3025	6262GA	9.435	11.2	11.4	11.3	11.3	1.20E-07	0.13	2.75E-05		
3026	6262GA	9.355	11.3	11.2	11.3	11.3	1.20E-07	0.13	2.77E-05		
3048	6262NJ	9.706	11.5	11.5	11.4	11.5	1.18E-07	0.10	2.13E-05	1.18E-07	2.01E-05
3049	6262NJ	9.166	10.7	10.8	10.8	10.8	1.17E-07	0.09	1.96E-05		
3050	6262NJ	9.46	11.3	11.3	11.4	11.3	1.20E-07	0.09	1.95E-05		
Oxidized and leached outwash:											
3012	712170	9.387	35.1	35.0	35.1	35.1	3.74E-07	0.43	9.20E-05	3.83E-07	9.25E-05
3013	712170	9.607	42.8	43.0	42.7	42.8	4.46E-07	0.47	9.78E-05		
3014	712170	9.23	30.7	30.1	30.7	30.5	3.30E-07	0.40	8.77E-05		
3027	610AM	9.138	127.8	127.9	127.8	127.8	1.40E-06	2.05	4.48E-04	1.39E-06	4.46E-04
3028	610AM	9.675	139.5	139.7	139.2	139.5	1.44E-06	2.21	4.56E-04		
3029	610AM	9.262	119.2	123.4	123.7	122.1	1.32E-06	2.02	4.35E-04		
3042	6261BE	9.684	92.4	92.3	92.6	92.4	9.54E-07	2.03	4.19E-04	9.52E-07	4.12E-04
3043	6261BE	9.481	89.9	89.9	89.9	89.9	9.48E-07	1.95	4.11E-04		
3044	6261BE	9.695	92.6	92.4	92.1	92.4	9.53E-07	1.97	4.07E-04		

Appendix VII-Magnetic susceptibility data (continued)

Wisconsin loess:

3054	6263NJ	9.107	11.5	11.6	11.7	11.6	1.27E-07	0.12	2.70E-05	1.33E-07	2.72E-05
3055	6263NJ	9.025	12.5	12.6	12.6	12.6	1.39E-07	0.13	2.77E-05		
3056	6263NJ	9.168	12.2	12.2	12.1	12.2	1.33E-07	0.12	2.71E-05		

< 0.0625mm

number sample sample wt read #1 read #2 read#3 average Xlf (m3 kg-1) J (A/M) Xarm (m3 kg-1) AV, XLF AV, XARM

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Unoxidized and leached:

3075	61EE	6.913	5.6	5.7	5.6	5.6	8.15E-08	0.06	1.69E-05	8.11E-08	1.69E-05
3076	61EE	6.792	5.3	5.4	5.3	5.3	7.85E-08	0.06	1.67E-05		
3077	61EE	7.008	5.8	5.9	5.8	5.8	8.32E-08	0.06	1.69E-05		
3078	711170	7.979	16.1	16.1	16.1	16.1	2.02E-07	0.08	1.95E-05	2.33E-07	2.11E-05
3079	711170	8.368	19.1	19.2	19.1	19.1	2.29E-07	0.09	2.13E-05		
3080	711170	8.464	22.6	22.6	22.7	22.6	2.67E-07	0.10	2.26E-05		
3081	6261RS	5.283	4.0	4.1	4.0	4.0	7.63E-08	0.04	1.47E-05	7.67E-08	1.49E-05
3082	6261RS	5.43	4.1	4.1	4.1	4.1	7.55E-08	0.04	1.51E-05		
3083	6261RS	5.277	4.1	4.1	4.2	4.1	7.83E-08	0.04	1.48E-05		
3084	621NH	6.876	8.6	8.7	8.6	8.6	1.26E-07	0.07	1.92E-05	1.21E-07	1.92E-05
3085	621NH	6.259	7.4	7.4	7.4	7.4	1.18E-07	0.06	1.85E-05		
3086	621NH	6.385	7.6	7.6	7.7	7.6	1.20E-07	0.06	1.97E-05		
3087	641NH	3.795	6.0	6.0	5.9	6.0	1.57E-07	0.04	1.95E-05	1.57E-07	1.96E-05
3088	641NH	3.771	6.0	5.9	6.0	6.0	1.58E-07	0.04	2.23E-05		
3089	641NH	4.24	6.6	6.6	6.6	6.6	1.56E-07	0.04	1.70E-05		
2982	6241EE	3.761	3.3	3.4	3.3	3.3	8.86E-08	0.04	2.11E-05	8.96E-08	2.12E-05
2983	6241EE	4.314	3.8	3.8	3.8	3.8	8.81E-08	0.04	2.06E-05		
2984	6241EE	3.807	3.5	3.5	3.5	3.5	9.19E-08	0.04	2.20E-05		
2985	6242NH	4.166	9.2	9.2	9.2	9.2	2.21E-07	0.13	6.08E-05	2.18E-07	5.52E-05
2986	6242NH	2.519	5.4	5.5	5.3	5.4	2.14E-07	0.06	4.97E-05		

Oxidized and leached:

3066	795A	4.455	5.7	5.7	5.6	5.7	1.27E-07	0.09	3.85E-05	1.29E-07	3.87E-05
3067	795A	4.465	5.7	5.8	5.8	5.8	1.29E-07	0.09	3.88E-05		
3068	795A	4.446	5.7	5.8	5.8	5.8	1.30E-07	0.09	3.88E-05		

Appendix VII-Magnetic susceptibility data (continued)

3090	661MN	4.288	5.4	5.3	5.3	5.3	1.24E-07	0.07	3.39E-05	1.25E-07	3.32E-05
3091	661MN	4.161	5.1	5.1	5.2	5.1	1.23E-07	0.07	3.27E-05		
3092	661MN	4.184	5.2	5.3	5.3	5.3	1.26E-07	0.07	3.30E-05		
3093	653PA	3.389	4.6	4.6	4.6	4.6	1.36E-07	0.06	3.45E-05	1.37E-07	3.42E-05
3094	653PA	3.369	4.5	4.5	4.6	4.5	1.35E-07	0.06	3.38E-05		
3095	653PA	3.255	4.5	4.5	4.7	4.6	1.40E-07	0.06	3.43E-05		
3096	831I69	7.729	12.8	12.9	12.8	12.8	1.66E-07	0.19	5.03E-05	1.66E-07	5.03E-05
3097	831I69	7.935	13.1	13.2	13.1	13.1	1.66E-07	0.21	5.20E-05		
3098	831I69	7.206	12.2	12	12	12.1	1.67E-07	0.18	4.86E-05		
3099	51AR	4.855	6.8	6.9	6.8	6.8	1.41E-07	0.09	3.72E-05	1.43E-07	3.69E-05
2959	51AR	4.466	6.7	6.4	6.4	6.5	1.46E-07	0.08	3.66E-05		
2969	51AR	4.767	6.8	6.9	6.8	6.8	1.43E-07	0.09	3.70E-05		
2973	6261GA	5.983	8.0	7.9	7.8	7.9	1.32E-07	0.14	4.62E-05	1.34E-07	5.88E-05
2974	6261GA	3.138	4.1	4.1	4.1	4.1	1.31E-07	0.12	7.45E-05		
2975	6261GA	5.471	7.7	7.6	7.6	7.6	1.40E-07	0.15	5.56E-05		
2976	6261NJ	4.857	5.0	5.0	5.0	5.0	1.03E-07	0.08	3.39E-05	1.05E-07	3.51E-05
2977	6261NJ	4.642	4.9	4.9	4.8	4.9	1.05E-07	0.08	3.52E-05		
2978	6261NJ	4.695	5.0	5.1	5.1	5.1	1.08E-07	0.08	3.62E-05		

Oxidized and leached outwash:

3060	610AM	7.199	112.0	111.9	112.1	112.0	1.56E-06	2.64	7.34E-04	1.56E-06	7.26E-04
3061	610AM	7.351	115.9	115.8	116.0	115.9	1.58E-06	2.68	7.29E-04		
3062	610AM	7.589	118.0	118.2	116.8	117.7	1.55E-06	2.72	7.17E-04		
3063	6261BE	7.209	92.2	92.3	92.2	92.2	1.28E-06	2.42	6.71E-04	1.28E-06	6.75E-04
3064	6261BE	7.033	90.8	90.6	90.8	90.7	1.29E-06	2.40	6.82E-04		
3065	6261BE	7.209	91.8	92.1	92.2	92.0	1.28E-06	2.43	6.73E-04		
2970	712I70	4.546	38.3	38.2	38.3	38.3	8.42E-07	0.69	3.03E-04	8.36E-07	2.95E-04
2971	712I70	3.772	31.3	31.3	31.4	31.3	8.31E-07	0.55	2.92E-04		
2972	712I70	3.39	28.4	28.4	28.3	28.4	8.37E-07	0.49	2.91E-04		

Ferrelview Formation:

3069	6262GA	8.35	8.4	8.4	8.4	8.4	1.01E-07	0.12	2.89E-05	1.04E-07	3.05E-05
3073	6262GA	8.225	8.3	8.3	8.2	8.3	1.01E-07	0.13	3.22E-05		
3074	6262GA	8.013	8.8	8.7	8.8	8.8	1.09E-07	0.12	3.05E-05		

Appendix VII-Magnetic susceptibility data (continued)

2979	6262NJ	6.386	7.1	7.0	7.1	7.1	1.11E-07	0.10	3.26E-05	1.16E-07	3.18E-05
2980	6262NJ	5.761	6.8	6.9	6.9	6.9	1.19E-07	0.09	3.13E-05		
2981	6262NJ	6.319	7.5	7.6	7.5	7.5	1.19E-07	0.10	3.14E-05		
Wisconsin loess:											
3070	6263NJ	5.148	6.4	6.4	6.4	6.4	1.24E-07	0.08	3.17E-05	1.26E-07	3.18E-05
3071	6263NJ	4.921	6.3	6.3	6.1	6.2	1.27E-07	0.08	3.13E-05		
3072	6263NJ	5.119	6.5	6.5	6.6	6.5	1.28E-07	0.08	3.23E-05		

Figure 15. Line drawing from photomosaic of exposed section in roadcut along Leavenworth Road, Wyandotte County, Kansas. Erosive channel bases are designated by ch. Outlines of boulders are traced from photo. Locations of pebble samples and test boring are noted.

