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DEPOSITIONAL ENVIRONMENTS OF GLACIAL SEDIMENTS AND LANDFORMS ON THE DES MOINES LOBE, IOWA

a field trip guide with research papers for the meeting of the North-Central Section of the Geological Society of America.

by Timothy J. Kemmis, George R. Hallberg, and Alan J. Lutenegger

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A field trip guide prepared for the 1981 North-Central Section Meeting of the Geological Society of America, sponsored by the Department of Earth Science, Iowa State University.

IOWA GEOLOGICAL SURVEY
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The stratigraphic nomenclature and classification used in portions of this report do not necessarily conform to the current formal usage of the Iowa Geological Survey.

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To all these people we extend our grateful appreciation.

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INTRODUCTION

The location of the "Cary" or Late Woodfordian age Des Moines Lobe in Iowa and the large-scale glacial landform areas that have been mapped in recent decades (see Ruhe, 1952, 1969; Prior, 1976) are shown in figure 1. The field trip area is located along the east-central portion of the lobe in Iowa (figures 1 and 2). The trip and guide book are a progress report on the detailed surficial geologic mapping program currently in progress by the Iowa Geological Survey.

The Des Moines Lobe forms part of the southwestern-most extension of the Late Wisconsinan Laurentide ice sheet. The Lobe traversed through North Dakota, Minnesota, and into north-central Iowa, terminating at the city of Des Moines.

The age of the Des Moines Lobe is well established by radiocarbon dates (Table 1; locations shown on figure 1). Dates from wood at the basal

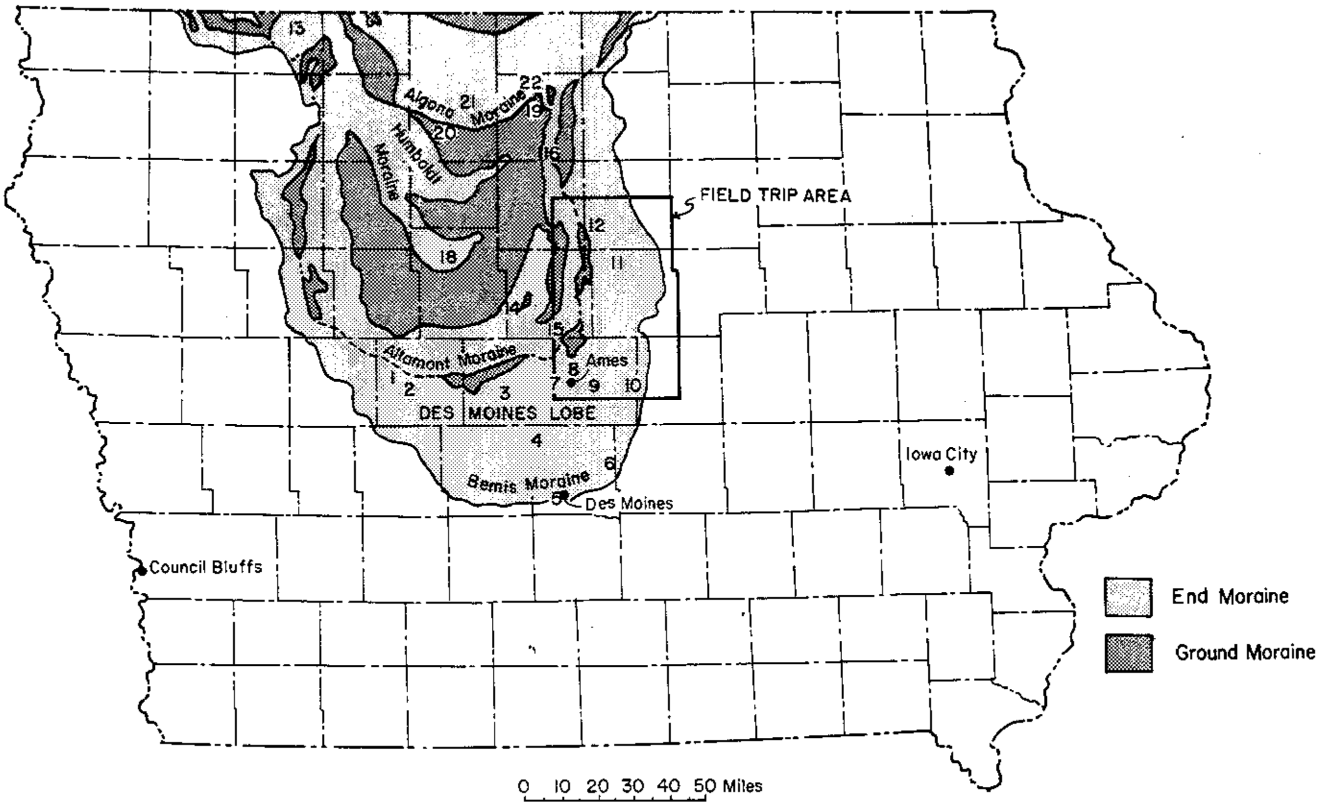


Figure 1. Map showing: 1) the location of the Des Moines Lobe in Iowa; 2) classic landform designations (after Ruhe, 1969; Prior, 1976); 3) field trip area (see figure 2); and 4) numbers show location of radiocarbon dates given in Table 1.

contact between the Des Moines Lobe till and the underlying loess range from 14,042 to 14,380 RCYBP. Dates from wood in the basal till range from 13,400 to 13,680 RCYBP. The initial advance of the Des Moines Lobe into Iowa is thus considered to have occurred at about 14,000 RCYBP. It should be noted that this is one of the few lobes of the Laurentide ice sheet where an advance dating as young as 14,000 RCYBP extended farther south than earlier Wisconsinan advances. This 14,000 RCYBP advance has traditionally been considered to mark the onset of "Cary" glaciation in Iowa (Ruhe and Scholtes, 1959; Ruhe, 1969).

Some problems still remain in the radiocarbon chronology of the Des Moines Lobe. Many original carbon-black dates, some of which are problematical, have been included in Table 1 for historical purposes. Most of these sites have been redated using modern (gas) techniques. Few sites have been dated in the central portion of the lobe and the radiocarbon chronology of this area remains sketchy. Recent dates from the youngest moraine system in Iowa, the Algona Moraine, place it at a significantly younger time period than previously recognized. These new dates (on wood from basal till and related outwash) suggest that the Algona advance occurred sometime around 12,000 to 12,500 RCYBP, but it would still be desirable to have more dates from this area.

Table 1. Radiocarbon dates from the Des Moines Lobe area, Iowa.

Radiocarbon Date in RCYBP	Lab No.	Map No.	Location	Date Submitted	Material Dated	Notes
	BASAL BOG SAMPLES					
11,530 ± 170	I-3145	22	Wood from basal silts, Woden Bog, Hancock County.	1967	Larch Wood	Same horizon as I-1416
11,570 ± 330	I-1416	22	From silts, 0.3 m above till, Woden Bog, Hancock County.	1965	DOC*	Same horizon as I-3145
11,635 ± 400	I-1019	15	From silts at till contact, Jewell Bog, Hamilton County.	1963	DOC	
13,775 ± 300	I-1015	10	From peaty muck, 2.4 m above till, Colo Bog, Story County.	1963	Peaty Muck	
13,990 ± 135	Wis- 835	13	From lake sediments, Lake West Okoboji, Dickinson County.	1977	DOC	
14,500 ± 340	I-1414	16	From peaty muck, 1.2 m above till, McCulloch Bog, Hancock County.	1965	Peaty Muck	
	SAMPLES FROM OUTWASH					
12,000 ± 105	Dic-1362	20	Log from peat and forest bed, within outwash, near Whittemore, Kossuth County.	1978	Spruce Wood	Associated with the Algona Moraine.
12,020 ± 170	I-8768	20	Tree stump, rooted in peat within outwash, near Whittemore, Kossuth County.	1975	Wood	Associated with the Algona Moraine.
12,970 ± 250	W- 626	19	Tree stump rooted in place, in outwash near Britt, Hancock County.	1957	Larch Wood	" See W-625
13,030 ± 250	W-625	19	Peat from buried soil in outwash below W-626, near Britt, Hancock County.	1957	Peat	See W-626. Associated with Algona Moraine?
	SAMPLES WITHIN THE TILL					
11,740 ± 100	Dic-1361	21	Log from basal till at depth of 10 m, in exposure in Algona, Iowa.	1978	Spruce Wood	Date from same log as ISGS-641. In till of Algona Moraine.
[1]11,952 ± 500	[1]C- 596	8	Log from basal till at depth of 7.6 m (1 m above base) in Cook's Quarry, near Ames, Story County.	1951	Hemlock Wood	Carbon-black date. See C-653, 664, and new date ISGS-553.
[1]12,220 ± 500	[1]C- 653	8	Log from same horizon as C-596, Cook's Quarry, near Ames, Story County.	1951	Hemlock Wood	Carbon-black date. See C-596.
12,610 ± 250	ISGS- 641	21	Log from basal till at depth of 10 m, in exposure in Algona, Iowa; see Dic-1361.	1978	Spruce Wood	Date from same log as Dic-1361.
[2]13,400 ± 130	Dic-1651	12	Log from basal till at 10 m depth, (0.7 m above base), from quarry near Dows, Franklin County.	1979	Spruce Wood	Date from same horizon as Beta-1076.
[2]13,525 ± 95	Beta-1076	12	Log from same stratigraphic position as Dic-1651.	1980	Spruce Wood	Date average of two analyses: 13,485 ± 145 13,565 ± 130
13,680 ± 80	ISGS- 552	8	Log from basal till at 10.4 m depth (1 m above base) Cook's Quarry, Story County; see old carbon black dates C-596, C-653, C-664.	1978	Spruce Wood	Date from same stratigraphic horizon as old carbon-black dates. C-596 and C-653; this new date in accord with the regional radio-carbon chronology.

Table 1, con't.

	SAMPLES FROM THE BASE OF THE TILL					
13,900 ± 400	I-1268	14	Wood from base of till at depth of 19.7 m, above interbedded silts and sands, near Stratford, Hamilton County.	1964	Spruce Wood	
13,910 ± 400	W- 517	1	Tree rooted in place in loess at lower contact of Cary till, near Scranton, Greene County.	1956	Spruce Wood	
[1]14,042 ±1000	[1]C- 664	8	Wood from sand and gravel just below Cary till, in Cook's Quarry, near Ames, Story County.	1951	Hemlock Wood	See C-596, C-653, ISGS-641.
[2]14,200 ± 500	I-1402	9	Wood from top of loess below Cary till, near Nevada, Story County.	1964	Spruce Wood	
[2]14,380 ± 180	I-9765	11	Log from contact of Cary basal till and weak paleosol in top of underlying loess, in Weaver Quarry, near Alden, Hardin County.	1976	Larch Wood	
14,470 ± 400	W- 512	2	Wood from top of loess, at contact with Cary till, near Scranton, Greene County.	1956	Spruce Wood	See W-513.
	SAMPLES FROM DEPOSITS BELOW THE TILL					
[1]12,120 ± 530	[1]C- 912	18	Wood from sand and gravel between calcareous tills, near Lizard Creek, Webster County. Lower till of unknown age, but may be Cary in age also. C-913 from same horizon.	1954	Hemlock Wood	Carbon-black date; see C-913.
[1]13,300 ± 900	[1]C- 913	18	Wood from same horizon as C-912.	1954	Hemlcok Wood	Carbon-black date; see C-912.
13,820 ± 400	W- 513	2	Wood within loess, 4.9 m below till, and below W-512, near Scranton, Greene County.	1956	Spruce Wood	See W-512.
14,700 ± 400	OWU- 153	7	Wood within loess 5.2 m below till, near Clear Creek, Story County; see older carbon-black date C-528.	1955	Hemlock Wood	See C-528.
16,100 ± 500	I-1024	4	Wood within loess, 0.6 m below till, near Madrid, Polk County.	1963	Spruce Wood	
16,100 ± 1000	I-1270	3	Wood within loess, 0.7 m below till, near Boone, Boone County.	1963	Spruce Wood	
[1]16,367 ± 1000	[1]C- 528	7	Wood within loess, 5.2 m below till, near Clear Creek, Story County; see OWU-153.	1949	Hemlock Wood	Carbon-black date.
16,720 ± 500	W- 126	6	Wood within loess, 4.3 m below till near Mitchelville, Polk County; see C-418.	1957	Spruce Wood	See C-481.
[1]17,000	[1]C- 481	6	Wood from same locality as W-126.	1949	Spruce Wood	Carbon-black date. See W-126.

*DOC - disseminated organic carbon and charcoal.

1. All University of Chicago dates by original carbon-black method. All other dates by gas methods.

2. Field trip stops.

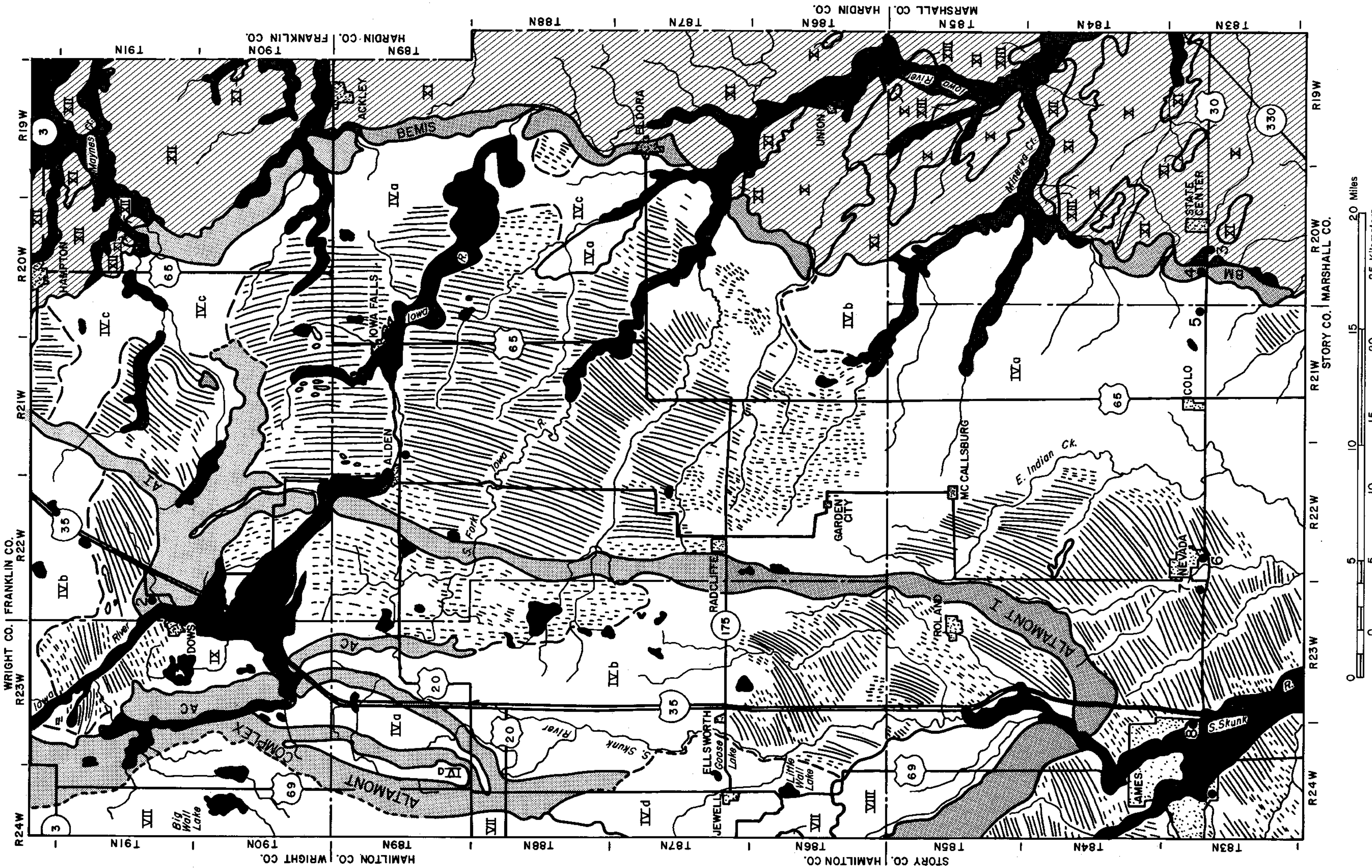
Lab Identifications: Beta-Beta Analytic, Inc.; C-University of Chicago; Dic-Dicarb Radioisotope Co.; I-Isotpoes, Inc.; ISGS-Illinois State Geological Survey; OWU-Ohio Wesleyan University; W-U.S. Geological Survey; Wis-University of Wisconsin.

12 - Location number as shown on index map, figure 1.

Figure 2. Surficial geologic map of field trip area.

Explanation:

Map Symbol	Landscape - Type	Materials	Stratigraphic Unit
LATE WISCONSINAN AND HOLOCENE			
	1. Outwash terraces in valley trains, and recent floodplains.	Sand and/or gravel in terraces. Holocene deposits comprised of silty to loamy alluvium over Late Wisconsinan sand and/or gravel	Undifferentiated at present.
	2. Large lake basins (and/or bogs), mostly drained or extinct; existing lakes with names shown.	Silty lacustrine sediments; some mucks and/or peats.	Undifferentiated
LATE WISCONSINAN			**DOWS FORMATION**
	Upland landscape - types		
	3. Prominent ridge forms; high to moderate local relief, irregular hummocky topography. Named moraines indicated. BM - Bemis Moraine; AI - Altamont I Moraine; AC Altamont Moraine Complex.	Thick (5-20 m) supraglacial sediments; interbedded till, diamictons, sorted glacio-fluvial, lacustrine sediments.	Morgan Member
IVa	4. a. Irregular hummocky topography, on broader topographic swells and swales; moderate local relief.	Moderate (3-6 m) thickness of supraglacial sediments, over basal till.	Morgan Member (over Alden Member)
IVb	4. b. As above unit, with common circular depressions.		
IVc	4. c. As above, but moderate to high relief.		
IVd	4. d. As above unit, with common circular ridges and depressions.		
	5. Small curvilinear ridge forms, generally 1-2 m in relief (minor moraines), inset on broader topographic swells and swales; moderate to low local relief. (Trends only, shown by lines.)	Dominantly basal till deposits (>5 m thickness).	Alden Member
	6. Discontinuous or poorly expressed ridge forms, as in above unit. Common moderate relief irregular hummocks (as in unit 4).	Dominantly basal till deposits (supraglacial sediments 1-5 m in thickness common).	Alden Member (Morgan Member inclusions common)
VII	7. Upland plain with diffuse circular ridges and depressions; low local relief.	Lacustrine sediments (0.5-2.0 m thick) over till of uncertain origin	Lake Mills Member over DOWS FRM. till undifferen-tiated.
VIII	8. Gently sloping plain, low in elevation and low local relief, with common small circular depressions (Story City Flats).	As above.	As above.
IX	9. Low elevation plain, with few large irregular depressions; low to moderate local relief.	Complex of thin (1-3 m) supra-glacial till and sediments, and thick outwash sand and/or gravel.	Complex of Morgan and Pilot Knob Members.
WISCONSINAN AND OLDER			
X	10. Stream dissected landscape, marked by stepped erosion surfaces along interfluves, and moderate to high local relief. Area dominated by loess-mantled Yarmouth-Sangamon and Late-Sangamon surfaces, with frequent small areas of Iowan erosion surfaces occurring along interfluves.	Thick loess (4-10 m) over clay to silty clay textured buried soils (1.5-4.0 m) which grade into loam till.	Wisconsinan loess over YARMOUTH-SANGAMON or LATE SANGAMON Paleosols developed in PRE-ILLINOIAN tills of the WOLF CREEK FORMATION.
XI	11. Stream dissected landscape, marked by stepped erosion surfaces along interfluves, and moderate to high local relief; but less steeply sloping than unit 10. Area dominated by loess-mantled Iowan erosion surfaces.	Thick loess (2-10 m) over loam till.	Wisconsinan loess over PRE-ILLINOIAN tills of the WOLF CREEK or ALBURNETT FORMATIONS
XII	12. As above	Thin loess (<2 m) over loam till. Loess may be absent on lower surfaces.	As above.
XIII	13. As above.	Thick eolian sand (4-10 m; with minor loess inclusions) over loam till.	Wisconsinan (and Holocene?) eolian sand and loess over PRE-ILLINOIAN tills as above.



WRIGHT CO. | FRANKLIN CO.
HARDIN CO. | FRANKLIN CO.
HARDIN CO. | MARSHALL CO.
STORY CO. | MARSHALL CO.
HAMILTON CO. | WRIGHT CO.
STORY CO. | HAMILTON CO.
T91N
T90N
T89N
T88N
T87N
T86N
T85N
T84N
T83N
R19W
R20W
R21W
R22W
R23W
R24W
HAMPTON
ACKLEY
IOWA FALLS
ALDEN
ELDORA
UNION
STATE CENTER
COLO
MC CALLSBURG
GARDEN CITY
RADCLIFFE
ELLSWORTH
JEWELL
ROLAND
NEVADA
AMES
DOWS
BEMIS
ALTAMONT I
ALTAMONT
COMPLEX
Big Wall Lake
Little Wall Lake
Goose Lake
Iowa River
S. Skunk River
E. Indian Ck.
Minerva Cr.
Mayne Cr.
S. Fork Iowa R.
0 5 10 15 20 Miles
0 5 10 15 20 25 Kilometers

Figure 2.

In the past, glacial landforms of the Des Moines Lobe have been categorized as end moraine and ground moraine, as have other lobes of the Wisconsinan age Laurentide ice sheet. In the context of today's rapidly expanding understanding of glacial sedimentation the extant mapping of end moraine and ground moraine on the Des Moines Lobe provides little insight into the detailed history of the deposits or glacial processes. Further, the Iowa Geological Survey's (IGS) applied programs require a detailed understanding of these materials and their behavior. The present level of mapping and landform classification provides little appropriate information. As a consequence IGS has undertaken a detailed study of the deposits of the Des Moines Lobe and their relationship to various glacial landforms. These studies, currently underway, show that: 1) there is a very complex assemblage of glacial landforms on the Des Moines Lobe; 2) there are many more glacial landforms present on the Des Moines Lobe than classic categories of ground moraine and end moraine; in fact, areas of ground moraine and end moraine, as defined and used elsewhere in the Midwest, are relatively rare on the Des Moines Lobe; 3) the complexity of glacial landforms is coincident with complexity in glacial sedimentation, both areally and with time; and 4) many landforms on the Des Moines Lobe differ dramatically from glacial landforms on adjacent lobes of the Laurentide ice sheet, particularly lobes to the east.

The field trip will examine glacial features on a variety of scales: 1) individual processes which took place, particularly different processes of "till" sedimentation; 2) the different processes involved in the formation of individual landforms; i.e., we will see that for some landforms there was a change in processes taking place through time as the landform was built up; and 3) areal variation and distribution in landforms, which can also be thought of as variations in glacial process both spatially and through time.

FIELD TRIP OBJECTIVES

Applied geology, whether for land-use planning, agriculture, construction (engineering), waste disposal or other environmentally-related uses, demands a detailed understanding of the nature of the sediment sequence, and the morphology and physical properties of each different sediment type. With this in mind, the field trip has a number of objectives:

1. To look at the nature of the sediment sequence in major landform types within the study area.

2. To see how till-like materials in the sediment sequences can be genetically differentiated or interpreted using criteria from recent studies of glacial sedimentation, and how these genetic interpretations provide a much more useful understanding of glacial sedimentation and landform development on the Des Moines Lobe.

3. To show some of the complexity of landform types on the Des Moines Lobe, both in the number of landform types present and in their distribution relative to one another over the study area.

4. To show that some individual landform types on the Des Moines Lobe are composed of more than one sediment type, indicating that there were time transgressive changes taking place in glacial sedimentation during the development of these glacial landforms. Consequently, since existing glacial landform categories are based solely on a single process or set of processes, these polygenetic landforms do not fit into any existing glacial landform categories.

5. To show how air photos and 7½ minute topographic maps, as well as careful field discrimination can be used to delineate different glacial landforms on the Des Moines Lobe in the study area.

6. To show the complexity of the sub-Des Moines Lobe surface, both in composition and configuration. It should be noted that the Des Moines Lobe sediments rest on bedrock over only a small fraction of the study area. In general the Des Moines Lobe deposits lie on other Pleistocene sediments.

HISTORICAL REVIEW

The Des Moines Lobe has been investigated by a very large number of workers. The purpose of this review is to provide a brief background of the major work which has been done on 1) landform mapping; 2) time stratigraphy; and 3) rock stratigraphy of the glacial deposits of the Des Moines Lobe.

Landform Mapping

Mapping of all or parts of the Des Moines Lobe has been undertaken by several investigators. A noteworthy feature of this mapping is the general inconsistency and disagreement between the maps of many investigators (see figure 3 for an example from the study area). As the field trip progresses, the complexity of landforms and sediments will become more apparent; it is this complexity which is largely responsible for the varied maps which have been produced for the Des Moines Lobe. This complexity also reveals itself as one recognizes that mapping to date has attempted to "shoehorn" a wide variety of landforms into the categories of moraine (end or recessional) and ground moraine.

Early Investigations

Chamberlin (1878), in a classic paper in which he synthesized much of the area which is now referred to as the area of Wisconsinan glaciation provided the first, crude outline of the Des Moines Lobe. Upham (1880), in an extensive field study, later mapped most of the outer margin of the Des Moines Lobe in Iowa and Minnesota providing a fairly good representation of the shape and location of the lobe. However, he mismapped much of the eastern margin of the lobe in Iowa, placing it roughly at the position of what we are presently referring to as the Altamont

I Moraine in the study area (figure 2, this volume) which is several miles west of the actual Des Moines Lobe margin. Chamberlin (1883), in a much more refined paper than that of 1878, adopted Upham's (incorrect) map and named the then known moraine systems on the Des Moines Lobe. The outermost moraine he named the Altamont Moraine because the outermost moraine was presumed to be contiguous with the ridge running through Altamont, South Dakota. Upham and Chamberlin both recognized that there was a second, inner moraine on the Des Moines Lobe which had not been mapped in detail. Chamberlin (1883) also proposed a formal name for this moraine series, and called it the Gary Moraine, presuming that the ridge running through the town of Gary, South Dakota was contiguous with the tract of the second, inner moraine in Iowa.

County Mapping by the Iowa Geological Survey (1896-1909)

In 1892 the Iowa Geological Survey began a systematic county-by-county study and mapping of the geology of Iowa which continued intermittently through 1941. The counties in the study area were mapped during the period from 1896-1909 (figure 3a). These were reconnaissance studies and the mapping was very inconsistently done. Apparently no attempt was made to match boundaries between counties even when contiguous counties were mapped by the same investigator. The mapping was also done in differing degrees of detail. For instance, Beyer (1899), in his report on Hardin Co., goes into great detail describing a morainal ridge, which we presently refer to as the Altamont I Moraine (figure 2, this volume), yet he did not show the moraine on his map (figure 3a). He did state, however, that he thought this ridge was a branch of the "Gary" Moraine extending north from northern Boone and Story Counties. However, this ridge is coincident with Upham and Chamberlin's Altamont Moraine.

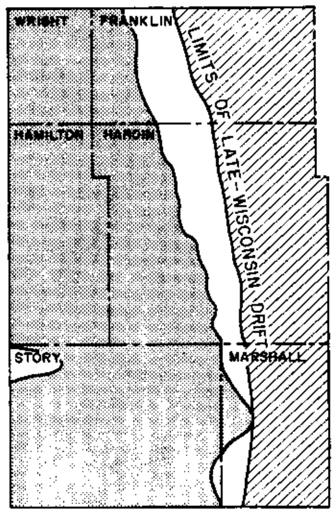
During this period the correct eastern margin of the Des Moines Lobe was mapped. However, because of the inconsistency and inaccuracy in landform mapping, the maps from this period are largely of historical interest only.

Regional Synthesis

Chamberlin (1895a), in Geikie's The Great Ice Age, reviewed the Quaternary history and stratigraphy of North America as it was known at that time. The Des Moines Lobe area was classified as part of the East Wisconsin Formation and moraine areas were shown. Later, Chamberlin (1895b) shortened the name to Wisconsin Formation, following the suggestion of Upham.

During the Iowa Geological Survey's county-by-county mapping program, various maps synthesizing the state-wide distribution of the drift sheets were produced. On these maps the age of the drift sheets and the morainal areas were shown. The field trip portion of Bain's 1898 map is shown on fibure 3b, and provides an interesting contrast to the maps produced in the county-by-county survey (figure 3a).

a.

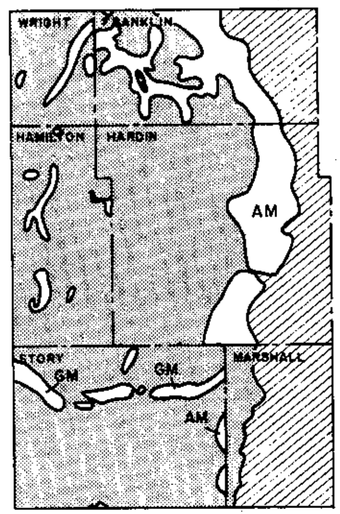


Wisconsin Drift

Wisconsin Moraine

From Bain, 1898.

b.

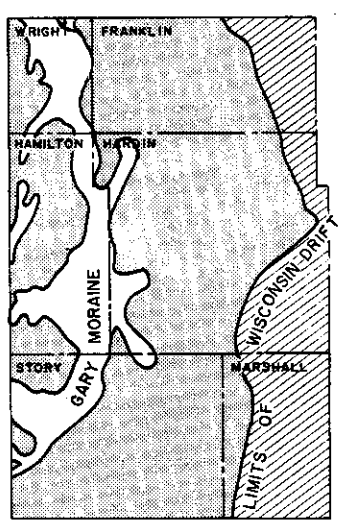


Wisconsin Drift

Wisconsin Moraine
AM - Altamont Moraine
GM - Gary Moraine

From Beyer, 1896–Marshall Co.; Beyer, 1898–Story Co.; Beyer, 1899–Hardin Co.; Williams, 1905–Franklin Co.; Macbride, 1909–Hamilton and Wright, Co's.

c.

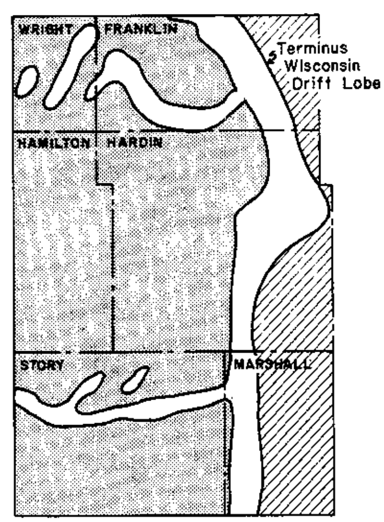


Wisconsin glaciated area

Morainal areas

From Smith, 1924.

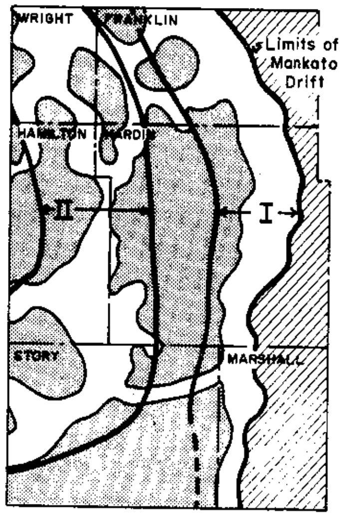
d.



Hilly morainal areas

From Kay and Apfel, 1929.

e.

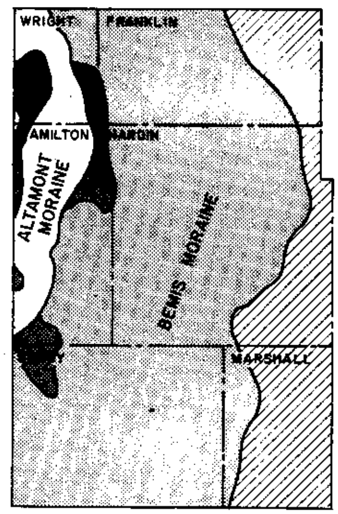


Hilly morainal areas

Major Mankato moraines
I - Bemis Moraine
II - Altamont Moraine

From Kay and Graham, 1943.

f.

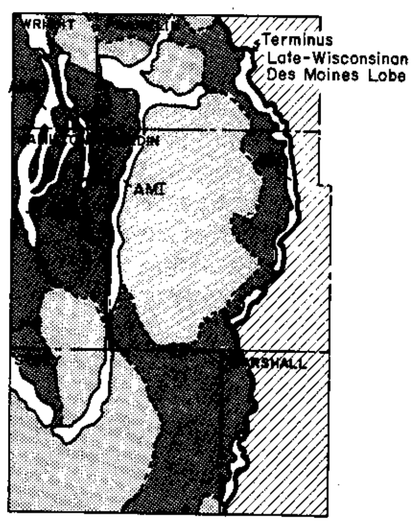


Wisconsin End Moraine

Wisconsin Ground Moraine

From Ruhe, 1969; 1952.

g.



High-relief ridge forms; moraines named
BM - Bemis Moraine
AMI - Altamont I Moraine
AMC - Altamont Moraine Complex

Moderate to low relief, lineated ridge forms, "Minor moraine" areas.

Other moderate relief irregular hummocky topography areas.

Dissected area; Wisconsinan loess over Pre-Illinoian tills.

For further details see map of field trip area.

Figure 3. Summary of the historical mapping in the field trip area.

As a result of field investigations in Minnesota and Iowa, Leverett (1922) extensively revised the nomenclature and mapping of moraine systems on the Des Moines Lobe. In his studies Leverett recognized that the outer margin of the Des Moines Lobe did not run through Altamont, South Dakota as Upham and Chamberlin had suggested, but that it instead passed through an adjacent ridge to the west which went through Bemis, South Dakota. Consequently, Leverett proposed that the outermost moraine of the Des Moines Lobe be designated as the Bemis Moraine. Leverett's 1922 map, although just a sketch, was the first map showing the regional extent of the second moraine system on the Des Moines Lobe. Leverett's mapping showed that the second moraine system in Iowa did in fact extend to the ridge running through Altamont, South Dakota, the ridge originally designated as the Altamont Moraine by Chamberlin (1883). As a result, Leverett proposed that the name Altamont Moraine be retained, but that it be used for the second, inner moraine system on the Des Moines Lobe instead of for the outermost moraine. In the study area it appears that Leverett designated the correct outermost portion of the Des Moines Lobe as the Bemis Moraine, while the term Altamont was applied to the same ridge which Beyer (1899) had designated as the Gary Moraine in his report on the geology of Hardin Co. and which Upham and Chamberlin had previously designated as the Altamont Moraine, thinking it was the outer limit of the Des Moines Lobe.

Smith (1924) noted that large, deep closed depressions on the Des Moines Lobe tended to occur in morainal areas. Since his study was concerned with the location of peat deposits, he felt that it was therefore imperative to know the distribution of moraines on the Des Moines Lobe. In his report he includes a detailed map of what he referred to as the recessional moraines of the Des Moines Lobe. He grouped these recessional moraine areas into successively younger moraines: the "Gary" (which he indicated in a footnote had now been revised to Altamont by Leverett, 1922), the Humboldt, and the Algona. This was the most detailed and *consistent* mapping done on the Des Moines Lobe to this time. It resulted in the recognition of two new moraine systems on the Des Moines Lobe: the Humboldt and the Algona Moraines. Neither the Humboldt nor the Algona Moraine runs through the field trip area. Figure 3c does, however, show the extent of the Altamont Moraine in the field trip area as mapped by Smith (1924).

Kay and Apfel (1929) reviewed the Quaternary history of Iowa, and produced a map showing the "hilly morainal areas" on the Des Moines Lobe. The hilly morainal areas which they depicted in the field trip area are reproduced on figure 3d.

Leverett (1932) described (but did not map) the Altamont Moraine system in Iowa. His description of the extent of the Altamont Moraine in the field trip area is essentially that shown for the Altamont Moraine on figure 2. The Altamont was depicted as an outer, main moraine (which we have depicted as Altamont I on figure 2), with an inner moraine system (Altamont C or complex on figure 2) extending northward from a position just west of the Skunk River valley.

Kay and Graham (1943) presented a comprehensive summary of the Illinoian and Post-Illinoian Quaternary geology of Iowa. Their map of the Des

Moines Lobe appears to have been little more than the addition of the Bemis Moraine area to Smith's 1924 map of the recessional moraine areas. Their map of the field trip area is shown on figure 3e.

Gwynne (1942), in an examination of air photos, discovered that there were distinct areas on the Des Moines Lobe where lineated, low relief ridges (relief less than 10 to 15 feet) were oriented transverse and slightly concave to the presumed direction of glacial flow. He reported that there were approximately 15 ridge sets per mile. He called these features "minor moraines" and produced a small map of the Des Moines Lobe showing their location and general trend. He noted that these ridges were composed almost entirely of till, and speculated that they were annual moraines.

Ruhe (1952a) remapped the Des Moines Lobe, significantly changing the extent and location of all of the moraine systems. Ruhe's mapping used criteria for "morainal" areas that were developed by R.F. Flint in Flint's mapping of the James River Lobe in South Dakota. These criteria were later published in Flint (1955, 1971). Ruhe included the extensive minor moraine areas (first identified by Gwynne, 1942) within the end moraines. This contributed to the unusually broad delineations for end moraine areas on the Des Moines Lobe (see for example the Bemis Moraine area on figures 1 and 3f). Ruhe's map has been adopted in all subsequent publications showing the extent of moraines on the Des Moines Lobe (Ruhe and Scholtes, 1959; Wright and Ruhe, 1965; Ruhe, 1969; Wright and others, 1973; Palmquist and Bible, 1974; Prior, 1976; Palmquist and Connor, 1978).

Palmquist and Connor (1978) used aerial photographs and soil survey information for a statistical study of landform distribution on the Des Moines Lobe. They produced a set of maps showing the percent occurrence of kames, bogs, alluvium and outwash, as well as maps showing the percent occurrence of landforms which were lineated, cross-lineated, circular, and non-patterned.

Walker (1966) analyzed and mapped a few large closed depressions or bogs in the study area in great detail. Walker's study was primarily concerned with soil development and landscape evolution in a "closed" drainage system. His analysis indicated that there had been episodic periods of erosion and sedimentation in the "closed" drainage systems during the Holocene, and that these changes have great importance to the problem of the "age" of the surface soils.

Time Stratigraphy

Time-stratigraphic designations of the Des Moines Lobe began with Chamberlin's landmark recognition that the "Ice Age" was in fact comprised of multiple glaciations rather than a single glaciation, and that landforms and features of the different glaciations could be recognized and mapped on a continental rather than local scale (Chamberlin, 1878, 1883). In this pioneering work it was recognized that the Des Moines Lobe was part of the youngest glacial events in the mid-continent, and at this stage of the investigation the Des Moines Lobe was attributed to the 'second glacial epoch.' Later, as glacial studies brought out more complexity to Pleistocene glaciation, the Des Moines Lobe was classified as part of the East Wisconsin Formation (Chamberlin, 1895a) which Chamberlin soon changed to the Wisconsin Formation following Upham's suggestion (Chamberlin, 1895b).

In the early 1900's the Wisconsin was informally subdivided into three substages: early, middle, and late Wisconsin. Leighton (1931) reviewed and revised this terminology, and formally proposed the terms Manitoban, Quebecan, and Hudsonian for respectively, the Iowan which previously had been considered a separate stage from the Wisconsin, the early and middle Wisconsin, and the late Wisconsin. The Des Moines Lobe area was included on a small map and shown as Hudsonian or late Wisconsin in age. Later, Leighton (1933) revised this stratigraphy, replacing Manitoban with Iowan (which he now regarded as a substage of the Wisconsin), dropping the terms Quebecan and Hudsonian, and replacing them with the respectively younger stages of Tazewell, Cary, and Mankato. In this new classification, the Des Moines Lobe became Mankato in age. The moraine systems of the Des Moines Lobe remained classified as Mankato in age in the comprehensive reveiw of Kay and Graham (1943).

Up to this time, the term "Wisconsin" was used in the sense originally used by Chamberlin (1895), that is, as both a time-stratigraphic and rock stratigraphic term. It was apparent, however, that "Wisconsin" was being used primarily in a time-stratigraphic sense for a variety of lithologies of similar age. Consequently, following practice established by the American Code of Stratigraphic Nomenclature for time stratigraphy, the adjectival ending -an was added to "Wisconsin," and the term given stage status. The first use of 'Wisconsinan Stage' was made by Frye and others (1948).

Ruhe (1952 a, b) presented a revised classification of the moraine systems on the Des Moines Lobe based upon erosional and topographic discontinuities. The Bemis Moraine was reclassified as Cary in age, while the younger moraine systems (respectively the Altamont, Humboldt, and Algona) remained as Mankato in age.

As radiocarbon dating became widespread in the 1950's, an absolute time chronology for the middle and late Wisconsinan became possible. Dates from the Des Moines Lobe area were found to be older than those attributed to classic Mankato areas, and fit more into the time frame of Cary age deposits (14,000 to 11,500 RCYBP). Consequently, the deposits of the Des Moines Lobe in Iowa were reclassified as Cary (Ruhe and Scholtes, 1959).

Radiocarbon dating, as well as extensive and detailed field investigations in the late 1950's and 1960's, indicated that the four-fold time-stratigraphic classification of the Wisconsinan needed extensive revision. Frye and Willman (1960) proposed a new classification of the Wisconsinan for the Lake Michigan Lobe, which was the type area for the Tazewell and Cary. Significant changes in both concepts and terminology were proposed. The Tazewell and Cary Substages were dropped and replaced with a single substage, the Woodfordian substage, since in the Lake Michigan Lobe there is no significant break in glacial sedimentation from what had been interpreted as the beginning of the Tazewell to the end of the Cary.

This time-stratigraphic classification of the Wisconsinan Stage in the Lake Michigan Lobe was adopted by the U.S. Geological Survey (Frye and others, 1968) with the implication that it was applicable to other areas of Wisconsinan glaciation. The abandonment of the type areas of the Tazewell and Cary (Frye and Willman, 1960) has important implications for the time-stratigraphic terminology of the Des Moines Lobe (and adjacent areas along the southwest margin of the Laurentide ice sheet) in that the type area for these two substages are not now formally recognized. Radiocarbon dates for the Des Moines Lobe do fall within the range of the late Woodfordian. "Tazewell" and "Cary" time-stratigraphic terminology are still used informally in Iowa and adjacent states to the north and west because, in contrast to the Lake Michigan Lobe, there appears to have been two significant, distinct periods of glacial advance and sedimentation during the Woodfordian. Formal time stratigraphy for the Des Moines Lobe is presently in need of revision.

Rock Stratigraphy

The deposits of the Des Moines Lobe have previously not been formally classified rock-stratigraphically, although the term "Cary" and/or "Mankato" have been applied as both time- and rock-stratigraphic prefixes to lithogenetic names such as till, drift, stratified drift, etc. Terms such as till, drift, stratified drift, etc. are vague in their specification of both glacial environment and specific glacial process. For example, the till deposits are treated with but brief description, as in Williams (1905) account of the Wisconsin Drift in Franklin Co.:

> ". . . It is typically composed of an extremely calcareous and sandy clay matrix which is filled with promiscuously distributed pebbles and boulders of a wide range of sizes and varieties . . . From the typical boulder clay, the drift grades into clayey gravels, argillaceous sands, and in the morainal tracts where the action of water has been of greater importance, beds of perfectly assorted sand and gravel occur."
>
> \- Williams (1905, pp. 492-493)

Other than this reference to glacial or glacially-related deposition little interpretation was made as to how the material was actually deposited.

Only Kay and Miller (1941) provided a sedimentologic analysis of deposits on the Des Moines Lobe. They studied the nature of sand and gravels, reporting the shape, sorting and particle size distribution, and mineralogy. They recognized that the sand and gravel deposits occur in two environmentally different settings: 1) as outwash in valley trains in front of the ice margins; and 2) as irregular masses either interbedded within the till or deposited on the till as kame-like knobs. Note that they recognized that the proglacial outwash deposits on the Des Moines Lobe differ from classic areas in that they are confined almost exclusively to channels and valley trains, classic proglacial outwash plains being extremely rare.

They also noted that upland sand and gravel deposits occur associated with the till in six different settings: 1) as deformed masses near the base of the till, which may or may not be mineralogically similar to the till; 2) as very large, undeformed beds near the upper surface of the till; 3) as numerous small interbedded lenses near the upper part of the till 4) as beds at the surface but inset within the till; 5) as kame-like knobs or small eskers; and 6) as sheet deposits over the till surface, sometimes filling in depressions. They recognized that these deposits associated with the till could not all have had the same origin, and proposed six different ways in which the observed sand and gravels may have been emplaced: 1) as pre-existing sand and gravel deposits which were eroded subglacially and later deposited with the till; 2) as proglacial outwash deposits subsequently overridden by the glacier then eroded and later deposited within the till; 3) as deposits in moulins, tunnels or other locations within active ice and then let down to their present position; 4) as deposits in moulins, tunnels, etc. in stagnant ice and either let down to ther present position as the ice melted or originally deposited in their present position; 5) as proglacial outwash at the margin of the glacier; and 6) as eskers or kames deposited in or just beyond subglacial or englacial tunnels. Kay and Miller discussed which situations the above hypotheses explained, but did not comment on such topics as: a) if the sands and gravels tended to occur primarily in one or more of these settings and not in others; b) if there was a systematic distribution of these different sand and gravel types on the Des Moines Lobe; or c) if there was a systematic distribution of the deposits, what was its significance to areal variations in glacial sedimentation of the Des Moines Lobe?

CURRENT RESEARCH

In applied geology it is critical to know what materials are present, what the physical properties of each are, and how the different materials are stratigraphically related. For design work this is done by detailed on-site investigations, but for regional engineering-geologic considerations a means for mapping and extrapolation must be developed. In the past, the Des Moines Lobe has been subdivided into areas of moraine (end or recessional) and ground moraine, but there are several reasons for re-evaluating this area for applied studies:

1. These designations, particularly in a modern context, provide little or no insight into the details of the nature of the materials, their behavior, or their genesis.

2. As a result of glacial studies during the past 15 years a more refined genetic differentiation of till-like deposits is possible. It is now known that till-like materials may be deposited by a number of different glacial processes. The tills deposited by these different processes may differ in sedimentologic properties, which in turn means that they may differ in geotechnical, agricultural, and hydrologic properties.

3. New concepts, in concert with new tools such as aerial photography and complete coverage with 7½ minute topographic quadrangle maps, as well as careful, systematic field work indicate: a) that there are many more glacial landforms on the Des Moines Lobe than classic categories of moraine and ground moraine, and b) that many landforms do not fit into existing categories for glacial landforms.

In consequence, research presently underway by the Iowa Geological Survey on the deposits of the Des Moines Lobe has several objectives:

1. The detailed quantification of the stratigraphic, sedimentologic, and geotechnical properties of the materials for applied purposes, as well as to provide interpretation of the genesis of the deposits.

2. Relating these sediment properties to the remnant glacial landforms. These landforms are then mapped in detail in the field with the assistance of color-infrared aerial photography. From this mapping, areal synthesis of the landform-material assemblages can be made which will provide information on probable glacial depositional regimes.

3. The establishment of nomenclature and terminology to deal with the descriptions and classification of the deposits.

This field guide will try to outline our present working model and methods, and show some of our initial findings in the field trip area. The following sections will provide a brief review of new concepts and our working methods on the Des Moines Lobe.

Till Sedimentation

Till-like materials are the dominant component of most upland landforms on the Des Moines Lobe. Until recently, the *processes* by which till deposition takes place were poorly understood. Recent studies, particularly in the past two decades, have concentrated on the factors which affect the occurrence and mechanics of glacial processes. Although understanding of glacial depositional processes is far from complete, many major aspects are now satisfactorily understood.

It has long been recognized that till-like deposits may form by deposition in two grossly different environments: subglacially, beneath the ice, and supraglacially, at the upper surface of the ice. Until recently, however, there was only a rudimentary understanding of both the depositional processes in these two environments and the sedimentological character and sequence of the till-like materials which resulted. We now recognize that till-like deposits can be genetically differentiated on the basis of properties inherited from the depositional processes. Tables 2 and 3, for instance, designate the type and properties for till-like sediments deposited by various processes from land-based glaciers as recognized respectively by Boulton (1976) and Lawson (1979).

Table 2. Boulton's criteria for distinguishing tills of different origin (from Boulton, 1976).

Properties	Flow Till	Melt-out Till	Lodgement Till
Nature of sequence and position of tills within it	Topmost of a sequence of tills. Often occurs directly above ice-contact outwash sediments. May coat hummocky terrain as a thin veneer. Sediment lenses of all sizes occur within the flow till	Occurs directly above lodgement till or eroded surface. Always overlain by sediment overburden	Occurs at the base of a sequence of sediments derived from glacier retreat
Grain size composition and its spatial variation	Often shows considerable variations in grain size composition. Local enrichment and depletion in fines due to sub-aerial washing on till surface	Relative small spatial variation in grain size composition	Relatively small spatial variation in grain size composition. May show boulder clusters of glacitectonic inclusion from underlying beds
Banding	Shows both sedimentary banding and shear banding. The former due to water sorting on the till surface, the latter due to streaking out during flow	Absence of banding	Absence of sedimentary banding but shear banding due to inclusion and streaking out of sub-till sediment
Clast orientation fabrics largest commonly occurring clast should be selected as the most reliable	Transverse and parallel to flow direction. Often parallel and transverse to ice flow direction, but not necessarily. Large within site fabric variability	Little studied, but well-defined transverse and parallel orientations probably tend to develop. a - b planes tend to lie in plane of bed. Highs within site fabric consistency	Tendency for the development of strong parallel fabric peaks with an up-glacier dip, except for those tills where postdepositional deformation has occurred, such as in flutes or folds transverse to flow. Here, transverse peaks may develop. Strong within site and between site correlation
Folding and faulting	Intra-formational folding due to flow; commonly seen asymmetric overturned or flat-lying isoclinal folds common. Anticlinal and synclinal fold noses preserved. Frequently overlie stratified sediments which show gentle folding and high angle faulting indicative of collapse over melting stagnant ice	No internal folding	Folding may be apparent when underlying beds have been incorporated. Folds generally isoclinal with flat-lying axial planes. Anticlinal fold noses rarely preserved. Synclines facing up glacier commonly found. Fold noses often completely streaked out. Folding in underlying beds similar to that in the till, though it may be less extreme. Structures reflect subglacial shearing
Geotechnical properties	Wide variation in index properties from the same site. Deviations to both sides of T-line. Reflects sorting processes	Relatively little within-site variation in index properties. Points fall on T-Line	Relatively little within-site variation in index properties. Points fall on T-line
Jointing	Joints primarily reflect drying out (vertical, polygonal in plan), and freezing (closely spaced 2 cm, and parallel to the surface)	Rarely jointed	Joints primarily reflect unloading (parallel to the surface, more widely spaced than joints due to freezing), and shearing (sub-parallel lenticular joints sets, or vertical conjugate sets)
Surface expression (geomorphology)	May occur below a low relief slightly irregular surface, or below an irregular hummocky ridged surface, or a series of ridges lying parallel to the glacier margin. The ridges may be composed primarily of flow till or of stratified outwash capped by flow till	Never exposed at surface	Almost invariably fluted and or drumlinised in the direction of ice movement. May have transverse pushed ridges superimposed, or an irregular pattern of till squeezed up in crevasses
Till thickness	Extremely variable, from very thin to very thick. Average thickness unlikely to the order of 1 - 2 m	Thin, unlikely to exceed 2 m	Any thickness. Average thickness may be large

Table 3. Some characteristics of the deposits, terminus region, Matanuska Glacier, Alaska (after, Lawson, 1979).

Process	Deposit	Internal organization: General	Internal organization: Structure	Internal organization: Pebble fabric	Contacts-basal surface features	Geometry-maximum dimensions	Miscellaneous properties
Lodgement at glacier sole	Lodgement till	Clasts randomly dispersed to clustered in matrix.	Massive; shear foliation, other "tectonic" features.	Strong; unimodal(?) pattern; orientation influenced by ice flow and substrate; low angle of dip.	Image of substrate	Discontinuous pockets or sheets of variable thickness and extent.	Usually dense compact.
Buried ice melt	Melt-out till	Clasts randomly dispersed in matrix	Massive; may preserve individual or sets of ice strata.	Strong; unimodal parallel to local ice flow; low angle of dip.	Upper sharp, may be transitional; sub-ice probably sharp.	Sheet to discontinuous sheet; km^2 to m^2 in area, m thick.	Internal contacts of strata are diffuse; loose.
Sediment flow	Sediment flow. Type I	Clasts dispersed in fine-grained matrix.	Massive.	Absent to very weak; vertical clasts.	Non-erosional, conformable contacts; contacts indistinct to sharp; load structures.	Lobe; maximum of 1000 m^2 in area, 2.5 m thick.	Dense, compact.
	Type II	Plug zone; clasts dispersed in fine-grained matrix;	Massive; intraformational blocks.	Absent to very weak; vertical clasts.	Non-erosional, conformable contacts; contacts indistinct to sharp.	Lobe; maximum 600 m^2 in area; 1.5 m thick; sheet of coalesced deposits.	Dense, compact.
		Shear zone; gravel zone at base, upper part may show decreased silt-clay and gravel content; overall, clasts dispersed in fine-grained matrix.	Massive; deposit may appear layered where shear and plug zones distinct in texture.	Absent to weak; bimodal or multimodal; vertical clasts.			
	Type III	Matrix to clast dominated; lack of fine-grained matrix possible; basal gravels.	Massive; intraformational blocks occasionally.	Moderate, multimodal to bimodal parallel and transverse to flow.	Non-erosional, conformable contacts; contacts indistinct to sharp.	Thin lobe; 200 m^2 in area; 0.5 m thick; fan wedge; 2000 m^2 in area; 3.5 m thick rarely; sheet of coalesced deposits.	Dense to loose.
	Type IV	Matrix, except at base, where granules possible.	Massive to graded (distribution, coarse tail).	Absent.	Contacts conformable; indistinct.	Thin sheet; 200 m^{2}in area, 0.3 m thick; fills surface lows of irregular size and shape.	Loose.
Spall	Slope colluvium	Clasts dispersed randomly in matrix to clast supported.	Massive to intraformational blocks in massive material.	Absent; vertical clasts.	Conformable to former surface, non-erosional.	Irregular cross sections; band parallel to former slope of variable length, 2 m thick.	Loose; chaotic intraformational block orientations.
Slump	Slump	Clasts dispersed randomly in matrix.	Massive to undisturbed blocks over slip plane.	Absent, except in some blocks.	Shear plane may occur; conformable contacts.	Irregular; hundreds of m^2 in area, 2.5 m thick.	Loose to dense.
Ablation	Ice slope colluvium	Clasts dispersed in matrix to clast supported.	Massive.	Weak; parallel to trend of ice slope; low to high angle of dip.	Conformable to former surface; non-erosional.	Discontinuous thin sheets to wedge of variable area; 3.5 m thick.	Loose to dense.
Meltwater flow	Meltwater sheet and rill deposits.	Matrix.	Parallel stratification; deltaic cross stratification; massive to graded.	Parallel to flow; downslope dip.	Conformable to non-conformable; erosional to non-erosional.	Thin sheets; wedges, lenses; 1000 m^2 in area; 0.5 m thick.	Dense; associated with sediment flow deposits commonly.

Till-dominated glacial landforms are obviously built up as a result of glacial deposition through time. When trying to understand the genesis of various glacial landforms it is thus extremely critical that one understand till sedimentational processes. The following sections provide a brief summary from recent studies on till depositional processes in the subglacial and supraglacial environments.

Subglacial Sedimentation

Subglacially-deposited till has classically been called lodgement till. It is now recognized that till may be deposited subglacially by three different processes: lodgement, regelation melt-out, and basal melt-out, rather than by just a single process of lodgement.

Lodgement is largely a mechanical process whereby frictional forces between a particle in traction and the bed become greater than the traction exerted by the moving ice, and the particle becomes "lodged" or deposited on the bed. Boulton (1974, 1975) provides a comprehensive theoretical treatment of lodgement including an analysis of the various factors involved (particle size, ice velocity, normal stress between the particle and the bed, etc.) and their influence on the kind and rate of subglacial processes taking place. Lodgement is probably most important for clast size particles, as opposed to matrix size particles, because these larger particles are capable of generating greater frictional forces relative to the tractive forces of the ice.

Particles within the basal ice may also be deposited during regelation melt-out. Where ice is at the pressure melting point and sliding over the bed, debris may be passively deposited by melt-out during the melting portion of the regelation process. This process is probably effective primarily for smaller sized debris, particularly the matrix size materials which dominate Midwestern tills. The limitation for the size of debris deposited by this process is related to the size of the obstructions causing regelation melting.

Basal melt-out is the name given to material melted out from the basal ice by geothermal heat and the heat produced by glacier movement (deformation and sliding, where sliding is taking place). In many glacier situations, these two heat sources are sufficient to melt out till on the order of 1-3 cm in thickness annually (Boulton, 1970; Mickelson, 1973; Sugden and John, 1976). There is still some confusion exactly under what conditions basal melt-out occurs. Basal melt-out is certainly important in stagnant ice conditions or where debris-rich ice has stagnated in hollows on the glacier bed, being overridden by cleaner, active ice. However, strict basal melt-out may be rare at the interface between the bed and actively moving ice which is at the pressure melting point. The reason for this is that the available heat may promote enhanced melting by regelation rather than by basal melt-out on the bed as a whole (i.e., melting may be concentrated at obstacles on the bed, rater than uniform melting over the whole bed). However, at present there is still a great need to understand the relationship between regelation melt-out and basal melt-out at the base of active ice at the pressure melting point.

It should be noted that of the three subglacial depositional processes, lodgement and regelation occur primarily particle by particle (or in some instances, small aggregates of particles). Basal melt-out, however, may include deposition of sizeable aggregates, such as lenses of till or other sediments in the ice, such as stratified sand, gravel or silt (Lawson, 1979).

Subglacial depositional processes may inherit fabric largely from the parent ice (Boulton, 1971, 1976; Lawson, 1979) with only partial re-orientation as the interstitial ice melts out. Since subglacially deposited tills are deposited beneath ice loads, they often become overconsolidated (in the geotechnical sense) and consequently have relatively high density. Subglacially-deposited tills may contain lenses of meltwater deposits. These deposits may originate as: 1) meltwater deposits eroded by the ice and subsequently deposited with the till; or 2) meltwater deposits in subglacial or englacial channels. In general, however, meltwater deposits volumetrically constitute only low proportions of subglacially-deposited sediments.

Dreimanis (1976) gives the generic name "basal till" to tills deposited subglacially (figure 4). Basal till is a useful term because it is not always possible to determine which depositional process may have taken place, and used in this sense, the term recognizes or implies that there may be more than one process of subglacial till deposition. More detailed discussions of subglacial sedimentation occur in Boulton (1972, 1976), Dreimanis (1976), Goldthwait (1971), Lawson (1979), Mickelson (1973), and Sugden and John (1976).

Supraglacial Sedimentation

Sedimentation in the supraglacial environment may be extremely complex (figure 5). More extensive discussions of sedimentation in the supraglacial environment can be found in Boulton (1972, 1976), Lawson (1979), Sugden and John (1976), and references cited in these publications.

Supraglacial sediments may consist of three basic types: 1) supraglacial melt-out till, which largely inherits its properties from the parent ice; 2) resedimented deposits (Lawson, 1979) or flow till (Hartshorn, 1958; Boulton, 1972), which consist of deposits which have been subject to flow, reworking and resedimentation on and/or next to the ice surface, and which derive their sedimentologic properties from the resedimentation processes; many of these deposits are till-like; and 3) supraglacial meltwater deposits, which represent resorted deposits in supraglacial channels and pools.

Supraglacial sedimentation begins quite simply with the melt-out of debris from the ice. In continental ice sheets, this debris originates either as basally-derived debris which, as a result of ice dynamics, has been transported up to an englacial or supraglacial position or may simply be debris-rich basal or englacial ice which has become exposed near the terminus as the ice surface is lowered by ablation. The heat for this supraglacial melt-out is supplied ultimately by solar radiation, but other factors, such as heat from meltwater streams and ponds, etc.,

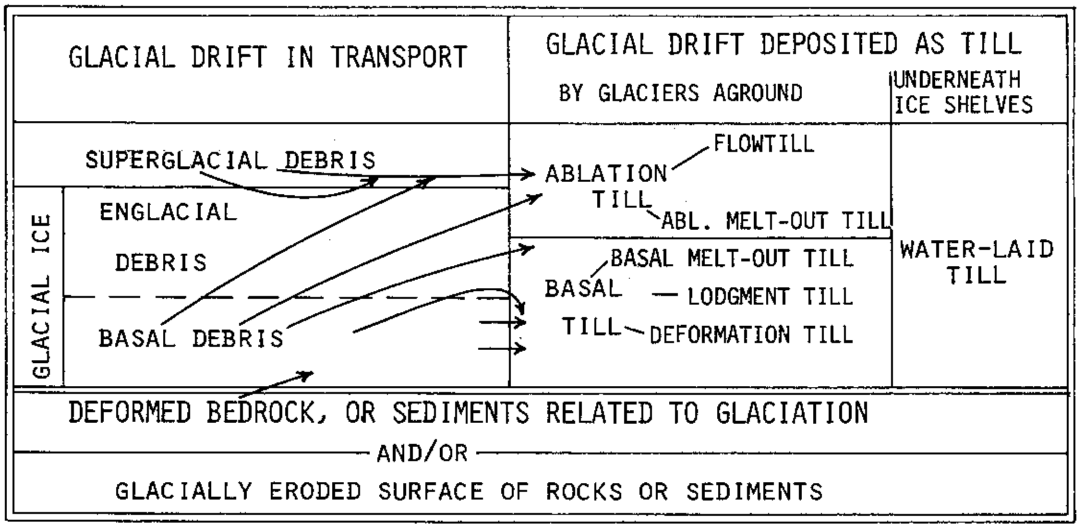


Figure 4. Dreimanis' genetic classification of tills and their relationship to glacial debris in transport (after Dreimanis, 1976).

may contribute to the melting. Since the debris in the ice is generally poorly-sorted, passive melt-out of the debris may result in a till-like deposit. After the debris has been melted out, a number of options may occur depending on the local conditions. In the simplest case, the material may simply be let down with virtually no disturbance. Till deposited in this manner is probably the true supraglacial melt-out till (Sugden and John, 1976). Alternatively, fines may be removed by meltwater on the ice surface, leaving a coarse-textured, poorly-sorted lag. This is the simplistic concept of ablation till, as used for many years by Flint, (1957; 1971). In both of the above cases, the material was simply let down as the underlying ice melted out.

The supraglacial debris may just as well have been subject to flow and resedimentation as described by Boulton (1972) and Lawson (1979). Lawson's study is the most comprehensive to date and will be used to briefly illustrate the resedimentation processes which may occur in the supraglacial environment. Till-like deposits may result from the following resedimentation processes:

1. Ice slope colluvium: deposits formed when debris melts out onto a sloping ice surface and accumulates at the base of the slope. These deposits may be transitional to melt-out till in some situations.

2. Slope colluvium: deposits formed when supraglacial sediments collapse by spall off a steep ice wall.

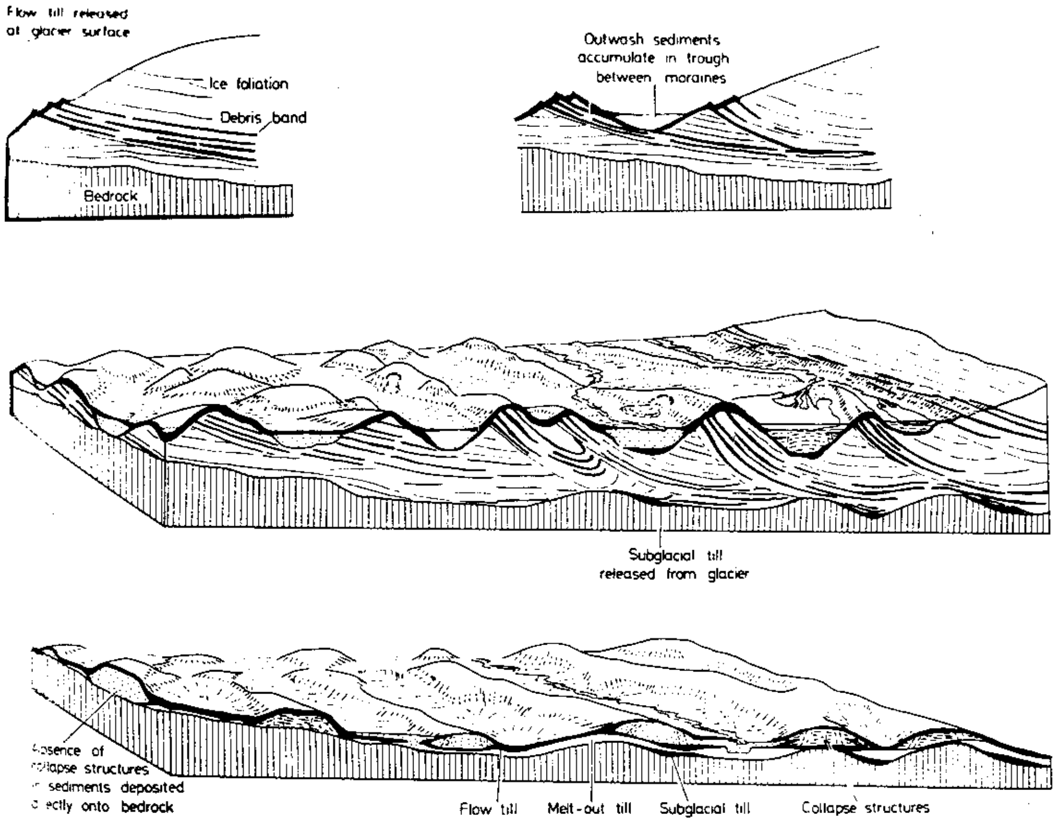


Figure 5. Schematic diagrams illustrating the complexity of sedimentation in the supraglacial environment (from Boulton, 1972).

3. Slump deposits: deposits formed when supraglacial material is subjected to slumping.

4. Sediment flow: deposits resulting from the flow of supraglacial sediments. Both Boulton (1972, 1976) and Lawson (1979) recognize that there are several different flow types which differ in the mode of flow and in the properties of the resulting sediments (Tables 2 and 3).

Supraglacial meltwater sediments are deposited in meltwater streams and ponds on the glacier surface. The texture of the meltwater deposits is largely a function of the particle sizes available for transport and the sorting which has taken place.

The supraglacial environment, in contrast to the subglacial environment, is one in which meltwater may play an important part. Certainly, the potential for meltwater activity is great. The effect of the meltwater is three-fold: 1) it may promote mass wasting of supraglacial sediments by various processes of sediment flow or slumping; 2) it may physically alter the constituency of till-like deposits by flow, winnowing, etc.; and 3) it may result in the complete reworking with the subsequent sedimentation of supraglacial fluvial and lacustrine sediments.

In addition to these single processes of sedimentation it should be realized that the supraglacial environment is a dynamic one: debris is always being released as the ice surface melts down. Also, differential melting of the glacier surface, as well as collapse (as a result of undercutting or the collapse of sub- or englacial meltwater channels) mean that the supraglacial surface is an ever changing one. Debris subject at one period to flow, may later be subject to collapse or slumping. That is, a particular unit may be subject to several periods of resedimentation before all of the underlying ice melts out. Supraglacial channels or ponds may in turn be drained suddenly by the collapse of adjacent or underlying ice, or clogged by the influx of sediment flows or slumps from adjacent higher slopes. Consequently, supraglacial sediments commonly consist of resedimented till-like materials interbedded with meltwater deposits. The till-like materials commonly show evidence for flow or some degree of reworking by meltwater but this need not always be the case. The supraglacial sediment assemblage may also show evidence for some sort of collapse or flow. Consequently, the sediment sequence and character of supraglacially-deposited sediments may differ recognizably from subglacially-deposited sediments.

Till Sedimentation and Stratigraphy on the Des Moines Lobe

Till-like deposits in Iowa are presently being differentiated by the Iowa Geological Survey into two fundamental categories: basal till and supraglacial sediments (basal till and ablation till in the generic sense of Dreimanis, 1976; see figure 4, this volume). Figure 6 illustrates the differences between the deposits of these two categories from boring 64 LH-3, Stop 5 on this field trip. The basal till and supraglacial sediments are differentiated through the combined use of several types of data: 1) texture; 2) the nature of stratification and sorting; 3) stratigraphic position within the sequence of sediments and the nature of contacts between units; and 4) geotechnical properties, particularly density, consolidation data, and consistency. These are the fundamental properties which we use to discriminate the deposits because they can be observed or measured from both drill cores and exposures. Exposures are where you find them, not always where you need them. Consequently, much of our work concentrates on detailed coring. When analyzing deposits in outcrop, additional observations on sedimentary structures and fabric are also important. These observations also help to interpret partial structures seen in the drill cores. Any one of the above criteria by itself may not be sufficient to generically discriminate the deposits, but when several criteria are integrated together, they generally allow differentiation.

Figure 6, again illustrates how these criteria can be used. The deposits consist of an upper unit of supraglacial sediments overlying uniform basal till. The supraglacial sediments consist of a sequence of till-like

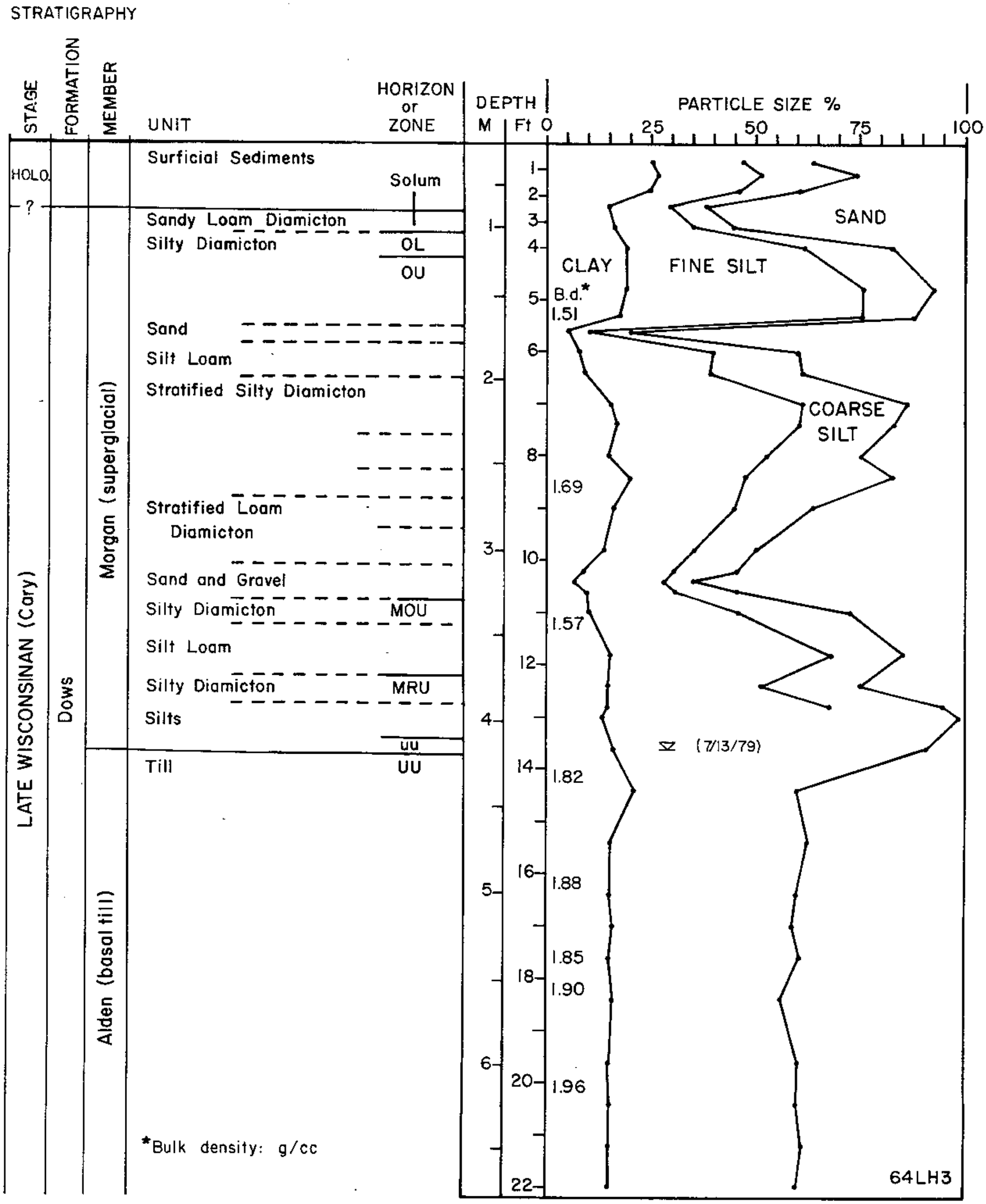


Figure 6. Stratigraphy and particle-size data for core 64-LH3, Stop 5. This core presents an excellent example of the supraglacial deposits overlying the basal till of the Des Moines Lobe.

deposits, here referred to as *diamictons*, interbedded with sorted silty and sandy deposits. The diamictons are texturally variable and sometimes exhibit graded bedding. They are variable in consistency, but generally are friable to loose, and have a moderate bulk density (1.51-1.69 g/cc). These properties are in sharp contrast to the *underlying* basal till which is very uniform in texture, lacks interbedded sorted deposits, is firm to very firm in consistency, and exhibits considerably higher density (1.82-1.96 g/cc).

The following sections will detail the properties and criteria used to differentiate till-like deposits in Iowa. The data presented are solely from the field trip area (shown on figure 2) and does not include data from other areas on the Des Moines Lobe. The data compiled includes all the stratigraphic sections presented in this report and several unpublished sections as well.

Standard weathering zone terminology, as outlined in Hallberg and others (1978), is used for the descriptions of the Quaternary sediments which are not in a solum or paleosolum. Standard pedologic terminology and horizon nomenclature for soils and paleosols (Soil Survey Staff, 1951, 1975) are used both in the descriptions and in the graphic plots (such as figure 6) for the stratigraphic sections. For convenience, enumeration of different materials within a paleosolum may begin with the uppermost material in the paleosol rather than at the landsurface. Standard USDA-SCS textural classes and terms are also used (Soil Survey Staff, 1975). Laboratory data are presented to quantify the physical characteristics of the materials. The laboratory methods used are particle size analysis, clay mineralogy, and analysis of sand-fraction lithology; standard procedures are outlined in Hallberg (ed., 1978). In addition, matrix carbonate content of the deposits are also evaluated using a Chittick apparatus, following the procedures outlined by Walter and Hallberg (1980).

Textural Properties and Stratification

Use of the term "texture" for this study generally refers to matrix texture only (the less than 2 mm fraction). The marked differences in the ranges of matrix texture between the basal till and the supraglacial sediments in boring 64 LH-3 (figure 6) is even more striking when data from the whole field trip are compared on ternary diagrams (figure 7). Over this entire area the basal till is loam-textured and quite uniform, with remarkably small standard deviations and a relatively small total range of textures. At an individual section the basal till is often remarkably uniform, varying only a few percent in any particle-size category (see figures 8 and 9, for example). This is clearly more analogous to subglacial deposits than those from the supraglacial environment (Dreimanis, 1976; Boulton, 1976).

There are a few common exceptions to the uniformity of the basal till. Most of these exceptions occur in the lowermost portion of the basal till. First, block inclusions of older substrate materials may occur within the till. These inclusions are generally small, identifiable, coherent masses of the local substrate (figure 10 shows an example).

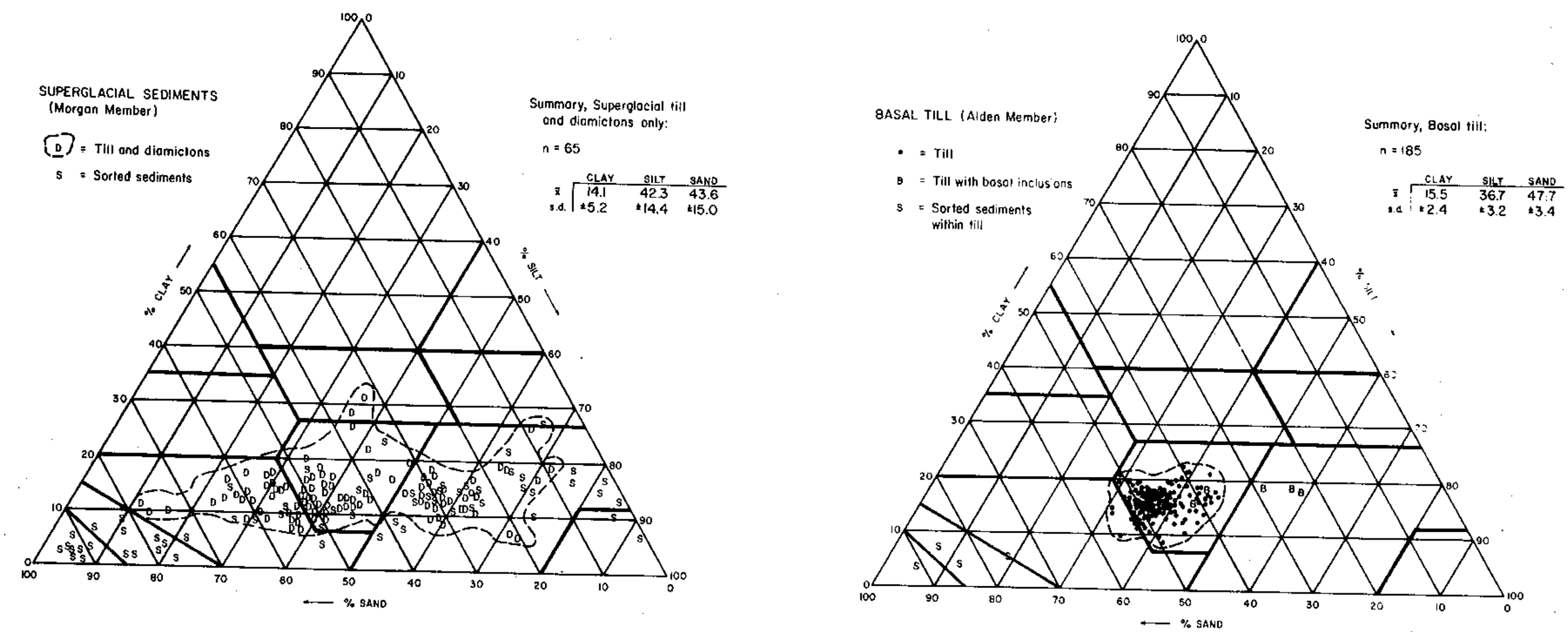


Figure 7. Summary of textural data for the supraglacial deposits and basal till of the Des Moines Lobe in the field trip area.

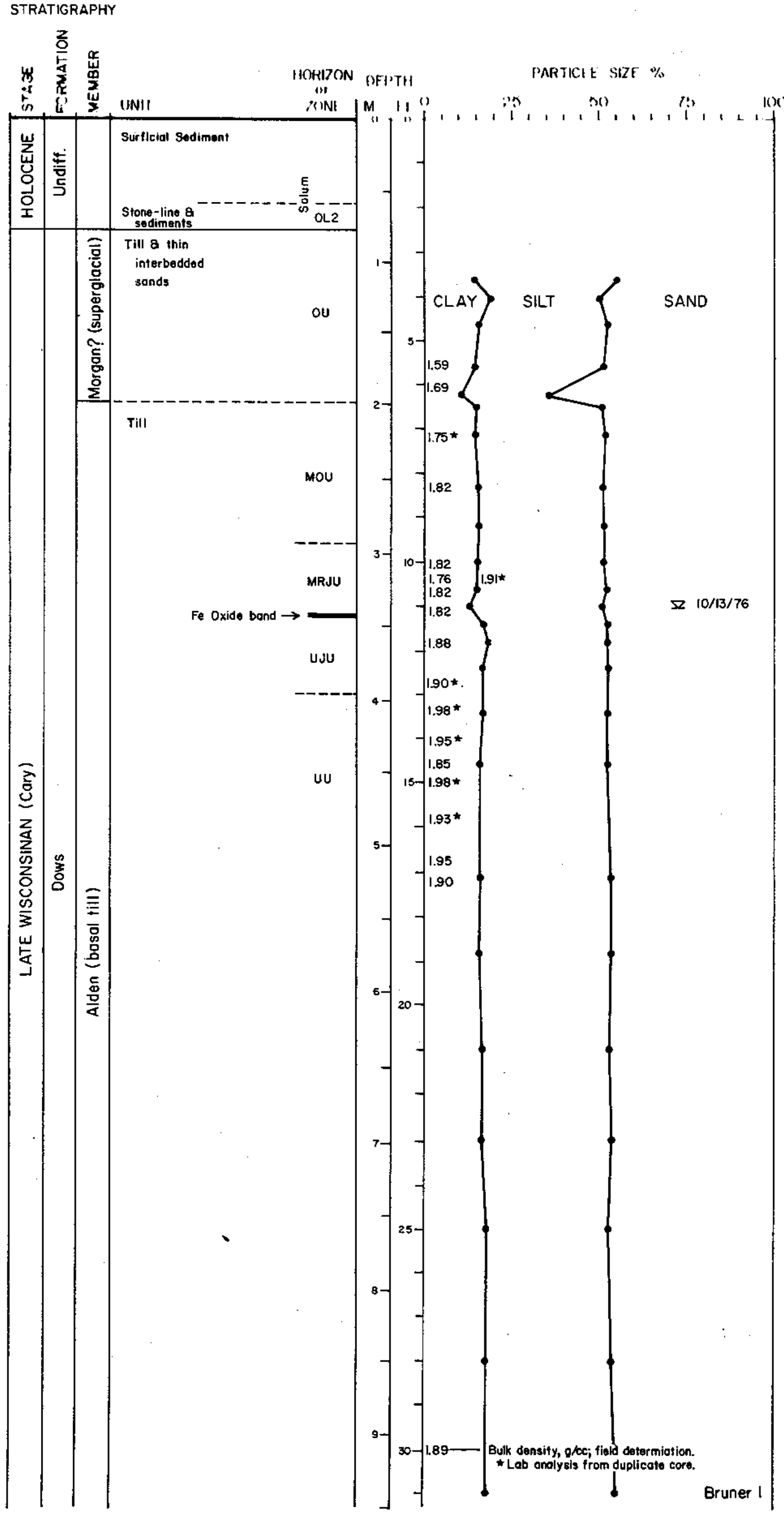


Figure 8. Stratigraphy and particle-size data for the Bruner 1 Section (see figure 9 also).

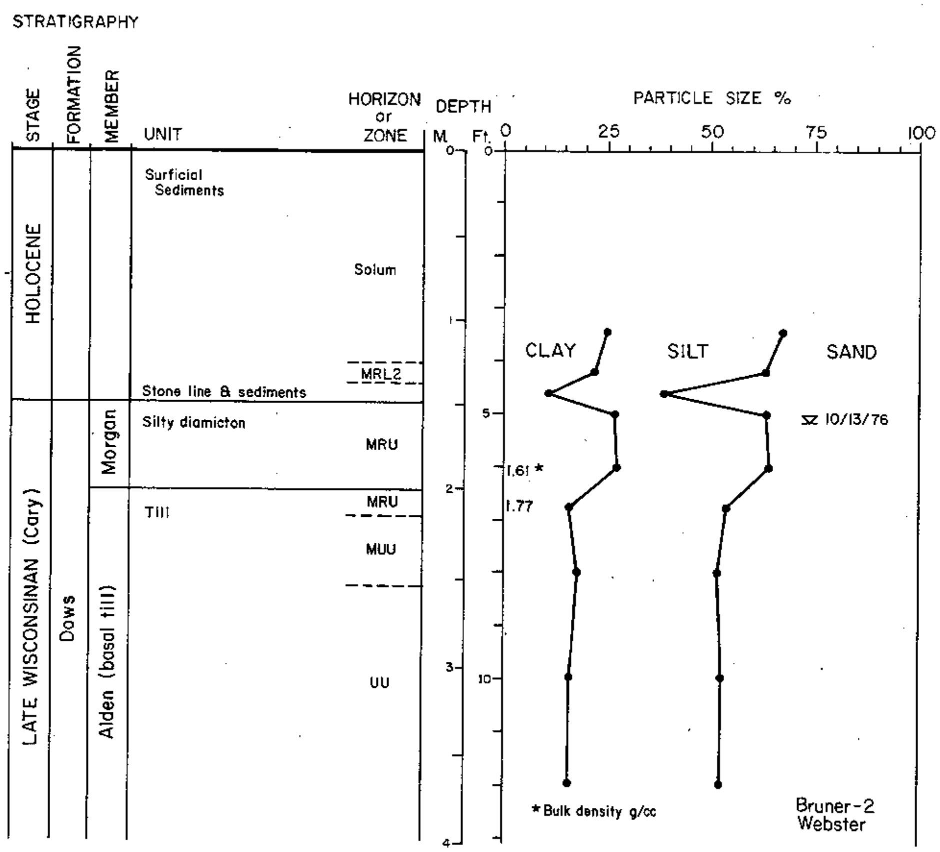


Figure 9. Stratigraphy and particle-size data for the Bruner 3 Section; downslope from Bruner 1 (figure 8).

These blocks were apparently eroded and deposited en masse within the till. Such features are common in the lower portions of basal till and may imply shearing and perhaps local basal freezing under active ice to entrain these inclusions (Dreimanis, 1976). These inclusions are generally deformed and sometimes slickensided (Hallberg, 1980) indicating active differential movement.

A second exception is a commonly encountered zone at the very base of the till where the local substrate material occurs dispersed and thoroughly mixed within the till. This zone is generally marked by a gradational change in properties upward from dominantly local materials at the base to the modal characteristics of the basal till. An example of this zone can be seen in the data from Stop 1, the Alden Section. In figure 7, the data points denoted by B's show the texture of samples from such a zone at Alden where the till overlies loess. For these samples there is a transitional decrease in silt content upwards, away from the contact with the loess (see discussion for Stop 1). Boulton (1970) showed that the vertical variation in erratic content, from nearby sources at the base, to more far-travelled debris higher in the section was related to stacking of till beds by basal melt-out. However, in most cases, the changes described here are so gradual and on such a small-scale that it implies a different mechanism such as repeated regelation (Kemmis, 1981).

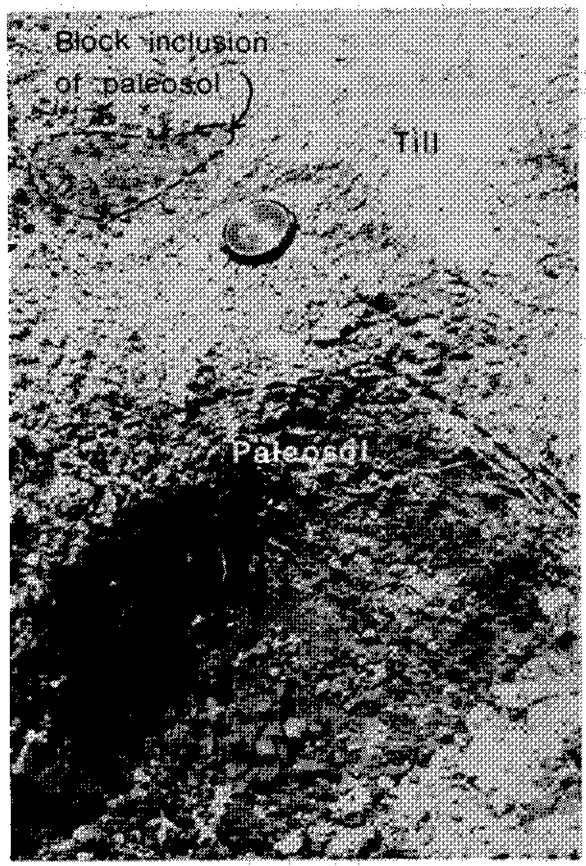


Figure 10. Block inclusion of paleosol in lower portion of basal till; inclusion is about 0.3m above the till-paleosol contact (from Stop 2).

Another interrelated occurrence worthy of note is the infrequent occurrence of lenses of stratified water-laid deposits (silts, sand and/or gravel) within the basal till. These inclusions tend to be thin (generally less than 2 feet) and discontinuous. Many appear to be block inclusions of proglacial outwash which have been overridden during advance of the ice. Others appear to have originated as subglacial or englacial meltwater deposits.

In some thick basal till sections individual beds of *till* 1-5 feet (0.3-1.5 m) thick occur. These individual units are discernible from subtle but abrupt changes in color and sometimes texture. Figure 8 shows such a break within the basal till at about 3.4 m depth. The till above the contact is MRJU (mottled, reduced, jointed, unleached), olive (5Y 5/4 and 4/4) and olive brown (2.5Y 4/4) in color, with strong brown (7.5YR 5/6) mottles, while the till below is UJU (unoxidized, jointed, unleached), a uniform dark greenish gray (5GY 4/1) color; these two till beds are separated by a 3 cm thick band of secondary iron oxides which are strong brown (7.5YR 5/6-8) in color. At other sites, thin sorted sediments will occur between such till beds, and we will see such an occurrence at Stop 8 on the field trip. These features might result from the basal melt-out of stacked debris bands as described from existing glaciers by Mickelson (1973) and Boulton (1970).

Although these exceptions to the uniformity of the basal till are important for understanding the nature and genesis of the deposits, it should be emphasized that they are areally restricted in occurrence. As suggested in figure 7, they volumetrically comprise only a very small percentage of the basal till.

In sharp contrast with the textural uniformity of the basal till is the great variability of materials and textures within the supraglacial deposits (figures 6 and 7). We have chosen to divide the supraglacial sediments into three sub-categories: 1) supraglacial till; 2) diamicton; and 3) interbedded, sorted, meltwater deposits.

The supraglacial till subcategory is similar in *some* respects to basal till, as can be seen in figure 8. The supraglacial till is massive and very similar in texture to the basal till. It often, however, exhibits, a lower density, a more porous appearance, and a noticeably more friable consistency than the basal till: features which are easily recognized in detailed field observations. Two thin sand seams also occur within the till of this increment. While the categorization of the till in this core may at first seem problematical, tracing the deposits laterally 37 m (120 ft) into an adjacent depression (about 1.9 m lower in elevation, figure 9) shows that the supraglacial till becomes significantly different in texture from the basal till and shows an even greater density contrast.

The deposits within the supraglacial sediments referred to here as *diamicton*, are till-like, or poorly sorted (by definition) , but differ in character from the supraglacial till. They often show some of the following characteristics: 1) individual units may be very thin, and they may be stacked on one another; 2) there is often a vertical gradation in matrix texture; 3) they often exhibit a vertical change in coarse (pebble) particle content, instead of the apparently uniform distribution of coarse fragments in the till; 4) the combination of 2) and 3) sometimes results in a grossly graded texture from coarse at the bottom to fine at the top; 5) there is often crude layering of diamicton beds (with no sorted material); 6) sometimes there is evidence of deformation of these beds; and 7) the contacts between the diamictons range from sharp to diffuse while in contrast the contact between diamictons and either till or sorted sediments (e.g. - fluvial sands) are usually sharp. The diamictons are very complex sedimentary units, and often difficult to describe. Their gross characteristics, however, closely resemble supraglacial sediment flows described by Lawson (1979). Figure 11 illustrates what one diamicton type looks like in the field on the Des Moines Lobe. This photograph of a "till-flow" shows graded bedding exhibited by the decrease upwards in pebble content. This type of flow seems analogous to the Type II or III sediment flows described by Lawson (1979), from the Matanuska Glacier in Alaska.

These examples hopefully point out that the supraglacial tills and diamictons exhibit a great deal of lateral and vertical variability. These till-like sediments, the "ablation" till of some authors, may not only be coarser-textured than the basal till, but they may also be the same texture, or often more fine-textured (figure 7). It should be apparent from figure 7 that the data for the supraglacial till tends to cluster

Figure 11. "Graded-bedding" in a till flow. Base of flow marked by shovel, top of flow near top of photo. Note decrease in pebble content upward in unit.

around the values exhibited by the basal till, the mean texture being just slightly siltier than the basal till; note, however, the standard deviations are 4 to 5 times greater.

The meltwater deposits within the supraglacial sediments ("s," figure 7) may be any texture depending on the energy of the system (i.e. - a pond vs. a fluvial channel on the ice surface). These deposits range from fluvially deposited silts, sands, and gravels, to lacustrine silts, to organic sediments from bogs or ponds. They may occur in small, easily recognized forms (channel sections, etc.) or may be deformed and contorted into a melange with the till-like deposits dependent upon how much reworking they have undergone in the supraglacial environment.

The preceeding discussion has principally been concerned with the till-dominated portion of the supraglacial deposits. Obviously, in the proper setting the meltwater deposits may volumetrically dominate these deposits. For example, glaciofluvial sands and gravels may predominate in kame-like areas, and thick, fine-textured lacustrine sediments may be present in former ice-walled lake plains.

As a final note, although it may seem self-evident, the supraglacial deposits (where present) are always superposed on the basal till. Except in the few cases where the supraglacial deposits constitute the entire thickness of the Des Moines Lobe deposits, in which case they rest on the underlying substrate and not on the basal till.

Consistency, Density, and Consolidation Characteristics

The geotechnical properties of till-like deposits are of importance for applied work. In addition geotechnical properties can assist in the genetic differentiation of till-like deposits. The properties of consistency, consolidation, and density which we routinely use for geologic interpretation are fundamental properties which influence the shear strength, bearing capacity, settlement characteristics, and primary permeability of the deposits, properties which *must* be known by the engineer for design work.

Consistency is a qualitative property which can be evaluated in the field. Consolidation and density characteristics are quantitative properties which can be measured using various types of instrumentation. These three properties are related to one another, as will be shown in the following sections, and provide a useful basis for genetically differentiating the till deposits.

Consistency, the term used by geotechnical engineers, and *consistence*, the term used by pedologists, are two nearly equivalent terms used to describe the adhesion or the resistance of a material to deformation or rupture. Consistency is related in large part to the density and shear strength. Consistency (or consistence) is a qualitative field characteristic. The terms for consistency, loose, friable, firm, etc., used here are based on procedures used by pedologists and outlined in the publications of the Soil Survey Staff, U.S. Department of Agriculture (1951, 1975). There are marked differences in the consistency between the diamictons and till-like supraglacial sediments and the basal tills. The supraglacial sediments tend to be loose or friable, while the basal till is, in sharp contrast, firm or even hard.

Density relates to consolidation (to be discussed later in this section) in that as a deposit is compacted or consolidated it becomes more dense. From a theoretical standpoint, one would expect that basal tills could become recognizably more dense than supraglacially-deposited tills or diamictons because they are deposited beneath an ice load rather than being melted out onto the ice surface. In comparing density data, however, one must compare samples of similar texture, because texture limits how dense a given particle assemblage can be consolidated (i.e. - one cannot compare a matrix-dominated till with a gravelly deposit).

Figure 12 summarizes the bulk density data for till-like sediments from the field trip area. The supraglacial deposits range in density from 1.44 to 1.85 g/cc with a mean value of 1.62 g/cc. This data is multimodal, highly variable, and ranges much lower in value than the basal till (figure 12). As a matter of perspective, the lower range of densities for the supraglacial sediments is comparable to values for Wisconsinan loess in parts of Iowa (Lutenegger, 1979; Hallberg, et al., 1980). The loess is eolian in origin and is generally "normally consolidated" and in some areas is even underconsolidated.

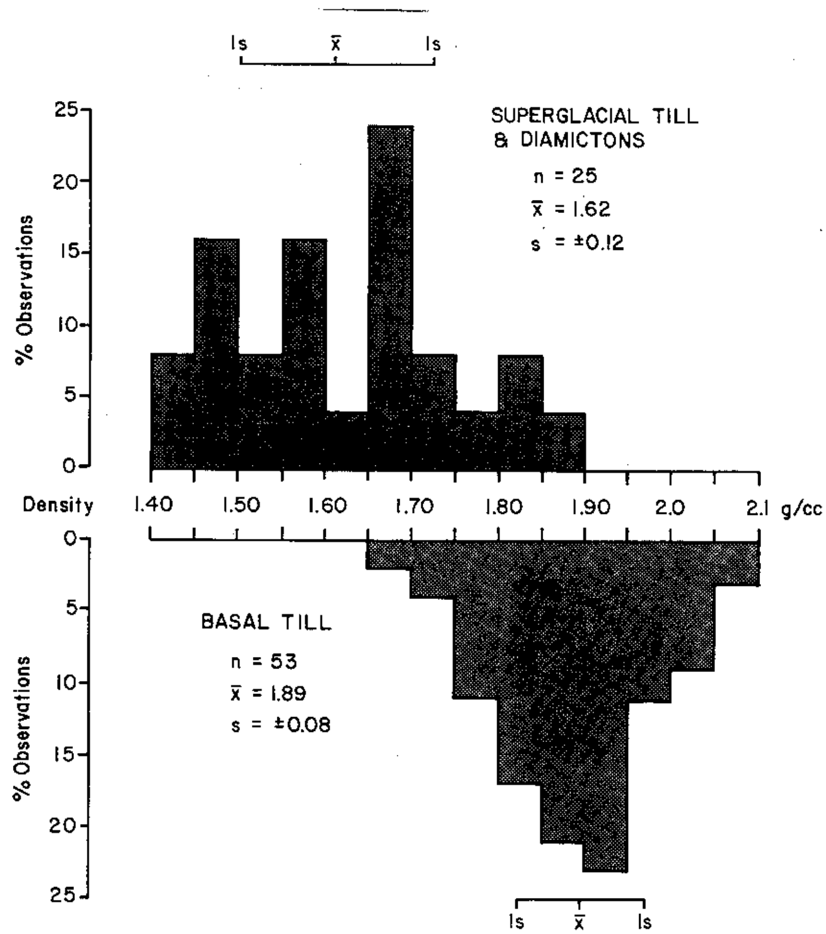


Figure 12. Summary of bulk density data for materials in the field trip area.

In contrast, the basal till ranges from 1.69 to 2.09 g/cc with a mean value of 1.89 g/cc. The bulk density of the basal till tends to be considerably higher than that of the supraglacial deposits and, as with the textural data, tends to be more uniform. It has a smaller standard deviation, a smaller range of values, and essentially a "normal distribution." For comparison, the density data for the basal till of the Des Moines Lobe (figure 12) are essentially identical to data for similar textured Illinoian and Pre-Illinoian basal tills in Iowa which may have been overridden in some cases by younger continental ice sheets at least 2 or 3 times (Hallberg, et al., 1980). Thus, the density data shows good agreement with theoretical expectations, and it correlates well with field observations on consistency.

Density contrasts (or related void-ratio data), such as this, have been used to discriminate basal till from other diamictons (Easterbrook, 1964; Dreimanis, 1976; McGown and Derbyshire, 1977; Kemmis, Hallberg, and Lutenegger, 1979; Moss, Zarth, and Matsch, 1979). The density data can be used in a comparative sense in materials of similar texture because the natural bulk density is a relative measure of the consolidation history of the deposit.

In figure 12 there is an overlap in densities between what we have interpreted as basal till and what we have interpreted as diamicton and supraglacial till. This overlap may be explained by understanding consolidation and consolidation theory.

Consolidation is the term used by geotechnical engineers for the reduction in volume, or strain, a soil mass undergoes when subjected to "compaction" or a compressive stress. Consolidation properties of a soil are derived from one-dimensional consolidation tests, a standard practice in geotechnical engineering (see Terzaghi, 1955 and Spangler and Handy, 1973 for a discussion). The preconsolidation pressure (i.e., the theoretically highest pressure to which the sample was subjected during its stress history) can be estimated theoretically from the consolidation test results by methods outlined by Casagrande (1936), Schmertmann (1955) or Janbu (1967). If the sample is "overconsolidated," the preconsolidation pressure will be greater than the stress of the present overburden on the sample. Preconsolidation can occur if sediments are subjected to an overburden pressure or stress and are allowed to drain; this stress causes the sediments to "compact" or consolidate to a higher density (within certain limiting values). When the stress is removed, the intergranular structure of the sediment may "rebound" somewhat, but in general, the structure will retain much of the effects of this *pre*consolidation (see Terzaghi, 1955 for further discussion). Note that for consolidation to occur, drainage must take place when the stress is applied; if not, consolidation cannot occur. Many environmental scenarios can be envisaged where drainage of tills beneath thick ice loads could not occur. For comparative purposes a means of standardizing consolidation test data is necessary. Geotechnical engineers standardize preconsolidation estimates by using the "overconsolidation ratio" (OCR), which is the ratio of the experimentally-derived preconsolidation pressure to the present overburden pressure on the sample (i.e. - the stress produced by the saturated weight of the sediments above the sampled horizon).

Figure 13 is a plot of the overconsolidation ratio (OCR) versus the initial bulk density (and initial void ratio) for 121 samples of till from Iowa. The calculated preconsolidation pressures for the samples range from 0.57 to 36.3 tsf (55-3,400 kPa).

The data in figure 13 are from several sources including the author's work, various engineering consulting firms, geotechnical test reports, etc. The data are not only from till of the Des Moines Lobe but also from Pre-Illinoian tills from central and eastern Iowa. All of these tills are matrix dominated (less than 8% greater than 2 mm particles), and loam to light clay loam texture.

There are many variables and vagueries in consolidation testing, and in results reported in the literature. These topics are beyond the scope of this discussion and will be presented in a subsequent paper. A few comments are appropriate. To obtain meaningful results for tills from the one-dimensional consolidation test, the maximum applied stress must be carried out to high pressures. For the data presented here, the samples were subjected to maximum applied stresses of at least 32 tsf (3,000 kPa) and most samples were run to a stress of 64 tsf (6,100 kPa) or higher.

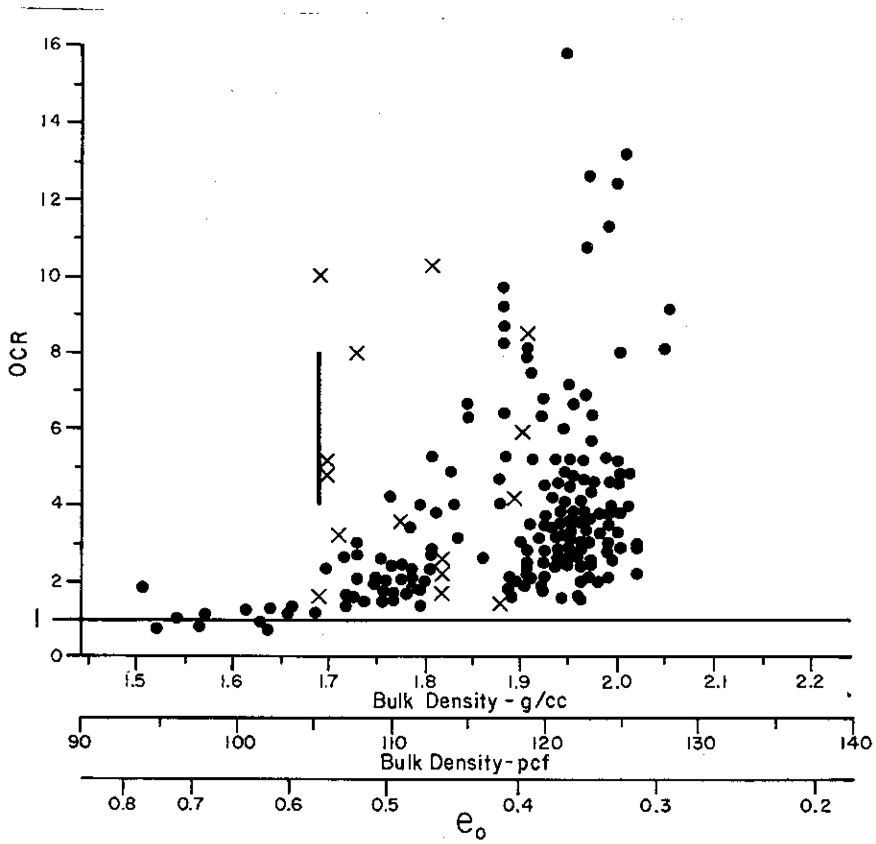


Figure 13. Plot of overconsolidation ratio vs. initial bulk density and void ratio for loam textured tills in Iowa.

The method of calculation of the preconsolidation stress also affect the results. Most of the data in figure 13 were calculated using the methods of Schmertmann (1955) or Janbu (1967). Most of the data are from samples interpreted as basal till; ten samples are supraglacial tills (7 of which fall below 1.7 g/cc density).

The data in figure 13 show quite a bit of scatter, but there are important trends: samples with an initial bulk density less than 1.68 g/cc tend to be "normally consolidated" (OCR ≃ 1); for values above 1.80 g/cc, the tills tend to be moderately to heavily overconsolidated. Comparing these trends to the density data for till-like samples from the field trip area (figure 12) indicates that the samples in the low range of densities for the basal till (compared with figure 13) were normally consolidated to lightly overconsolidated. The bulk of the basal till densities are high enough to suggest that they are moderately to heavily overconsolidated. If densities for the supraglacial tills and diamictons (figure 12) are compared to figure 12, they would indicate that the samples are normally consolidated to lightly overconsolidated.

Most previous investigators (MacDonald and Sauer, 1970; Kazi and Knill, 1973; Radhakrishna and Klym, 1974; and Marcussen, 1975) have stressed that basal tills tend to be heavily overconsolidated. Harrison (1958) went so far as using the preconsolidation pressures to calculate the thickness of the former glacial ice. While there may be errors in some of the assumptions used (see Boulton and Paul, 1976, p. 174), there does seem to be overall agreement that the very high values of preconsolidation found (up to 45 tsf; OCR up to 25) are related to glacial loading of basal till.

Recent investigations (Mickelson, et al., 1979; Dreimanis, 1976) report that some basal tills may be normally consolidated or even soft. There are two major reasons why basal tills or portions of basal tills may not be heavily overconsolidated. First, the tills may be remolded (deformed) during or after deposition which would cause a looser, less dense structure. Secondly, Boulton and Paul (1976) point out that basal tills need not be heavily overconsolidated because subglacial drainage (or porewater dissipation) may be inhibited. We suggest that the lower density values for the basal tills in the field trip area may have resulted from either post-depositional deformation, rebound or local conditions which did not permit drainage while the till was overlain by a thick ice load. Some low values are likely the result of testing problems as well.

Boulton (1975, 1976) suggests that secondary effects, such as desiccation, may produce densities and preconsolidation values in flow tills similar to lodgement tills. The data presented in Boulton and Paul (1976) show that densities (their data is shown as void ratios instead of as density) in dried out flow tills are similar to the remolded surface horizons of lodgement till, but are not nearly as dense as the bulk of the lodgement till at depth. Their observations would easily explain the overlap in density values between the supraglacial till and diamictons and the basal till in the study area (figure 12).

In summary, although there are indeed many variations possible for density and consolidation data, the general conclusions (see Boulton, 1975; Boulton and Paul, 1976; Dreimanis, 1976; McGown and Derbyshire, 1977; Mickelson and others, 1979) are that basal tills tend to be more dense and overconsolidated. Our data are consistent with that expected theoretically and with data on tills deposited from existing glaciers. The basal tills tend to be firm to very hard in consistency, high in density, and overconsolidated (figures 12 and 13). These properties, when combined with data on texture (figure 7) and sedimentary structures, support the interpretation of a subglacial origin for these deposits. The deposits we have interpreted as being supraglacial in origin differ in character from the basal tills with regard to consistency, density, and consolidation data, as well as texture and sedimentary structures. The multimodal nature of the data for the supraglacial till and diamictons arise because of the complexity of the supraglacial environment. Some of the lower density deposits likely were deposited as highly fluid mud (till) flows, or even as supraglacial melt-out till which had a high initial ice content and thin overburden cap. The higher density values for the supraglacial till or diamictons may either result from subaerial desiccation or may be compact supraglacial melt-out till relatively unmodified by secondary effects.

Sedimentary Structures

Sedimentary structures, observed principally in exposures, provide additional criteria for the genetic interpretation of the glacial deposits on the Des Moines Lobe. Some of these features have already been introduced, such as the block inclusions in the basal till, the contact relations between thin, dense basal till units, and the porous appearance, graded bedding, and contact relationships in the supraglacial sediments.

Several kinds of features have been observed in the lower-most portion of or below the basal till that are indicative of subglacial deposition. Striated pavement can sometimes be observed beneath the basal till where the till rests on bedrock. Analogous features occur where the basal till overlies older Pleistocene deposits, including such features as ribs, wedges, slickensides, and undulations at the contact as described by Ehlers and Stephan (1979). Another feature which seems related to the block inclusions are smudges, described by Kruger (1979). Smudges are thin (0.1-5 cm), elongate (0.2-1 m) inclusions of plastic substrate material in the basal till. The long axis of the smudges generally parallel the direction of glacial flow (Kruger, 1979). They are often found with large, irregular block inclusions of the same material. They likely are block inclusions which have been sheared or smeared into these thin elongate masses (see figure 14 for an example).

Other structures infrequently observed in the basal tills include sheared, overturned folds at the top of the immediately underlying substrate and streamlined bedforms caused by basal sliding and smoothing (Moran, et al., 1980). Both of the features have also been documented in older basal tills in Iowa (Hallberg, 1980). Frequently the basal till exhibits prominent vertical joints, and is relatively massive between the joints. The supraglacial deposits, in contrast, may also exhibit vertical joints where till-like materials predominate, but the joints are not as strongly expressed as in the dense basal till. Sometimes the basal till will also exhibit the strong, sub-horizontal platy structure or fissility generally attributed to basal tills (see Marcussen, 1975; Shaw, 1977; Boulton, 1970, 1976; Hallberg, 1980). The supraglacial tills will sometimes show a similar structure (Boulton and Paul, 1976), but in our experience it is expressed more as a parting than as the strong platiness found in the basal till.

The supraglacial deposits also exhibit unique structures. These deposits often show a variety of features resulting from reworking and flow of the materials such as gentle plastic folds, apparent slump structures, stacking of many thin individual diamictons with sharp or diffuse contacts, deformation of overlying beds around the larger pebbles, thin rill-fillings of sorted sediments, etc. The supraglacial deposits also exhibit structures which likely resulted from collapse over melting ice including small, high-angle faults, particularly in glaciofluvial sediments, or other more gentle deformation structures. Figure 15 shows a deformed meltwater channel filled with stratified sand and gravel at Stop 2. This channel probably originated as an ice-walled channel which was later deformed as the ice wall melted out. It was subsequently covered by supraglacial till deposits. In some exposures the deformation is severe

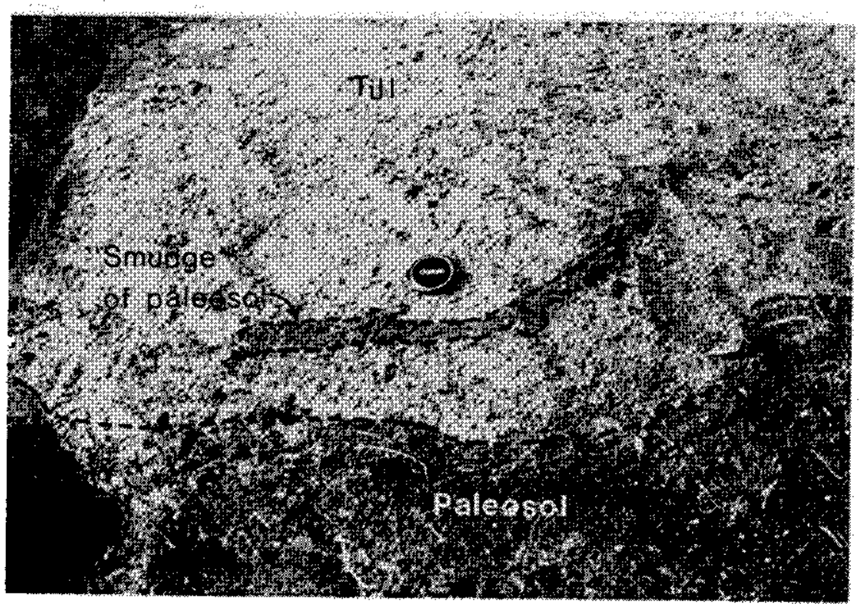


Figure 14. "Smudge" of paleosol incorporated in overlying basal till.

enough that it creates a melange of contorted, interbedded diamictons and meltwater deposits. This melange probably results because the supraglacial environment is such a dynamic one; the deposits may be subjected to several periods of flow, reworking, and collapse before all of the underlying ice melts out.

Till Sedimentation on the Des Moines Lobe: Epilogue

The previous sections have indicated that the occurrence of specific glacial processes can be inferred from various features in the till at individual locations. For example, features are present in the basal till which infer classic lodgement, basal shear, basal sliding, and deposition by regelation melt-out and by basal melt-out. It may be very difficult, if not impossible, however, to identify which of these processes occurred for the entire sequence of basal till in a single core or outcrop. Likewise, although it is possible sometimes to identify in outcrop individual flows, meltwater channel deposits, etc. in a sequence of supraglacial sediments, it is not possible to reconstruct all of the processes and events which took place in the build-up of the supraglacial deposits. Even so, the criteria outlined in the previous sections allow us to differentiate the deposits into the two generic categories of basal till and supraglacial sediments. Thus, what we are faced with is the need to change the scale of our classifications. On the smallest scale we can identify with reasonable certainty the processes responsible for the deposition of certain sediments in the sequence. Applying the criteria defined in the previous sections allows us to differentiate the rest of the deposits into the broader categories of basal till and supraglacial sediments.

In the previous sections we have identified the occurrence of many different glacial processes. At any one locale, a suite of these processes

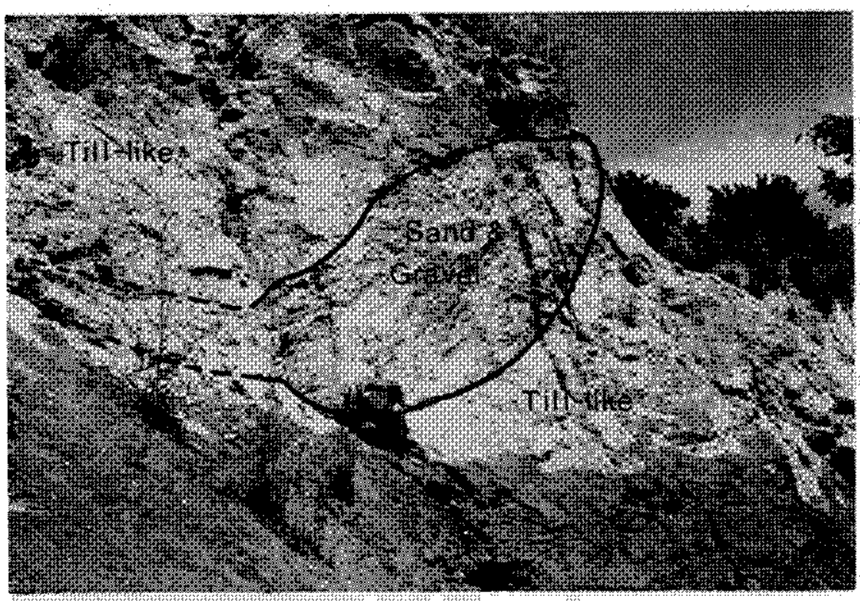


Figure 15. Collapsed meltwater channel within supraglacial sediments at Dows Quarry Section, Stop 2.

may have occurred concurrently or successively. For example, the basal till deposits may have been built-up or altered by the simultaneous occurrence across the bed of classic lodgement, basal shear, basal sliding, and deposition by both regelation melt-out and basal melt-out. There also were probably time-transgressive changes in processes and ice dynamics taking place during advance and retreat of the Des Moines Lobe ice. The transition from basal tills to supraglacial sediments in certain landform types (figure 6) certainly indicates time-transgressive changes in sedimentation. The sequence of supraglacial tills, diamictons and meltwater sediments in the supraglacial deposits also indicates changing processes through time.

We will see later in the field trip that the refined differentiation of glacial deposits in the field trip area permits us a much better understanding of how different glacial landforms were built-up. In addition, a three dimensional view of the different glacial sediment types can be gained by analyzing both the distribution of the different landform types and the configuration of the sub-Des Moines Lobe surface. This can in turn help us understand areal variation in glacial processes and ice dynamics. We will see that there were both temporal and spatial variations in glacial sedimentation. Although temporal and spatial variations have been reported for other areas of the Laurentide ice sheet (Whittecar and Mickelson, 1979; Moran, et. al., 1980), the variations on the Des Moines Lobe in Iowa were different than those occurring at these nearby areas.

Rock Stratigraphy of the Glacial Deposits of the Des Moines Lobe in Iowa

In Iowa there has been no formal rock-stratigraphic classification for the sediments of the Des Moines Lobe. "Wisconsin," "Mankato," or "Cary" have been used as time-rock prefixes for "till" or "drift." In Minnesota, Matsch (1972) has referred to the till of the Des Moines Lobe as the New Ulm Till.

To deal with the level of detail in our current studies of the Des Moines Lobe deposits, the Iowa Geological Survey is evolving a formal rock stratigraphic framework. Details of this rock-stratigraphic classification will not be presented here, only a brief outline of some tentative proposals. We welcome your comments and critique.

The various drift deposits of the Des Moines Lobe in Iowa are tentatively classified rock-stratigraphically as the Dows Formation. The principal reference section for the Dows Formation is the Dows Quarry Section, Stop 2 on this field trip. The Dows Formation is tentatively subdivided into four members. The reference sections for two of these members will be viewed at Stops 1 and 2 on the field trip.

The Dows Formation is well-defined stratigraphically. It consists of the surficial glacial deposits in north-central Iowa and the youngest Wisconsinan ("Cary") glacial deposits in the state. In the outer, older portions of the Des Moines Lobe, the deposits date ca. 14,000 RCYBP, while the younger, northernmost areas in Iowa date ca. 12,300 RCYBP (see Table 1 and the discussion in the Introduction).

The Dows Formation overlies a variety of stratigraphically older deposits: 1) Wisconsinan loess; 2) older Wisconsinan (Woodfordian) tills (the "Tazewell" till in Iowa); 3) various paleosols; 4) various Wisconsinan and Pre-Wisconsinan sediments; 5) various Pre-Illinoian age tills; and 6) Cretaceous and Paleozoic age bedrock. The formation may be bounded at the top by a stone line and overlain by Wisconsinan and Holocene colluvium and alluvium.

The Dows Formation has distinctive physical properties of texture (figure 7) and mineralogy (Table 4). Three of the properties, shale clast abundance and composition, clay mineralogy, and carbonate mineralogy, distinguish the Dows Formation from other Quaternary rock-stratigraphic units in Iowa.

The mineralogy of the Dows Formation is unique and related to the provenance of the deposits. As the Des Moines Lobe ice traversed southern Canada, the Dakotas and entered Minnesota, it passed over large areas of Upper Cretaceous shales and claystones. A conspicuous element of the deposits of the Des Moines Lobe, as noted by Wright (1972) and Matsch (1972), is the abundance of Cretaceous (Pierre-type) shale fragments in the cobble, pebble, and sand-size fractions. This is an obvious field characteristic of the till and distinguishes it from older, underlying Pre-Illinoian age tills. The shale fragments vary from light-gray, to pale-olive, to olive-gray in color. The clay mineral composition of 15 shale clasts taken from the till from sections all around the Des Moines Lobe averages: expandables - 67 ± 3%; illite - 27 ± 3%; kaolinite (plus chlorite)- 6 ± 2%. These values are in marked contrast to the generally illitic nature of Paleozoic shales in the region (see Hallberg, 1980, p. 133). The mineralogy of the Cretaceous shale also seems to have strongly influenced the clay mineralogy of the Dows Formation. The mineralogy of the Dows Formation (Table 4) is nearly identical to the Cretaceous shale clasts.

The clay mineralogy and shale clast lithology of the Dows Formation distinguishes it from the Pre-Illinoian age tills which underlie the Des Moines Lobe and form the surficial tills outside of the Des Moines Lobe in the field trip area. The tills of the Pre-Illinoian age Wolf Creek Formation are also high in expandable clays, but unlike the Dows Formation these older tills always exhibit higher kaolinite than illite percentages (Hallberg, 1980). Pre-Illinoian tills also have very little or no Cretaceous shale in the sand (or pebble) fraction in this region (Hallberg, 1980) or in northwest Iowa and adjacent Minnesota (Van Zant, 1974; Matsch, 1971).

Another contrast is apparent in the matrix carbonate data. The total matrix carbonate content (analyzed by the Chittick method) averages 16.2% with a relatively low (0.29) calcite/dolomite ratio (Table 4). In the total matrix, dolomite is 3.5 times higher than calcite, while in the coarse-sand fraction, limestone grains average about 4 times greater than dolostone. The Dows Formation exhibits a much higher dolomite content and a lower C/D ratio than the Pre-Illinoian tills (Hallberg, 1980), which also came from the north of Iowa. The only older till which exhibits such high dolomite (low C/D) is the Illinoian Kellerville Till in southeast Iowa, which is an eastern-derived till (Hallberg, Wollenhaupt, and Wickham, 1980; Kemmis and Hallberg, 1980).

The only till in Iowa known to be similar to the Dows Formation, is the "Tazewell till" of northwest Iowa. This till also exhibits noticeable amounts of Cretaceous shale in the sand and pebble fraction (Van Zant, 1974; Matsch, 1972). It also exhibits high percentages of expandable clays, with illite slightly higher than kaolinite, and it exhibits a high dolomite content, and low C/D ratio (Hallberg and G.A. Miller, unpublished data).

The Dows Formation is currently subdivided into four different members: the Alden Member (basal till); Morgan Member (supraglacially-deposited till, diamictons and associated meltwater deposits); Lake Mills Member (dominantly fine-grained glaciolacustrine sediments); and Pilot Knob Member (upland sand and gravel deposits, dominantly ice-contact glaciofluvial deposits). A brief description of these different members follows.

<u>Alden Member (basal till)</u>

The Alden Member is comprised predominantly of basal till. The reference section for the Alden Member is the Alden Section, Weaver Construction Quarry, Stop 1 on this field trip. The properties of the Alden Member have been described in the discussion of the basal till, and the properties of the Member are summarized in figures 7 and 12 and Table 4.

Table 4. Summary data for Late Wisconsinan ("Cary") Dows Formation.

CLAY MINERALOGY - %
n = 94

	Ex.	Ill.	K+C
Alden Member - basal till			
mean	69	19	12
s.d.	4	3	3
range	56-78	14-26	8-18
Morgan Member - superglacial till-like deposits n = 19			
mean	67	20	13
s.d.	5	4	3
range	56-74	12-28	9-18
Total n = 113			
mean	69	19	12
s.d.	4	3	3
range	56-78	12-28	8-18

SAND-FRACTION LITHOLOGIES - %

	C/D (ratio)	T.C.	Sh.	T.S.	Q.-F.	T.X.
Alden Member - basal till n = 62						
mean	3.8	27	14	42	50	58
s.d.	6.3	6	8	9	8	9
range	0.6-NoD	19-33	1-39	24-72	28-68	28-76
Morgan Member - superglacial till-like deposits n = 11						
mean	4.8	27	14	42	50	58
s.d.	5.1	4	9	7	8	7
range	0.6-NoD	21-36	4-36	35-60	30-58	40-65
Total n = 73						
mean	4.0	27	14	42	50	58
s.d.	6.1	6	8	9	8	9
range	0.6-NoD	19-36	1-39	24-72	28-68	28-76

MATRIX CARBONATES - %

	C/D	Cal.	Dol.	T.C.
Alden Member - basal till n = 38				
mean	0.29	3.5	12.3	15.8
s.d.	0.13	1.4	2.0	2.5
range	0.11-0.43	0.6-5.2	5.5-15.8	6.1-19.2
Morgan Member - superglacial till-like deposits n = 9				
mean	0.27	3.8	14.2	17.9
s.d.	0.05	0.8	1.9	2.3
range	0.15-0.33	1.9-4.4	12.4-18.5	14.7-22.8
Total n = 47				
mean	0.29	3.6	12.6	16.2
s.d.	0.12	1.3	2.1	2.6
range	0.11-0.43	0.6-5.2	5.5-18.5	6.1-22.8

KEY

Ex. - expandable clay
Ill. - illite
K+C - kaolinite plus chlorite

C/D - calcite/dolomite ratio
T.C. - total carbonate
Sh. - shale
T.S. - total sedimentary grains
Q.-F. - quartz-feldspar grains
T.X. total crystalline grains (Q.-F. plus igneous and metamorphic)
Cal. - calcite
Dol. dolomite
MATRIX CARBONATES determined using Chittick apparatus after methods of Walter and Hallberg, 1980

With the few exceptions previously discussed, the basal till is quite uniform texturally (figure 7) and mineralogically (Table 4). The till generally exhibits a light loam texture averaging about 15% clay, 37% silt, and 48% sand in the matrix. The basal till of the Alden Member is generally more dense than the till-like sediments of the Morgan Member, and has a mean bulk density of 1.89 g/cc (figure 12).

The till of the Alden Member was probably deposited by a number of subglacial processes: classic lodgement, regelation melt-out, and basal melt-out. Identifying precisely which of these processes occurred at any one site may be difficult. It is likely that more than one process occurred at any one site, and these processes may have taken place either successively or concurrently.

The till of the Alden Member is variable in thickness, of course. These thickness variations occur for a variety of reasons. Modal thicknesses, however, range from approximately 30-55 feet (10-17 m) in areas other than the ice-marginal (moraine) areas.

<u>Morgan Member (supraglacially-deposited till-like sediments and associated meltwater deposits)</u>.

The reference section for the Morgan Member is the Dows Quarry Section, Stop 2 of this field trip. The Morgan Member consists of supraglacially-deposited till-like sediments, diamictons, and associated meltwater deposits. In most areas till-like sediments are volumetrically the largest component. However, in a few locales the till-like sediments may be conspicuous, but constitute less than 50% of the sediments.

The till-like sediments of the Morgan Member tend to be variable in both morphology and properties. The till-like materials may vary from sediments which locally are massive to sediments which show evidence for some type of flow, reworking, or deformation from the collapse of underlying ice. As previously discussed, the till-like materials of the Morgan Member may be quite variable in matrix texture (figure 7). The clay mineralogy, sand fraction lithology, and matrix carbonate composition of the till-like sediments of the Morgan Member are nearly identical to those of the Alden Member - the basal till (Table 4). This indicates that the till-like sediments of both the Alden and Morgan Members have the same provenance; they differ solely in the environment and process of deposition.

The till-like sediments of the Morgan Member are interpreted to not have been deposited under a thick ice load, but by melt-out on or near the glacier surface. The density values for the till-like sediments of the Morgan Member are very variable, just like the matrix texture. The values tend to be lower than the values for the basal till (Alden Member), although there is some overlap.

Meltwater deposits are common within the Morgan Member. They may be of any texture depending on the energy of the meltwater system (channel or pond on the ice surface, etc.) and the texture of the available debris. These deposits may have been deposited in large part in ice-walled or ice-floored channels or ponds. In consequence, they sometimes show evidence of deformation or collapse. These meltwater deposits are frequently overlain by resedimented till-like deposits (flows, etc.).

The Morgan Member is very variable in thickness. In some landform areas it is absent or occurs as only a thin veneer at the surface. In other landforms, notably the lateral positions of former ice-marginal positions on the Des Moines Lobe (i.e., "moraines"), the Morgan Member may comprise all or nearly all of the Dows Formation present at the site. In still other landform categories, the Morgan Member may comprise a significant proportion of the sediments in the landform, but not the whole sequence. Figure 6 shows such a landform which is comprised of significant proportions of both Alden Member (basal till) at the base and Morgan Member (supraglacially-deposited till-like sediments and associated meltwater deposits) at the top.

Lake Mills Member (glaciolacustrine sediments).

Lake Mills Member deposits will not be seen on this field trip although they are the surficial deposits of a small portion of the western part of the map area (figure 2). The reference section for the Lake Mills Member is the Lake Mills Section, a composite roadcut and borehole located in the SE/c, SW¼ of sec. 16, T. 99N., R. 23W., Winnebago Co., Iowa. The Lake Mills Member consists of glaciolacustrine sediments deposited in either proglacial, ice-walled or ice-floored lakes. Sediments of the Lake Mills Member are surficial deposits and solely glaciolacustrine in origin; minor glaciolacustrine sediments interbedded within the Morgan Member are not classified as Lake Mills Member but are instead included in the Morgan Member.

The sediments of the Lake Mills Member are dominantly fine-grained, silty clay loam, silty clay, clay or silt loam in texture. The Lake Mills Member may also include coarser-grained beach and bar deposits which are high energy facies equivalents to the lower energy glaciolacustrine deposits. In most areas, coarse-grained sediments of the Lake Mills Member probably constitute only a small proportion of the member.

Pilot Knob Member (upland sand and gravel deposits, dominantly ice-contact glaciofluvial deposits).

Deposits of the Pilot Knob Member will not be seen on this field trip although they occur at scattered locations across the study area. The reference section for the Pilot Knob Member is Section 95 PK-1, a gravel pit in a kame-like knob located in the SW¼, SE¼ of sec. 25, T. 98N., R. 23W., Winnebago Co., Iowa, approximately 2½ miles northeast of Pilot Knob State Park.

The deposits of the Pilot Knob Member consist predominantly of coarse-grained glaciofluvial deposits, mostly sands and gravels, although till balls and/or thin beds of poorly-sorted, till-like sediments may occasionally occur. The deposits of the Pilot Knob Member are considered to be dominantly ice-contact glaciofluvial sediments, deposited in kame-like settings or in ice-walled or ice-floored channels. The deposits of the Pilot Knob Member occur as the uppermost glacial sediments at any locale where they are mapped. In contrast, glaciofluvial deposits interbedded within the till-like sediments of the Morgan Member are included with the Morgan Member and are not classified as Pilot Knob Member deposits. Outwash sands and gravels in distinct proglacial channels, and occurring as outwash terraces and valley fill will be included in another rock-stratigraphic unit, as yet unnamed.

Glacial Landforms of the Study Area -

Explanation for a New Classification

Glacial landform classifications have always been morphogenetic. Tables 5 and 6 show respectively Chamberlin's early classification (1894) and Goldthwait's recent one (1975). In all landform classifications to date, the following assumptions seemingly have been used: one particular landform type -- is comprised of one material -- is the result of one basic set of processes. As previously discussed, the upland glacial landforms of the study area have essentially been classified as moraine (end or recessional) and ground moraine in all studies to date (figure 3). This type of classification may still be appropriate in some regions (such as portions of the Woodfordian Lake Michigan Lobe). However, at the more detailed level of our present studies on the Des Moines Lobe a much more complicated picture is indicated in the types of landforms present, their genesis, and their distribution. There are three main reasons for this. First, aerial photographs depict a much greater variety of landforms than classically recognized. You can get some idea of the diversity and wide variety of landforms in the study area from the selected air photos included in this report. Secondly, recent studies of glacial sedimentation provide a more comprehensive and quantitative understanding of glacial sedimentation. In consequence, a more refined genetic interpretation can be made of the deposits of the Des Moines Lobe in Iowa, and, as a result, the genesis of many areas has been (or will be) significantly reinterpreted. And finally, when the sediments which comprise the various glacial landforms are studied in detail, a much greater complexity of landform evolution is revealed.

A 'first step' classification used for the study area is shown as the legend for figure 2. The main categories have simply been given roman numeral designations and subclasses for individual categories have been given lower case letters. In more detailed mapping, which is ongoing, further subdivisions or refinements will be made.

Glacial landforms are complex, comprised of many different elements. Landform classifications attempt to depict two basic elements: 1) the form of the landsurface of landscape; and 2) the materials which make up that landform. Our classification attempts to provide specific but *separate* information on both of these elements.

Table 5. Genetic classification of glacial landforms (after Chamberlin, 1894)

MATERIAL	LANDFORM	DEPOSITIONAL ENVIRONMENT		
		DEPOSITIONAL LOCATION	RELATIONSHIP TO FLOW	RELATIONSHIP TO MARGIN
Till dominant	I. Till Sheet (surface not bedrock controlled)	Subglacial	---	Back from margin
	II. Subglacial till aggregations			
	A. Drumlins			Back from margin
	1. Lenticular or elliptical hills (whale back forms)	Subglacial	Parallel	
	2. Elongate ridges (flutes; length >> width)	Subglacial	Parallel	
	3. Mammillary hills (length slightly > width)	Subglacial	Parallel	
	4. Till tumuli (immature drumlin nuclei)	Subglacial	Parallel	
	B. Aggregations not strictly drumlinoid in form			Back from margin
	1. Crag and tail (till in lee of bedrock crag)	Subglacial	Parallel	
	2. Pre-crag (till deposited on the stoss side of bedrock crags)	Subglacial	Parallel	
	3. Veneered hills (uniform till covering but surface bedrock controlled)	Subglacial	---	
	4. Till billows	Subglacial	Random to transverse	
	5. Irregular till hills	Subglacial	Random	
	C. Submarginal till ridges parallel to margin			
	1. Lodge moraines (a variety of terminal moraines); processes same as that of till sheet or ground moraine, but represents marginal thickening	Subglacial	Transverse	At or near margin
	2. Local transverse ridges	Subglacial	Transverse	Local accumulation only
	III. Englacial and supraglacial materials deposited at margin or let down during ice wastage			
	A. Dump moraines (a variety of terminal moraine)	Supraglacial	Transverse	At margin
	B. Englacial or supraglacial till sheets (as for subglacial till sheets but different material and origin)	Supraglacial	---	---
	C. Medial Moraines	Supraglacial		Deposition at margin
	IV. Products of mechanical action at the ice edge			
	A. Push moraines (a variety of terminal moraine); may consist of drift or non-drift materials.	Sub - or pro-glacial		At margin
	B. Lateral Moraines			

Table 5, con't.

Glaciofluvial sediments dominant	V.	Deposits of subglacial streams			
		A. Eskers	Subglacial	---	Back from margin
		B. Kames (patches of drift on or within till)	Subglacial	---	Back from margin
	VI.	Deposits of supraglacial streams			
		A. Supraglacial Eskers	Supraglacial	---	Back from margin
		B. Supraglacial Kames	Supraglacial	---	Back from margin
	VII.	Marginal Deposits			
		A. Kames (associated with terminal moraines; deposited along active ice margin)	Largely proglacial	---	At margin to proglacial
		B. Esker deltas or fans (outwash fans formed when esker reached margin)	Proglacial	---	Proglacial
		C. Overwash aprons (outwash aprons proglacial to terminal moraines)	Proglacial	---	Proglacial
		D. Pitted outwash plains	Proglacial	---	Proglacial

The form of the landform is determined largely in the field with the aid of topographic maps where necessary. Aerial photographs assist in determining the pattern of some landform types, as well as the precise boundary between different landform assemblages. Local relief seems to be relatively constant for any one landform category. To aid in the description of the landform we assign one of the following semi-quantitative relief classes:

	Local Relief	
	m	ft.
Very low	0-1.5	0-5
Low	0-3	0-10
Moderate	3-10	10-30
High	10-15	30-50
Very High	>15	>50

The materials comprising the landforms are classified rock-stratigraphically. Their classification and genesis were discussed in the previous sections. An explanation of the different categories in the map area (figure 2) follows.

Table 6. Goldthwait's (1975) classification of glacial deposits and landforms.

Dominant Materials		Conjectured Situation		Shape or Morphology
Lodgement till subglacial, basal, nonbedded, compact	*Till* till dominated, poorly sorted	*Ground moraine* under ice and off retreating edge	I	*Till plain* or rolling hills washboard moraine *minor moraines
		Streamlined sliding melting base	II	*Drumlin* grooved till crag-tail
Ablation till superglacial, loose lens, bedded, contorted		*End moraine* at standing or advancing ice edge	III	*Lobate/looped moraine* push/thrust boulder belt lateral/interlobate moraine *kame moraine
		Disintegration stagnant, decaying marginal area, buried ice masses	V	*Controlled/uncontrolled disintegration* dead ice knobs/rings disintegration ridge inverted lake
Glaciofluvial coarse cobble to silt, channeled or cross-bedded	*Wash* well sorted	*Ice contact* dipping, deformed, irregular beds in ice pit, channel, or tunnel	IV	*Esker* *crevasse filling chain (of kames)
				Kame *field/kame and kettle kame moraine moulin kame kame terrace/plain
Glaciolacustrine fines: fine sand to colloid clay, laminated		*Proglacial* at grade, uniform beds extending away from ice	V	*Outwash plain/fan* valley train kettled/pitted outwash *collapsed outwash
				Lacustrine/marine delta strand/raised beach glacial *varve*

*Other forms often attributed to stagnant ice disintegration.

Landform Categories I and II: Late Wisconsinan and Holocene outwash valley trains and recent floodplains; lake basins, existing or drained

Category I. Outwash terraces in valley trains, and recent floodplains

This category is generally self-explanatory. It sould be noted, however, that these valleys have probably undergone a complex development since their inception. The major river valleys are generally comprised of discontinuous terraces occurring at a number of different levels. These valleys have probably undergone a complex history of development during the Holocene, as documented for other parts of Iowa by Daniels and Jordan (1966), Hoyer (1980), and Thompson and Bettis (1980). Little study has been done specifically on river valleys of the Des Moines Lobe itself. A treat deal of work remains to be done on this aspect of the area.

It should be noted that along the lateral margins of the moraines of the Des Moines Lobe in Iowa, outwash was concentrated in channels which are the location of major rivers today. Classic outwash aprons, although common along the frontal margins of moraines on the Des Moines Lobe, are virtually absent along the lateral margins.

Category II. Large lake basins (and/or bogs); mostly drained or extinct

This category, too, should be self-explanatory. It should be noted that the larger basins depicted here tend to be concentrated in close proximity to the hummocky, high-relief areas which constitute the lateral ice-marginal positions, or moraines, of the Des Moines Lobe in Iowa.

Landform Categories III through IX: Late Wisconsinan Upland Glacial Landforms

Category III. Prominent ridge forms; high to moderate local relief, irregular hummocky topography

These landforms constitute the former ice-marginal, or morainal positions, in a classic sense. There are two important things to note about the landforms of this category: 1) the landform consists of high-relief hummocks and closed depressions; and 2) the landform is comprised primarily of thick supraglacial sediments (thickness commonly 10-20 m). It is uncertain at this time if basal till (Alden Member) is present everywhere beneath the supraglacial sediments in these landforms or what thicknesses the basal till may attain. The hummocky topography and thick supraglacial sediments are characteristic of the lateral portions of moraines on the Des Moines Lobe in Iowa.

The oldest, outermost moraine on the Des Moines Lobe has been mapped as the Bemis Moraine (figure 2). Detailed mapping shows, however, that the eastern lateral margin of the Des Moines Lobe is not everywhere marked by a prominent terminal ridge. Where the Des Moines Lobe terminus is marked by a prominent ridge form in the study area we have mapped it as the Bemis Moraine. The other portions of the Des Moines Lobe terminus are marked by other landforms which may slope gently to the margin. In some areas the till and/or supraglacial sediments simply pinches out along an interfluve, over the underlying Wisconsinan loess.

The Altamont Moraine in the field trip area is complexly made up of a series of ridge forms. The outermost ridge of the Altamont Moraine System is designated as Altamont I on figure 2. In most areas, the elevations in front of Altamont I are approximately the same as those behind it. In most places Altamont I is a prominent ridge form, standing 10-15 m above the surrounding landscape. The position of Altamont I on figure 2 closely follows the description given by Leverett (1932) for the course of the Altamont Moraine through the study area. Ruhe (1952a, and subsequent publications) did not recognize the Altamont I ridge as a separate moraine and included it with a host of other landforms in the Bemis Moraine (see figure 3).

Behind, or to the west of the Altamont I, is another set of ridges which we have designated as Altamont Complex or Altamont C on figure 2. This part of the Altamont Moraine System is very complicated. It consists of a series of discontinuous ridges which are sometimes poorly defined and difficult to trace in the field. The westernmost edge (or "backside") of the Altamont Complex, near Big Wall Lake in the northwestern portion of the study area, is denoted with a dashed line. In this area, the Altamont consists of a broad, hummocky slope leading up westward onto a plateau-like low-relief area. That is, this part of the Altamont Moraine System is not a ridgeform, as are other parts of the Altamont Complex, but a broad hummocky slope or scarp, which faces in the former down-glacier direction. The Altamont Complex is not continuous to the south. It's southern boundary plunges or slopes into a flatter, more gently rolling area designated as part of Category IVd. Probably the easiest way to visualize this southern boundary of the Altamont Complex is to think of it as looking like a gently plunging anticlinal ridge. The Altamont Complex is included as part of the Altamont Moraine System because the adjoining landforms to the south, although not ridgeforms, continue around and merge with ridgeforms outside of the map area which join the Altamont I Moraine System. Also, the name Altamont Moraine has been applied to the landforms here designated as Altamont Complex or Altamont C for 40 years (see figure 3).

On this field trip we will examine sediments comprising this landform category at: Stop 2 in the Altamont I ridge at Dows Quarry; and Stop 4 in the Bemis Moraine at the terminal ridge near State Center, Iowa.

<u>Category IVa. Irregular hummocky topography inset on broader topographic swells and swales; moderate local relief</u>

This landform category points out some of the great complexity to landforms on the Des Moines Lobe. In this category there is complexity to the landform itself. It consists of moderate relief hummocks (10-30 ft or 3-10 m local relief) set on a broader scale system of gentle swells and swales. The sediment sequence comprising this landform will be viewed at Stop 5. Here again, complexity can be seen in the types of sediments comprising the landform (figure 6). This landform is comprised of moderately thick supraglacial sediments of the Morgan Member (3-6 m in thickness is a common range) overlying uniform basal till of the Alden Member. This sediment sequence indicates that there has been a time-transgressive change in glacial sedimentation during the development of this landform type. Initial sedimentation was subglacial , with the deposition of basal till, followed by supraglacial sedimentation leaving a moderately thick cover of Morgan Member deposits. This landform category has no correlative in classic glacial landform classifications because the classic classifications do not recognize that landforms may evolve with time-transgressive changes in processes.

<u>Category IVb. Irregular hummocky topography with common circular depressions, inset upon broader topographic swells and swales; moderate local relief.</u>

This landform category is similar to the preceding category (IVa) both in the nature of the sediment sequence and in the fact that the sediment sequence indicates that there was a time-transgressive change from subglacial to supraglacial sedimentation during the development of the landform. This category, IVb, differs from IVa solely in the surficial expression of the landform. In category IVb, most of the depressions between the hummocks are circular or rounded in plan view, while in category IVa the depressions generally show no definite pattern. The significance of this is unknown at the present time.

Category IVc. Irregular hummocky topography with common circular depressions, inset upon broader topographic swells and swales; moderate to high local relief

This category is similar to category IVa and b in materials, moderately thick supraglacial sediments of the Morgan Member over basal till of the Alden Member, as well as in the pattern of the landform. It differs from the preceding category only in local relief, having noticeably greater local relief. Local relief in this category may be greater than 30 feet (10 m) over extensive areas. The added relief is likely related in part to greater stream dissection (because of the proximity of major streams) and/or possibly to thicker increments of supraglacial deposits. This landform association generally occurs at or near an ice-marginal, high-relief ridge form of Category III where such a ridge form (moraine) occurs at the terminus.

Category IVd. Irregular hummocky topography with common circular ridges and depressions, inset on broader topographic swells and swales; moderate to high local relief

The sediments comprising this landform category are the same as those for the other landforms in category IV: moderately thick supraglacial sediments of the Morgan Member overlying basal till sediments of the Alden Member. Category IVd differs from the other classes of category IV solely in landform. In this category, both the ridges and depressions tend to occur in circular or rounded forms or patterns.

Category V. Small curvilinear ridge forms, generally 1-2 m in relief, inset on broader topographic swells and swales; moderate to low local relief

These landforms have been discussed previously in the literature and are the "minor moraines" and "swell and swale" topography of Gwynne (1942a and b; 1951). "Minor moraine" *areas* in Iowa are comprised of more than one type of landform feature. These areas are dominated by low-relief ridge forms (the "minor moraines" proper) inset on broader topographic swells and swales. The low-relief ridges or "minor moraines" are subparallel to one another and form broadly arcuate patterns, concave up-glacier; that is, the "minor moraine" trends are *transverse* to the glacier flow direction and sub-parallel to the glacier margin. Other landforms also occur in scattered locations 1) within the "minor moraine" belts; 2) at the lateral junctions or "scallops" between "minor moraine" belts; and 3) near the margins of the "minor moraine" belts with adjacent landform categories. These other features probably differ in origin from the low-relief ridges or "minor moraines" proper as we will show later. The origin of "minor moraines" has long been debated, and their origin has often been considered the same as other parallel ridgeforms oriented transverse to glacier flow, some of which may differ strikingly in morphology and/or in materials. In the following discussion we will detail: 1) the nature of the "minor moraine" or low-relief ridge landscape; 2) the materials comprising the minor moraine landscape; 3) the other features occurring within the "minor moraine" landscape; 4) published theories of the origin of "minor moraines"; and 5) our interpretations of the origin of the "minor moraines" and their relationships to the other features.

The "minor moraines" are very subtle low-relief features, some of the smallest of the sub-parallel, transverse to flow, glacial ridge forms (see Elson, 1968). These low-relief ridges are in turn set on broader, irregular topographic undulations which in the field trip area appear to have a "wavelength" of approximately 3-6 km (2-4 miles). The height of the "minor moraines" is often so low that they can scarcely be seen from the ground (particularly when the corn is up). Their present relief, from ridge crest to intervening depression is generally 1-2 m. Since the "minor moraine" areas have been subject to subaerial, post-glacial (late Wisconsinan and Holocene) modification, the initial relief can be estimated by "removing" the eroded surficial sediments from the depressions and "replacing" it on the ridge (see Walker, 1966 for example). Even by these estimates the local relief becomes only 1.5 to 4.5 m (5-15 feet) total. The spacing between individual ridges range from about 30-180 m (100-600 feet) averaging about 105 m (350 feet; Foster, 1969). This results in a frequency of about 9 ridges/km (15 ridges/mile). The ridges are so subtle that the width of an individual ridge is difficult to measure. It appears, however, that in general the widths of the ridges range from 20-90 m (65-300 feet). These ridgeforms which comprise the "minor moraine" belts are actually discontinuous and of varying heights and widths. However, they show up prominently on air photographs (such as shown on the cover of this guidebook) because the pattern of light-toned "dapples" in composite fashion give the impression of longer, curvilinear ridge trends. These curvilinear trends give the impression from air photographs to range in length from 0.2-2.4 km (0.25-1.5 miles), but generally are in the range of 0.4-1.0 km (0.25-0.6 miles). The "minor moraines" tend to occur as belts or clusters of these curvilinear "ridges" trends oriented transverse to the glacier flow direction. Where these adjacent, broadly curved belts join, they form a "scalloped" pattern; i.e., the ridges in opposing clusters curve in toward each other and up-glacier (figure 2). Foster (1969) termed these junctions "scalloped belts." Note that on figure 2, the scale is such that neither the individual ridge segments nor separate curvilinear ridge trends could be mapped. Instead, only the *trend* of the "minor moraine" belts could be shown.

"Minor moraine" areas in Iowa comprise a large part of the field trip area (figure 2), and large parts of the southern and central portions of the Des Moines Lobe in general. In all these settings the "minor moraine" areas occur as a plain lower in elevation thatn the surrounding upland glacial landforms. The change in elevation from the "minor moraine" areas up to the surrounding glacial landforms generally varies from 3-15 m (10-50 feet).

On the field trip outcrops and cores in the "minor moraine" areas will be viewed at Stops 1, 6, 7, and 8. Data will also be presented in the road log for the Gateway Section and Clark Site which are also located in "minor moraine" areas. The mapping of "minor moraines" has not been consistently done. Prior to this study, minor moraines in Iowa had been included in the mapping of broad end morainal areas (Ruhe, 1950, 1952a, 1969). Elsewhere, because of their low relief, similar features have been mapped as ground moraine (Clayton and Freers, 1967, p. 2).

We have found that the low-relief ridges or "minor moraines" are composed of thick, uniform, relatively dense basal till (Alden Member) overlain by relatively thin slopewash and colluvial sediments (figures 16 and 17). Thicknesses of basal till in the minor moraine areas commonly range from 10-15 m (30-50 feet) where unaffected by stream erosion. As discussed, the basal till is uniform with only minor amounts of interbedded meltwater deposits. For example, Foster (1969) reported that in drilling a total of 263 m (864 feet) in numerous "minor moraines" less than 2% of the footage consisted of stratified deposits. The basal till in the "minor moraines" also tends to be quite dense. Densities as high as 1.90 g/cc continue to within about 1 m from the land surface (immediately below the B-horizon of the modern soil) at many locations. However, some of the lowest densities for the basal till have been recorded at shallow depths within the "minor moraines" (a density of 1.69 g/cc is shown for the basal till at a depth of 1.5 m in the North Dakota Section, figure 17). Pebble fabric data for the basal till in the "minor moraines" of the field trip area have been reported by Foster and Palmquist (1969). They found from measurements at 9 sites that the principal fabric azimuth: 1) approximates the orientation of nearby glacial striae; 2) is approximately normal to the ridge crests (i.e., parallel to the presumed flow direction); and 3) exhibits a consistent up-glacier dip. They also noted a minor secondary orientation in some samples which was parallel to the ridge orientation (transverse to flow). They concluded that this fabric data was indicative of "lodgement" till and consistent with a subglacial origin for the "minor moraines."

The Gateway Section (data shown in the Road Log, figure 23) is the only section investigated in the low-relief ridges or "minor moraines" to date which has any supraglacial sediments. At this section about 1 m of interbedded fluvial sand and gravel, friable sandy till, and fluvial silts occurred in a shallow trough in the very crest of the ridge.

While the low-relief ridges or "minor moraines" are the predominant landform in this category, they are not the only landform present in these areas. Other landforms occur: 1) at scattered locations within the minor moraine belts; 2) as linear ridges parallel to flow in the "scalloped" junctions between "minor moraine" belts or as forms draped and superposed on the "minor moraine" ridges; and 3) as numerous hummocks which occur where there is a transition area between the "minor moraine" belts and adjacent landforms of Category IV (a-d). These landforms constitute only a small proportion of the "minor moraine" areas, and only one such landform is large enough to be mapped at the scale of figure 2. They all occur at higher elevations than the surrounding low-relief ridges or "minor moraines." We will see these other landforms along the field trip route but none constitutes one of the stops. Where these landforms have been investigated they appear to have a sediment sequence similar to that shown in figure 6: moderately thick supraglacial sediments (interbedded tills, diamictons, and meltwater deposits) of the Morgan Member overlying basal till of the Alden Member. It appears that

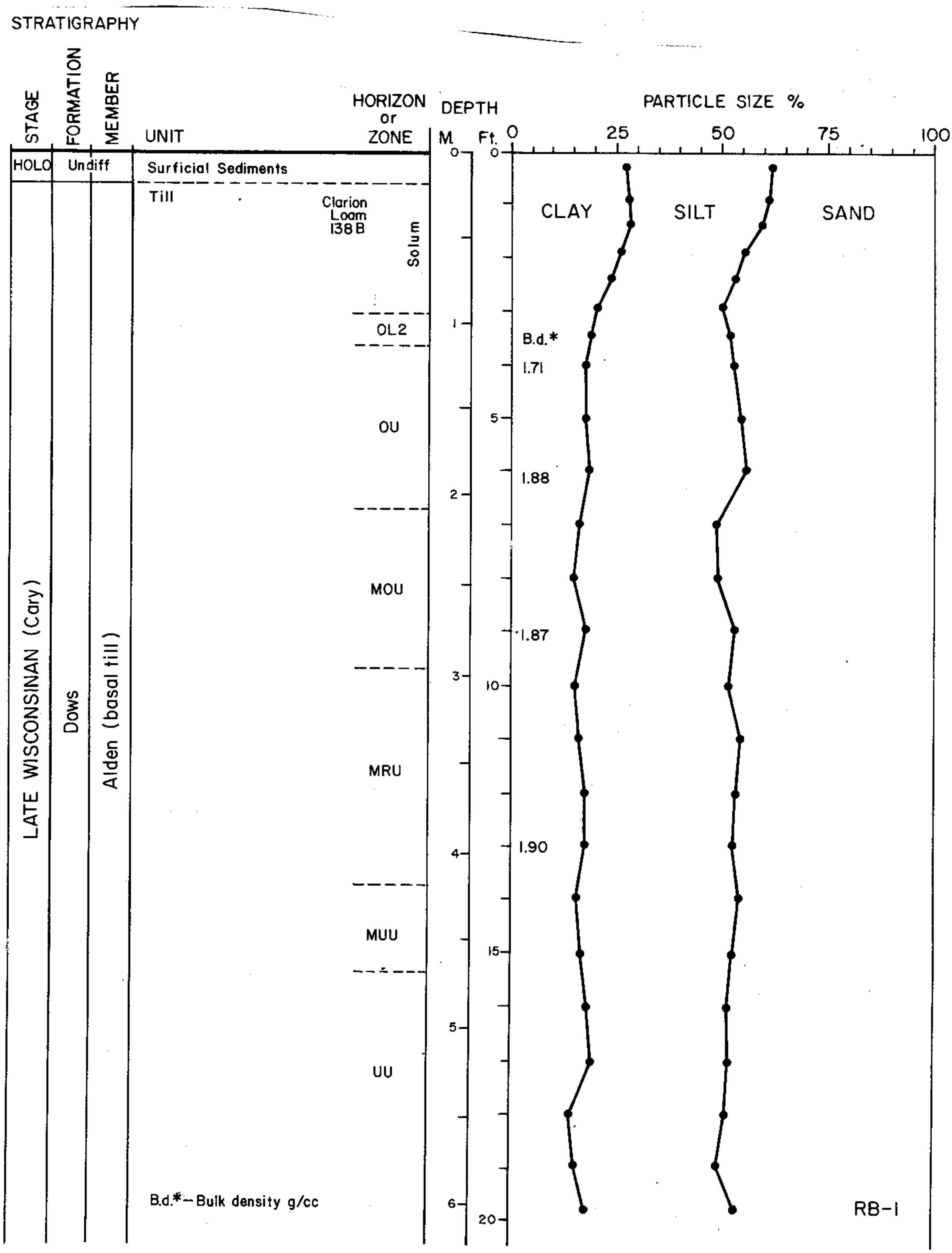


Figure 16. Particle-size data and stratigraphy core-hole RB-1; in crest of minor moraine.

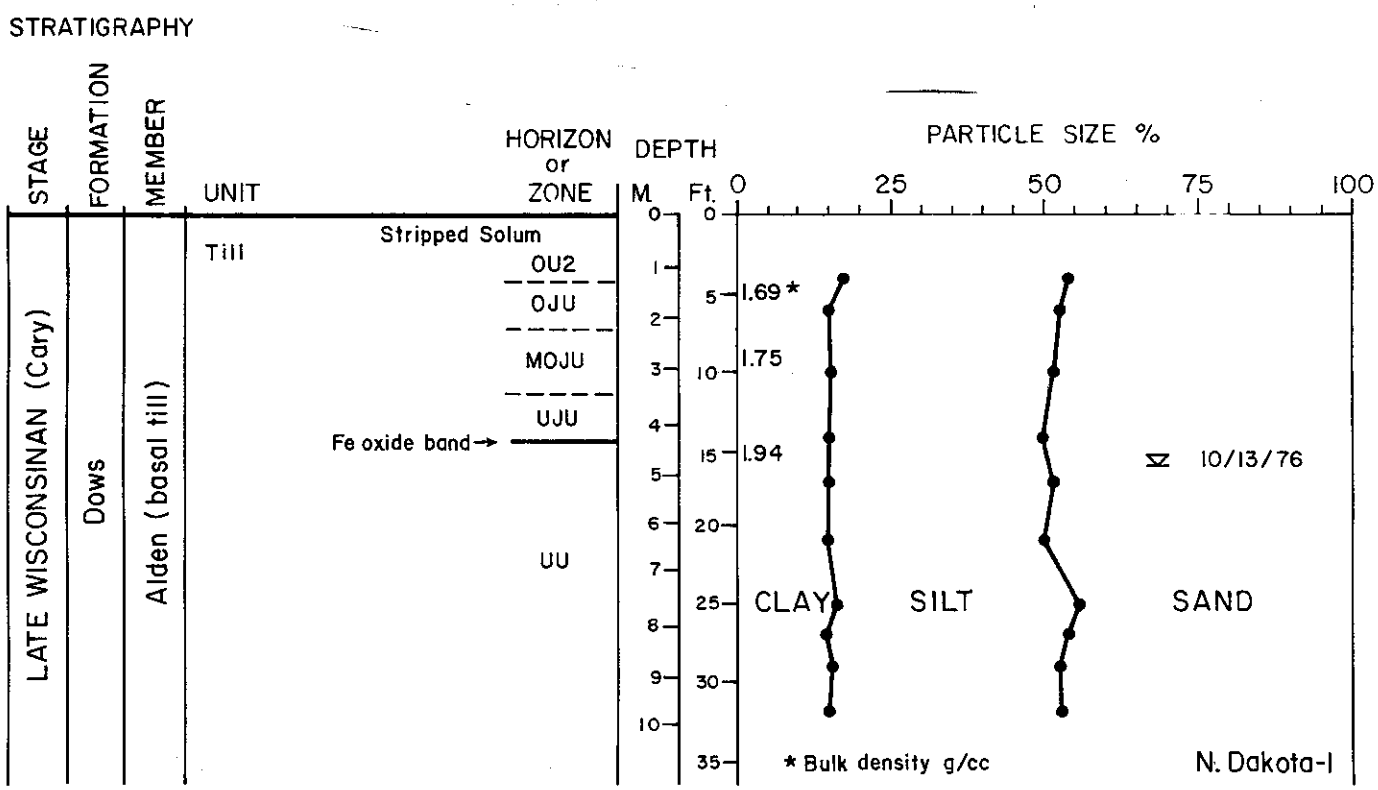


Figure 17. Particle-size data and stratigraphy for N. Dakota Section; in a minor moraine.

these landforms are areas where englacial or supraglacial materials were present in the ice and were superimposed on the "minor moraines."

The literature lists several theories for the origin of "minor moraines" and other glacial landforms which occur in parallel or sub-parallel belts oriented transverse to flow, such as De Geer moraines, cross-valley moraines, ribbed moraines, Rogen moraines, washboard moraines, ice-thrust ridges, etc. There has been an unfortunate tendency to try to give a common origin to these different features simply because they are all oriented transverse to flow and there appears to have been a periodicity in their development, even though the size, morphology, and sediment sequence may differ between some of these different landforms. These discrepancies have previously been pointed out by Prest (1968), Elson (1968), and Cowan (1968). In the following discussion we will present a brief literature review of the theories of the origin of these various landform features as a background for our interpretation of the origin of the "minor moraines."

Most glacial landforms oriented transverse to flow have been presumed to be active ice features. De Geer (see Elson, 1968) interpreted small morainal ridges to be annual ridges, resulting from ice-push of lodgement till by winter advances during general recession of the ice. However

Hoppe (1959) concluded that De Geer moraines, as did Andrews (1963) about cross-valley moraines in Canada, were features resulting from the squeezing of subglacial debris up into crevasses. Gwynne (1941, 1942, 1952) had also proposed that the "minor moraines" in Iowa and adjacent areas were annual push moraines.

Ribbed moraine and Rogen moraine, which are much larger features than the Des Moines Lobe "minor moraines," also commonly have drumlinized surfaces and are thought to be subglacial in origin (Lundquist, 1969). Theories of genesis vary from a subglacial origin as till megaripples (Carl, 1978), to a basal melt-out phenomena (Shaw, 1979), or to the bulldozing and overriding of sub- and proglacial debris (Cowan, 1968). In all theories the periodicity of the ridges is not considered time significant.

Ice-thrust ridges (Kupsch, 1962) are occasionally discussed with minor moraine forms as well. These forms are "transverse compressional features" (Clayton and Moran, 1974) comprised of subglacial folds and thrusts of substrate materials often including bedrock.

The ridgeforms and theories most often and perhaps most appropriately associated with the Des Moines Lobe "minor moraines" are the discussions of washboard ridges by Elson (1957) and Gravenor and Kupsch (1959). They concluded that the washboard ridges were deposited subglacially at the base of thrust planes in the ice. The washboard pattern is characteristically lobate, outlining the position of the thrust planes in the live ice. Gravenor and Kupsch (1959) regarded the preservation of the ridges as the result of ice stagnation, where the ice ultimately separated (or opened) along the shear planes during ice retreat. They considered these ridges as disintegration features exhibiting "inherited flow control" (i.e., "controlled disintegration features"). Lawrence and Elson (1953) noted other ridge forms which occurred at acute or right angles to the washboard ridges. These were thought to be more typical of the linear disintegration of crevasses, and these features appear analogous to the higher elevation transverse ridges which occur superposed on the "minor moraine" ridges and at the "scalloped" junction between two minor moraine belts.

Clayton and Moran (1974) invoke a variation of Gravenor and Kupsch's (1959) ideas. They include "minor moraines" as part of their "superglacial element" of glacial landforms. They speculate that these features are the result of nonuniformity of englacial sediment and infer that these ridges form as the result of greater concentrations of glacial sediment along periodically spaced transverse shear zones. This englacial sediment is concentrated near the base of the glacier where it has little ice under it, so that the sediment undergoes little reworking when the ice melts. According to Clayton and Moran (1974) upon melting these shear-plane masses are let down intact to form the washboard moraine. They also contend that this occurs where the glacial deposits are only 1 to 3 m thick.

Sugden and John (1976) suggest that parallel till-ridge forms may result from compressive flow in warm-based ice, especially near a glacier margin. They suggest that upward shearing of ice layers along thrust planes may accentuate pressure melting, lodgement, and gradual ridge construction at the base of the shear planes. Thus, some of the debris is deposited subglacially at the base of the shear plane, forming the ridge; the rest of the debris (above the *base* of the shear plane) is carried up into englacial positions to be deposited down-glacier.

While shearing is the most common process invoked to explain the transverse ridges, squeezing of material into basal crevasses may be just as valid a process. Till ridges or "minor moraines" have been documented in formation in the Glacier Bay region, Alaska by Goldthwait (1974) and Mickelson and Berkson (1974). As the temperate ice disappeared the till released was sometimes "knee-deep and soupy" (Goldthwait, 1974). The till ridges which formed were entirely composed of basal till which had been squeezed-up into transverse crevasses occurring in the thin glacier ice within a kilometer of the terminus. The basal till in the small ridges appeared identical to the underlying basal till.

Other types of smaller "ribbed hummocky moriane" may result from supraglacial processes. Concentric debris bands may melt out at the margin of an ice sheet resulting in a series of ice-cored moraines (Boulton, 1967; 1972). As the ice melts out the deposits are reworked in the supraglacial environment resulting in oriented hummocky moraine or "controlled disintegration features" (Boulton, 1967, 1972). While these features may be locally important, it seems very unlikely that they could be as areally widespread and consistent in pattern as some of the other lineated ridge forms discussed.

From the field evidence in Iowa, the "minor moraines" or low-relief ridges certainly appear to be the result of subglacial processes. A supraglacial origin seems ruled out both because of the virtual absence of supraglacial sediments in the low-relief ridges ("minor moraines" proper) and because it is hard to envisage how "controlled disintegration" could form such regular, extensive areas (take another look at the extent of the "minor moraine" areas on figure 2). While "controlled disintegration features" occur elsewhere, they do not comprise the low-relief ridges ("minor moraines") of Iowa.

Although a subglacial origin for the "minor moraines" is apparent, determining precisely which subglacial process(es) took place may be difficult as the various proposed processes do not necessarily yield unique features. Our interpretation of the origin of the "minor moraines" favors a combination of the observations and theories of Sugden and John (1976), Mickelson and Berkson (1974), Goldthwait (1974), Elson (1957), and Gravenor and Kupsch (1959). The concave up-ice curvilinear or arcuate pattern of the minor moraines and the till fabric data are clearly compatible with a relationship to shear planes in ice under compressive flow.

Since the "minor moraines" are essentially composed entirely of uniform dense basal till, Sugden and John's (1976) ideas that "minor moraine" ridges may have accumulated by basal melting and lodgement are appealing. If, as Gravenor and Kupsch (1959) propose, the formation of the ridges involves movement of till into the base of the shear plane, it likely took place in the late phases of ice-retreat in this area. The till may have moved by shear just into the base of the shear-plane, or, alternatively it may have simply been squeezed into these fractures as the ice-retreated and separated (or opened like a crevasse) along the shear planes (as described by Mickelson and Berkson (1974; and Goldthwait, 1974). The till, being exposed and perhaps "soupy" (Goldthwait, 1974), explains the few anomalies that we see in the material properties of the "minor moraines." The soupy till squeezed into the crevasses would result in the lower densities occasionally observed in the upper portion of the "minor moraines." The open crevasses would also allow supraglacial or englacial debris to be let down onto, or into, the basal till in the base of the crevasse. Also, in late stages, if meltwater flow occurred within the crevasse, it might also produce stratified deposits. In either of these instances the materials would be preserved in the crest of the "minor moraine" upon final melting of ice.

It seems unlikely that Clayton and Moran's (1974) theory on the origin of "washboard" or "minor moraines" applies to the "minor moraines" of the Des Moines Lobe in Iowa. It is difficult to envisage how "nonuniform englacial sediment" could be let down to form the thick, dense basal till observed or how the let-down of englacial sediment could form such large, extensive "minor moraine" belts that are as much as 15-25 km (10-15 miles) wide. There is also the discrepancy that the till sequence in the Des Moines Lobe "minor moraines" is generally 10-15 m thick rather than the 1-3 m thicknesses discussed by Clayton and Moran (1974). Their inference is, of course, that this 1 to 3 m of deposits was englacial debris not basal till. If 1-3 m of englacial debris was let down on the basal till, somewhere we would expect to find some kind of discontinuity between this englacial debris and the basal till. Nowhere have we observed any discontinuities between the till <u>in</u> the ridges and the underlying basal till. Also, in our experience, even where just a few meters of supraglacial material occurs the result is to obscure the "minor moraine" pattern by a draping or superimposing of an irregular hummocky form over the liner "minor moraine" trend.

<u>Category VI. Curvilinear ridge forms similar in some respects to category V, but discontinuous or poorly-expressed, and including common moderate-relief, irregularly-shaped hummocks similar in form to those occurring in category IV</u>

This landform category is transitional in appearance, origin and sediments between "minor moraine" areas, category V, which consist predominantly of basal till (Alden Member), and landforms of Category IV which generally consist of moderately thick (3-6 m) supraglacial sediments (tills, diamictons, and associated meltwater deposits of the Morgan Member) over moderate to thick basal till of the Alden Member. We envisage this landform category to be like category V except that there is a veneer of supraglacial sediments superimposed on the subglacially-derived "minor moraine" pattern, locally obliterating it. Supraglacial sediments in this landform category are commonly 1-5 m thick, and are thicker in the hummocky, higher relief areas occurring within the category.

<u>Category VII. Upland plain with diffuse circular ridges and depressions; low to moderate local relief</u>

This landform category occurs along the northwestern edge of the map area and consists of a veneer of heavy-textured glaciolacustrine sediments

(Lake Mills Member), 0.5 to 2.0 m thick, over till-like sediments. The origin of this landform category is at present still uncertain.

Category VIII. Gently sloping plain, low local relief and low in elevation to surrounding areas, with common small circular depressions (Story City Flats)

This area occurs in the west-central portion of the map area. It consists of the same materials as category VII, relatively thin, heavy-textured glaciolacustrine sediments (Lake Mills Member) over till-like sediments, but it differs in land form. The origin of this landform category is also unknown at this time.

Category IX. Plain, low in elevation in comparison to surrounding upland areas, with few large irregular depressions; low to moderate relief

This area occurs near the northwest corner of the map area and is a unique landform assemblage on the Des Moines Lobe. It lies within the limits of the Altamont Moraine Complex, and is composed of a complex sequence of supraglacial till-like sediments and associated meltwater deposits (Morgan Member), as well as thick outwash sands and gravels (Pilot Knob Member).

Landform Categories X through XIII: Wisconsinan and Older Largely Erosional Landscapes

Landform categories X through XIII lie beyond the eastern margin of the Des Moines Lobe in the map area. They consist of a mantle of Wisconsinan loess or eolian sand which overlies various Pre-Illinoian (classic Kansan and Nebraskan) tills (Hallberg, et al., 1978; Hallberg, 1980) which have been truncated over extensive areas by subsequent subaerial erosion during major erosional episodes in the Late Sangamon, Wisconsinan (the "Iowan Erosion Surface"), and Holocene time periods. A description of these different landscape areas follows.

Category X. Stream dissected landscape marked by stepped erosion surfaces along interfluves; moderate to high local relief

Areas such as this were classically called "Kansan." Work by Ruhe, et al., (1968) and Hallberg, et al., (1978) has provided a detailed understanding of this kind of landscape. The highest parts of the landscape consist of the Yarmouth-Sangamon Paleosol developed in Pre-Illinoian age tills, mantled by thick (4-10 m) Wisconsinan loess. Before the deposition of the Wisconsinan loess, the Yarmouth-Sangamon surface had been truncated by the development of the Late Sangamon erosion surface upon which the Late Sangamon Paleosol subsequently developed. Remnants of the Late Sangamon surface now occur on interfluves as the first "step" below the Yarmouth-Sangamon surface. The Late Sangamon surface in this area is also mantled with thick Wisconsinan loess, the loess thickness is comparable to or slightly thinner than that on the Yarmouth-Sangamon surface. The Late Sangamon Surface has in turn been truncated during the Wisconsinan forming the Iowa Erosion Surface. Remnants of this surface now occur on interfluves as the first "step" below the Late Sangamon surface and the second step below the Yarmouth-Sangamon upland. The Iowan Erosion Surface is also loess-mantled, but since loess deposition and the cutting of the erosion surface were in part contemporaneous, the loess mantle on the Iowan Erosion Surface is less than that on the adjacent Yarmouth through Sangamon surfaces upslope. During the Late Wisconsinan and Holocene, major periods of erosional truncation have again occurred, forming the Holocene floodplain and terrace systems. These fluvial systems have probably undergone a complex history of Late Wisconsinan and Holocene development as described for fluvial systems in other parts of Iowa by Daniels and Jordan (1966), Thompson and Bettis (1980), and Hoyer (1980).

Category XI. Stream dissected landscape marked by stepped erosion surfaces along interfluves with moderate to high local relief, but generally less steeply sloping than category X; area dominated by thick loess-mantled Iowan Erosion Surfaces

This area is similar in many respects to that of category X except that the Iowan Erosion Surface extends over dramatically greater areas, leaving the older (and relatively higher) Yarmouth-Sangamon and Late Sangamon surfaces as small erosional remnants at isolated locations on the landscape. In this category, the Wisconsinan loess mantle is relatively thick, commonly 2 to 10 m in thickness.

Category XII. Stream dissected landscape marked by stepped erosion surfaces along interfluves with moderate to high local relief, but generally less steeply sloping than category X; area dominated by thin loess-mantled Iowan Erosion Surfaces

This category is similar to that of category XI in that "Iowan" erosion has extended over extensive areas, leaving Yarmouth-Sangamon and Late Sangamon surfaces as only small, isolated erosional remnants comparison to category XI, category XII has a thinner mantle of Wisconsinan loess, the loess generally being less than 2 m in thickness.

Category XIII. Stream dissected landscape marked by stepped erosion surfaces along interfluves with moderate to high local relief, but generally less steeply sloping than category X; area dominated by Iowan Erosion Surfaces developed on Pre-Illinoian age till mantled by thick eolian sands, commonly 4 to 10 m in thickness, with minor loess inclusions

This category is identical to that of category XI except that instead of having a thick loess mantle, this category has a thick mantle of eolian sand with some silt (loess) inclusions.

A Note on Postglacial Erosion on the Des Moines Lobe

The previous sections have seemingly presumed the sediments and landforms we see today are the same as when they were deposited. It is, of course, obvious from aerial photography, etc., that the landforms on the Des Moines Lobe are at least remnants of the original constructional topography. However, postdepositional erosion has clearly made some alterations.

The major river valleys are deeply incised into the Des Moines Lobe and in the proximity of these valleys, stream dissection has obliterated the constructional topography. This dissection generally extends only a short way back from the valleys, however, commonly only 0.5-1.5 km (0.25-1.0 miles).

In upland areas away from the streams, hillslope erosion has also had effects. In closed depressions in the undissected glacial landform regions, Walker (1966) reports that various large, deep bogs contain from 3.6-10.0 m (12-32.5 feet) of postglacial sediment. Van Zant (1979) reports that at least 12 m (39 feet) of postglacial sediments is deposited in Lake West Okoboji. These bogs or lakes are all in moderate or moderate-to-high relief areas dominated by supraglacial sediments.

Walker (1966) reconstructed the erosion and sedimentation history of two large bogs in great detail. At Colo Bog, in a moderate relief area, his reconstruction estimated that an average of 0.9 m (2.8 feet) of A-horizon material was eroded from the slopes in the closed basin during the postdepositional period. At Jewell Bog, in a moderate to high relief area, he estimated that 2.0 m (6.6 feet) of soil was eroded from the slopes during postglacial time.

The situation in the moderate to low relief "minor moraine" areas contrast with Walker's findings. The observations of the authors and many soil scientists in Iowa show that the postdepositional sediments in the depressions between "minor moraines" only attain thicknesses of 1-2 m. Between many ridges the sediments are less than one meter thick. The amount of material removed from these areas would be measured in centimeters not meters, and is not a significant factor in elevating the "minor moraines."

The principal effects on the glacial landforms is obviously to decrease the apparent relief by filling in the depressions at the expense of the uplands. The data also show that in places, some substantial volumes of original glacial sediments have been removed. However, the losses would not be distributed evenly across the landforms. The largest volumes of material would have been eroded from the steeper sideslopes, and the least amount would have been removed from the gently sloping crests of the landforms. The presence of stone-lines, which are continuous across even the crests of most landforms on the Des Moines Lobe and covered by loamy hillslope-surficial sediments, indicates that erosion has affected nearly everything. To minimize these effects we confine our observations on the relations of the sediments and landforms to the most stable and least eroded portion of the landscape.

In summary, it must be recognized that the glacial landforms are only remnants of constructional features. However, the problems created by postdepositional erosion can be handled with careful investigation, and do not seriously effect the geologic evaluation of the landforms and materials.

The Sub-Des Moines Lobe Surface:

Encounters with the Third Dimension

One last facet of our research program is to look at the third dimension of the Des Moines Lobe deposits through the analysis and mapping of the sub-Des Moines Lobe (or sub-Dows Formation) surface. Even a general understanding of the thickness of the Des Moines Lobe (DML) deposits and the configuration of the sub-DML surface will provide important information for both applied and scientific interpretations. For example, one of the more fundamental factors affecting the dynamics of a glacier and its resultant depositional regime is the topography over which the glacier advanced. Analyzing the configuration of the sub-DML surface might permit us to understand what flow regime (extending, parallel, compressive) the Des Moines Lobe ice may have been in, and if there is any relationship between this possible flow regime and the distribution of the different glacial deposits and landforms we are mapping.

Certain aspects of the sub-DML surface are obvious from a regional overview of drainage patterns around the periphery of the Lobe. On the east and particularly the southeast sides of the Lobe, including the field trip area, the DML ice was advancing down the regional slope. This is indicated because the pre-existing major streams all flow to the southeast, directly away from the Lobe, and there is no evidence of any significant ice-marginal changes in drainge patterns. Conversely, on the west and southwest flanks of the Lobe, serious drainage derangements (e.g., Hoyer, 1980) and peripheral ice-marginal drainage patterns are evident. In this area the ice was flowing uphill or against the regional slope.

These regional drainage patterns, however, do not provide enough detail to relate to the intricate pattern of landform-material associations which are becoming apparent from our surficial mapping. Thus, we are attempting to map the sub-DML surface in more detail.

Figure 18 shows the topography of the sub-DML surface for the southern portion of the field trip area. The dots indicate the control point data used for this mapping. The data are derived from: 1) our own outcrop and boring data; 2) other published sections; 3) other published reports which mapped the sub-DML surface over a limited portion of the area (Palmquist, Bible, and Sendlein, 1974); and 4) other subsurface and well log information on file at the Iowa Geological Survey. Many well logs could not be used in this mapping because there were poor or insufficient samples of the Quaternary deposits, or because there was no clear lower boundary which could be interpreted for the Des Moines Lobe deposits.

Two other maps were generated from this data. Figure 19 shows the thickness of the sub-Dows Formation (sub-DML) Pleistocene deposits, or the depth to bedrock below the base of the Dows Formation. Figure 20 shows the generalized thickness of the Dows Formation (DML deposits). These two maps were produced using the same data as figure 18, and by comparing

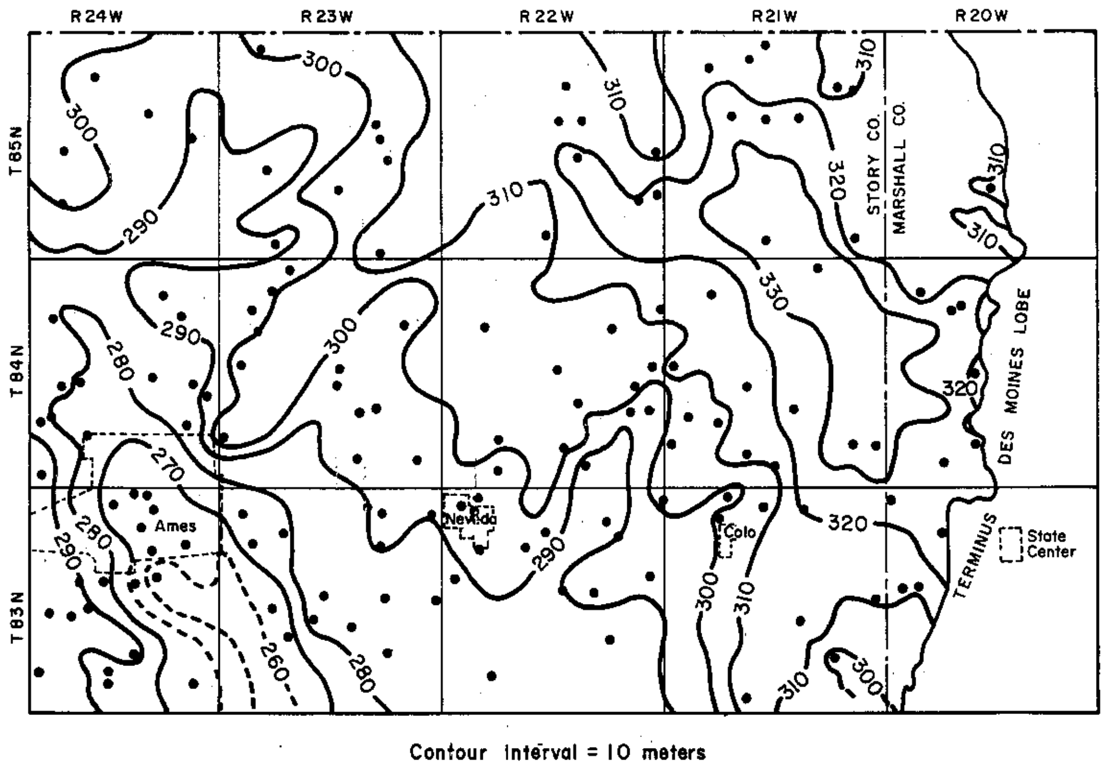


Figure 18. Elevation of the sub-Des Moines Lobe surface.

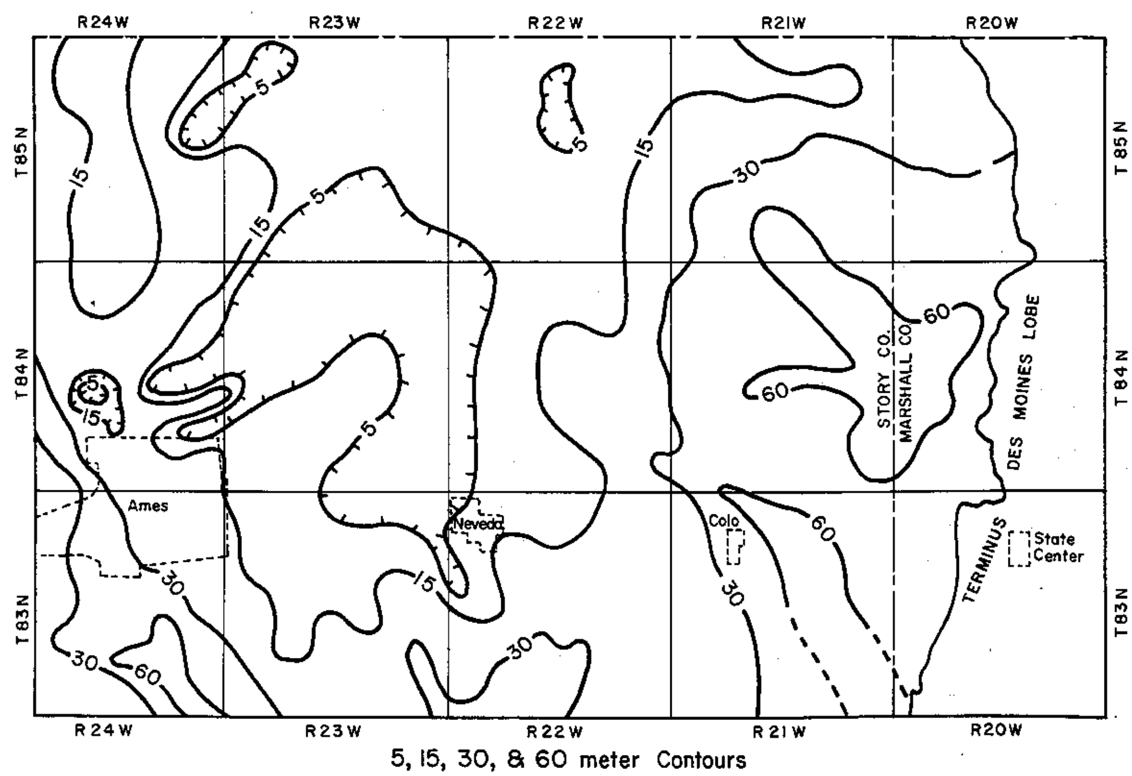


Figure 19. Isopach of the pre-Dows Formation Pleistocene deposits (depth to bedrock below the Dows Formation).

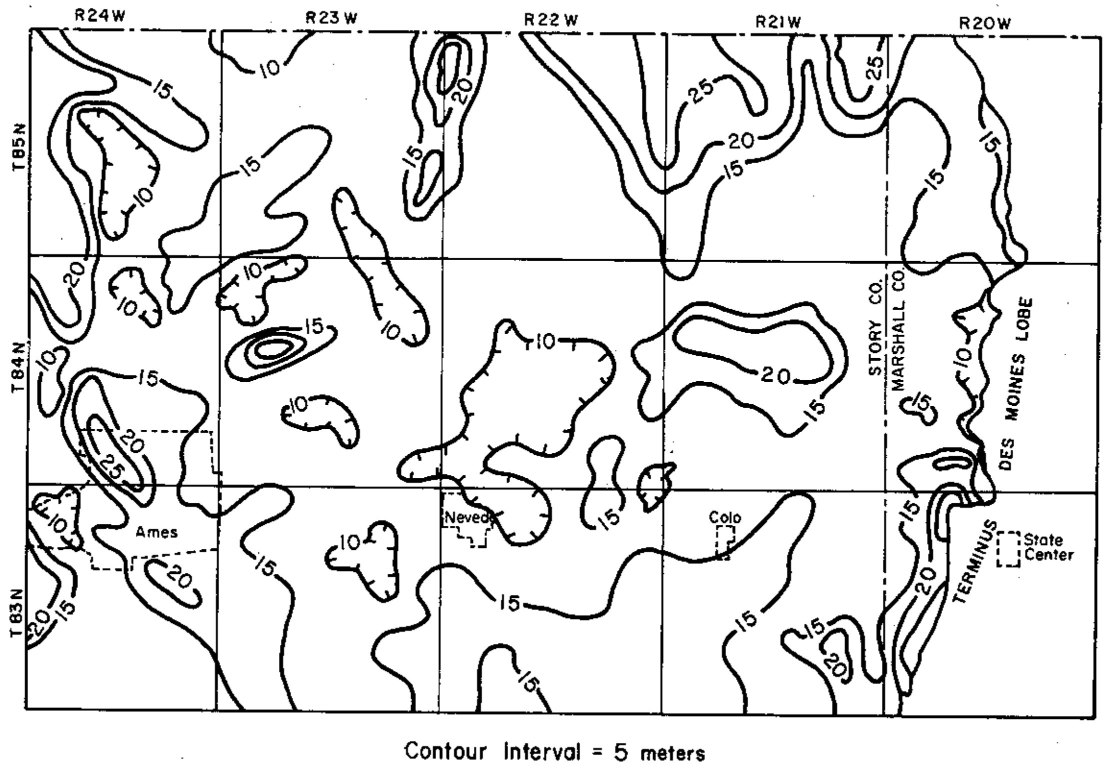


Figure 20. Generalized isopach of the Dows Formation.

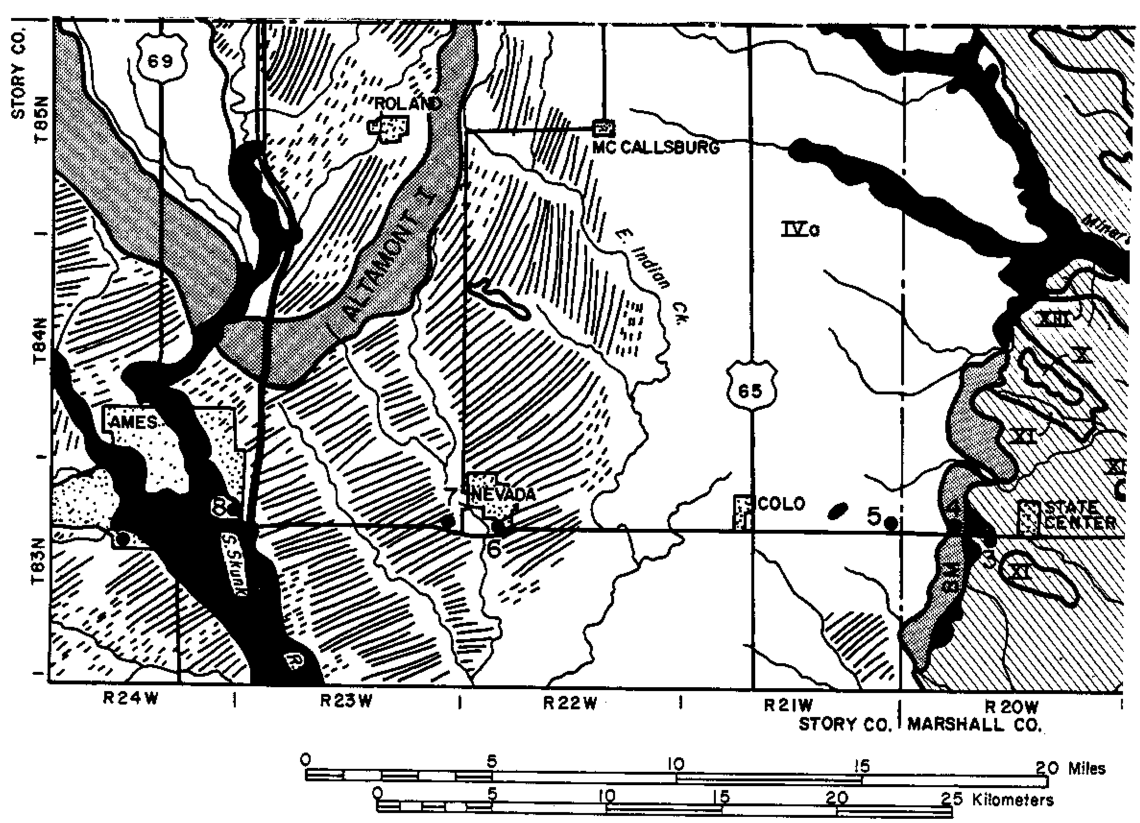


Figure 21. Surficial geologic map, after figure 2.

the sub-DML surface (figure 18) with two other datums, the bedrock topography and the present landsurface, respectively. For comparison with these maps figure 21 shows the surficial geologic units for this area, taken from figure 2.

Two points must be made about the sub-DML surface. First, it is comprised of a variety of materials: Wisconsinan loess, pre-Wisconsinan paleosols and older Pre-Illinoian tills; fluvial sediments; and Paleozoic bedrock (principally Mississippian and Pennsylvanian rocks). As shown on figure 29 very little of the sub-DML surface is on bedrock. In many areas 15 to over 60 m of older Quaternary sediments lie between the DML deposits and bedrock. Second, wherever the sub-DML surface has been studied in detail the same conclusions are apparent: erosion by the Des Moines Lobe ice in this area was minor and usually localized. The stratigraphic units present just beyond the DML terminus are also largely preserved beneath the DML. In fact in many sections noted by the authors and by Ruhe (1969), weak buried soils in the loess are preserved beneath the basal till of the DML. As a consequence we believe the sub-DML (or sub-Dows Formation) surface should be a reasonable approximation of the surface which affected the DML ice.

The preservation of Quaternary sediments beneath the DML deposits has obvious significance: we are not dealing with a simple relationship between bedrock and the DML deposits. Palmquist and Bible (1974) have shown an apparent relationship between glacial landforms on the DML and bedrock topography. Some of their results are fortuitous, and stem from the fact that in some areas very high bedrock elevations are mimicked by the sub-DML surface. In the current study area this can be seen in the high bedrock area (figure 19, 5 m area) which is partly concident with the sub-DML ridge (figure 18) which underlies the Altamont I moraine (figure 21). However, in large areas, as shown on these maps, there is little relationship between the bedrock surface and the sub-DML surface. Also, in figure 22, which is a cross-section along the traverse from Stop 3 to Stop 8 on the field trip, the marked discordance between the sub-DML and bedrock surfaces is obvious. To begin to interpret possible ice-flow dynamics in relation to landforms the sub-DML surface, not the bedrock surface, is the one which must be analyzed.

With this rationale in hand some comparisons can be made between the sub-DML surface (figure 18) and the surficial geologic features (figure 21) in the area. Several relationships are apparent. In a general sense, the sub-DML surface slopes back from the terminus area to a pre-DML valley along the western and southwestern parts of the map area. More specifically, the highest elevations and most prominent ridges on the sub-DML surface are either coincident with or just "up-ice" from the high-relief ridge forms or moraines (Landform category III; figure 21). In contrast, the areas where the eastern margin of the DML is not marked by a high-relief ridge form (particularly the northeastern portion of figure 21) are coincident with lows or lengthy "downhill" slopes toward the margin on the sub-DML surface.

Further, the extensive "minor moraine" areas (figure 21, category V) occur over relatively broad flat areas on the sub-DML surface. The

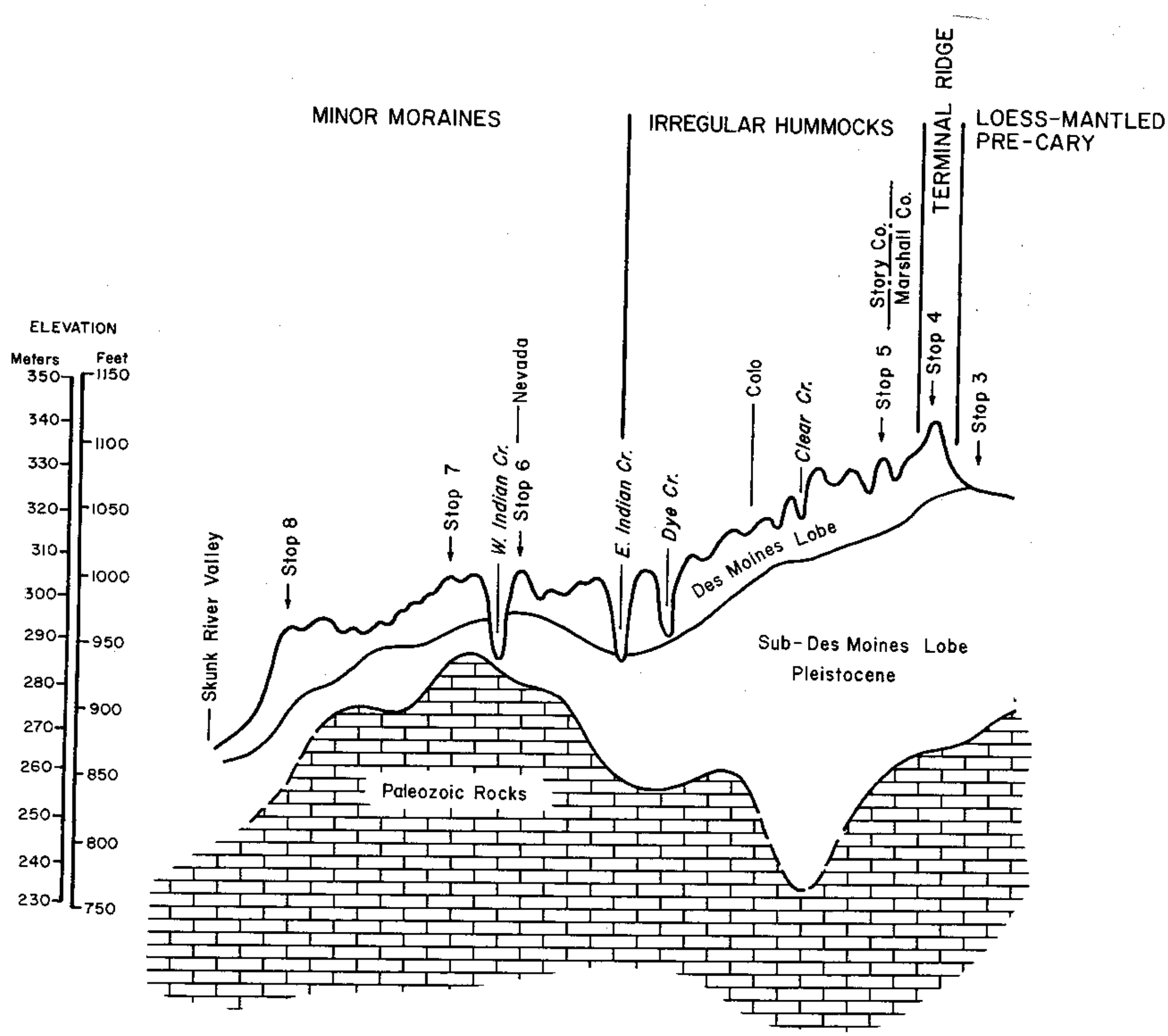


Figure 22. Cross-section of field trip route from Ames to State Center.

moderate-relief hummocky areas (category IV, figure 21) between the "minor moraines" and the morainal ridges are generally coincident with slopes opposed to the ice-flow direction. These relationships are also well-shown on the cross-section (figure 22).

Thickness variations of the Dows Formation (DML) deposits are also complex, as shown in figure 20. It must be noted that this map provides a generalized indication of the maximum thickness of the Dows Formation. In generalizing the information it does not show that the Dows Formation deposits are entirely eroded away along some of the major streams particularly the Skunk River (see figure 21) and even some minor streams (see figure 22). Several trends are apparent. The greatest thickness of the DML deposits (figure 20) are related to the prominent ridge-forms or moraines, (the Bemis and Altamont I Moraines, figure 21), or to lows on the sub-DML surface. The morainal ridges average 15 to over 25 m in thickness. By contrast, the thinnest deposits occur in the "minor moraine" areas, which average 10 to 15 m. The moderate-relief, irregular hummocky area, between the "minor moraines" and the Bemis Moraine (figure 21) are intermediate in thickness, generally ranging from 15-20 m. Overall there is a general thickening of Dows Formatin deposits from east of the Altamont I Moraine to the DML terminus, or Bemis Moraine.

At this point, knowing the sediment sequence in each of the landform categories becomes important. The "minor moraines," category V, are comprised virtually of all basal till (Alden Member); the moderate-relief hummocks, category IV, are comprised of moderately thick supraglacial sediments (Morgan Member) over basal till (Alden Member); and the high-relief morainal ridge forms, category III, are comprised mostly, if not entirely, of supraglacial sediments.

Thus, there are important spatial variations in both the thickness and nature of the glacial sediments over this area: basal till extends out just to the terminal region. Supraglacial sediments are absent or of minor importance in the "minor moraine" area but thicken progressively across the irregular hummocky area to their maximum thickness at the DML terminus. There is also a gross temporal variation in the sediments, as the supraglacial sediments, where present, always overlie the basal till. There was a time-transgressive change from subglacial to supraglacial sedimentation in these areas.

An Initial Synthesis

Even these initial observations on the Des Moines Lobe begin to present an interpretive picture in which all the observed data can be fit together. Though our work is still in the formative stages, an initial synthesis from the field trip area may demonstrate the potential we hope for in our research program.

The second half of the field trip, Stops 3 through 8, constitutes a traverse through the various landform and material areas between Ames and State Center (figure 21). The traverse roughly parallels the ice-flow direction and extends from in front of the Altamont I Moraine, the second major ice-marginal position on the Des Moines Lobe in Iowa, to the terminus of the Des Moines Lobe, the Bemis Moraine. Figure 22 shows a cross-section along this portion of the field trip route from Ames to State Center.

To begin this synthesis let us briefly review some of the relationships noted in the previous sections. The transect begins in the "minor moraine" belt to the east of Altamont I (figure 21). The "minor moraine" areas consist of 10-15 m of DML deposits dominated by basal till. The "minor moraines" occur in a region where the sub-DML surface is relatively flat, but locally has a gentle gradient opposing the ice-flow direction.

Proceeding down-ice, the land surface rises in elevation, the "minor moraine" areas become obscured by superposed moderate-relief irregular hummocky landforms (category IV), and then east of Nevada (figure 21) these hummocky landforms dominate the landscape. The total thickness of DML deposits increases to the east from 10-15 m to 15-20 m, and the hummocky areas are dominated by a moderate thickness (3-6 m) of supraglacial deposits overlying basal till. The hummocky regions are coincident with relatively steep sub-DML slopes opposed to the ice-flow direction (figure 22). These trends continue to the terminus along the traverse (figure 22). The land surface also continues to rise in elevation and the local relief increases until we reach the high-relief ridge form, or Bemis Moraine. The total thickness of DML deposits increases to 15-25 m, at the terminal ridge which is dominated by supraglacial deposits.

A brief outline of events may be proposed for this area. The initial DML sedimentation occurred subglacially, building up a significant thickness of basal till. The steeper, opposing slopes on the sub-DML surface, down-glacier from the "minor moraine" areas promoted compressive flow in the ice. This caused some of the basal debris in the ice to be carried up into englacial and supraglacial positions. This pattern would culminate at the terminus where large volumes of this debris were deposited supraglacially, forming a prominent ridge, the Bemis Moraine (Stop 4). With final wastage, the remaining englacial and supraglacial debris was deposited (or superimposed) upon the underlying basal till, forming the moderate-relief irregular hummocky area (category IV). The landforms in category IV are thus compound landforms consisting of basal till overlain by supraglacial sediments. In the "minor moraine" areas (category V), the sub-DML topography was nearly flat and the debris was concentrated in the basal ice. Consequently, evolution of this landform from the initial to final stages was dominated by subglacial sedimentation, as previously discussed. Scattered throughout the "minor moraine" areas are minor amounts of supraglacial deposits, inherited somewhere up-ice, which have subsequently been superimposed on the basal till. These supraglacial deposits form irregular hummocks which locally obscure the low-relief ridge trends of the "minor moraines."

This synthesis is only an initial attempt and by no means a complete explanation of all the features even in the traverse area. However, it is an attempt to demonstrate that these relationships between the sub-DML surface, the distribution of the different landforms, and the variations in the type and sequence of glacial sediments provide a powerful tool for understanding the variations in glacial sedimentation and ice dynamics of the Des Moines Lobe. The conclusions presented here are, at this point, simplistic, but provide a fundamental understanding of the major aspects of glacial sedimentation in the area.

As a final comment, we would like you to note that glacial sedimentation on the Des Moines Lobe (or any lobe) was complex. The sequence of landforms and sediments present along the traverse is *not* representative of the sequences present for all the other areas of the Des Moines Lobe (in fact, other traverses for the field trip area, figure 2, could go through a quite different sequence of landforms, for instance).

The pattern of glacial sedimentation presented here is not intended to apply to other areas glaciated by continental ice sheets, nor does it even apply to all other areas of the Des Moines Lobe, for that matter. We do hope, however, that in the final analysis this approach will contribute considerably more insight into the nature and complexity of glacial sedimentation by the Des Moines Lobe in this area than previously recognized, and that it will allow a rational reconstruction of the Des Moines Lobe based on the actual corroborative field evidence.

ROAD LOG AND STOP DESCRIPTIONS

The objective of the field trip is to investigate the materials and upland glacial landforms on the Des Moines Lobe in the map area. The field trip can be divided into two basic parts. In part 1, stops 1 and 2, the principles we use for the genetic interpretation of till and till-like sediments on the Des Moines Lobe in Iowa will be reviewed. At these stops the two basic generic classes of glacial sediments we consider, the basal till and supraglacial deposits, can be examined in large quarry exposures. In part 2, stops 4 through 8, we will look at a transect through successively different glacial landforms, beginning at the Des Moines Lobe terminus near State Center, Iowa and extending back roughly parallel to the former ice flow direction to Ames. The objective of this transect is to view spatial and temporal changes in glacial sedimentation back from the Des Moines Lobe terminus.

The road log is quite detailed. Along the route however, we hope to give the reader a chance to view the regional spatial and topographic relations between the various landform categories.

Road Log

Accumulated Mileage (km)	Increment Mileage (km)	Discussion
0.0 (0.0)	0.0 (0.0)	Log begins at eastbound on-ramp at junction of Elwood Drive and U.S. Highway 30; just east of the Gateway Center; on moderate relief "minor moraine" area. During construction of the Gateway Center complex the authors examined and sampled, a variety of outcrops and drill cores. Figure 23 shows the nature of the composite section from one "minor moraine" ridge. Table 7 shows lab data for this site, and Table 8 shows lab data from other sites discussed. As noted in the section on "minor moraines" this is the only section in a "minor moraine," examined by the authors, where any significant supraglacial deposits have been present. The 2 m of interbedded glaciofluvial sediments and till-like material occurred in a trough, set in basal till, in the very crest of the "minor moraine" ridge.
0.3 (0.5)	0.3 (0.5)	On overpass, U.S. 30 descends east onto upper (late-Wisconsinan) terrace along the Squaw Creek and Skunk River. Terrace locally capped with eolian sand.

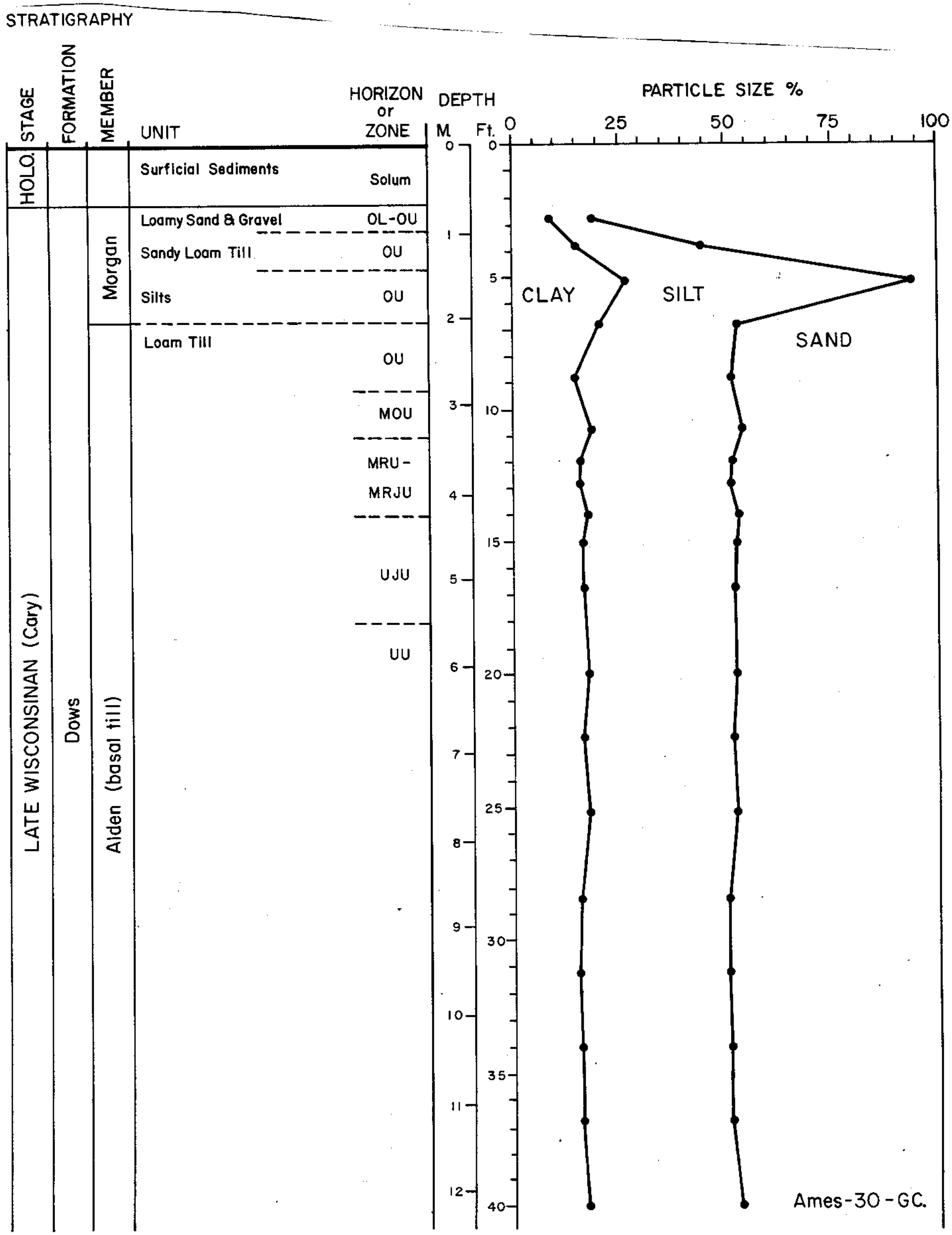


Figure 23. Particle-size data and stratigraphy; Gateway Center Section.

Table 7. Additional laboratory data, Gateway Center Section (Ames-30-GC).

Depth M(ft)	Horizon or Zone	Clay Mineralogy % Ex.	Ill.	K+C	Sand-fraction Lithology % C/D	T.C.	Sh.	Ts.	Q.-F.	Tx.
		LATE WISCONSINAN								
			DOWS FORMATION							
				Morgan Member - supraglacial deposits						
(4)	OU	69	21	10	1.0	26	16	42	50	58
				Alden Member - basal till						
(8)	OJU	71	20	9	1.3	28	13	41	53	59
(10)	MOJU				0.8	21	16	37	51	63
(11)	MRJU				0.7	19	17	36	54	64
(18)	UJU	69	20	11	0.9	24	15	39	52	61
(30)	UU	69	19	12						

Chittick Carbonates

Depth M(ft)	Horizon or Zone	C/D	Cal	Dol	T.C.
(11)	MRJU	0.39	4.2	10.9	15.1
(22)	UU	0.43	4.4	10.2	14.6

1.8 (2.9)	1.5 (2.4)	Cross escarpment on terrace and descend to Holocene alluvium and the floodplain of the Skunk River.
2.2 (3.5)	0.7 (1.1)	Cross Skunk River; note there is no Wisconsinan terrace on east side of the valley in this area.
3.0 (4.8)	0.8 (1.3)	Cross under Interstate-35 (I-35); rise back up onto till upland, marked by moderate relief "minor moraine" topography. Eolian sand and silt cap the till locally, adjacent to the valley. These eolian deposits systematically thin and get progressively finer textured away from the Skunk valley. Within about 3/4 miles they are no longer recognizable.
5.7 (9.2)	2.7 (4.3)	In this area, if you try hard, you can see the gentle lineated "swell-and-swale" pattern of the "minor moraines," which are oriented E-NE. The "minor moraines" consist of discontinuous low-relief ridge-forms, generally 1-2 m in height. They are spaced about 100 m (350 feet) apart on the average. The landscape they are set on exhibits broader scale undulations with a "wavelength" of 3-6 km (2-4 miles). They are discussed in more detail in the text.

Table 8. Additional Laboratory data.

Depth M(ft)	Horizon or Zone	Clay Mineralogy % Ex.	Ill.	K+C	C/D	Sand-Fraction Lithology % T.C.	Sh.	Ts.	Q.-F.	Tx.
	Site: RB-1;									
	LATE WISCONSINAN									
		DOWS FORMATION								
			Alden Member - basal till							
3.7 (12)	MRU	70	20	10	*	28	9	38	51	62
	Site: N. Dakota - 1;									
1.5 (5)	OJU	70	22	8	6.5	26	10	38	50	62
4.3 (14)	UJU	65	18	17	35.0	36	6	43	51	57
8.2 (27)	UU	68	21	11	1.3	27	9	36	59	64
	Site: Bruner - 1;									
			Morgan Member - supraglacial deposits							
1.7 (5.7)	OU	71	19	10	*	36	4	40	40	60
			Alden Member							
3.0 (9.7)	MOU	80	14	6	14.0	47	15	63	29	37
3.2(10.5)	MRJU	72	20	8						
3.3(11.0)	MRJU	71	21	8						
3.4(11.3)	UJU	74	15	11	7.0	35	7	42	55	58
3.8(12.4)	UU	66	23	11	5.2	25	17	42	47	58
5.5(18.0)	UU	61	25	14	2.1	26	18	44	49	56
7.6(25.0)	UU	68	21	11						
9.1(30.0)	UU	63	24	13						
9.5(31.0)	UU	65	21	14	7.0	45	14	60	36	40
	Site: Bruner - 2;									
			Morgan Member							
1.8(6.0)	MRU	71	20	9	15.0	28	18	41	52	59
			Alden Member							
2.1(6.8)	MRU	80	14	6	15.0	28	26	54	40	46
3.1(10.0)	UU	70	22	8						
3.7(12.0)	UU	65	25	10	7.0	21	16	37	57	63

* Not Calculated

Data from another core in the crest of a "minor moraine" (well-drained, Clarion loam soil) from this area is shown in figure 24. Note the uniformity of the till; this is typical of the till in the "minor moraines," as discussed in the text.

5.9 (9.5)	0.2 (0.3)	Looking south down the gravel road, you can see the regular undulations of the "minor moraines."
8.7 (14.0)	2.8 (4.5)	Rising on overpass; look N or S and see the "minor moraines."
8.9 (14.3)	0.2 (0.3)	Just east of overpass turn left (N) on Story County road S-14.

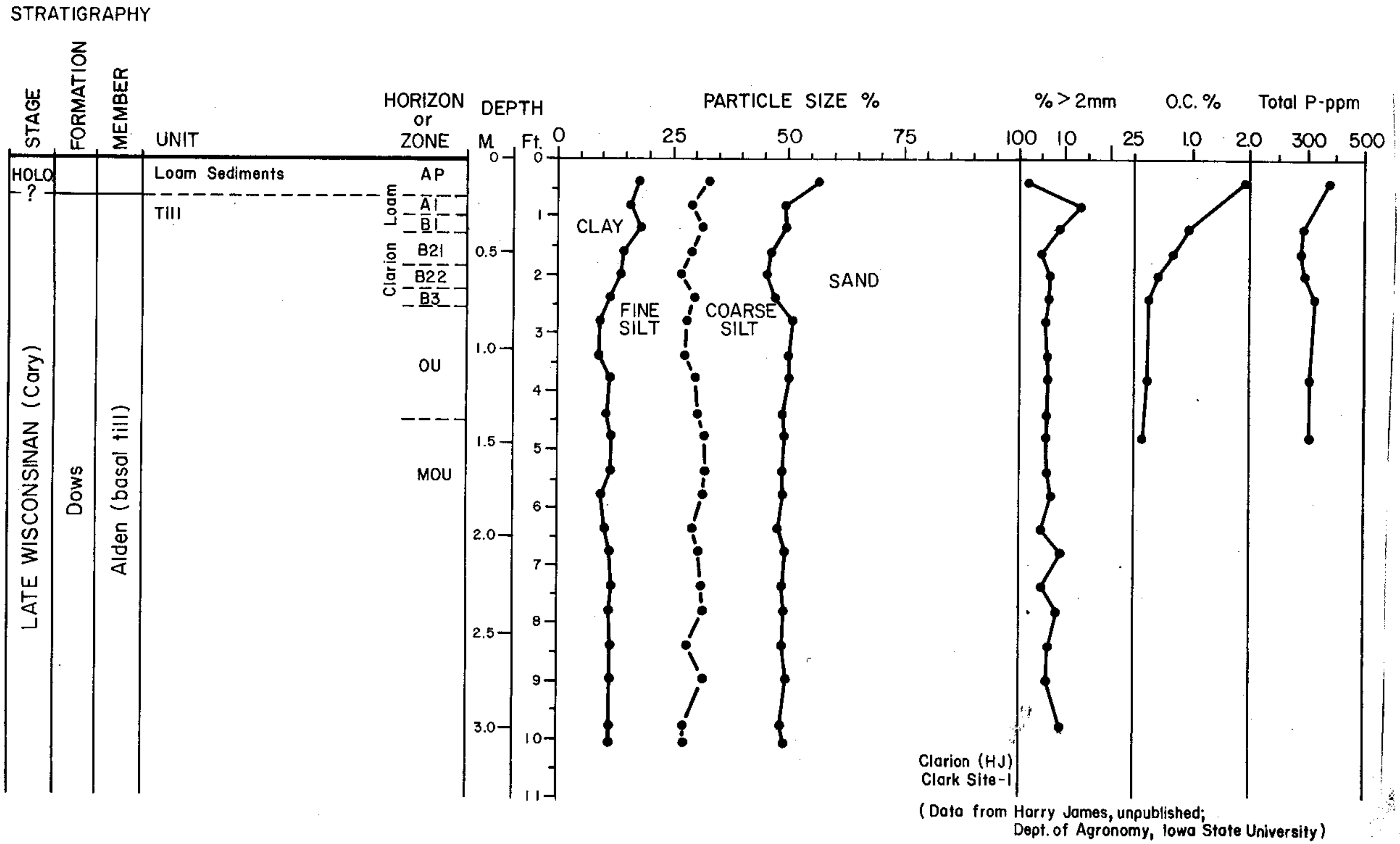


Figure 24. Stratigraphy, particle-size, organic carbon, and total phosphorous data for the Clark site; in the crest of a "minor moraine." Unpublished data from Harry James.

9.2 (14.8)	0.3 (0.5)	"Minor moraines," oriented E-NE, cut across road.
9.6 (15.5)	0.4 (0.6)	On outskirts of Nevada, Ia; some stream dissection here in the proximity of W. Indian Creek.
9.7 (15.6)	0.1 (0.2)	Cross W. Indian Creek.
9.8 (15.8)	0.1 (0.2)	Turn right (E), continue on S-14.
10.0 (16.1)	0.2 (0.3)	Turn left (N), on S-14 (the first street).
10.2 (16.4)	0.2 (0.3)	Turn left (W), on Lincolnway (S-14).
10.4 (16.7)	0.2 (0.3)	Turn right (N), on S-14, at Catholic Cemetery.
11.7 (18.8)	1.3 (2.1)	Landscape still affected by stream dissection; W. Indian Creek just off to left (W).
14.5 (23.3)	2.8 (4.5)	To right, at 2 o'clock (NE) is a prominent NW-SE oriented ridge. The ridge was called a "drumlinoid" hill by Thomas, Hussey, and Roy (1955). The ridge is composed of interbedded till, diamictons, silts, and sands. The ridge is up to 12 m (40 feet) higher than the surrounding "minor moraine" area. This feature is similar in setting and composition to a number of small ridge forms, which are oriented transverse to the trend of the "minor moraines." We consider them to be supraglacial materials, and landforms, which are superposed on basal-till dominated "minor moraines."
16.1 (25.9)	1.6 (2.6)	To the left at 11:00 (NW) is another ridge; this is the front of the Altamont I moraine (figure 2), which the route will follow for much of the morning. This ridge-form constitutes the outermost ridge of the Altamont Moraine system, on the east side of the Des Moines Lobe. It was described by Leverett (1932) and others before him as the Altamont Moraine, however, for many years this feature has been lumped with other landforms in the Bemis Moraine.
17.9 (28.8)	1.8 (2.9)	Altamont I directly to the west; road rises along the eastern edge of the ridge just ahead.

18.9 (30.4)	1.0 (1.6)	View lower elevation, and lower relief, "minor moraine" landscape to right (NE).
20.2 (32.5)	1.3 (2.1)	Turn right (E) on county road E-18. Surrounding landscape is on the edge of NNE oriented "minor moraines," with local dissection from E. Indian Creek just to the right (S)
23.5 (37.8)	3.3 (5.3)	Town of McCallsburg.
24.1 (38.8)	0.6 (1.0)	Turn left (N) on county S-27. To the north on S-27 the landscape rises in elevation as we leave the lower elevation "minor moraine" area and rise onto a higher elevation region marked by moderate relief, irregular hummocky topography. The hummocks are comprised of moderate thickness (3-8 m) of supraglacial deposits over the basal till (see figure 6, and stop 5).
26.7 (42.9)	2.6 (4.2)	Note the greater number, size, and circularity of closed depressions in this landform region, compared to the minor moraine areas.
27.1 (43.6)	0.4 (0.6)	Story-Hardin County line.
29.0 (46.7)	2.3 (3.7)	Stop sign with Hardin Co. road D-65.
29.4 (47.3)	0.4 (0.6)	Turn left (W) continuing on S-27; note to right (NE) the lower elevation terrain. This lower area is marked by weak minor moraines. The general divide elevations are about 1130 feet (345 m) in this area, while the general elevations are about 1190 feet (360 m) in the hummocky area to the S-SE.
29.9 (48.1)	0.5 (0.8)	Garden City; follow S-27 to north and west through town.
31.8 (51.2)	1.9 (3.1)	Turn right (N) continuing on S-27; high ridge to left (W) is the Altamont I moraine again.
35.0 (56.3)	3.2 (5.2)	On crest of high elevation area in the irregular, hummocky landform region; ahead and left (N and NE) view the distinctly lower elevation "minor moraine" region again; "minor moraines" oriented slightly E of N.
35.7 (57.4)	0.7 (1.1)	Stop; junction Ia. 175; Town of Radcliff; continue straight (N) on S-27; to left (NW) high elevation hummocky topography nearly merges in elevation with the Altamont I moraine.

37.6 (60.5)	1.9 (3.1)	Cross Honey Creek, which heads just to the left (W) at the Altamont I ridge.
37.7 (60.6)	0.1 (0.2)	Road turns right (E); in Honey Creek Valley.
38.6 (62.1)	0.9 (1.5)	Turn left (N) on S-27; in "minor moraine" area; "minor moraines" oriented N-S.
39.6 (63.7)	1.0 (1.6)	Turn right (E) on S-27; to the east the landscape rises up slightly in elevation; in this area some irregular hummocks are superimposed on, and obscure the "minor moraine" patterns.
40.6 (65.3)	1.0 (1.6)	Turn left (N) follow S-27.
43.6 (70.2)	3.0 (4.8)	Stop sign, Jct. D-41; continue N on S-27. Altamont I can be seen, about 3 miles (4.8 km) to the left (W).
45.1 (72.6)	1.5 (2.4)	Stop sign; Jct. Iowa 359; continue N on 359. "Minor moraines" oriented NNE in this area.
47.2 (75.9)	2.1 (3.4)	Descend into and cross valley of S. Fork of the Iowa River; note terraces. (Route now on figure 25).
50.9 (81.9)	3.7 (6.0)	Cross RR tracks, south edge of Alden; Altamont I very prominent to left (W) about 1 mile (1.6 km); a few small outwash fans flank the moraine in this area.
51.6 (83.0)	0.7 (1.1)	Stop; Jct. U.S. 20; turn right (E) on U.S. 20.
52.7 (84.4)	1.1 (1.8)	Turn right (S) into quarry.

Stop 1. Alden Section; Weaver Construction Company Quarry; described section located on the south side of U.S. Highway 20 in the NE¼, of the NW¼, of the NW¼, of sec. 20, T. 89N., R. 21W., Hardin Co. Elevation 1150 feet (350 m). The Alden Section is in a moderate relief "minor moraine" area, with local modification by stream dissection.

Objectives: There are four primary objectives at this stop;

1. Examine the character of the basal till of the Des Moines Lobe;
   a. Note the uniformity in morphology and texture of the basal till both vertically and laterally. The till is almost devoid of any interbedded stratified deposits.

Figure 25. Black-and-white print of Iowa Geological Survey color-infrared aerial photograph, showing Stop 1 in "minor moraine" area, and adjacent landscape on the Des Moines Lobe. Note prominence of Altamont I. Iowa River traverses from NW to E center of photo.

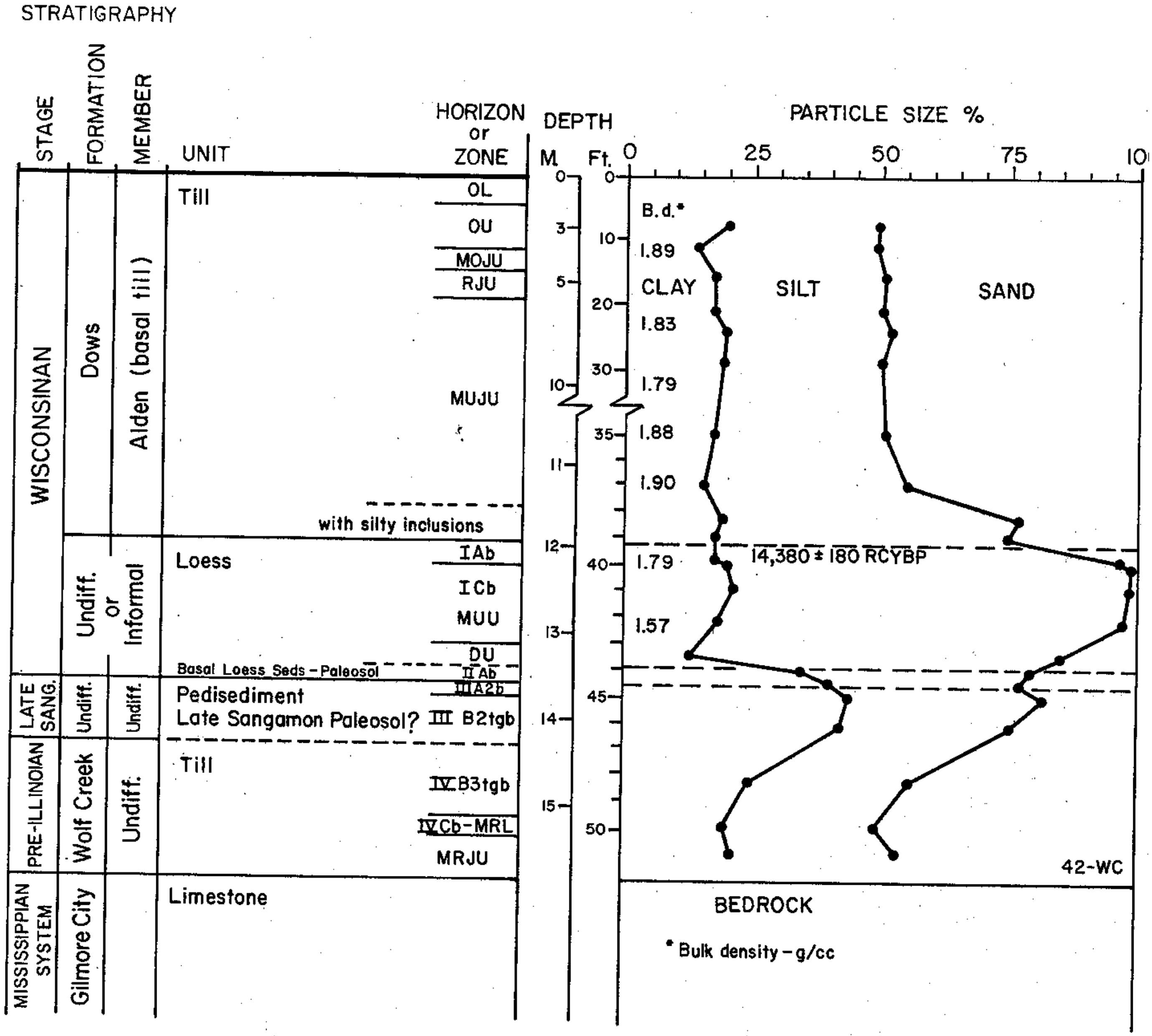


Figure 26. Stratigraphy, particle-size and bulk density data for the Alden Section.

b. Note that the only exception to this uniformity is at the bottom of the till where the local substrate (loess) has been incorporated into the lower 0.3 m of the till.

2. Note the relationship of the basal till to the landform type ("minor moraine", Category V of figure 2).

3. Note the stratigraphic setting of the Des Moines Lobe deposits; i.e., the basal till lies on Wisconsinan loess and older Quaternary sediments, not bedrock.

4. Look at the nature of Late-Wisconsinan (post-glacial) and Holocene changes to the landsurface demonstrated by the presence of stone-lines and thin overlying hillslope sediments.

The stratigraphy of the Alden Section, as originally described and sampled in 1976, is shown in figure 26. The accompanying mineralogy data for this section is given in Table 9. In brief the section is comprised of about 12 m of Late-Wisconsinan basal till of the Des Moines Lobe which overlies about 1.5 m of Wisconsinan loess. The loess in turn overlies a well-developed paleosol developed in pre-Wisconsinan sediments resting on Mississippian age underburden.

This section forms the reference section for the proposed Alden Member (basal till) of the Dows Formation. The principal features of the Alden Member, or basal till of the Des Moines Lobe in Iowa, are illustrated at this section. The till is dense and very uniform in its textural, mineralogical, and morphological properties throughout the exposure. The till is loam textured and ranges in thickness from 9 to 14 m (30 to 45 feet). Note that accross the hundreds of meters of linear exposure in the quarry, only a few small inclusions of stratified sediments occur in the till. A conspicuous feature of the till of the Des Moines Lobe is the presence of clasts of Upper Cretaceous shale (Table 9). These clasts can readily be seen in the till at this outcrop.

The only major exception to the remarkable uniformity of the basal till occurs in a zone located at the bottom of the till. The lowermost 0.3 m (1-2 feet) of the basal till is enriched in silt content as shown on figure 26. There is a gradational change upward in particle-size distribution from till which is high in silt content (near the loess contact) to the uniform till texture typical of the basal till both at this site and regionally. Zones of this type are common in the basal till; only infrequently have a few small, discrete block inclusions of loess been discernible in the till. Generally it appears that loess has been incorporated and dispersed throughout the till matrix, and that these locally-derived materials have been progressively diluted upward in the section. This dilution may likely be caused in large part by repeated regelation at the base of the ice. Kemmis (1981) hypothesizes that such zones in the lower increments of basal till, are related to erosion-transportation-deposition resulting from recurrent regelation in the basal ice as it moved over an unlithified sediment bed (in this case loess). Where these zones occur, local substrate mterials, such as the loess, may have been eroded particle-by-particle during regelation freezing, diluting the normal, farther-travelled debris load in the basal ice. As net deposition of till took place on the bed, more and more local source materials (loess in this case) would have become covered up, no longer contributing to the debris load. Thus with time the character of the basal till would change: initially, local materials, such as the loess, would dominate the composition of the till matrix, but progressively these local materials would form lower and lower proportions of the matrix materials as more of the local substrate became covered up. Finally, after the local source was completely covered up, the farther-travelled, better homogenized material would constitute the till matrix.

Table 9. Mineralogy data, Alden Section.

	Depth M(ft.)	Horizon or Zone	Clay Mineralogy % Ex.	Ill.	K+C	Sand-Fraction Lithology % T.C.	Sh.	T.X.	Q.-F.	T.X.
			LATE-WISCONSINAN (Cary)							
			DOWS FORMATION							
			Alden Member (basal till)							
2.4	(8.0)	OU	72	17	11					
3.4	(11.0)	OU	65	22	13	34	6	42	48	58
5.0	(16.5)	RJU	70	18	12					
6.6	(21.5)	MUJU	71	16	13	27	13	41	52	59
7.3	(24.0)	MUJU	74	14	13					
9.0	(29.5)	MUJU	65	20	15	31	10	42	50	58
10.7	(35.0)	MUJU	64	24	12					
11.3	(37.0)	MUJU	60	24	16	28	8	39	57	61
11.7	(38.5)	MUJU	69	16	15	30	6	36	57	64
11.9	(38.9)	MUJU	62	24	14					
			WISCONSINAN							
			Loess undiff.							
12.0	(39.5)	IAb	58	28	14					
12.2	(40.0)	MUU	62	24	14					
12.5	(41.0)	MUU	63	24	13					
13.3	(43.5)	MUU	70	23	8					
			PRE-ILLINOIAN							
			WOLF CREEK FORMATION							
			Till Undiff. (Hickory Hills Till Mem?)							
15.4	(50.5)	MRJU	61	19	20					
15.6	(51.1)	MRJU	62	17	21	31	1	34	54	65

Ex. - expandable clay minerals
Ill. - Illite
K+C - Kaolinite plus chlorite
Q.-F. - quartz-feldspar

T.C. - total carbonate grains
Sh. - shale
T.S. - total sedimentary grains
T.X. - total crystalline grains

The upper part of the Alden Member (basal till) at this site and elsewhere has been subject to late Wisconsinan ("post glacial") and Holocene slope development and possibly some minor eolian activity. Across the high points on the landscape surficial sediments, commonly 15-20 cm (6-8 inches) thick, overlie a stone line. Downslope, the stone line grades into a thicker zone of pebbles and cobbles in minor drainageways, and the overlying sediments may thicken to approximately 1 m (3 feet). It is important to recognize that these sediments are related to the post-glacial, subaerial modification which these landforms have undergone, and that they should not be comfused with supraglacial sediments.

At this stop we also want to emphasize that the minor moraine landforms (Landform Category V on figure 2) are comprised predominantly of the basal till of the Alden Member. Post-depositional modifications, if anything, has acted to reduce the local relief of the "minor moraines." At this stop we can see the relationship between the basal till and the "minor moraines" in outcrop. Later in the day we will see identical relations only in cores at Stops 6, 7, and 8.

At this stop we should also note the relationship of the Des Moines Lobe deposits to the underlying strata. Beneath the basal till in the described section, a weak A/C soil profile occurs at the top of the Wisconsinan loess. The A-horizon in the loess was 15-25 cm (6-10 inches) thick, and was leached of carbonates. The leaching extended 5-8 cm (2-3 inches) into the underlying C-horizon. At the contact between the till and the paleosol several broken logs occurred. Two different log fragments were identified as larch (*Larix* undiff., Dr. Dwight Bensend, Dept. of Forestry, Iowa State Univ., pers. commun.). One of these logs from the contact was radiocarbon dated at 14,380 ± 180 RCYBP (I-9765). This dates the advance of the Des Moines Lobe ice in this area. No loess overlies the Des Moines Lobe deposits and this and other dates mark the upper limit for significant regional loess deposition at about 14,000 RCYBP in Iowa.

The loess in turn overlies a strongly developed paleosol formed in Pre-Wisconsinan sediments and till. This till is correlated with the Wolf Creek Formation of Pre-Illinoian age (Hallberg, 1980) and overlies Mississippian bedrock.

Since the original sampling, the quarry operation has expanded significantly, and the face of the Quaternary deposits has been moved more than 30 m (100 feet). The Wisconsinan section is still very similar to that described (figure 26). However, beneath the loess the paleosol which occurs is now seen to be developed in fine-textured pre-Wisconsinan alluvial sediments which in turn overlie bedrock. Note that across the quarry, the basal till does not lie on bedrock but on older Quaternary sediments. Thus, in analyzing the sub-Des Moines Lobe surface, one *cannot* deal just with bedrock surface. In fact, since only a very small percentage of the Des Moines Lobe deposits in Iowa rest on bedrock, one must be extremely cautious in using the configuration of the bedrock topography as the basis for inferring the flow regime of the Des Moines Lobe ice.

Road Log

Accumulated Mileage (km)	Increment Mileage (km)	Discussion
		Turn left (W) to exit from quarry onto U.S. 20. The route can be followed on figures 25 and 27 (as well as figure 2).
53.8 (86.6)	1.1 (1.8)	Turn right (N) at Jct. U.S. 20 and Ia. 359, and go into town of Alden. To the west, about 1 mile (1.6 km) Altamont I can be seen.
54.3 (87.4)	0.5 (0.8)	Stop sign, Water Street; continue straight across Iowa River and

OMISSION: P. 84; entry at 59.3 miles in road log; turn left (west) county road S-13.

54.5 (87.7)	0.2 (0.3)	Turn left on paved road (County S-25) on north side of Iowa River. Traverse low terrace along river; to the southeast this level is in part a rock bench.
54.9 (88.3)	0.4 (0.6)	Rise back onto uplands, marked by somewhat dissected N-S oriented "minor moraines."
56.0 (90.1)	1.1 (1.8)	Look to left (W) across Iowa River and see the high terrace; the terrace is inset about 30 feet (9.4 m) below the uplands, the terrace scarp is about 35 feet (10.7 m) high; the terrace sands and gravels are about 15 feet (4.6 m) thick and are then underlain by till of the Des Moines Lobe.
57.1 (91.9)	1.1 (1.8)	T-intersection; turn left (W) on S-25; onto low terrace.
57.1 (92.2)	0.2 (0.3)	Road S-25 curves back to right (N); enter Franklin County.
57.8 (93.0)	0.5 (0.8)	Rise back onto uplands; just to left (W) about 0.2 mile (0.3 km) is the Altamont I moraine. The road is on a low relief, non-patterned area between Altamont I and "minor moraines" to the right (E).
59.3 (95.4)	1.5 (2.4)	Jct. S-13; higher elevation areas of the Altamont I ridge to north and west.
59.9 (96.4)	0.6 (1.0)	Rise up on to the Altamont I ridge.
60.2 (96.9)	0.3 (0.5)	Road curves to right (N).
60.7 (97.9)	0.5 (0.8)	Road turns left (W), on crest of Altamont I. Topographically lower area to west marked by poorly expressed N-NW trending "minor moraines," with irregular hummocks superimposed.
61.1 (98.3)	0.4 (0.6)	Descend backslope to Altamont I; the complex Altamont I ridge swings to the NW from this area.
62.1 (99.9)	1.0 (1.6)	Stop sign; in town of Popejoy. Continue straight on county road S-13.
62.6 (100.7)	0.5 (0.8)	Gradually descending onto outwash-terrace complex along Iowa River.
63.1 (101.5)	0.5 (0.8)	Descend to lower terrace.
63.6 (102.3)	0.5 (0.8)	Road turns to right (N).

Figure 27. Black-and-white print of Iowa Geological Survey color-infrared aerial photograph showing Stop 2 in high-relief hummocky ridge form area of Altamont I. This photo overlaps with figure 25.

63.8 (102.7)	0.2 (0.3)	Rise onto high terrace surface.
64.7 (104.1)	0.9 (1.5)	Very gradual rise, off of terrace, onto low-relief, nearly featureless till upland.
65.6 (105.6)	1.8 (2.9)	Cross RR tracks; backside of Altamont I just ahead (to N).
66.1 (106.4)	0.5 (0.8)	T-intersection of paved roads; turn left (W) on S-13; return onto complex outwash deposits.
62.7 (107.3)	0.6 (1.0)	Cross RR tracks.
67.3 (108.3)	0.3 (1.0)	Overpass, over I-35.
67.6 (108.9)	0.3 (0.5)	Road turns to right (N).
68.4 (110.1)	0.8 (1.3)	Cross RR tracks.
68.7 (110.5)	0.3 (0.5)	Road veers right (NE); enter belt of high-relief "knobby drift" as it was recognized and called by Owen in 1852.
69.0 (111.0)	0.3 (0.5)	Continue straight, paved road goes to left.
69.2 (111.3)	0.2 (0.3)	Turn right, just before bridge over Iowa River; continue on gravel road, through Owen's knobby drift. Everything that has been traversed on the trip to this point (from the minor moraine areas to the present high-relief hummocky topography) has been included as part of the Bemis "Moraine" in recent mapping (1940's on) of the Des Moines Lobe. The high-relief "knobby" drift in this region is part of the Altamont I ridge complex of this report (see discussion in text).
70.3 (113.1)	1.1 (1.8)	Go across creek and turn left into Weaver Construction Co., Dows Quarry Section, Stop 2.

Stop 2. Dows Quarry Section; Weaver Construction Company Quarry located on the west side of the gravel road in the NE¼ of the SE¼, sec. 30, T. 91N., R. 22W., Franklin Co. Elevation 1160 feet (353 m). the Dows Quarry Section is on the flanks of the high-relief Altamont I ridge complex.

Objectives:

There are several items which we want to observe and emphasize at this site:

1. The nature of the supraglacial sediments. At this site we can observe a number of features indicative of deposition in the supraglacial environment.

2. The contrast between the supraglacial sediment sequence and the dense, uniform basal till.

3. The nature of "block inclusions" which occur in basal till. Block inclusions are blocks of local substrate which have been eroded and deposited intact within the basal till.

4. One of the subglacial deformational structures, slickensides, which have developed in a paleosol that occurs just beneath the basal till of the Des Moines Lobe deposits.

5. The stratigraphic relationship between the Des Moines Lobe deposits and the underlying materials. This site, as at Stop 1, consists of Des Moines Lobe deposits which overlie a complex sequence of older Quaternary sediments, not bedrock.

The Dows Quarry Section is the principal reference section for the Dows Formation (Des Moines Lobe deposits in Iowa) and a member of that formation, the Morgan Member. This member consists of supraglacial tills, diamictons, and any included meltwater deposits. The location of the Dows Quarry Section and its relationship to various glacial landforms in the area are shown on figure 27. The Dows Quarry Section is located on the back side of a hummocky, high-relief ridge, the Altamont I Moraine.

In brief, the sequence at this location consists of approximately 13 m (40 feet) of Des Moines Lobe deposits (Dows Formation) of which the upper 8 m (25 feet) consists of supraglacial tills, diamictons, and associated meltwater deposits (Morgan Member), while the lower 5 m (15 feet) consist of basal till (Alden Member). The Des Moines Lobe deposits overlie a second till, which we have informally designated as Till 2. Till 2 is up to 3 m (9 feet) thick across the section. The lithologic and mineralogic data for Till 2 are very similar to the "Tazewell" till (early Woodfordian) of northwestern Iowa, rather than to Pre-Illinoian age tills in east-central Iowa. Till 2 in turn overlies a well-developed paleosol developed in pre-Wisconsinan sediments that rest on a third till of Pre-Illinoian age. The combined thickness of these sediments and the third till in the sequence is approximately 5 m (15 feet) across the section. These units in turn rest on Mississippian age limestone.

The stratigraphy, particle size, clay mineral, and carbonate data for only the Dows Formation of the sampled section is shown on Figure 28. Clay mineralogy data for the Dows Formation and the underlying Till 2 are shown on Table 10. The Dows Formation at this site consists of a thick sequence of supraglacial tills, diamictons, and meltwater deposits (Morgan Member) over basal till (Alden Member). In the described section, the supraglacial sediments (Morgan Member) are 8 m (24.5 feet) thick. At other parts of the section, the Morgan Member constitutes nearly all of the Dows Formation at the site. This section displays one of the best sequences of supraglacial sediments in the state. A number of features indicative of supraglacial sedimentation are present including interbedded till-like sediments and meltwater deposits which show various structures indicative of collapse of adjacent and underlying ice. Figure 15 shows deformed meltwater sediments from what appears to be a collapsed ice-walled channel.

The great variability in the supraglacial sediments across the section makes sampling difficult. To present the section and data for documentation we have simply sampled one vertical section as an example of the variability present (figure 28). There are two questions we would like you to ponder as you study this section: 1) what would these materials look like in a core, and how would they differ from the basal till sediments viewed at Stop 1; and 2) from a practical standpoint, would the differences in properties between supraglacial sediments and the basal till be important in applied studies, such as delineation of soil series, or in construction work, where slope stability, foundation design, septic tank suitability, seepage etc. must be evaluated?

Although one would always like to be able to reconstruct the exact sequence of events that have occurred at a site, this may not always be possible in a sequence of supraglacially-deposited sediments, even when they are as well or convincingly exposed as at this section. The reason for this is because of the dynamic nature of the supraglacial environment. This mixture of till-like sediments and meltwater deposits has likely been subjected to more than one period of post-depositional flow and collapse as the underlying ice melted out obscuring the record. The result of these multiple periods of deformation would be to produce a chaotic mixture of till-like sediments and meltwater deposits. For instance while the boundaries of one till-flow might be easy to recognize, if subsequent flow or collapse involves only a portion of that flow, reconstructing the sequence of events becomes significantly more difficult. Imagine what the difficulty becomes if parts of this flow were subject to several such events.

This section provides one of the principal correlation sections between landforms and sediments on the Des Moines Lobe. Thick supraglacial sediments tend to occur in the hummocky, high relief areas. The Dows Quarry Section in this case is located on the back side of a hummocky, high relief ridge system, the Altamont I Moraine, which is part of the eastern, lateral ice-marginal position of the Altamont Moraine. We will see a similar setting of thick supraglacial sediments, but in a core, at the hummocky, high relief ridge (Bemis Moraine) at Stop 4. Using cores at Stop 4, we can sample the materials from the very crest of the ridge form.

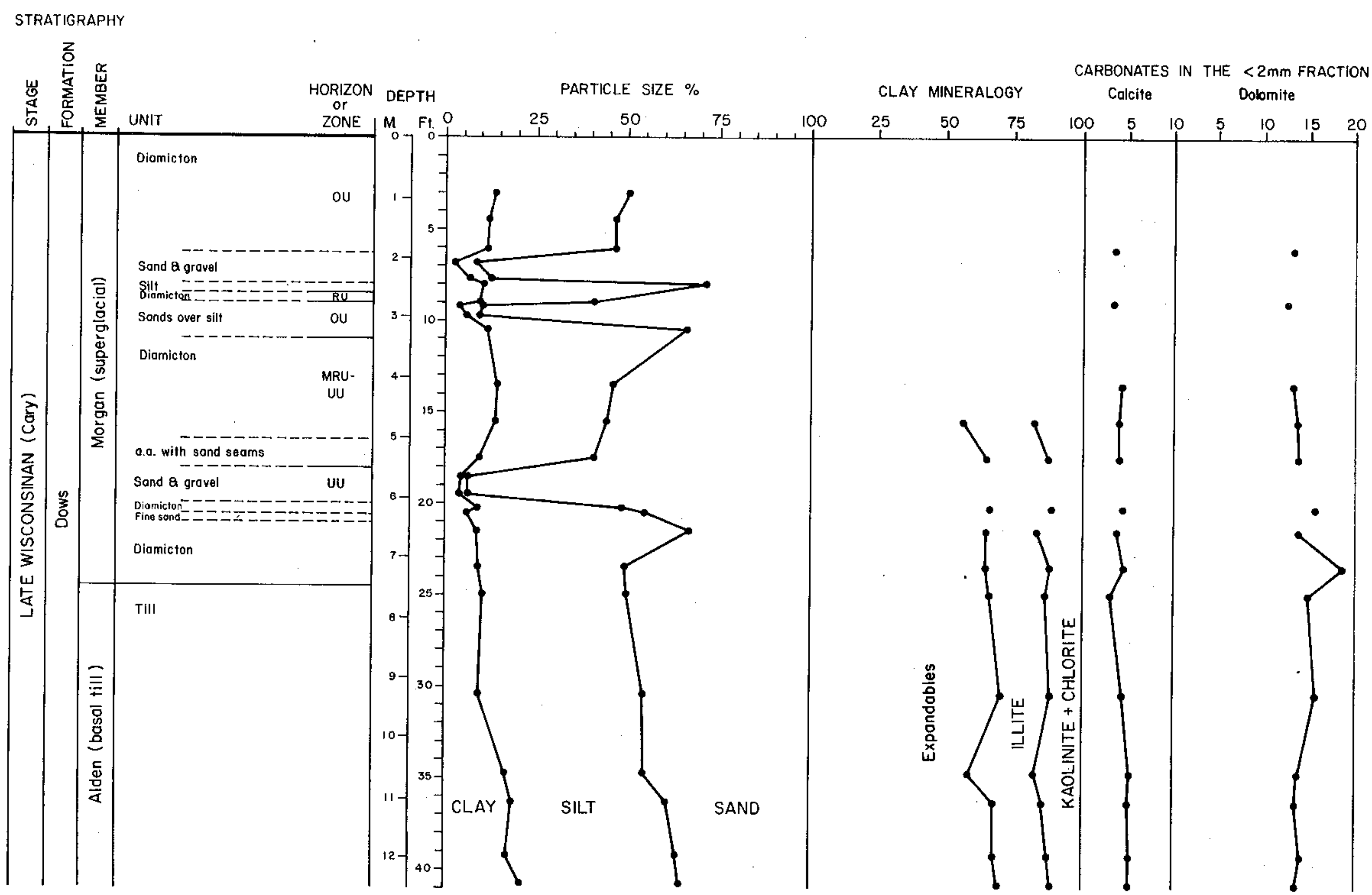


Figure 28. Stratigraphy, particle-size and mineralogy data for the Dows Formation, Des Moines Lobe deposits at the Dows Quarry Section.

The Alden Member at this section displays typical features of basal till; it is dense and uniform in composition and has essentially no interbedded meltwater deposits: a strong contrast to the overlying supraglacial sediments. The basal till at the described section (figure 28) is 5 m (16.5 feet) thick. This is about the thickest area of basal till in the exposure. In other places in the exposure, the basal till may thin to as little as 0.5-1.0 m (2-3 feet). Two pieces of spruce wood from the lower 0.8 m of the basal till have been dated at 13,525 ± 95 RCYBP (Beta-1076) and 13,400 ± 130 RCYBP (DIC-1651; see also Table 1).

The Des Moines Lobe deposits at this site rest on a second till, "Till 2," or where this till is truncated they overlie a paleosol developed in pre-Wisconsinan sediments. The clay mineralogy data for Till 2 appear in Table 10, while particle size and matrix carbonate data appear in Table 11. Additional data on Till 2 will be handed out on the field trip.

Till 2 is oxidized (yellowish brown color) over much of the exposure, and as a consequence, the abrupt contact with the unoxidized (dark greenish gray) basal till of the overlying Dows Formation is pronounced. Till 2 is truncated at the very north end of the Dows Quarry exposure. Elsewhere, Till 2 varies from 1-3 m (2-9 feet) in thickness and is comprised primarily of basal till.

At the north end of the exposure "block inclusions" are present within Till 2. They consist of blocks of underlying substrate which have been eroded and deposited intact within the basal till. The block inclusion which we will see (figure 10) is a block of the underlying paleosol. The color and texture contrast between the gleyed paleosol and the oxidized basal till of Till 2 is pronounced, making these block inclusions easy to recognize. At this section a valuable stratigraphic marker, the Wisconsinan loess, is absent. Till 2 could thus be either an earlier Woodfordian till (the "Tazewell" till of Iowa) or a Pre-Illinoian age till from which the overlying loess and paleosol have been eroded. In the absence of "complete" stratigraphic sections, regional data on till lithology provide a method for correlation. Lithologic data (Tables 10 and 11) suggest that Till 2 correlates with the "Tazewell till." Till 2 is loam textured, but the silt content is greater than the sand content. The clay mineralogy shows a high expandable content with illite slightly higher than kaolinite, and the matrix carbonate data show a relatively high total carbonate content and a C/D ratio between 0.3 and 0.4. These lithologic data contrast with data for Pre-Illinoian age tills in east-central Iowa (Hallberg, 1980; Hallberg, Wollenhaupt and Wickham, 1980), but are very similar to data on the "Tazewell till" in northwest Iowa (Hallberg and G.A. Miller, unpublished data). In outcrop, Till 2 also has physical features different from those typically found for Pre-Illinoian age tills in the area. It does not have the pervasive jointing often found in the Pre-Illinoian tills, and what joints are present lack the strong secondary alteration found along joints in Pre-Illinoian age tills in Iowa. Till 2, although oxidized across most of the section, is not oxidized to the bright yellowish-brown and reddish brown colors typically found for the Pre-Illinoian age tills. One discrepancy between Till 2 and typical "Tazewell till," however, is in the content

Table 10. Clay Mineralogy - Dows Quarry Section.

Depth M(ft.)	Horizon or Zone	Clay Mineralogy % Ex.	Ill.	K+C
LATE WISCONSINAN (Cary)				
	DOWS FORMATION			
		Morgan Member (superglacial deposits)		
4.7 (15.5)	UU	56	26	18
5.3 (17.5)	UU	64	23	13
6.1 (20.0)	UU	66	22	12
6.6 (21.5)	UU	64	18	18
7.2 (23.5)	UU	64	24	12
		Alden Member (basal till)		
7.6 (25.0)	UU	66	20	14
9.1 (30.0)	UU	70	18	12
10.7 (35.0)	UU	61	21	18
11.0 (36.0)	UU	67	18	15
11.9 (39.0)	UJU	67	20	13
12.5 (41.0)	UJU	69	19	12
WISCONSINAN (Tazewell) or older?				
	Till 2			
Variable	RJU	61	19	20
"	RJU	65	18	17
"	UJU	58	17	15

Table 11. Laboratory data for till 2, Dows Quarry Section.

Particle Size % Clay	Silt	Sand	C/D	Chittick Carbonate % Cal.	Dol.	T.C.
20.4	45.0	34.6	0.41	5.3	13.0	18.3
21.4	44.1	34.5	0.41	5.7	13.9	19.6
21.9	42.2	35.9	0.37	5.3	14.2	19.5
21.3	44.5	34.2	0.38	6.1	16.1	22.2
23.5	41.9	34.6	0.40	5.8	14.5	20.3

of shale clasts. Till 2 at this site contains only about 2% Cretaceous shale clasts in the ½-1 inch pebble fraction. Cretaceous shale clasts in the "Tazewell till" of northwest Iowa are much more conspicuous and occur in higher percentages (Van Zant, 1974). Even so, we tentatively correlate Till 2 to the "Tazewell till."

[During the preparation of the guidebook a radiocarbon date was run on wood fragments from the base of Till 2. The date was 25,390 ± 1380 RCYBP (Beta-1764). This date is somewhat older than the 20,000 RCYBP dates reported by Ruhe (1969) for the Tazewell till in northwestern Iowa. Further details on this section will be handed out on the field trip.]

Till 2 rests on a paleosol developed in pre-Wisconsinan sediments that in turn rest on a Pre-Illinoian age till. Where Till 2 is truncated, the Dows Formation (Des Moines Lobe deposits) rests on the truncated paleosol. The total thickness of the pre-Wisconsinan sediments and the Pre-Illinoian age till is approximately 5 m (15 feet) across the section. The Pre-Illinoian till is poorly exposed over most of the exposure. It is probably thickest at the north end of the quarry, reaching thicknesses of a few feet. To the south it appears to thin while the overlying sediments thicken to comprise nearly all of this interval. Data on the sediments, paleosol, and Pre-Illinoian age till will be handed out on the field trip. Based on mineralogic data, the till correlates with the Pre-Illinoian age Wolf Creek Formation (Hallberg, 1980).

At the north end of the exposure, where the (truncated) paleosol in the pre-Wisconsinan sediments is directly overlain by the basal till of the Dows Formatin (Des Moines Lobe deposits), are features worthy of note. The truncated paleosol has been strongly deformed by the overriding ice of the Des Moines Lobe. The paleosol exhibits well-expressed slickensides on large shear faces of varying orientation. This is a good exposure to see these features resulting from subglacial deformation of unlithified sediments.

A final note on the Dows Quarry Section, this section, as at Alden (Stop 1), does not display the simple relationship of till over bedrock. A well-preserved sequence of older Quaternary strata underlie the Des Moines Lobe deposits. What are the implications of this sequence? First, the bed of the Des Moines Lobe ice consisted largely of what is thought of as "soft" sediment. The good preservation of much of the sequence in Iowa suggests that at this part of the Des Moines Lobe, glacial erosion was minimal. Secondly, when one wants to construct the sub-Des Moines Lobe surface to aid in the interpretation of the ice dynamics of the Des Moines Lobe, one cannot use the bedrock surface. This should be obvious. One must use the configuration of the deposits immediately beneath the Des Moines Lobe sediments, be they older Quaternary deposits, as they are over most areas of the Des Moines Lobe in Iowa, or bedrock. Also, the Quaternary rock units must be recognized and defined to accomplish this.

Also, the exposures at Alden and here at Dows are typical of most exposures beneath the Des Moines Lobe in that there is no evidence of any large-scale deformation beneath the Des Moines Lobe. Over large areas relatively plastic and "deformable" sediments show generally sharp continuous contacts, with evidence for only minor, local erosion or deformation. A prime example is the widespread preservation of the buried A-horizon in the loess below the basal till at Alden. These sequences clearly argue against Boulton and Jones (1979) hypotheses of large-scale, pervasive deformation in Quaternary sediments toward the margin of the Laurentide ice sheet.

Road Log

Accumulated Mileage (km)	Increment Mileage (km)	Discussion
70.3 (113.1)		Turn left (N) out of Dows Quarry.
70.8 (113.9)	0.5 (0.8)	Turn right (E) at stop sign with paved road, C-47.
71.5 (115.0)	0.7 (1.1)	Approaching Int.-35; in this area and particularly to the right (SE) the high-relief, irregular hummocky topography of the Altamont I moraine is apparent. To the left (N) is a lower elevation, moderate relief "minor-moraine" area.
71.8 (115.5)	0.3 (0.5)	Turn right (S) onto southbound Interstate 35.
74.4 (119.7)	2.6 (4.2)	Near overpass, the Altamont I ridge swings off to the left (SE) from this area; road drops down in elevation to complex outwash area and terraces along the Iowa River.
75.6 (121.6)	1.2 (1.9)	I-35 MP (mile-post) 156; drop down onto low terrace along Iowa River.
76.6 (123.3)	1.0 (1.6)	I-35 MP-155; Wright County line; cross Iowa River. Continue across floodplain and outwash terraces.
78.3 (126.0)	1.7 (2.7)	To right (W) is an elevated outwash plain in front of the Altamont II moraine complex; the area is marked by kame-like knobs; note numerous gravel pits. Some of the pits contain a few feet (1 m) of till over coarse sands and gravels; within the gravels are occasional inclusions of till and till balls. The gravels are over 75 feet (23 m) thick locally.
79.8 (128.4)	1.5 (2.4)	Woolstock exit; in moderate relief area on ridgeform, which is the easternmost ridge of the Altamont Moraine Complex (Altamont Complex or Altamont C, figure 2).

81.3 (130.8)	1.5 (2.4)	Enter lower elevation, low to moderate relief, irregular hummocky landform area; to left and right (W and E) the area is bordered by higher elevation ridges forms which are part of the Altamont Moraine Complex. These ridges merge to the south (see figure 2).
84.4 (135.8)	3.1 (5.0)	At overpass Co. Road D-20; rising up onto ridge of Altamont Complex.
85.7 (137.9)	1.3 (2.1)	Coming down in elevation off the front of the ridge; town of Williams to left (E).
86.3 (138.9)	0.6 (1.0)	From overpass look to right (W) to see ridges of Altamont Complex merging.
87.3 (140.5)	1.0 (1.6)	Overpass for U.S. 20. From here south to Ames the route will parallel the Skunk River Valley, just off to the right (W). Some of the areas traversed will show the affects of stream dissection because of the proximity to the Skunk River. The upland constructional topography is marked by moderate relief, irregular hummocky knobs, with some circular depressions and some circular ridge forms.
93.1 (149.8)	5.8 (9.3)	Drop down in elevation in proximity to Skunk River Valley to right (W).
98.3 (158.2)	5.2 (8.4)	Ellsworth and Eldora exit; from here one can look ahead (S) and down into a lower elevation area, which again is marked by "minor moraines" oriented NE-SW.
101.5 (163.3)	3.2 (5.2)	Land-surface drops off in elevation again, in slightly dissected area in the proximity of the Skunk River.
103.2 (166.1)	1.7 (2.7)	Overpass at Randall exit; low area which trends to SE is the axis of the "Randall scalloped" belt (Foster, 1969); this marks the linear junction between convergent curvilinear orientations in adjacent "minor moraine" belts.
105.0 (169.0)	1.8 (2.9)	I-35 MP-126; Story County line, West Skunk River valley.
106.1 (170.8)	1.1 (1.8)	Rise back up into upland "minor moraine" area; south from there the road skirts the Skunk River valley, passing through dissected "minor moraine" area. On horizon to left (E) is the backside of the Altamont I ridge.

111.2 (178.9)	5.1 (8.2)	Adjacent to junction of Skunk River and Bear Creek; note remnant upland "island" to right (W); Altamont I ridge ahead to S and E).
113.1 (182.0)	1.9 (3.1)	Rise up onto backslope of Altamont I morainal ridge.
114.4 (184.1)	1.3 (2.1)	Descend foreslope of Altamont I onto much lower elevation "minor moraine" topography.
116.3 (187.1)	1.9 (3.1)	National Animal Disease Lab on right (W).
118.9 (191.3)	2.6 (4.2)	Junction with U.S. 30; exit onto eastbound U.S. 30, to Nevada. The cloverleaf is on the edge of the Skunk River floodplain; U.S. 30 East rises back up onto "minor moraines" in upland. This will repeat part of the route from the first part of the trip.
121.9 (196.1)	2.9 (4.7)	Looking to right (S) down the gravel road, the regular undulations of the "minor moraines" can be seen; the "minor moraines" are oriented E-NE in this area.
124.7 (200.6)	2.8 (4.5)	Rising on overpass; look N or S for good view of "minor moraines."
124.9 (201.0)	0.2 (0.3)	Junction county road S-14. The route from here to the terminus of the Des Moines Lobe gradually and continuously rises in elevation (except for the interruption of stream valleys); see figure 22 and discussion in text.
125.5 (201.9)	0.6 (1.0)	Cross West Indian Creek.
125.9 (202.6)	0.4 (0.6)	Intersection on southeast-side of Nevada; location of Stop 6 on return route.
128.2 (206.3)	2.3 (3.7)	Cross East Indian Creek. "Minor moraines" end. East of here the landsurface rises in elevation into an area of moderate relief, irregular hummocky topography. From here to Dry Creek the area is also modified by stream dissection.
129.4 (208.2)	1.2 (1.9)	Cross Dry Creek.
129.8 (208.9)	0.4 (0.6)	Out of dissected area into region of relatively undissected moderate relief, irregular hummocky landforms.
132.3 (212.9)	2.5 (4.0)	Colo, Iowa, on left (N).

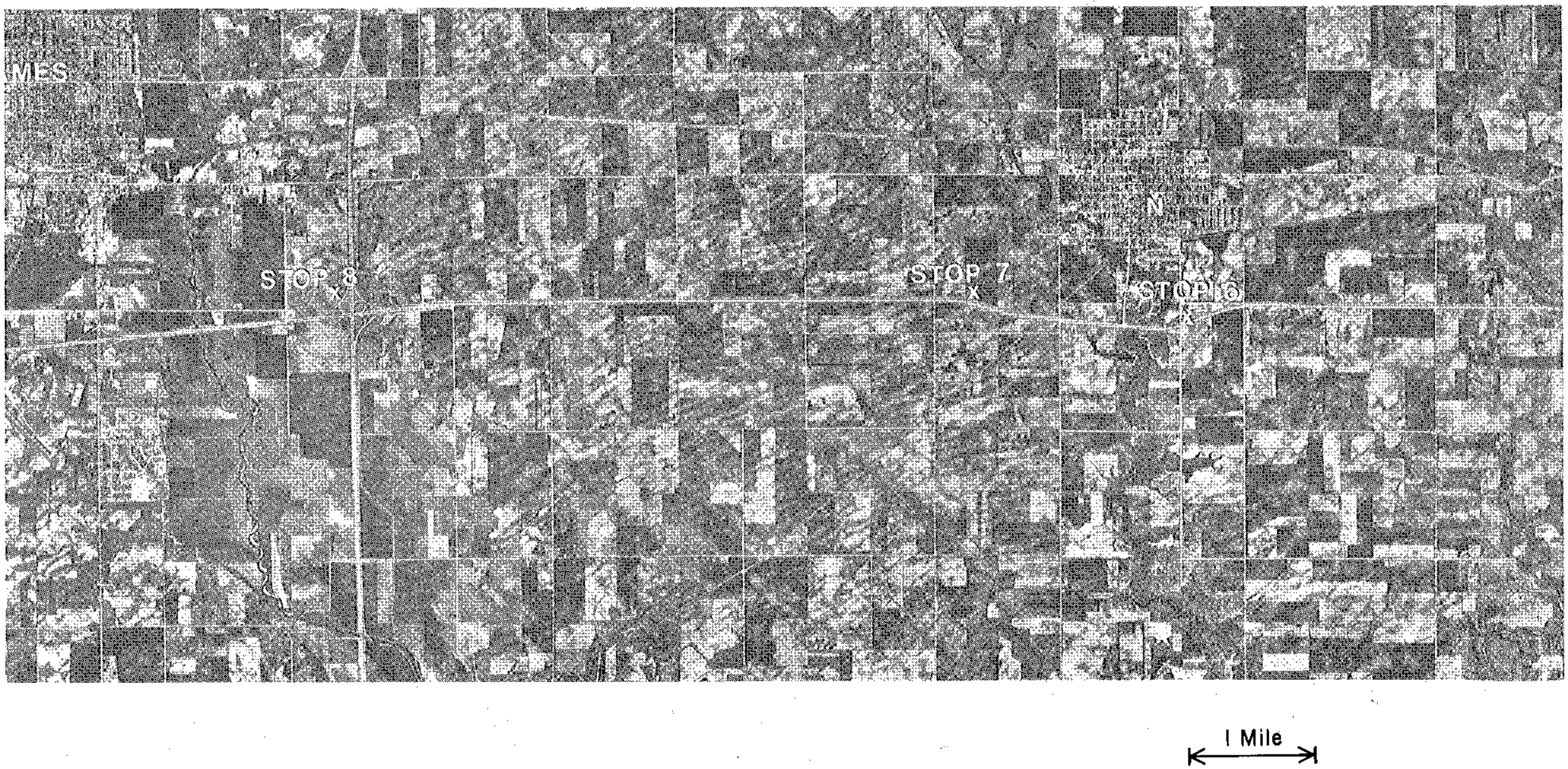


Figure 29. Black and white print of Iowa Geological Survey color-infrared aerial photograph. Photo shows field trip route along U.S. 30 from Ames to Nevada, and Stops 6-8. Area dominated by moderate to low relief "minor moraine" ridges. Superimposed irregular hummocks become more common to the east (right). Compare with figures 2 and 22.

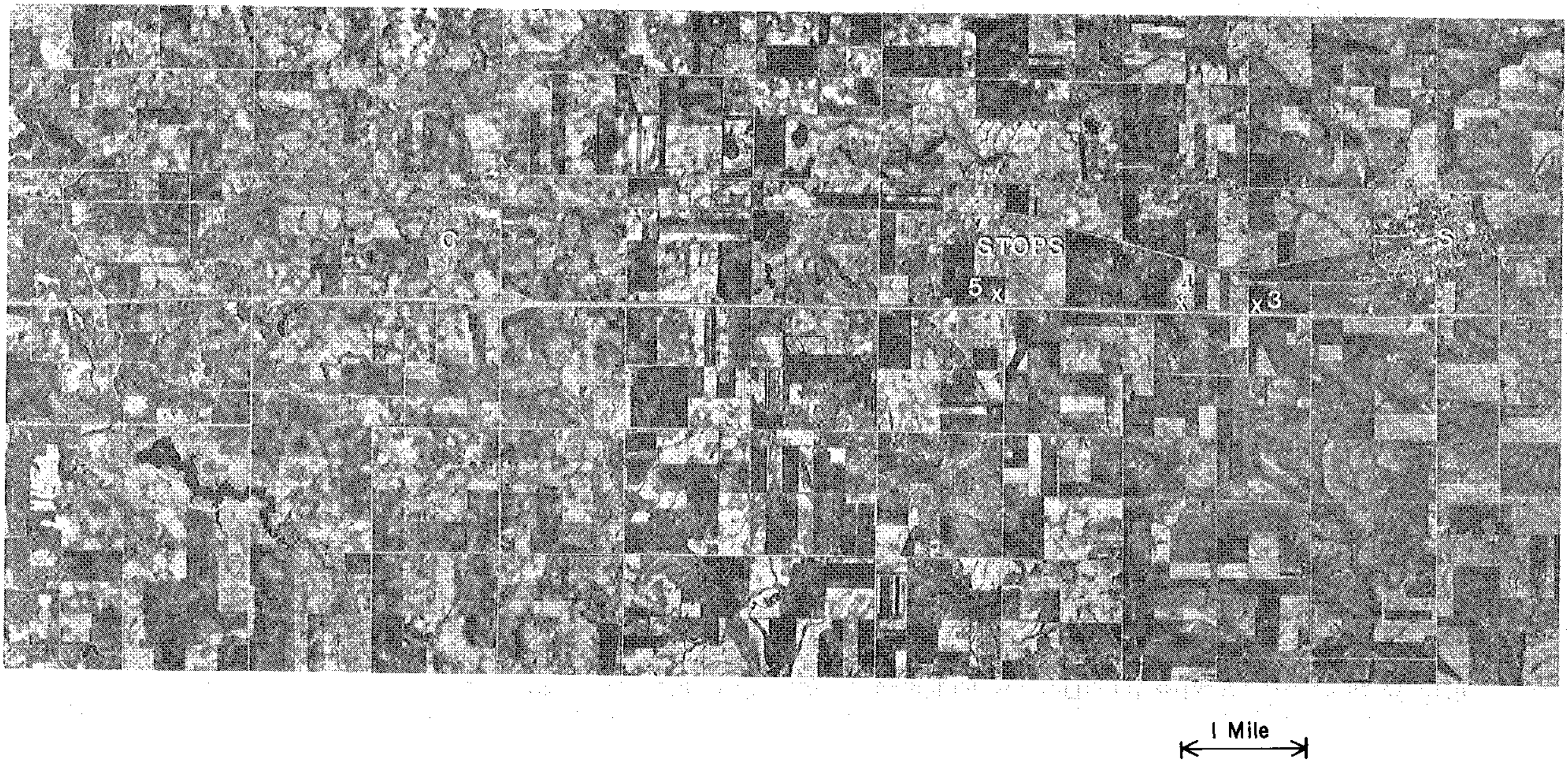
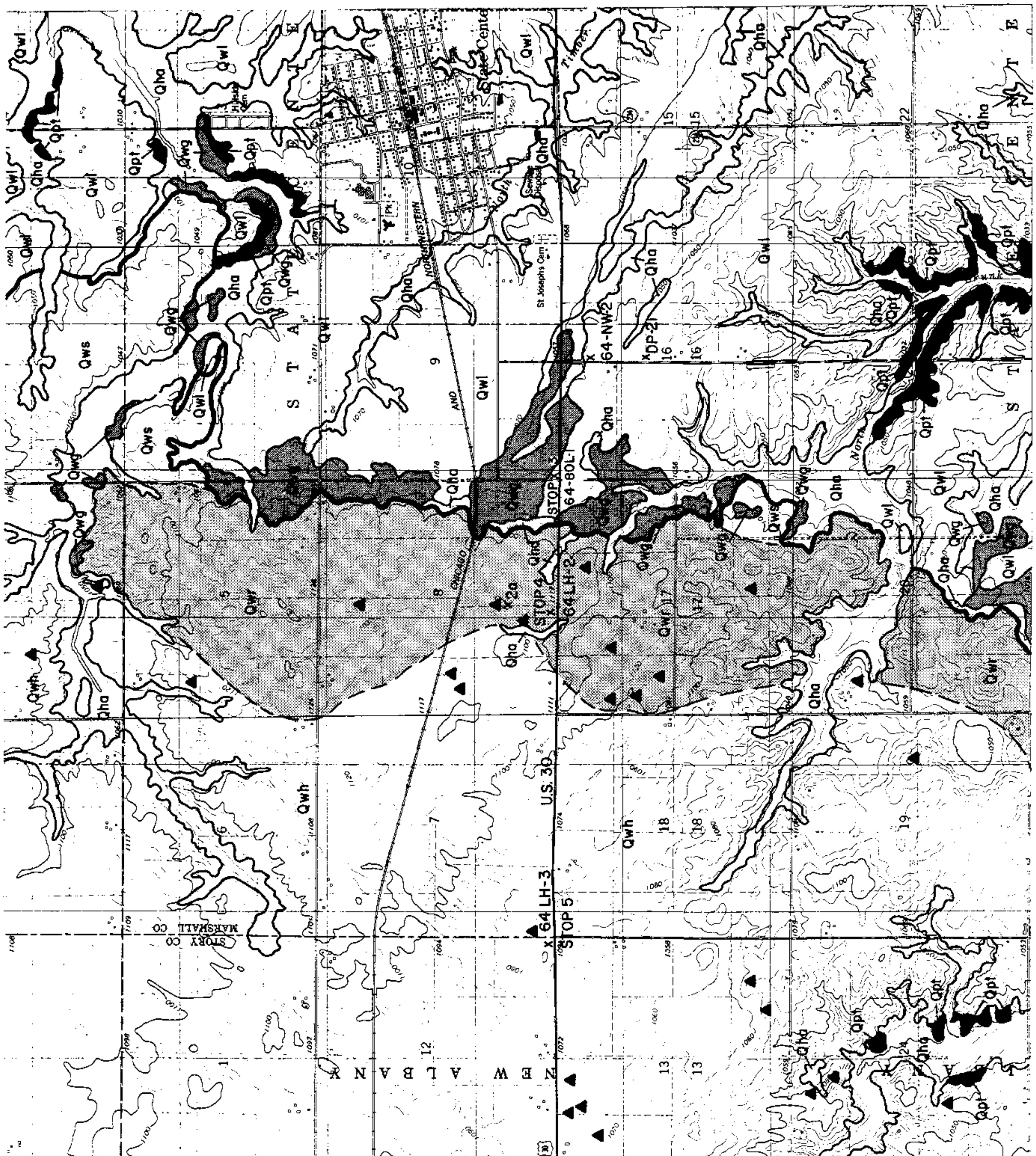


Figure 30. Black and white print of Iowa Geological Survey color-infrared aerial photograph. Photo shows field trip route along U.S. 30 from Nevada through Colo to State Center. Area is dominated by moderate relief irregular hummocky topography which rises in elevation and increases in relief to the east (right). Stop 4 is on the terminal ridge or Bemis Moraine. Stop 3 is on the loess-mantled pre-Wisconsinan uplands outside the moraine. Compare with figure 31, 2, and 22.

Figure 31. Geologic Map of the State Center Area.

EXPLANATION

Map Symbol	Unit
HOLOCENE AND LATE WISCONSINAN	
Qha	Holocene alluvium and colluvium; silty to loamy textured deposits; may overlie Qwg. Holocene sediments on slopes and in closed depressions on Des Moines Lobe deposits not mapped.
Qwg	Late-WISCONSINAN fluvial deposits, including glaciofluvial outwash; coarse sands with minor gravel. May be overlain by minor Qha.
LATE WISCONSINAN	
Des Moines Lobe Deposits (DOWS FORMATION)	
	Eastern limits of Des Moines Lobe till deposits (Qwr, Qwh, Qws).
Qwr	Thick (5-20 m) superglacial deposits (till, diamictons, and, related sediments) in high-relief terminal ridge.
Qwh	Moderate thickness (3-6 m) of superglacial deposits (generally over basal till), in areas of moderate-relief, irregular hummocky topography.
Qws	Moderate to thin superglacial deposits in gently sloping areas at the terminus of the Des Moines Lobe deposits
▲	Small outcrop of sand and/or gravel within superglacial deposits.
WISCONSINAN	
Qwl	Loess, silt loam, minor sandy zones; 5-6 m in thickness on divides.
SANGAMON TO PRE-ILLINOIAN	
Qpt	Yarmouth-Sangamon or Late-Sangamon Paleosols and Pre-Illinoian till of the Wolf Creek Formation; occur in small outcrops on sideslopes.


U.S. 30
STOP 4
STOP 5
64 LH-3
64-LH-2
64-NW-2
64-80L1
DP-2
St Josephs Cem
STORY CO
MARSHALL CO
N E W   A L B A N Y
190 000 FEET
T 84 N
T 83 N
Qwl
Qha
Qpt
Qwh
Qws
Qwg

132.8 (213.7)	0.5 (0.8)	Jct. U.S. 65.
135.0 (217.2)	2.2 (3.5)	To east (straight ahead) you can begin to see the rise of the terminal ridge of the Des Moines Lobe. The landsurface continues to rise in elevation and local relief also increases.
136.7 (220.0)	1.7 (2.7)	Story-Marshall County Line; approaching terminal ridge.
137.6 (221.4)	0.9 (1.5)	Begin rise on backside of terminal ridge - the Bemis Moraine - of the Des Moines Lobe.
138.2 (222.4)	0.6 (1.0)	On crest of terminal ridge; view to the east shows lower elevation landscape (50-80 feet; 15-25 m lower) which is comprised of moderately thick loess over Yarmouth-Sangamon and Late Sangamon Paleosols developed on Pre-Illinoian tills. Descend onto this surface.
138.8 (223.3)	0.4 (0.6)	Turn left onto gravel road; Stop 3.

Stop 3. Core Site 64-80L-1; the core was taken from natural surface on the north side of U.S. 30, at the junction with the gravel road; the location is the SW¼, of the SW¼, of the SW¼, sec. 9, T. 83N., R.20W., Marshall County (see figure 31). Elevation 1076 feet (328 m). The site is on a loess-mantled Yarmouth-Sangamon upland, only 0.3 km (0.2 mile) from the terminus of the Des Moines Lobe.

Objectives:

The purposes of this stop are:

1. To view the prominent terminal ridge of the Des Moines Lobe;
2. To note the relations of the landforms and materials at and in front of the margin of the Des Moines Lobe;
3. To examine the older Quaternary sediments in front of the Des Moines Lobe, which can be traced back under the Lobe deposits.

The location of Stop 3 is shown on figures 30 and 31. Figure 31 shows the surficial geology of this area around State Center near the terminus of the Des Moines Lobe. From this location you can look back to the west and view the prominent terminal ridge of the Des Moines Lobe. The ridge rises 60-80 feet (18-25 m) above the elevation of Stop 3, which is on the loess-mantled divide just in front of the terminal ridge.

The stratigraphy of the site is (a detailed log with particle-size data will be handed out):

WISCONSINAN Loess

0-1.3 m (0-4.3 ft):	Modern solum (Tama-Muscatine intergrade)
1.3-2.9 (4.3-9.6):	MOL-MDL loess
2.9-3.6 (9.6-11.8):	MOU loess
3.6-3.7 (11.8-12.0):	MDU loess
3.7-5.3 (12.0-17.4):	DU loess; snail shells from here down.
5.3-5.5 (17.4-18.0):	MUU loess
5.5-6.4 (18.0-21.1):	UU loess
6.4-6.6 (21.1-21.6):	UU sandy loess
6.6-7.0 (21.6-23.1):	UU loess
Basal loess sediments	
Basal loess paleosol	
7.0-7.4 (23.1-24.3):	IIAb; silt loam to silty clay loam

YARMOUTH-SANGAMON PALEOSOL

undifferentiated sediments	
$7.4\text{-}7.9^{+}$($24.3\text{-}25.9^{+}$):	III Btgb; silty clay.

The till in which the Yarmouth-Sangamon Paleosol is also developed was not sampled here. But in nearby locations the surficial till is correlated with the Pre-Illinoian Wolf Creek Formation (Hallberg, 1980). The stratigraphy here just in front of the terminal moraine of the Des Moines Lobe is correlative to the sub-Des Moines Lobe stratigraphy at the Alden Section (Stop 1) and the Nevada Sections (Stop 6).

The basal loess paleosol from nearby LeGrand, Iowa has been radiocarbon dated at 24,500 ± 820 RCYBP (ISGS-553). This brackets loess deposition in the area between ca. 24,500 and 14,000 RCYBP (see Table 1).

The Yarmouth-Sangamon surface in this area appears to exhibit two levels. A drilling transect from just east of Stop 3 is shown in figure 32. The upper loess-mantled surface occurs above 1070 feet in elevation. This surface gently slopes down to a lower loess-mantled surface which occurs at about 1050-1060 feet in elevation. Both levels exhibit the same essential loess thickness (figure 32), and both show thick, gleyed paleosols developed on fine-textured sediments overlying till. The two levels seem to merge to the south from here. In this area, the typical Late-Sangamon surface and paleosol are inset below these surfaces along interfluves.

We also want to note the nature of the terminus of the Des Moines Lobe and related materials in this area. First, note on figure 31 that there is relatively little "outwash" (Qwg) associated with the terminus. What little glaciofluvial deposits are shown are relatively thin.

In several areas the slope on the terminal ridge is separated from the loess-mantled divide surface by colluvium in the footslope where they join. Another feature of note are the areas where the terminal ridge does not constitute the actual terminus of the Des Moines Lobe deposits. These areas are shown as Qws on figure 31, and can be seen both north

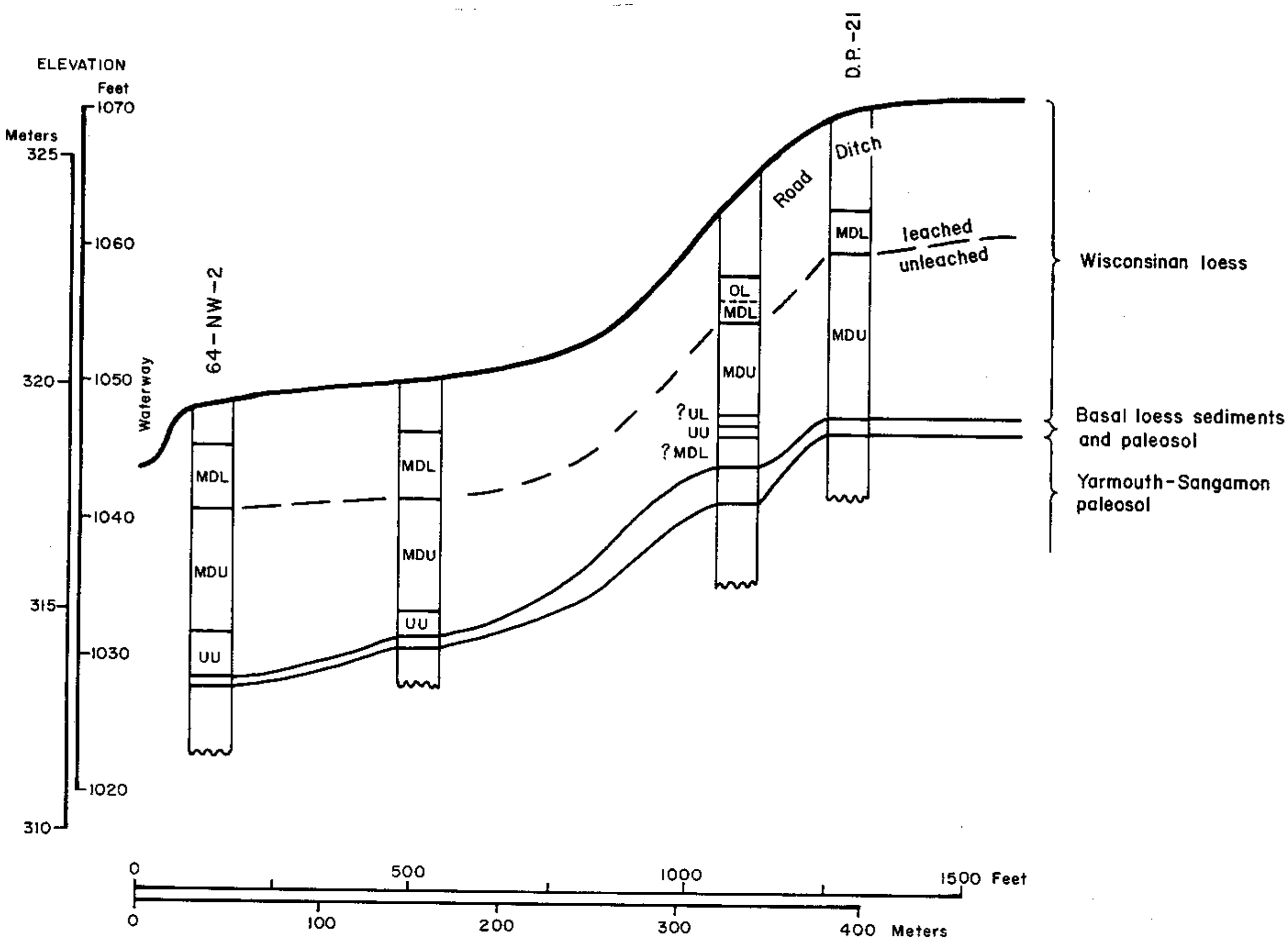


Figure 32. Drilling transect and cross-section across ridged, loess-mantled Yarmouth-Sangamon surface in the State Center area. Location of transect shown on figure 31. Data, in part, from unpublished work by Doug Oelmann and Norm Helzer.

and south of Stop 3. In these areas the Des Moines Lobe deposits occur on gently sloping interfluves. The deposits are comprised of silty diamictons and other supraglacial deposits which thin down these long slopes, and eventually pinch-out. These areas have been delineated, in part with the aid of modern, detailed soil surveys.

Road Log

Accumulated Mileage (km)	Increment Mileage (km)	Discussion
		Return onto U.S. 30, and go west retracing our route. Rise back up onto terminal ridge of Des Moines Lobe.

139.2 (224.0)	0.4 (0.6)	Stop 4; Core Site 64 LH-2; Marshall County; in the SE¼ of the SW¼, sec. 8, T. 83N., R. 20W. On the terminal ridge or Bemis Moraine of the Des Moines Lobe. Cores were taken from the road cut on right (N) side of U.S. 30.

Stop 4. Core Site 64 LH-2; the cores were taken from the benched road cut on the north side of U.S. 30; in the SE¼ of the SE¼ of the SW¼ of sec. 8, T. 83N., R. 20W.; Marshall County. Elevation 1135 feet (346 m). The section is from along the crest of the high relief terminal ridge, or Bemis Moraine, of the Des Moines Lobe. The location of the site is shown on figures 30 and 31.

Objectives:

The principal objectives of this stop are:

1. To examine the sequence of sediments which comprise the high-relief terminal ridge form.

2. To look at the topographic setting of the terminal ridge;

3. To briefly discuss postglacial modifications on the ridge.

Starting at this site on the terminal ridge we will begin our transect through successively different glacial landforms and different glacial sediment associations. The route will proceed back to the west, toward Ames, and roughly parallels the former ice-flow direction.

At Stops 1 and 2 we viewed in outcrop the two fundamental, generic categories of glacial deposits we will be concerned with: the basal till or Alden Member; and the supraglacial sediments of the Morgan Member. At most of the sites along this transect we will look at cores of the sediments comprising the landforms. You can relate these cores to what was observed in the exposures at Alden and Dows.

From the vantage point of Stop 4 of the terminal ridge you can look back to the east, toward Stop 3, and view the lower-lying loess-mantled landscape outside of the Des Moines Lobe. Looking to the west, toward the interior of the Lobe, the change in elevation is more gradual on the backside of the ridge. From this direction the ridge rises 30 to 60 feet (10-20 m) above the moderate-relief, irregular hummocky topography.

Within 1.5-2.0 miles (2.5-3.0 km) to the west the surface elevation on the Des Moines Lobe deposits gradually decline to the same elevation as the loess-mantled Yarmouth-Sangamon uplands in front of the Des Moines Lobe to the east. As discussed in the text and shown on figure 22, both the present land-surface on the Des Moines Lobe deposits, and the sub-Des Moines Lobe surface rise-up in elevation continuously from Ames to here at the terminus. In particular, from about Nevada the Des Moines Lobe glacier was advancing up hill until it stopped in this area, leaving this ice-marginal ridge.

At Stop 4 we are in the same general landform category, a high-relief ridge form, as at the Dows Section (Stop 2). Here, however, we can look at cores from a high point on the ridge. The stratigraphy, particle-size and bulk density data for this site are shown on figure 22; mineralogic data are given on Table 12.

The upper 10 m (32.5 feet) of sediments are comprised of a sequence of till-like deposits or diamictons, interbedded with sorted, bedded, silts and sands, and even some organic rich silts. Many of the diamictons are thin (0.2 m; 0.5 feet), and show changes in their particle-size distribution from top to bottom. This is typical of certain types of supraglacial mudflows (Lawson, 1979). We would interpret the upper 10 m here, as a sequence of supraglacial mudflows, interbedded with minor, thin, fluvial sediments (sorted sands and silts) and/or paludal sediments (organic silts and bedded silts). The local landscape relations suggest that there may be an additional 4.5 to 6.0 m (15-20 feet) of supraglacial sediments in the highest knobs on the ridge.

Compare the highly variable particle-size data and the types of sediments to those at Alden and Dows. Also note how variable the bulk densities are in vertical sequence compared to the Alden Section, and other sections of the basal-till presented in the text.

Although no large sand bodies occur here, some do occur locally in the supraglacial deposits. Small outcrops of sand and/or gravel are noted on figure 31 (triangle spot symbol).

The lower 2 m (7.5 feet) of sediments (figure 33), that could be penetrated here, have the characteristics of the basal till; particularly the lower 1.5 m (5 feet). These deposits consist of dense, texturally uniform till. Well logs from this general area suggest that there may be 2.5-5.0 m (8 to 17 feet) more Des Moines Lobe deposits below our cores. Without penetrating the entire sequence of deposits here it is difficult to make definitive interpretations. If these lower sediments are truly basal till then the Des Moines Lobe ice must have advanced to this position. Another alternative is that these lower most increments represent blocks or sheets of till that were: 1) either little altered by supraglacial processes; or 2) or were carried intact, as coherent blocks within a debris flow.

For the deposition of the thick supraglacial deposits, which constitute most of the terminal ridge, it seems likely that the ice front stood some distance back from the terminus. As till reached the surface of the melting ice some of it, because of its water content or steep slope, flowed down slope and into the terminal ridge area. The change from "till" to a mudflow created many of the sedimentological characteristics described for the diamictons (see Lawson, 1979). Some fluvial deposition also occurred in this ice-marginal setting, but these deposits were of very minor importance in this area. Organic rich debris, and or laminated silts may have accumulated in some local depressions. These small pond deposits may have also formed on the ice, and then moved as a debris flow as well. As ice blocks melted some of these materials may have been reworked several times. All these subaerial processes acted to produce the complicated sequence of relatively low-density, interbedded

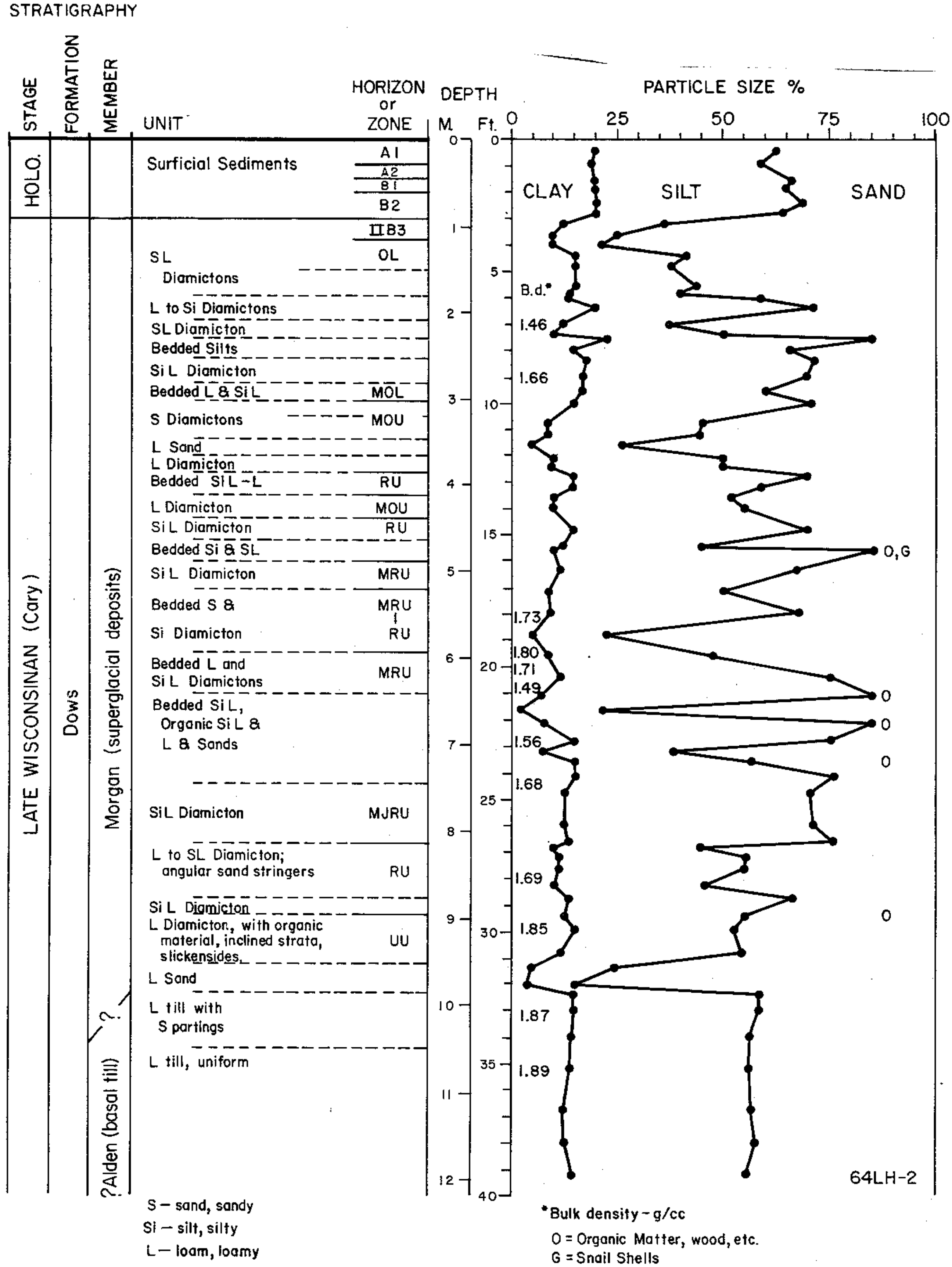


Figure 33. Stratigraphy, particle-size and density data core site 64 LH-2, Stop 4.

Table 12. Additional laboratory data, 64LH-2.

Depth M	(ft.)	Horizon or Zone	Clay Mineralogy % Ex.	Il.	K+C	C/D	Sand-Fraction Lithology % T.C.	Sh.	T.S.	Q.-F.	T.X.
			LATE WISCONSINAN (Cary)								
			DOWS FORMATION								
			Morgan Member (superglacial sediments)								
3.1	(10.0)	MOU				10	25	22	49	46	51
3.7	(12.2)	MOU	74	12	14	1.2	24	36	60	30	40
5.3	(17.5)	MRU	70	17	13						
6.1	(20.0)	MRU	69	13	18	8.3	28	9	38	58	62
6.3	(20.7)	MRU				0.6	27	10	37	55	63
7.7	(25.4)	MRJU	70	14	16	2.5	21	11	35	56	65
			?Alden Member (basal till?)								
9.8	(32.2)	UU				1.5	30	9	39	50	61
10.1	(33.2)	UU				1.2	24	14	38	51	62
10.7	(35.0)	UU	70	18	12						
11.6	(38.0)	UU	68	19	13	2.3	26	4	31	63	69

deposits of till-flows (diamictons), paludal, and fluvial sediments described. When the ice finally melted these terminal deposits became a ridge by topographic inversion, as the topographically higher ice front to the west disappeared. The overall nature of the terminal ridge deposits is strikingly similar to those in the terminus of the Illinoian deposits in southeastern Iowa (see Hallberg and Baker, 1980).

Other questions that may be pondered here regard the nature of the ice, the abrupt terminus of the deposits, and the lack of any significant glaciofluvial deposits? It would not seem that melt-water activity was very significant in this area. Looking back to the loess-mantled upland at Stop 3 is a good example. Except for some slope-wash and colluvium there is essentially a rather abrupt contact between the terminal ridge deposits and the loess-mantled surface to the east. On figure 31, some outwash deposits are shown along the margin of the moraine -- but these are very small areas and the deposits are quite thin.

Another point of interest here, for those interested in hillslope evolution, is the relationship between the hillslope - surficial sediments and the local landscape. As we have tried to point out we are dealing with modified remnants of constructional glacial features. That is also the case here on the knobby terminal ridge. Figure 34 shows a cross-section from the high knob just north of Stop 4. Even on these relatively young deposits rather familiar components of a "fully-developed" slope and erosion surface complex (Ruhe, 1975a, b; Hallberg, et al., 1978) are beginning to develop.

From the summit of the hill a stone-line, or erosional lag, has developed on the eroding backslope. The stone-line descends beneath a thin veneer

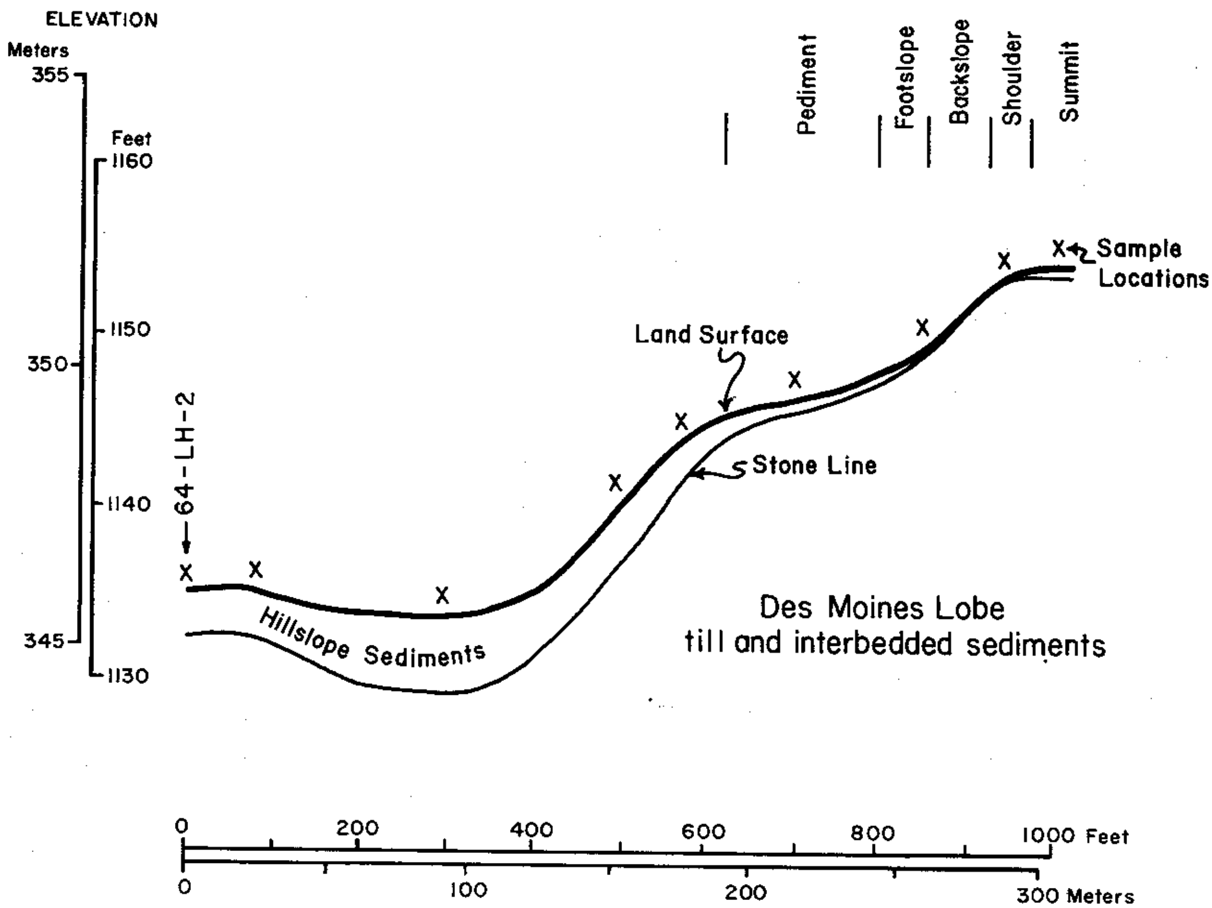


Figure 34. Cross-section through hillslope in terminal ridge area north of Stop 4 (64 LH-2).

of surficial sediments (or pedi-sediment) which mantle the long-sloping pediment surface. These sediments thicken downslope and onto the lower-lying surface occupied at Stop 4.

On the summit of the hillslope 5-10 cm of surficial sediment overlies the stone-line locally. This likely results from minor eolian activity, which may leave thin sediments on even the highest local summits.

Road Log

Accumulated Mileage (km)	Increment Mileage (km)	Discussion
		Continue west on U.S. 30; dropping down in elevation; lose high relief of terminal ridge and grade into moderate relief, irregular hummocky landforms.
140.9 (226.7)	1.7 (2.7)	Stop 5; Core site 64 LH-3; Story-Marshall County line.

Stop 5. Core Site 64 LH-3. The cores were taken from the crest of a hummock on the north side of U.S. 30, just west of the Marshall-Story County line. The site is located in the SE corner of sec. 12, T. 83N., R. 21W., Story County. Elevation 1098 feet (335 m). The section is located in the moderate-relief, irregular hummocky landform area. The location is shown on figures 30 and 31.

Objectives:

1. To examine the typical sequence of glacial sediments comprising the irregular hummocky areas (landform category IV).

2. To compare the properties of the supraglacial sediments and the basal till where they occur respectively in sequence in a core.

The stratigraphy of the site is shown on figure 35. The glacial sediments in this area are composed of 2-5 m of supraglacial deposits overlying basal till. This core is an excellent example of how great the contrast between supraglacial sediments and basal till can be even in a core. The supraglacial sediments consist of a sequence of interbedded diamictons (till-like sediments) and meltwater deposits. The diamictons have relatively low density and are very variable in texture. The basal till, in contrast, is dense, uniform in texture, and lacks interbedded meltwater deposits. The basal till at this site also has the same mineralogic composition with respect to clay mineralogic and coarse sand fraction lithology (Table 13) as found for the Alden Member throughout the field trip area.

From Stop 4 on the terminal ridge of the Des Moines Lobe we have come down 10.7 m (35 feet) in elevation to this stop, and the supraglacial sediments have thinned by at least 6 m (20 feet).

As we will see in the field, Stop 5 is located on a moderate relief hummock. The supraglacial sediments are slightly greater in thickness than the local relief. This suggests that much of the relief in this landform category is related to variation in thickness of the supraglacial sediments. This presents a problem in the classification of this landform. Some would say that since most of the landform is in the supraglacial sediments, the landform should be categorized as one of the "ablation," "ice-contact," or supraglacial "disintegration" landforms. But the implication of the "disintegration" landform categories is that only one process or one set of closely-related processes were responsible for the development of the landform. These implications would clearly be incorrect for this landform. Figure 35 indicates unmistakenly that there has been a *time-transgressive change from subglacial to supraglacial sedimentation in this area.* Since classic glacial landform categories (see for instance Tables 5 and 6 this volume) are based on the premise that glacial landforms are produced solely in either the subglacial or the supraglacial environment, the compound nature of this landform means that it has no correlative in existing classifications of glacial landforms. This landform is thus neither ground moraine, end moraine, or any one of the different "disintegration" type landforms. Compound

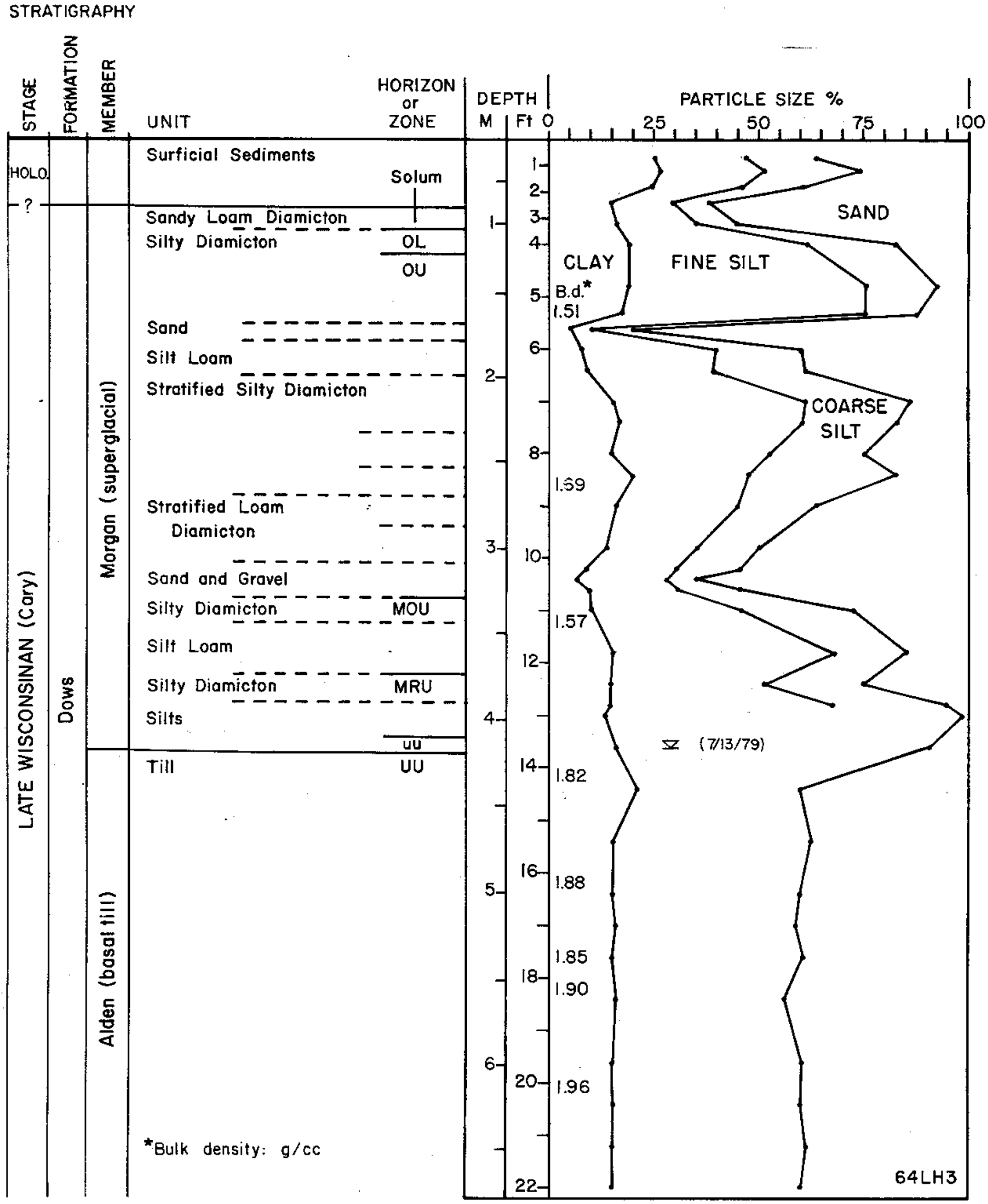


Figure 35. Stratigraphy, particle-size and bulk density data for core site 64 LH-3; Stop 5.

Table 13. Additional laboratory data, 64 LH-3.

			Clay Mineralogy %			Sand-Fraction Lithology %					
Depth M	(ft.)	Horizon or Zone	Ex.	Ill.	K+C	C/D	T.C.	Sh.	T.X.	Q.-F.	T.X.
LATE WISCONSINAN (Cary)											
DOWS FORMATION											
Morgan Member (superglacial sediments)											
1.6	(5.2)	OU	60	28	12						
1.9	(6.1)	OU	74	18	8						
2.4	(8.0)	OU	66	20	14	No. D?	30	6	38	51	62
3.9	(12.7)	MRU	67	21	12	1.3	27	14	44	54	56
Alden Member (basal till)											
4.3	(14.1)	UU	72	20	8						
4.5	(14.8)	UU				0.6	30	15	45	47	55
4.9	(14.8)	UU	71	17	12	2.5	28	6	34	56	66
5.2	(16.0)	UU				1.4	33	20	55	35	45
5.8	(19.0)	UU	69	17	14	2.7	26	4	34	59	66

landforms of this or related types (categories IV a-d) occur over a sizeable portion of the field trip area (figure 2) and the Des Moines Lobe as a whole. We wish to propose that existing landform categories need to be re-evaluated and expanded to include a category or categories for compound landforms such as these which result from the time-transgressive change from subglacial to supraglacial sedimentation.

Road Log

Accumulated Mileage (km)	Increment Mileage (km)	Discussion Colo Bog
		Continue west on U.S. 30. Going west the route continuously declines in elevation toward Ames.
142.9 (229.9)	2.0 (3.2)	To the right (N) of U.S. 30 is Colo Bog. Colo Bog was analyzed by P.H. Walker (1965, 1966). Walker principally analyzed the bog and hillslope sediments to study the sedimentation and soil development. He was not concerned with the nature of the till deposits. Our present work indicates that the remnant constructional features in this area are dominated by supraglacial facies sediments, such as at Stop 5, 64 LH-3. Figure 36 shows a plot of Walker's particle size data from his well-drained soil sites, from materials he describes as "Cary" till, "stratified till," and drift.

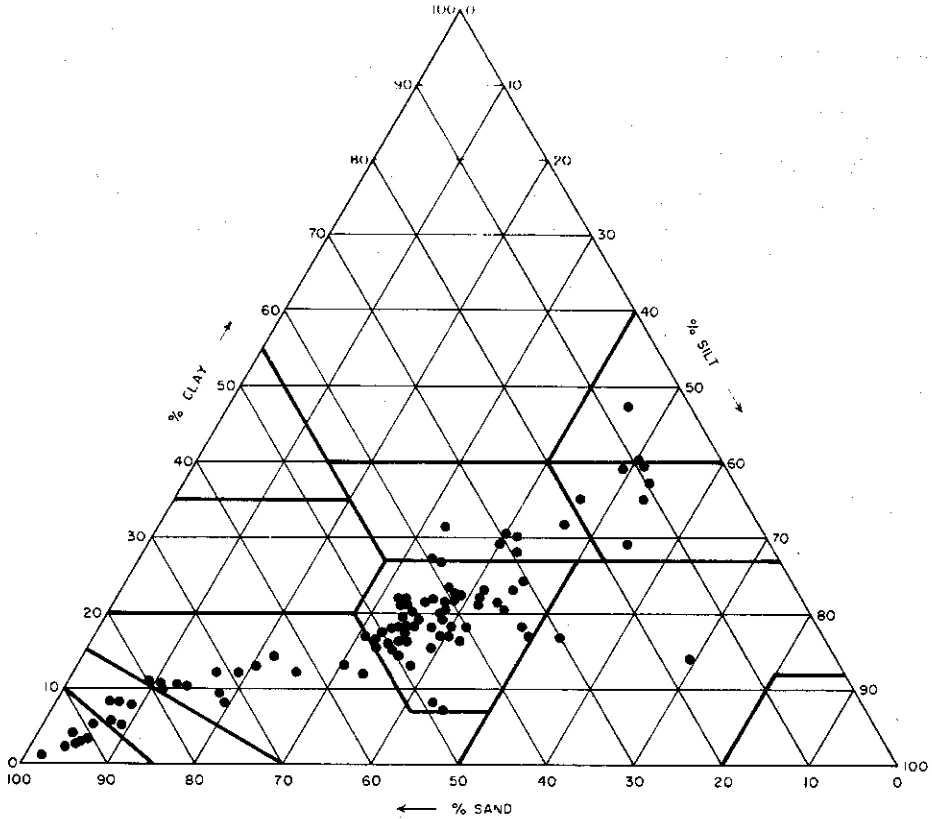


Figure 36. Plot of textures of glacial sediments ("Cary till, stratified-till, and drift") from the Colo Bog area (data from Walker, 1965).

Compare this plot with figure 7 in the text. The wide scatter of data corroborates our other findings in this area. Also, Walker (1966) shows a range of density values for these materials from 1.34 to 1.80 g/cc (84-112 pcf), which is also typical of the supraglacial deposits in this area (see figure 12).

144.8 (233.0)	1.9 (3.1)	Jct. U.S. 65; Colo, Iowa (C, figure 30) to right (N).
147.8 (237.8)	3.0 (4.8)	Enter stream-modified area along Dry and East Indian Creeks.
148.2 (238.5)	0.4 (0.6)	Cross Dry Creek.
149.4 (240.4)	1.2 (1.9)	Cross East Indian Creek. On west-side of creek route reenters "minor moraine" area (figure 29).
151.7 (244.1)	2.3 (3.7)	Intersection with local road, southeast side of Nevada, Iowa. Stop 6; Nevada Test Site.

Stop 6. Nevada Section. This site is composed of cores and outcrops on the north side of U.S. 30, in the southeast portion of Nevada, located in the SW¼ of the NW¼ of the NW¼ of sec. 17, T. 83N., R. 22W., Story County. Elevation 1000 feet (305 m). The Nevada area is on the eastern edge of a "minor moraine" belt, where local irregular hummocks are superposed on and obscure the "minor moraine' pattern. Minor stream dissection, in the proximity of West Indian Creek also affects the area locally.

Objectives:

1. To learn to pronounce Nevada (nuh-vay-duh) as it is done in this area;

2. To examine the glacial sediments in the transition zone between the "minor moraine" area and the irregular hummocky landform area.

3. To review some complexities on the local sub-Des Moines Lobe substrate and stratigraphy.

Our investigations in this area were done before, and during, the construction of all the buildings now surrounding this intersection. Although the construction activities provided several exposures, the leveling work and construction presently obscure some of the relations.

The various cores and outcrops in this area exhibit many interesting features both in the relationships of the various Des Moines Lobe sediments, and in the nature of the sub-Des Moines Lobe surface. The stratigraphy of the sites is outlined in figures 37 through 39. Additional laboratory data is shown in Table 14. Our location at this stop is in the vicinity of core site Nevada-3.

Core site Nevada-2 (figures 38 and 39) was located on the flank of the higher elevation hummock to the east of Stop 6 (now leveled, and occupied by the buildings uphill to the east). This site exhibited about 2.7 m (9 feet) of supraglacial deposits, comprised of very silty, crudely stratified, diamictons. As at Stop 5, these supraglacial deposits, overlie uniform loam-textured basal till.

Site Nevada-1 was from a composite exposure and core. It was located in the cropped field north of Stop 6 along the crest of an E-NE oriented "minor moraine." The "minor moraine" ridge was clearly separated from the "hummock," by an intervening depression. It is at a lower elevation than the hummock of site 2 (figure 39). Nevada-1 showed no evidence of supraglacial deposits, but rather exhibited about 4 m (12.5 feet) of very uniform basal till. Core-site Nevada-3, our location at Stop 6, is in a lower-elevation location at the end of the slopes coming off of the hummocks to the east and south. Beneath 0.3 m of surficial sediments Nevada-3 exhibited about 1.0 m of supraglacial sediments on top of about 3.0 m of dense uniform basal till (figure 37).

The relationships shown here are consistent with other observations of the authors. The moderate relief, irregular hummocks of Stop 5 and

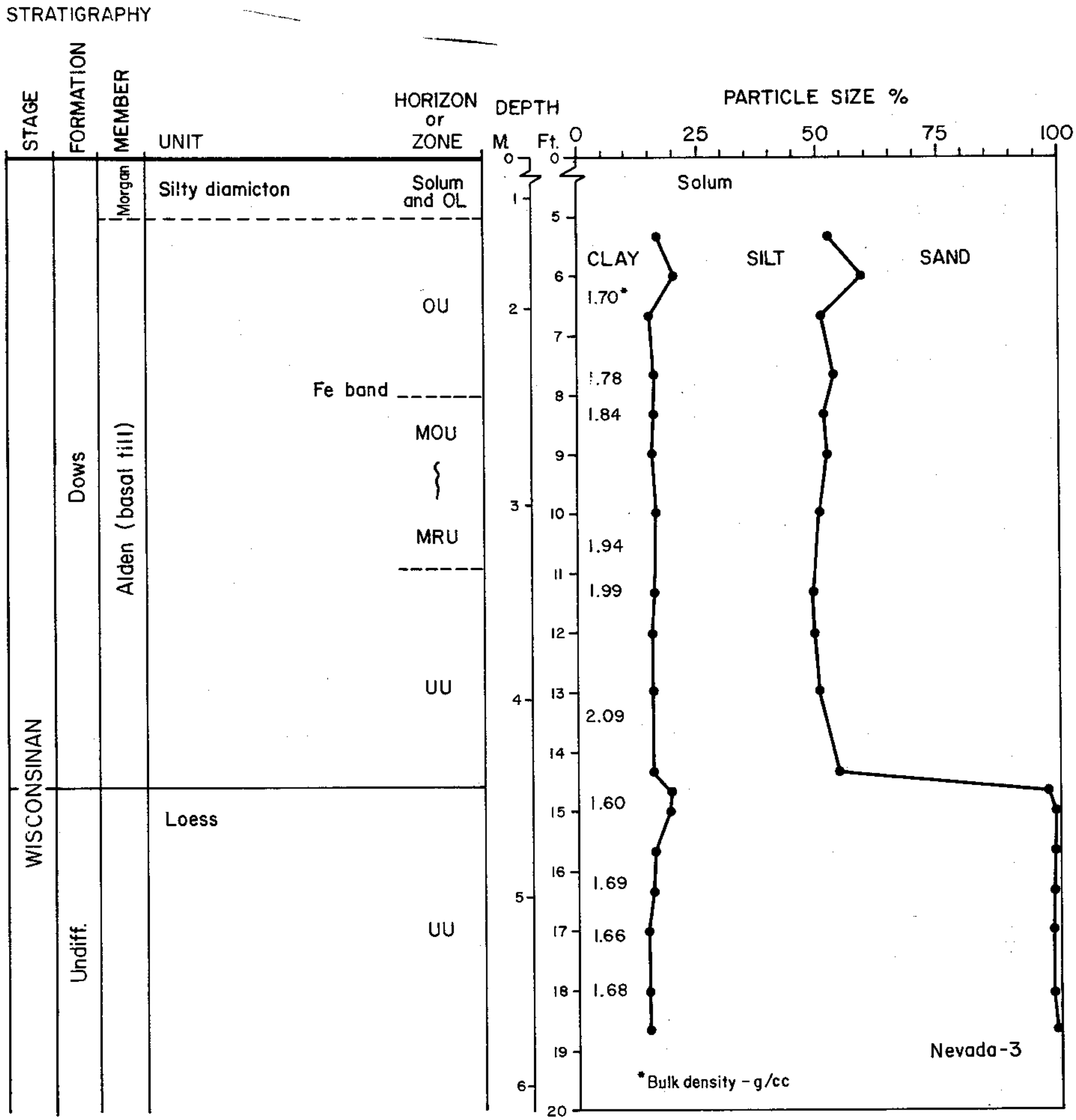


Figure 37. Stratigraphy, particle-size, and bulk density data for the Nevada 3 Core section, Stop 6.

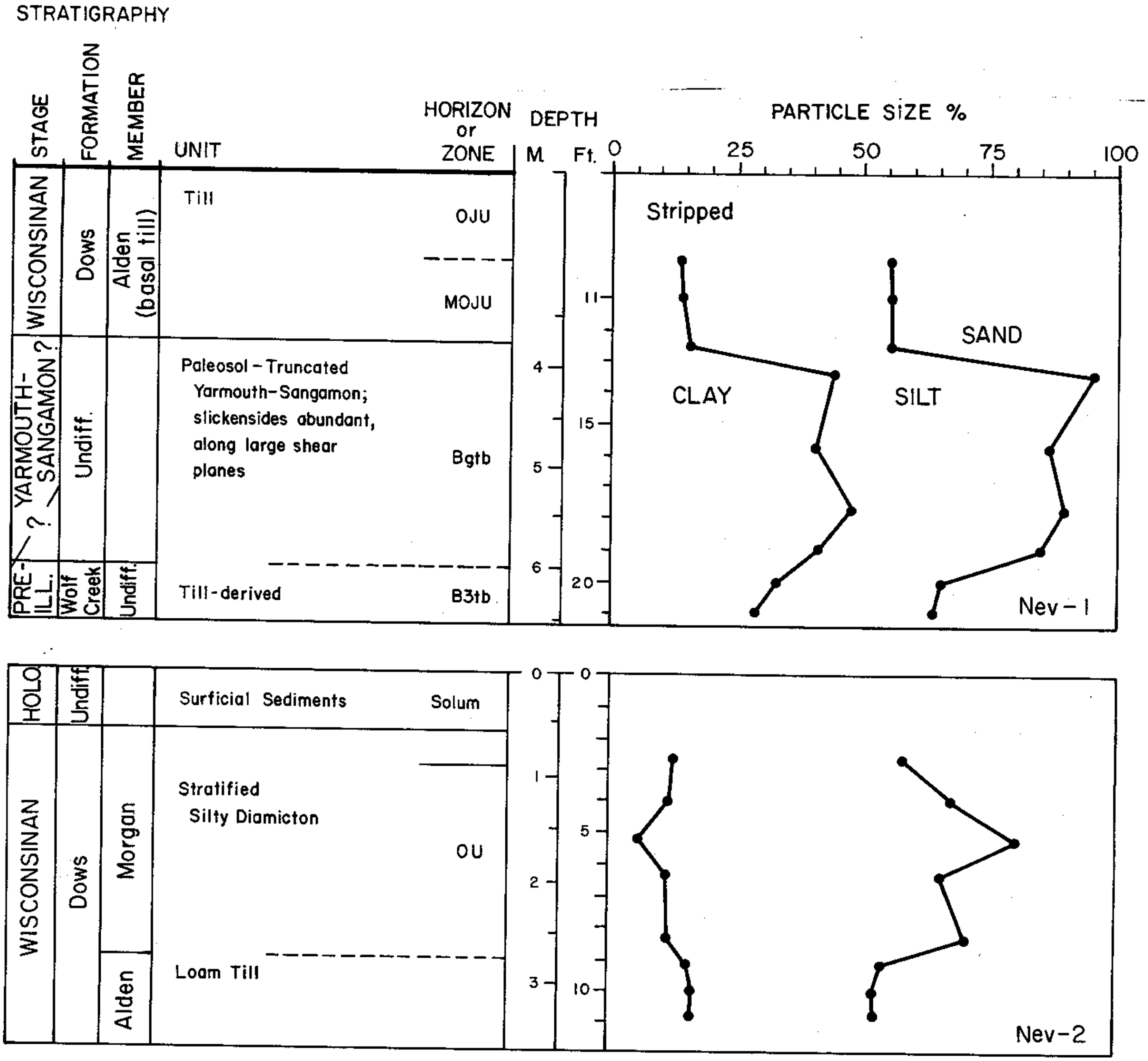


Figure 38. Stratigraphy and particle-size data for the Nevada Core sections 1 and 2; Stop 6.

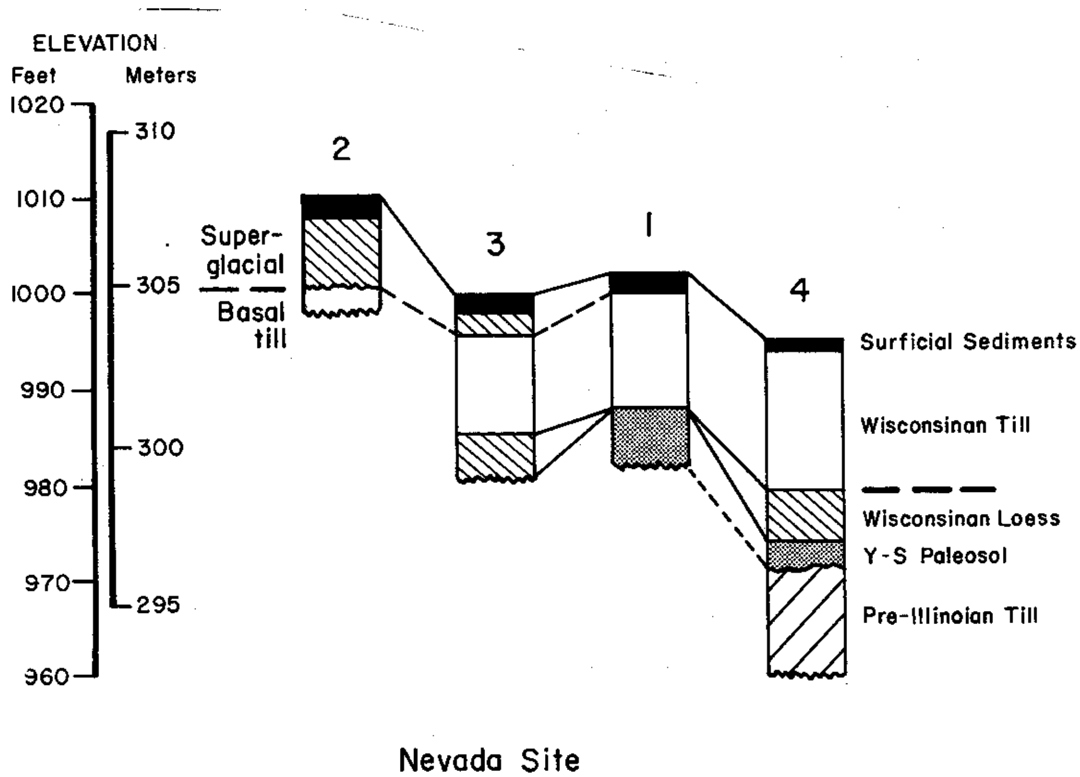


Figure 39. Schematic section showing the relationship between the core and outcrop sections at Nevada; Stop 6.

here at Nevada are comprised of a moderate thickness of supraglacial sediments. The distinguishable ridges of the "minor moraines" are comprised of basal till. Within the "minor moraine" areas occasional hummocks occur. This is particularly frequent in areas such as Nevada, where the "minor moraine" belt borders the large area of hummocks (figure 2) to the east. In these settings the supraglacial deposits of the hummocks are superposed on the basal till of the "minor moraines," and the hummocks effectively obscure the narrow linear ridge-form of the "minor moraines."

In this small study area the different sites show some diverse relations at the lower contact of the Des Moines Lobe deposits as well. At Nevada sites 3 and 4 (figure 39) the basal till of the Des Moines Lobe overlies Wisconsinan loess. At neither site is a buried-soil present in the top of the loess as at the Alden Section (Stop 1). At Nevada-3 (figure 37) the loess is quite dense and very firm, likely because of the overriding of the Des Moines Lobe glacier. The bulk density of the loess, outside of the Des Moines Lobe, in this part of Iowa would typically be about 1.4 g/cc.

The loess was so firm at this site we could not penetrate it by coring. At site 4 the loess overlies an eroded Yarmouth-Sangamon (?) Paleosol which is about 1.0 m thick, and grades into Pre-Illinoian till. Site 4 (figure 39) is the exposure along the tributary gully to West Indian Creek, northwest of Stop 6, on the west side of the road in section 18.

Table 14. Additional laboratory data, Nevada Site.

Site No.	Depth M	(ft.)	Horizon or Zone	Clay Mineralogy % Ex.	Ill.	K+C	Sand-Fraction Lithology % C/D	T.C.	Sh.	T.S.	Q.-F.	T.X.
				LATE WISCONSINAN (Cary)								
				DOWS FORMATION								
				Morgan Member (superglacial sediments)								
2	2.0	(6.5)	OU	68	18	14	3.7	28	8	36	56	64
				Alden Member (basal till)								
1	3.4	(11.0)	MOJU	65	19	16	5.6	33	11	44	48	56
4	2.1	(7.0)	OU	69	17	14						
3	2.3	(7.6)	OU				3.2	25	3	31	64	69
3	2.6	(8.5)	MOU				No. D?	21	1	24	68	76
3	3.0	(9.8)	MRU	71	16	13	6.3	29	7	36	54	64
3	3.7	(12.0)	UU				4.0	25	10	35	51	65
3	4.3	(14.2)	UU	70	20	10	23.0	24	6	30	65	70
				WISCONSINAN								
				Loess undiff.								
3	4.5	(14.7)	UU	69	23	8						
3	4.9	(16.0)	UU	70	21	9						
3	5.3	(17.5)	UU	71	21	8						
3	5.7	(18.7)	UU	69	21	10						
				PRE-ILLINOIAN								
				WOLF CREEK FORMATION								
				Undiff. Till (Aurora Till Mem?)								
4			MOU	57	20	23	No. D	23	--	27	68	73

Site No.	Horizon or Zone	Particle Size Clay	Silt	Sand	Chittick Carbonates C/D	Cal	Dol	T.C.
4	MOU	29.4	32.9	37.7	1.4	2.0	1.4	3.4
4	MOU	27.8	37.1	35.1	0.5	2.0	3.7	5.7

At Nevada Site 1, the highest elevation for the base of the Des Moines Lobe till occurs (figure 39). Here the Wisconsinan loess is missing, and the till is in direct contact with the Yarmouth-Sangamon Paleosol. The paleosol is at least 2.7 m (9 feet) thick, but has been disturbed and possibly sheared by the overriding of the Des Moines Lobe ice; the paleosol is cut by many shear planes, at various angles, which exhibit strongly slickensided surfaces.

Further west, and at a lower elevation again, in the road cuts along U.S. 30, near West Indian Creek, Ruhe (1969) describes 4.0 m (13 feet) of Des Moines Lobe till over 4.3 m (14 feet) of loess which overlies a stone-line directly on unleached till. Wood from near the top of the loess was dated at 14,200 ± 500 RCYBP (I-1402; Ruhe, 1969), very similar to our date at Alden, Stop 1 (see Table 1).

These different sites point out two complexities in sub-Des Moines Lobe relations. First, as the sub-Des Moines Lobe surface rises in elevation locally, more glacial erosion is apparent. This is shown by the difference in thickness of the loess as it is truncated from 4.3 m to 1.7 m in thickness, and then at the highest location, Nevada-1, it is entirely absent and the Des Moines Lobe till lies directly on the glacially-disturbed paleosol. This same phenomenon has been documented in Illinoian (Hallberg, 1980, ed.) and Pre-Illinoian (Hallberg, 1980a) sequences in Iowa, where the local sub-till highs are eroded off but sub-till lows are left essentially intact. These features should be recognized for evaluating the stratigraphy as well as for drawing conclusions about the behavior of the glacier as it advanced through this area.

Second, as the sub-loess surface declines in elevation the paleosol on the Pre-Illinoian till is progressively truncated until it is entirely missing in the road cuts to the west described by Ruhe (1969). These changes reflect the development of the Iowan Erosion Surface (Ruhe, 1969; Ruhe, et al., 1968; Hallberg, et al., 1978) which is so prevalent to the east of the Des Moines Lobe (see figure 2). This widespread erosion surface was developed during the interval ca. 17-20,000 RCYBP. It is commonly expressed even under the Des Moines Lobe, and sections such as this must be interpreted with caution. The absence of a paleosol below the buried loess does not mean that the sub-loess till is earlier Wisconsinan, it is just as likely that it is Pre-Illinoian. Here again lithologic and mineralogic criteria can be used to correlate rock units to more complete sections.

Road Log

Accumulated Mileage (km)	Increment Mileage (km)	Discussion
		Continue west on U.S. 30.
152.9 (246.0)	1.2 (1.9)	On overpass; good view of moderate relief minor moraines oriented E-NE.
153.2 (246.5)	0.3 (0.5)	Stop 7; Core Site 85-80L-2 on north side of road.

Stop 7. Core Site 85-80L-1. This site consists of a transect of cores from the top of a "minor moraine" ridge and proceed into the adjacent swale. The site is located on the north side of U.S. 30, in the NW¼ of the NE¼ of sec. 13, T. 83N., R. 23W., Story County. Elevation at the top of the transect is 1000 feet (305 m).

Objectives:

At this stop we will examine the relationship of the basal till and the postglacial surficial sediments to a "minor moraine" ridge and adjacent depression.

(The laboratory data for this site was not available in time for printing and will be handed out on the trip).

At this stop we will view "minor moraines" in the field and look at cores of the uniform basal till which makes up this landscape. The core transect begins on the crest of the "minor moraine," in the position of the well, to moderately well-drained Clarion loam soil. The cores at the top of the "minor moraine" ridge shows:

Depth in	Depth m	
0-15	0-0.4	Loam textured surficial sediments, all within the A horizon of the modern soil profile; the material is free of pebbles from 0-11 inches.
15-34	0.4-0.9	B-horizon, in till; there is a hint of textural stratification in the B-horizon. Is there a minor amount of supraglacial sediments here within the solum or are these alterations because of soil development? The till is calcareous below 28 inches.
Below 34-	0.9-	Below 34 inches (0.9 m) the core clearly shows the uniform basal till. The textural plot of this core would be very similar to figures 16 or 24. The only changes noted are gradual color-related weathering zone changes. These changes result from oxidation changes and mobilization of secondary iron oxides in relation to the moisture regime of the site (see Hallberg, Fenton, and Miller, 1978).
34-78	0.9-2.0	Oxidized and unleached (OU) loam till; Alden Member or basal till of the Dows Formation.
78-84	2.0-2.1	As above, but mottled-oxidized (MOU).
84-112	2.1-2.8	As above, but mottled, iron-stained joints become more apparent; mottled-oxidized, jointed, and unleached (MOJU).
112-134	2.8-3.4	As above, transitional with below.
134-148	3.4-3.7	As above, but mottled-reduced-jointed and unleached loam till (MRJU).
148-195	3.7-4.9	As above, reduced-jointed and unleached till (RJU).
195-200	4.9-5.1	Iron-band cementing till.
200-204	5.1-5.2	As above, mottled-unoxidized-jointed and unleached till (MUJU).
204-217	5.2-5.5	As above, unoxidized-jointed and unleached till (UJU).

217-238	5.5-6.0	As above, unoxidized and unleached till, joints die out.

The core transect proceeds downslope with a series of cores that are from 4 to 4.5 m depth. The surficial sediments thicken downslope and into the adjacent depression (which is about 9 feet, 2.6 m, lower than the crest of the adjacent "minor moraine"). The surficial sediments vary in thickness from 30 to 54 inches (0.8-1.4 m) in this depression. These thicknesses of the surficial sediments are typical for the low-relief "minor moraine" areas. These thicknesses are substantially less than the 6 to 10 m of sediments reported in large bogs in higher relief areas (Walker, 1966; see discussion in text of this report). These minor thicknesses of sediments indicate that there have not been major postglacial alterations in the "minor moraine" areas, and that the principal effect of the sediments is to reduce the local relief.

In this landscape position note that the till is mottled and reduced immediately below the surficial sediments. These colors are indicative of the poor drainage conditions in the depression.

Also, note the uniformity of the till in the cores across the "minor moraine." As repeatedly discussed this uniformity is typical of the basal till. Glacial deposition in the "minor moraine" areas appears to be dominated by the subglacial deposition of basal till.

Road Log

Accumulated Mileage (km)	Increment Mileage (km)	Discussion
		Note ridge immediately west of Stop 7 is broader and higher in elevation than surrounding minor moraines. It is a ridgeform with irregular hummocks seemingly superimposed upon the minor moraines. It is comprised of interbedded silty diamictons and thin sorted sediments to a depth of at least 7 feet (2.1 m). This is in contrast to the uniform till in the minor moraine of Stop 7.
		Continue west on U.S. 30 through minor moraine area.
158.3 (254.7)	5.1 (8.2)	Overpass I-35; drop down into Skunk River Valley.
158.8 (255.5)	0.5 (0.8)	Turn right (N) on local road.
159.2 (256.2)	0.4 (0.6)	Turn right (E) into drive into borrow area; Stop 8.

Stop 8. Whatoff's Borrow Pit Section. This section is an exposure in a borrow area on the southeast side of Ames, located in the NE¼ of the SW¼ of sec. 7, T. 83N., R. 23W., Story County. Elevation 935 feet (285 m).

Objectives:

At this stop we will view the basal till in a borrow pit at the edge of a "minor moraine" belt. We particularly want to note:

1. The relations of the basal till to the "minor moraine" landforms.

2. The uniformity of the basal till, laterally and vertically, as documented here by detailed laboratory analyses.

3. The presence of "stacked" basal till units.

The pit is located at the edge of the "minor moraine" belt, along the east wall of the Skunk River valley. The area is somewhat modified by stream dissection, and is locally mantled with eolian sand.

Note the difference in elevation from here to Stop 4 at the terminal ridge. The elevation here is 935 feet while at the terminal ridge the elevation was 1135 feet. As discussed in the road log and in the text (see figure 22) both the present land surface on the Des Moines Lobe deposits and the sub-Des Moines Lobe surface slope uphill to the terminus.

The borrow pit exposure is composed of a series of borrow areas which step lower in elevation from north to south. A composite section, below the eolian sand and other surficial sediments is:

Depth ft.	m	Abbreviated Description
0-2	0-0.6	Oxidized and leached (OL) firm loam till; basal till (Alden Member of the Dows Formation).
2-17	0.6-5.2	Oxidized and unleached (OU), firm loam till; lower contact gradual to abrupt.
17-21	5.2-6.4	Reduced, jointed, and unleached (RJU) firm loam till; lower contact with UJU till is abrupt; in places, this contact is marked by 1-2 cm thick sand lenses and in other areas by a 1-3 cm thick band of iron-oxide cement.
21-24	6.4-7.3	Unoxidized, jointed, and unleached (UJU), firm to hard, loam till. In places there is an abrupt lower contact with the UU till below; locally 2-10 cm of sand and or gravel occur at this contact; these stratified sediments thicken in one locality to a 45 cm (1.5 feet) thick lens of sand and gravel; joints end at this lower contact.

Table 15. Laboratory data for basal till (Alden Member) at Whatoff Borrow Pit Site.

Zone	Sample No.	Particle Size Clay	Silt %	Sand	C/D	Sand Fraction Lithologies T.C.	Sh.	T.S. %	Q.F.	TX.	Notes	Clay Mineralogy Ex.	Ill. %	K+C	C/D	Chittick CO3 C.	D. %	T.C.
OU	1	14.4	36.7	48.9														
	1A	14.3	36.9	48.8	1.4	24	10	34	58	66		70	17	13				
	1B	13.9	37.4	48.7														
	2	14.7	35.0	50.3														
	2A	15.5	35.6	48.9														
	2B	13.7	36.9	49.4								71	17	12				
	3	14.0	37.3	48.7	1.62	34	12	46	46	54								
	4	17.4	32.6	50.0	1.43	34	16	50	42	50								
	5	15.1	34.8	50.1	1.82	31	5	36	54	64								
	6	14.9	30.0	55.1								69	19	12				
	7	13.8	37.3	48.9								70	19	11	0.33	3.7	11.1	14.8
	8	15.0	34.8	50.2	0.55	31	11	42	49	58								
	9	14.5	37.8	47.7														
	10	13.8	35.8	50.4								68	17	15				
	10A	14.8	35.6	49.6														
	10B	13.8	35.4	50.8														
	11	15.9	35.5	48.6	0.67	20	11	31	55	69		74	17	9				
	12	14.4	38.1	47.5	0.83	33	18	51	41	49		70	18	12				
	13	18.6	29.4	52.0	0.55	31	13	44	40	56								
	13A	13.6	31.0	55.4	1.29	16	21	37	54	63		70	17	13	0.18	2.3	12.8	15.1
	13B	15.8	32.5	51.7	0.62	21	10	31	56	69		67	20	13				
	Mean	14.9	35.1	50.1	1.08	28	13	40	50	60		70	18	12				
	s.d.	1.3	2.6	2.1	0.5	7	5	7	7	7		2.0	1.2	1.6				
RU	1R	13.3	34.7	52.0	1.25	18	15	33	53	67		68	20	12				
	2R	14.7	34.4	50.9														
	A	19.3	30.1	50.6														
	B	14.9	34.1	51.0														
	13R	15.0	33.9	51.1	1.00	32	14	46	51	54		69	21	10				
	Mean	15.4	33.4	51.1														
	s.d.	2.3	1.9	0.5														
UU	1U	12.9	35.5	51.6								68	19	13	0.22	2.7	12.4	15.1
	2U	13.6	35.6	50.8	1.23	29	20	49	40	51								
(Above	A	12.3	35.5	52.2	1.27	25	14	39	53	61		68	18	14				
S & G)	B	14.1	36.8	49.1	0.80	18	15	33	60	67					0.11	0.6	5.5	6.1
	C	14.3	36.9	48.8								71	18	11				
	D	13.7	36.9	49.4	1.89	26	16	43	48	57	Coal							
	E	14.0	37.4	48.6														
	Mean	13.6	36.4	50.1	1.30	25	16	41	50	59								
	s.d.	0.7	0.8	1.5	0.5	5	3	7	8	7								
(Below	B	12.0	36.9	51.1	1.20	22	15	38	47	62	Coal	69	20	11				
S & G)	C	8.9	34.6	56.5														
	F	14.1	38.3	49.6	1.15	28	19	47	41	53		67	18	15				
	S	13.9	37.3	48.8														
	Mean	12.2	36.8	51.5														
	s.d.	2.4	1.6	3.5														
Grand Mean		14.4	35.3	50.4	1.14	26	14	41	49	59		69	18	12	0.21	2.3	10.5	12.8
S.D.		1.7	2.3	2.0	0.4	6	4	7	7	7		1.9	1.3	1.7	0.09	1.3	3.4	4.5

24-29 7.3-8.8 Unoxidized and unleached (UU) very firm to hard, loam till.

The section is comprised dominantly of firm to hard, dense, texturally uniform, loam basal till. Lab data for this site is shown on Table 15, and the density data is given on Table 16 (listed by weathering zone). As would be expected from the field consistency, the till is quite dense. The bulk densities from throughout the exposure are in the high range for the basal till of the Des Moines Lobe (compare with figure 12). The unoxidized samples exhibit a slightly higher density than the samples from the oxidized or reduced zones.

To analyze the textural uniformity of the till, the particle size distribution of 38 samples were analyzed (Table 15). Samples were taken laterally across the exposure at 20 stations (1-13, A-F and S) which were spaced 15-20 feet apart. The first sample was taken at about 4 to 5 feet above the local floor of the borrow area. At several stations samples were also taken vertically at about 2 feet (0.6 m) increments above and below the first sample. These vertical samples are indicated by a letter designation after the station number (i.e., Samples 1, 1A, 1B, 1R, and 1U all come from one vertical section at station 1). As can be seen by the data in Table 15 the till is very uniform and there are no significant differences in any of the textural data, vertically or laterally, or by the different weathering zones (as noted in the description above). This is illustrated by the very low standard deviations for the grand means, which range from only 1.7 to 2.3% for the different particle size categories.

The mineralogic data shown on Table 15 also show this same kind of uniformity in properties. Each of the different types of mineralogic data are virtually identical to the modal characteristics for the basal till of the field trip area (compare with figures 7 and 12, and Table 4).

Based on the textural, mineralogic,consistency, and density data we feel that the till units at this site are clearly basal till of the Des Moines Lobe. However, the "bedded" nature of the till in this sequence is worthy of discussion. The abrupt weathering zone contacts described, particularly between the reduced and unoxidized till, and within the unoxidized till, are unusual. As seen in the previous cores these changes are generally much more gradual. These gradual changes in weathering zones would be expected as they are related to the drainage conditions in the sediments in relation to the depth to the water table over time (Hallberg, Fenton, and Miller, 1978). Abrupt contacts between weathering zones such as this generally only occur at contacts between either different materials and/or stratigraphic units because of the abrupt change in material properties. At this site the materials are all Des Moines Lobe basal till. However, the change in bulk density noted for the unoxidized till is a property which would effect the moisture regime, through related changes in porosity, hydraulic conductivity, and moisture retention capacity.

The presence in places of iron-bands and thin, discontinuous sorted sediments at these abrupt contacts also give the impression that the till between the contacts may be individual beds of till within the total

Table 16. Bulk densities (g/cc) for the basal till (Alden Member) at Whatoff Borrow Pit Site.

OU	RU	UU
1.89	1.89	2.01
1.91	1.88	1.90
		2.02
		2.03

basal till sequence. The question for discussion here is: could these features result from the basal deposition or melt-out of stacked debris bands near the base of the ice (such as described by Mickelson, 1973; and Boulton, 1970)? Perhaps the till beds were deposited from debris-rich ice, and where basal melting of intervening debris-poor ice caused minor subglaciofluvial activity resulting in thin sorted deposits which were subsequently buried by the deposition of the next till bed.

These features, as discussed in the text, are interesting as they are one of the few kinds of discontinuities which we see in the basal till, albeit infrequently.

SUMMARY

On this field trip, and in the accompanying research papers, we have attempted to outline the present working framework of our research program on the Des Moines Lobe in its initial stages. Here, at the end of the field trip, is a good time to emphasize the practical necessity of this work.

Perhaps the practical aspects of this can be made most emphatic by pointint out that *every stop* (except the loess core at Stop 3) on this field trip, from the high-relief supraglacial ridges, to the hummocky landform areas, and then to the low relief "minor moraines" and their basal till, was included within the broad area mapped as the Bemis Moraine during the last two decades. Obviously this former mapping provided us with little information on the nature of the materials for any applied evaluation. As a consequence we have undertaken the program outlined here.

In the preceeding sections we have tried to show:

1. That using the multiple criteria of texture, the nature of stratification and sorting, geotechnical properties, and sedimentary structures and fabric, we feel we can subdivide the Des Moines Lobe deposits into generic classes of glacial deposits: the basal till and supraglacial sediments.

2. These deposits can be separated both in cores and outcrop.

3. That by combining these observations on the nature of the glacial deposits with the detailed mapping of landforms, we can develop an understanding of the individual landforms, and also provide a two-dimensional view of the depositional regime of the Des Moines Lobe glacier.

Further, when this information is combined with our analysis of the sub-Des Moines Lobe surface, we feel this three dimensional view will allow us to accomplish 2 primary goals. Fist, we can develop a detailed engineering-geologic map of the Des Moines Lobe, which will be useful for many applied purposes. Secondly, from a scientific standpoint, we hope to develop a detailed picture, from the field evidence, of the behavior, or ice-dynamics of the southern end of the Laurentide ice sheet in the Iowa portion of the Des Moines Lobe.

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