

**SURFICIAL GEOLOGIC MAP
OF THE DES MOINES LOBE OF IOWA
Phase 7: Clay and Osceola Counties**

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INTRODUCTION

Phase 7 of 1: 100,000 scale surficial geologic mapping on the Des Moines Lobe (DML) includes Clay (43095-B2-CF-100) and Osceola ((43095-D6-CF-100) county maps. These counties cover an area from 42° 54' to 43° 31' N latitude and 95° 53' to 94° 54' W longitude. The DML landform region occupies the north-central one-fifth of Iowa. This landscape area is the product of a Late Wisconsin lobate extension of the Laurentide Ice Sheet that flowed down a regional topographic low into Iowa approximately 15,000 years before present. The DML landform is bounded by pre-Wisconsin topographic highs on the east (Mississippian bedrock) and west (pre-Wisconsin glacial deposits comprising the Prairie Coteau). In the map area, bedrock consists of mid-Cretaceous age Dakota Formation, consisting primarily of the lower dominated sandstone Nishnabotna Member and an upper shale and mudstone dominated Woodbury Member. Deposits that overlie bedrock consist of Pre-Illinoian and Wisconsin-age glacial and glaciofluvial sediments that range from less than 300 to 500 feet thick. In the map area, the Dows Formation, Late Wisconsin-age glacial and glaciofluvial sediment package can vary in thickness from 90 to 140 feet thick and is underlain by the older Wisconsin-age Sheldon Creek Formation, formerly referred to as the "tazewell till". The Sheldon Creek diamicton is the product of a several Wisconsin-age glaciations that occurred between 40,000 and 26,000 years before present. The diamicton has very similar properties to Dows Formation Alden Mbr. diamicton (same source area) so identification in the field is difficult. Identification is aided by the preservation of weathered Sheldon Creek surfaces (oxidation and noncalcerous) and in some instances the presence of a proglacial sand and gravel unit. The Sheldon Creek was encountered in all cores that penetrated the Dows Formation glacial and glaciofluvial sediments. The thickness of this formation is not definitively known. In the map area, and off the Des Moines Lobe landform it may be as thick as 150 to 200 feet thick in places. At times it can be differentiated by a weathering zone developed in the underlying older sediments or proglacial sands and gravels. The Sheldon Creek Formation is underlain by much older undifferentiated Pre-Illinois-age glacial, fluvial or colluvial sediments.

Previous surficial geologic mapping in the map area consists of the Des Moines 4° x 6° Quadrangle at a scale of 1:1,000,000 (Hallberg et al., 1991). The previous years of surficial geologic mapping on the DML (Phase 1: Hancock, Kossuth, Winnebago and Wright Counties, Phase 2: Hamilton and Webster Counties, Phase 3: Boone and Story Counties, Phase 4: Dallas County and Humboldt County, Phase 5: Polk County) and Phase 6: Dickinson and Emmet Counties has significantly increased our understanding of complex landform sediment assemblages in glaciated terrains (Quade et al., 1999, 2000, 2001, 2002, 2003, and 2004).

BRIEF GEOLOGIC HISTORY

The distinctive landform region called the DML formed from a lobate extension of the last great continental glacier. During the Wisconsin Episode, the southern edge of the Laurentide Ice Sheet split into several lobes that each flowed down regional topographic lows. The DML extended from central Canada through the Dakotas and Minnesota into Iowa, terminating at what is now the city of Des Moines.

Because of recent scientific advances, the DML's glacial record can now be better interpreted. Beginning in the 1970s, research at modern glaciers began to provide a more complete understanding of glacial depositional environments, identifying the processes by which glaciers form their distinctive deposits, the variations in glacial processes and environments, and the characteristic sedimentary associations which form. Since the late 1970's, tools such as topographic maps and aerial photographs have enabled better identification and mapping of the different kinds of glacial landforms that constitute the DML. An important part of a reevaluation of the DML is the development of a lithostratigraphic framework for the Lobe's sediments. This stratigraphic framework allows us to better map and understand the surficial materials of the DML. One aspect of STATEMAP mapping is reevaluating Kemmis' (1991) remapping of the mar-

gins of former glacial advances, which has significantly increased our understanding of the complex landforms and landform assemblages related to those advances. This reevaluation of sedimentary sequences, landforms, and the associations among sedimentary sequences and landforms indicates that the DML resulted from a special type of glacial behavior known as surging. Surging, consisting of rapid, out-of-equilibrium glacial advance and subsequent stagnation, accounts for the different timing, different types of glacial landforms, and the different depositional sequences of the DML when compared to other glacial lobes in states to the east.

The age of the DML is well established by radiocarbon dates. The Lobe entered Iowa shortly before 15,000 radiocarbon years before present (RCYBP) and reached the terminal position at Des Moines about 13,800 RCYBP. After reaching its terminus the glacier stagnated. The lobe readvanced to the position of the Altamont ice margin just north of Ames and Boone about 13,500 years ago, and then stagnated. At that time, proglacial meltwater was carried from the central portion of the glacier front by Beaver Creek and the Skunk River (the Des Moines River had not yet originated on the Lobe; Bettis and Hoyer, 1986; Bettis et al., 1988). Between 13,500 and 12,600 RCYBP, there were three minor readvances marked by the Clare, Renwick, and West Bend moraines. The morainic topography associated with these advances is discontinuous, and only the terminal margins are formally recognized. The final advance into Iowa to the Algona ice margin occurred about 12,300 RCYBP. This advance too, was followed rapidly by stagnation and wastage of the glacier. It was during the Algona advance that the upper Des Moines River, the major axial drainage of the Lobe originated (Bettis and Hoyer, 1986; Bettis et al., 1988).

The DML was active in Iowa between about 15,000 and 12,000 RCYBP, about 5,000 to 8,000 years after glacial lobes to the east made their southernmost maximum advance (Johnson, 1986; Fullerton, 1986). The Lobe advance occurred well into a period of regional warming and was thus climatically out of equilibrium (Kemmis et al., 1994). Shortly after 12,000 RCYBP the glacier was gone from Iowa and the subsequent history of the Lobe involves subareal development of the drainage network, infilling of depressional areas, and slope evolution under changing climate, vegetation, soil, and shallow groundwater conditions (Walker, 1966; Van Zant, 1979; Kim, 1986; Van Nest and Bettis, 1990; Burras and Scholtes, 1987; Steinwand and Fenton, 1995).

The DML glacier advanced southward along the regional slope, particularly on the east and southeast side of the Lobe. This is indicated by the fact that the pre-existing major stream valleys all flow to the southeast, directly away from the Lobe, with no major changes in ice-marginal drainage patterns. On the west and southwest margins, however, major drainage derangements (Hoyer, 1980) and peripheral ice-marginal drainage patterns are evident, indicating that the ice was flowing against the regional slope, onto the Prairie Coteau in South Dakota and Minnesota and in Iowa onto its southern extension, the Mississippi-Missouri divide.

DESCRIPTION OF LANDFORM SEDIMENT ASSEMBLAGE MAP UNITS

Recent studies and mapping indicate that the map area encompasses a complex suite of depositional landforms and sediment sequences related to supraglacial, subglacial and proglacial sedimentation. To map a relatively large area with such diverse glacial terrains we selected the most comprehensive mapping strategy—a landform sediment assemblage approach. Various glacial landforms are the result of specific processes at work in the glacial system. Glacial landforms typically have similar relief, stratigraphic and sedimentologic characteristics (Carney and Mooers, 1998). Recognition of the genetic relationship among landforms and their underlying sediment sequences allows one to generalize and map complex glacial terrains over areas of large extent (Sugden and John, 1976, Eyles and Menzies, 1983).

Eyles and Menzies (1983) recognized three broad terrestrial glacial environments: subglacial, supraglacial and proglacial. Each of these environments is characterized by a unique relief pattern, stratigraphy and sedimentology.

In the map area, it appears all environments are related to supraglacial and/or proglacial processes. After much deliberation, review of pertinent literature, and review of the associated sediment packages; we are formally re-characterizing areas with large tracts of discontinuous elongated hummocks and aligned ridges oriented transverse to glacier flow from subglacially-controlled areas (Quade et al., 2001) to areas of supraglacial origin. This decision was based on observation of relatively thick (3-8+ m) packages of supraglacial diamicton associated with these landform features and the regional extent of these features across DML till plains associated with recessional ice advances. The supraglacial environment is typically characterized by hummocky terrain that forms arcuate belts of moraine complexes and undulating plains with thick increments of supraglacial sediment (>3 m). It is now recognized from recent STATEMAP mapping efforts that numerous low-relief recessional moraines are present down the central axis of the DML. These features are not evident on the land surface but are visible on high-altitude imagery. Most likely these features are related to supraglacial as well as proglacial processes. Along the northwestern margin of the Des Moines Lobe moraines are higher relief features. It appears that readvances of ice during a span of several thousand years have complicated the mapping of end moraines thus, necessitating the lumping of moraines into complexes. In the southern part of Clay County the Bemis Moraine is mapped. Further north, the individual moraines appear to coalesce so the area is referred to as the Bemis-Altamont Moraine Complex. The Bemis Moraine was most likely overridden by several younger Altamont Advance(s) which are referred to as the Altamont Moraine Complex. The proglacial environment is characterized by a host of relief patterns that encompass coarse-grained glaciofluvial ice-contact sediments associated with glacial plains, fans and channel deposits, and fine-grained glaciolacustrine deposits. i.e., lake plains, and ice-walled lake plains.

Twelve landform sediment assemblage units were identified in the map area utilizing digital elevation models (DEMs), high altitude aerial photography, orthophotos, topographic expression, digitized soil and existing and new subsurface boring information. Twenty-five cores were collected in the county which represents well over 840 feet of new subsurface information obtained as part of this mapping project. The twelve units are: Hudson Episode: depressions, and alluvium; Wisconsin Episode: till ridges (Bemis Moraine, Bemis-Altamont Moraine Complex, and Altamont Moraine Complex), till plain, older Wisconsin-age till, valley-train outwash, lake plains, sand dunes and sand sheets, and unnamed erosion surface sediments. The following is a description of each landform sediment assemblage listed by post-glacial and glaciogenic origin.

HUDSON EPISODE

Landform Sediment Assemblages of Post-Glacial Origin

Qo - Depressions (DeForest Formation-Woden Mbr.)

Generally 2.5 to 6 meters of black to very dark gray, calcareous, muck, peat and silty clay loam colluvium and organic sediments in drained and undrained closed and semi-closed depressions. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.) or Noah Creek Fm. sand and gravel. Associated with low relief features that occupy depressions and low sags on the landscape. Supports wetland vegetation and can be permanently covered by water. High water table.

Qal - Alluvium (DeForest Formation-Undifferentiated)

Variable thickness (<1 to 5 meters) of very dark gray to brown, noncalcareous to calcareous, stratified silty clay loam, clay loam, loam to sandy loam alluvium and colluvium in stream valleys, on hill slopes and in closed depressions. May overlie Dows Formation (Morgan or Alden Mbrs.), or Noah Creek Formation. Off the Des Moines Lobe this unit overlies Sheldon Creek Formation diamicton. Associated with

low-relief modern floodplain, closed depressions, modern drainageways or toeslope positions on the landscape. Seasonal high water table and potential for frequent flooding.

WISCONSIN EPISODE

Landform Sediment Assemblages of Supraglacial and Subglacial Origin

Qtr_{bm} - Till ridge (Dows Formation-Morgan Mbr.) Generally 3 to 5 meters of yellowish to grayish brown, usually calcareous and fractured, stratified loam to silt loam; stratified sands and gravels to sandy loam diamicton; textures can be quite variable. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). The Alden Mbr. in this mapping unit rarely extends to depths greater than 12 to 15 meters; and overlies the Sheldon Creek Formation diamicton. At the DML margin, this landform may be mantled with a thin layer of Peoria Formation silt. Low to moderate relief hummocky landform features exceed 3 to 5 meters of local relief. This landform is associated with the Bemis Moraine. The surface pattern is irregularly shaped patterns. Seasonal high water table.

Qtr_{bamc} - Till ridge (Dows Formation-Morgan Mbr.) Generally 7 to 10 meters of yellowish to grayish brown, usually calcareous and fractured, stratified loam to silt loam; stratified sands and gravels to sandy loam diamicton; textures can be quite variable. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). The Alden Mbr. in this mapping unit can extend to depths in excess of 15 meters, and in southeastern Dickinson county it appears the Alden Mbr. is underlain by proglacial outwash and underlying lake sediments. This proglacial package overlies the Sheldon Creek Formation diamicton. Low to high relief hummocky landform features exceed 3 to 10 meters of local relief. This landform is associated with the Bemis Altamont Moraine Complex in Dickinson and Emmet counties. The surface pattern is irregularly shaped and some rounded irregularly shaped patterns. Seasonal high water table.

Qtr_{amc} - Till ridge (Dows Formation-Morgan Mbr. or Pilot Knob Mbr or Lake Mills Mbr.) Generally 9 to 15 meters of yellowish to grayish brown, usually calcareous and fractured, stratified loam to silt loam; stratified sands and gravels to sandy loam diamicton; textures can be quite variable. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). The Alden Mbr. in this mapping unit can extend to depths in excess of 25 meters. This sediment package overlies the Sheldon Creek Formation diamicton. Moderate to high relief hummocky landform features exceed 3 to 10 meters of local relief. This landform is characterized by moderate to high relief hummocks, esker and kame features and ice-walled lakes; and is associated with the Altamont Moraine Complex in Dickinson and Emmet counties. The surface pattern is primarily rounded circular to rounded irregularly shaped patterns. Seasonal high water table.

Qtp- Till plain (Dows Formation-Morgan Mbr.) Less than 8 m of yellowish brown, often calcareous and fractured, stratified loam to silt loam to sandy loam diamicton; textures can be quite variable. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-- Alden Mbr.). Low to moderate relief (3 to 8 m), undulating plains with irregular surface patterns. Seasonal high water table.

Qsc -- Glacial Till (Sheldon Creek Formation-undiff.) Generally 30 to 40 meters of a yellowish brown to gray, calcareous fractured to massive clay loam; at depth this unit can be variably textured and contain significant sand and gravel bodies. It is not uncommon to see Pierre Shale clasts in core samples. This unit overlies Pre-Illinois diamicton. In Clay county, this unit outcrops along steep slopes adjacent to the Little Sioux River valley and steep slopes along other major tributaries flowing into the Little Sioux River off the Des Moines Lobe landform.

Landform Sediment Assemblages of Proglacial Origin

Qoch - Valley train outwash (Noah Creek Formation) Generally 8 to 15 meters of dark gray, dark grayish brown, dark brown to dark yellowish brown medium to coarse sand, gravelly sand to pebbly gravel. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). In valley positions, it is at the land surface of older terraces. On the modern floodplain it is buried by DeForest Fm. alluvium. Low-relief landforms expressed as broad terraces; long, narrow longitudinal terraces or cusped-shaped point terraces. Terraces associated with the major valleys are benched on a gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). In southwestern Dickinson county which is beyond the extent of the Des Moines Lobe landform this unit is benched on Wisconsin-age Sheldon Creek Fm diamicton. This unit encompasses deposits that accumulated in stream valleys during the Wisconsin Episode. No flooding potential.

Qglp- Lake plain (Dows Formation-Lake Mills Mbr.) Generally less than 3 m of dark grayish brown, massive, calcareous silty clay loam, or silt loam; often overlying a thin basal increment of sand and gravel (<1 m). Overlies yellowish to grayish brown usually calcareous, stratified loam to silt loam to sandy loam diamicton; textures can be quite variable (Sheldon Creek Fm. diamicton). Low relief broad plain with less than 3 m of local relief. Seasonal high water table.

Qglp(ss) - Lake Sediment small-scale landform features (Dows Formation-Lake Mills Mbr.) Generally less than 3 meters of dark grayish brown, massive, calcareous silty clay loam, silt loam overlying a thin (<1 meter) basal increment of sand and gravel. Unit overlies yellowish to grayish brown calcareous, stratified loam to silt loam to sandy loam diamicton; textures can be quite variable (Dows Fm.-Morgan Mbr.) or it may overlie a gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). Small former glacial lake beds associated with very low relief till plain with reticulate linked-depression systems. High water table.

WISCONSIN EPISODE

Landform Sediment Assemblages of Wind and Erosion Origin

Qe - Sand Dunes and Sand Sheets (Peoria Formation-sand facies) Generally less than 3 meters of yellowish brown, massive, calcareous loamy sand to fine sand. It may overlie yellowish-brown coarse-grained sand and gravel (Noah Creek Fm.), or it may overlie yellowish to grayish brown, usually calcareous, stratified loam to silt loam to sandy loam diamicton (Dows Fm.-Morgan Mbr.). Usually restricted to a narrow belt along major river valley bottoms or adjacent uplands on the Des Moines Lobe. Off the Des Moines Lobe this unit is not restricted to dunes along valley areas and may occur as sand stringers overlying unnamed erosion surface loamy sediments.

Qsc2 -- Loamy Sediments Shallow to Glacial Till (Unnamed erosion surface sediment) One to three meters of yellowish brown to gray, massive to weakly stratified, well to poorly sorted loamy, sandy and silty erosion surface sediment. Map unit includes some areas mantled with less than one meter of Peoria Formation (silt or sand facies). Overlies massive, fractured, slightly firm glacial till of the Sheldon Creek Formation.

DESCRIPTION OF DES MOINES LOBE STRATIGRAPHY

An important aspect of surficial geologic mapping on the DML is development of map units that utilize a previously established lithostratigraphic framework for the DML sediments in Iowa. This stratigraphic framework allows us to better understand the surficial materials of the DML. Wisconsin and Hudson Episode deposits (Johnson et al., 1997) of the DML are included in five formations: Dows, Noah Creek, Peoria Formation and Sheldon Creek Formations (Wisconsin) and DeForest Formation (Hudson). The following section provides a description, of formations and members of the DML sediments.

STRATIGRAPHIC FRAMEWORK FOR THE DES MOINES LOBE

Surficial deposits of the DML are grouped into five formations: the Dows, Noah Creek, Peoria, Sheldon Creek and DeForest formations. The Dows and Sheldon Creek Formations consists of upland glacial deposits. The Noah Creek Formation is composed predominantly of coarse-grained glaciofluvial and fluvial deposits in stream valleys and on outwash plains. The Peoria Formation consists of wind-transported sediments. The DeForest Formation includes post-glacial sediments (Hudson Episode) that are primarily fine-grained alluvial, colluvial, and paludal deposits. The Dows and DeForest formations are further subdivided into lithologically different members.

DOWS FORMATION

The Dows Formation includes all upland glacial deposits on the DML. The formation is subdivided into four different members: the Alden, Morgan, Lake Mills, and Pilot Knob members. Information on the formation as a whole is presented first, followed by that for individual members.

Source of name: the town of Dows, Franklin County, Iowa.

Type Section: the Martin-Marietta quarry located in the NW 1/4, NE 1/4, SE 1/4 of section 30, T. 91 N., R. 22 W., Franklin County, Iowa (Kemmis et al., 1981). The type section is located on the flanks of the high-relief Altamont glacial-ice margin complex.

Description of Unit: The Dows Formation includes all upland glaciogenic deposits on the DML in north-central Iowa. It is subdivided into four members. The Alden Member consists predominantly of massive, dense, compositionally uniform diamicton. The Morgan Member consists of diamicton interbedded with generally thin, discontinuous beds of sorted sands, silts, silty clays, and gravels. The Lake Mills Member consists predominantly of massive to laminated silts and silty clays, frequently with a thin basal zone of sand and gravel. The Pilot Knob Member consists predominantly of upland sands and gravels occasionally interbedded with thin, discontinuous diamicton beds. At the type section, the Dows Formation consists of deposits of the Alden Member overlain by the Morgan Member (Kemmis et al., 1981).

Nature of Contacts: The Dows Formation unconformably overlies various older stratigraphic units including proglacial sand and gravel deposited during lobe advances, Peoria Formation loess, older Wisconsinan glacial deposits of the Sheldon Creek Formation, diamictons of the Pre-Illinoian Wolf Creek and Alburnett formations, buried soils developed in diamictons of the Pre-Illinoian Wolf Creek and Alburnett formations or undifferentiated alluvial and colluvial deposits overlying these formations, Cretaceous shale, various Pennsylvanian sedimentary rocks, and Mississippian and Devonian carbonate rocks. The

formation usually overlies Quaternary sediments. It rests on Cretaceous, Pennsylvanian, Mississippian, and Devonian bedrock in only small, restricted areas.

The formation is at the surface over most of north-central Iowa, except on outwash plains where it is buried by sand and gravel of the Noah Creek Formation. Locally the Dows Formation is overlain by younger colluvial, alluvial, or paludal sediment of the DeForest Formation. In stream valleys, the Noah Creek and DeForest Formations are often incised through the formation.

Differentiation from other Units: The Dows Formation is distinguished by its distinctive clay mineralogy. Compared to other formations, the massive diamicton is higher in expandable clay minerals (smectite group) and, unlike other northern-source glacial formations (Sheldon Creek, Wolf Creek, and Alburnett formations), the illite percentages are higher than the kaolinite-plus-chlorite percentages.

The distinctive clay mineralogy of the Dows Formation is similar to the clay mineralogy of Cretaceous Pierre Shale, a distinctive bedrock lithology that was glacially eroded and incorporated into the Dows Formation. The clay-mineral composition of fifteen Pierre Shale fragments taken from the Dows Formation is 67±3% expandables, 27±3% illite, and 6±2% kaolinite plus chlorite (Kemmis et al., 1981). This compares with the clay mineralogy of the fine-grained matrix of massive Dows Formation diamictons of 69±4% expandables, 19±3% illite, and 12±3% kaolinite plus chlorite.

Regional Extent and Thickness: The Dows Formation is continuous across uplands on the DML in Iowa. Formation and member thicknesses vary. The formation is typically 15 to 20 m (45 to 60 ft) thick across most of the Lobe. It thickens to over 30 m in ridges and escarpments deposited at the edge of former ice advances ("end moraines"). Stream valleys are cut into or through the upland Dows Formation deposits; the lower reaches of most major streams, such as the Des Moines, Iowa, Raccoon, and Boone rivers, have incised completely through the Dows Formation sequence at many sites.

Origin: The Dows Formation includes all upland glacial deposits on the DML. Members of the formation are distinguished by their characteristic lithologic properties (see member discussions below). Although these properties are not defined by the origin of the deposits, the members are usually associated with distinctive glacial environments. The massive diamicton of the Alden Member is usually till that has been deposited in a subglacial environment. The interbedded diamicton and sorted deposits of the Morgan Member were usually deposited in ice-marginal and supraglacial settings. The fine-grained, generally pebble-free deposits of the Lake Mills Member usually were deposited in glacial lakes. The coarse-grained, sand-and-gravel deposits of the Pilot Knob Member are found in the core of kame and esker landforms deposited in association with glacial meltwater.

Age and Correlation: The Dows Formation was deposited by advances of the DML dating from approximately 15,000 to 12,000 radiocarbon years before present (Kemmis et al., 1981; Ruhe, 1969). The formation is correlative to the New Ulm Till of Minnesota (Hallberg and Kemmis, 1986) for which Matsch (1972) provides limited textural and compositional data.

Alden Member

Source of name: the town of Alden, Iowa, near which Alden Member deposits are well exposed in the Martin-Marietta quarry located just southeast of town in the NE 1/4, NW 1/4, NE 1/4 of section 20, T. 89 N., R. 21 W., Hardin County, Iowa.

Type Section: same as that of the Dows Formation; the Martin-Marietta quarry located in the NW 1/4, NE 1/4, SE 1/4 of section 30, T. 91 N., R. 22 W., Franklin County, Iowa.

Description of the Unit: The bulk of the Alden Member consists of massive, compositionally uniform diamicton. The diamicton is matrix-dominated, with the sand-silt-clay matrix typically comprising 94 to 96% of the diamicton by weight. The matrix texture tends to be uniform both with depth at any one site and regionally from site to site. Several exceptions to this textural uniformity occur locally. At the base of the unit, the texture may vary because of incorporation of local substrate material. Discontinuous pods and lenses of sorted deposits (usually pebbly sands, sands, pebble gravels and silts) are also common at the base of the diamicton. In some cases, block inclusions of intact local substrate occur in the diamicton,

but these are rare. Smudges, inclusions of local substrate that have been smeared out in or at the base of the glacier (Kruger, 1979), are also rare. The matrix texture of the diamicton is loam across the Lobe, although there is local variation within the range of sand-silt-clay percentages that comprise the loam textural group. The only systematic variation observed to date occurs south from the latitude of Ames where loess becomes the dominant substrate material below the Dows Formation. Glacial erosion of the loess and its incorporation into the Alden Member diamicton matrix has resulted in a systematic increase in the silt content of the diamicton downglacier to the terminus in Des Moines.

Rod-shaped (prolate) pebbles in the massive diamicton are usually strongly and consistently oriented. The orientations of prolate pebbles in the Alden Member are oriented parallel to the glacial flow direction inferred from ice-margin orientations, and are interpreted to have been oriented by a pervasive subglacial stress field at the base of an actively moving glacier. Pebble fabrics measured in massive Alden Member diamicton from around the DML are well oriented and show similar consistency between measurement sites at a given location.

Massive diamicton of the Alden Member is usually dense and "overconsolidated" (compacted to greater densities than possible just by the stress, or weight, of overlying deposits). Densities vary little and have a mean of about 1.9 g/cc. Where unweathered, Alden Member diamicton is unoxidized, very dark gray, and unleached. Various secondary pedogenic and weathering changes may have altered the deposits, depending on the local relief, vegetation, and geomorphic history.

Nature of Contacts: The Alden Member abruptly overlies various older Quaternary deposits or bedrock. The basal contact is abrupt and almost always planar with little undulation, but in restricted local areas the contact is deformed. Clasts at the basal contact are sometimes embedded ('lodged') in the underlying substrate. Clark (1991) stated there was a fairly continuous striated clast pavement beneath the DML in Iowa, although no specific data were given. Such a striated clast pavement is very rare and restricted in occurrence. Out of forty-two sites we've described in detail, only two have a striated clast pavement, while two others have clasts concentrated at the basal contact but no clast "pavement" as such.

The basal contact sometimes appears to be conformable, but usually is erosional to various degrees. The tendency toward a flat, planar bed has resulted in differential erosion where the higher, better drained paleolandscape positions have usually been eroded away, while the more poorly drained positions (and their associated paleosols) are commonly preserved beneath the Alden Member.

The substrate underlying the Alden Member is almost always overconsolidated (compacted), the deformation resulting in a reduction of pore space, the expulsion of pore water, and an increase in density. Other deformation of the substrate appears to be minimal. Where paleosols are preserved beneath the Alden Member contact, even small-scale features like soil horizons and soil structure (measured in centimeters and millimeters) are preserved. Local shear displacements of the underlying deposits (such as low-angle thrust faults) are occasionally observed, but displacements are usually a few tens of centimeters (1-3 ft) to a few meters (10 ft or less) in length, and these features are not common.

The upper contact varies. In places, the Alden Member is at the surface. Where buried by the interbedded diamictons and sorted deposits of the Morgan Member, the contact may vary from gradational to abrupt. Contacts with overlying Lake Mills and Pilot Knob members, and the Noah Creek and Peoria formations are always abrupt. Contacts with overlying sediments of the DeForest Formation are marked by a discontinuous to distinct stone line or a basal zone of coarse sand.

Differentiation from Other Members: The Alden Member differs from other members of the formation primarily in texture and bedding structures. The generally thick, massive diamicton of the Alden Member contrasts with the diamicton of the Morgan Member, which usually occurs as beds with sorted sands, silts, and pebbly sands. Diamicton beds in the Morgan Member are usually massive too, but sometimes include various sedimentary structures that indicate resedimentation (detailed in the following section on the Morgan Member). In addition, unlike for the bedded sequence of the Morgan Member, Alden Member diamicton usually shows no evidence for collapse from deposition on or next to stagnant ice.

Diamicton of the Alden Member contrasts with the well-sorted fine-grained and sandy deposits of the Lake Mills Member, and the coarse, well to poorly sorted gravels and sands of the Pilot Knob Member.

Extent and Thickness: The Alden Member is the thickest and most extensive member of the formation, underlying nearly all upland sites on the DML. Thicknesses vary depending on the landform type and topographic position. Typically, massive diamicton of the Alden Member ranges from 10 to 20 m (30 to 60 ft) in thickness. However, near the southern DML terminus, thicknesses typically range from 4 to 6 m (13 to 20 ft), whereas at or near former ice margins, thicknesses can approach 30 m (100 ft).

Origin: The Alden Member was deposited by various advances of the DML into Iowa. Its typical lithologic properties (massive structure, poor sorting, overconsolidation, high density, and strongly oriented pebble fabrics) suggest the Alden Member diamicton is usually till formed subglacially by lodgement, melt-out, or deformation.

Morgan Member

Source of name: Morgan Township, Franklin County, and the township in which the type section for the Dows Formation is located.

Type Section: same as that for the Dows Formation: the Martin-Marietta quarry located in the NW 1/4, NE 1/4, SE 1/4 of section 30, T. 91 N., R. 22 W., Franklin County, Iowa.

Description of the Unit: The Morgan Member consists of interbedded diamicton and sorted sediment. Diamicton beds in this sequence are distinctive. Most are massive, some have basal gravel layers, and others become finer grained upward although these 'normally graded' beds are rare. Matrix textures often fall in the loam category, but there can be variation both within beds and between beds. Individual beds sometimes contain small clasts of sorted sediment, and some beds grade upward to laminae or thin beds of sorted sediment. Overall, there is greater variation in matrix texture for the diamicton beds of the Morgan Member compared to the thick, massive diamictons of the Alden Member. Bulk densities of diamicton beds in the Morgan Member vary and tend to be lower than those of the massive diamicton comprising the Alden Member.

Diamicton beds in the Morgan Member vary from 1 centimeter to as much as 2 meters (1/4 inch to 6 ft) in thickness, but most beds are less than 0.7 m (2.5 ft) thick. The beds are discontinuous, occurring either in sheets or pods. From two-dimensional exposures it is difficult to tell the exact extent of these sheets and pods, but individual sheets often extend for several meters, perhaps as much as 15 m (40 to 50 ft). Diamicton pods are less extensive, and commonly range from 0.5 to 5 m (2 to 15 ft) in extent.

Rod-shaped (prolate) pebbles in the diamicton beds are usually not strongly or consistently oriented. Even within an individual bed, orientations may diverge.

Contacts between adjacent diamicton beds may be gradational or abrupt, whereas contacts between diamicton beds and beds of sorted sediment are usually abrupt. These contacts are commonly deformed, resembling soft-sediment deformation (Lowe, 1978) that occurs when sediment strength is locally exceeded by increasing weight as overlying sediment successively accumulates.

Sorted sediments in the Morgan Member include a wide range of textures. The fine-grained deposits are usually pebble-free, and include loam, silt loam, clay loam, silty clay loam, and silty clay textures. Coarser-grained deposits include sands, pebbly sands (matrix-supported pebble gravels), and well sorted (clast-supported) pebble gravels. Clasts larger than coarse pebbles are infrequent in the sorted sediments.

The sorted sediments occur in a wide variety of bedding structures, including laminae, massive beds, plane beds, ripple-drift cross-lamination, cross-bed sets, inversely and normally graded beds, and channel fills [(both small-scale individual fills and large-scale fills composed of multiple beds and sedimentary structures--the multi-storey type fills described by Ramos and Sopena (1983)]. Individual beds are usually thin, ranging from lamina to beds 0.5 m (1/10 in. to 1.5 ft) in thickness. The beds occur as sheets or as part of channel fills. Individual sheets are discontinuous. From two-dimensional exposures it is difficult to tell how far individual sheets extend, but they may extend several meters, perhaps as much as 15 m (50 ft). Channel fills tend to be small scale, rarely more than a few meters (5 to 50 ft) in width and usually less than 2 m (6 ft) deep.

Bed contacts are usually abrupt and often contorted. Sometimes conjugate high-angle normal and reverse faults displace the sequence of sorted sediments and diamicton beds in the Morgan Member. The faults

appear to have formed as a result of collapse when adjacent or underlying ice melted out (McDonald and Shilts, 1975).

Nature of Contacts: The Morgan Member has always been observed overlying other members of the Dows Formation. It occurs as thin to thick sequences, 0.5 to about 8 m (2 to 25 ft) thick, overlying the Alden Member and as generally thin veneers (less than 3 m--10 ft thick) over Pilot Knob Member sand and gravels. Basal contacts with the Alden Member vary from abrupt to gradational, whereas those with the Pilot Knob Member are typically abrupt.

The Morgan Member often occurs at the present land surface. In places it is overlain by either the Lake Mills Member, or the Noah Creek, Peoria, or DeForest formations. Contacts with these units are abrupt and unconformable.

Differentiation from other Members: The bedded diamictons and sorted sediments of the Morgan Member are distinctly different than other members of the Dows Formation. The Alden Member differs in being composed almost exclusively of massive diamicton. Diamicton beds are extremely rare in the Lake Mills Member; the member usually consists of massive fine-grained sediment overlying a thin increment of sand and pebbly sand. The Pilot Knob Member also consists predominantly of sorted sediments, but the sediments are dominantly coarse sand and gravel. Diamicton beds may occur within the Pilot Knob sequence at some locales, but they are not abundant. The distinction between the Pilot Knob and Morgan members is made on the abundance of diamicton beds. Deposits are classified as Morgan Member when diamicton beds are abundant; in the field, this usually means that diamicton beds constitute 30% or more of the sedimentary sequence.

Extent and Thickness: The Morgan Member varies in both extent and thickness. The member is common in 'hummocky' areas where thicknesses vary from thin, 1 to 3 m (3 to 6 ft) in thickness, to thick, 10 m or more (over 30 ft); often the deposits occur as alluvial-fan like wedges draping and flanking 'hummock' cores. Morgan Member deposits tend to be thin (2-4 m, 6-12 ft) and generally restricted to linked depression systems in low-to-moderate relief areas.

Origin: The geometry and lithologic properties of the bedded diamictons and sorted sediments comprising the Morgan Member suggest the deposits accumulated primarily in ice-marginal (ice-contact) or supraglacial settings where there was repetitive mass-wasting resulting in the deposition of diamicton beds, and in fluvial/lacustrine environments where sorted sediments accumulated (see Lawson, 1979a, 1979b, and 1989 for a discussion of processes in these environments).

Lake Mills Member

Source of name: the town of Lake Mills, Winnebago County, Iowa.

Reference Section: Deposits of the Lake Mills Member are not present at the type section of the Dows Formation, and so the 95 Lake Mills SE section, located in the SE 1/4, SE 1/4, SW 1/4 of section 16, T. 99 N., R. 23 W., Winnebago County, Iowa is designated as the reference section for this member (Kemmis, 1991).

Description of the Unit: The Lake Mills Member is usually less than 3 m thick. It typically consists of an upper, massive, generally pebble-free, fine-grained increment overlying a thin basal increment of stratified sand and pebble gravel. The member usually ranges between 0.75 and 3 m (2.5 to 10 ft) thick. Where thin (less than 1 m thick), basal sand and gravels are often absent although a stoneline may be present. Fine-grained deposits predominate the member at all sites, and are typically massive (unless altered by the development of secondary soil structure). Sand content is low, often less than 15%, and clay content is usually greater than 25%. Typical textures include silty clay loam, silty clay, and clay. The basal increment of sand and gravel is usually thin, less than 0.6 m (2 ft) in thickness, and commonly varies across a site. The contact between the upper fine-grained and lower coarse-grained increments varies from abrupt to gradational.

Nature of Contacts: Where present, the Lake Mills Member occurs at the land surface. Its lower contact is abrupt and unconformable with either the Morgan or Alden members of the Dows Formation. At some

sites, the basal contact is offset by high-angle normal and reversed faults where supraglacial lake deposits collapsed when underlying ice melted out.

Differentiation from Other Members: The massive fine-grained sediment and basal sand and gravel of the Lake Mills Member contrast with the poorly sorted diamictons of the Alden and Morgan members. The sorted sediments of the Lake Mills Member are thicker and laterally more extensive than those in the Morgan Member. In contrast to the Pilot Knob Member, the Lake Mills Member is predominantly fine-grained sediment instead of coarse-grained sand and gravel.

Extent and Thickness: The Lake Mills Member is usually thin, typically ranging between 0.75 and 3.0 m (2.5 to 10 ft) in thickness. It occurs as a mantle on certain circular "hummocks" outlined by linked-depression systems comprising former ice-marginal positions of the Bemis, Altamont, and Algona advances (Graeff, 1986; Kemmis, 1991). It also occurs over broad, undulating uplands denoted as Glacial Lake Jones (Kemmis, 1981), Glacial Lake Wright, and Glacial Lake Story City. The exact extent and depositional setting of each of these three glacial lakes needs further research. Preliminary work suggests that Glacial Lake Jones is related to proglacial drainage of the Algona advance blocked by landforms of the older West Bend advance to the south. Glacial Lake Wright, located just behind the Altamont margin, is similar in setting to supraglacial lakes that form behind the bulged margin of surging glaciers during the quiescent phase after a surge advance (Croot, 1978). The origin of Glacial Lake Story City (locally called the Story City Flats) is unknown.

Origin: The massive, laterally uniform fine-grained sediments of the Lake Mills Member were deposited in glacial lakes. These lakes probably occurred in different depositional environments. The Lake Mills Member, where it mantles the tops of 'hummocks' at the reference section and at other hummocky sites bordered by linked-depression systems at or near former ice-marginal ('end moraine') positions, formed in a supraglacial or ice-walled lakes (Graeff, 1986; Kemmis, 1981 and 1991). Some sites, like Glacial Lake Jones in front of the Algona glacial margin in Kossuth and Hancock counties, appear to have formed as proglacial lakes.

The fine-grained upper increment that dominates stratigraphic sequences of the Lake Mills Member is typically massive, lacking varve couplets, suggesting that the sediment was deposited in shallow lakes. Varves only form where lakes are deep enough for thermal stratification to develop and seasonal turnover to take place. Paleoenvironmental interpretations based on fossil ostracode assemblages collected from a site similar to the reference section, but 0.5 km (1/4 mile) away, indicate that the environment was in the littoral (near shore) zone where lake depth was shallow, ranging between 0.6 and 3.0 m (2 to 10 ft), and mean annual temperature was between 0.8^o and 3.6^o C (33.5^o to 38.5^o F) (Graeff, 1986). The present mean annual temperature in the Lake Mills area is 8^o C (46.3^o F).

The thin zone of coarser sand and gravel often found at the base of the Lake Mills Member either formed from initial wave wash on the underlying Morgan or Alden members or as coarse sediment influx into the lake from adjacent lake margins (which were ice-cored in some settings).

Pilot Knob Member

Source of name: Pilot Knob, the prominent glacial hummock in Pilot Knob State Park, located east of Forest City, Winnebago County, Iowa.

Reference Section: Deposits of the Pilot Knob Member are not present at the type section for the Dows Formation, but are well exposed in an excavation at the 98 LaHarv-1 site, located in an east-west trending esker in the NE 1/4, SE 1/4, SE 1/4 of section 30, T. 98 N., R. 22 W., Worth County, Iowa which is designated as the reference section for the member.

Description of the Unit: The Pilot Knob Member consists predominantly of sands and gravels occurring in irregularly shaped hummocks and low-sinuosity ridges in uplands on the DML. Textures and bedding structures often vary significantly over short distances both laterally and vertically. Bedding structures include all of the flow-regime bedforms described by Simons et al. (1965) and the various channel-fill types recognized by Ramos and Sopena (1983). Beds of virtually pebble-free, fine-grained sediment and diamictons sometimes occur at the top of or within the member, but are uncommon. The diamicton beds

tend to occur as isolated, channelized pods. The stratified sequence comprising the member is sometimes offset by high-angle normal and reverse faults resulting from collapse of the sediment when the glacier's supporting ice walls melted away. The modern soil profile is developed in the top of the Pilot Knob Member where it is the surficial deposit. Sands and gravels within the member are oxidized where they occur above the water table and unoxidized below.

Nature of Contacts: The base of the Pilot Knob Member is rarely exposed. It is presumed to be unconformable on underlying diamicton sequences of the Morgan Member or the massive diamicton of the Alden Member. At many sites the Pilot Knob Member occurs at the land surface. At some sites it is overlain unconformably by 3 m (10 ft) or less of interbedded diamictons and sorted sediments of the Morgan Member or by a stoneline and thin colluvium of the Flack Member of the DeForest Formation.

Differentiation from Other Members and Formations: Unlike all other members of the Dows Formation, the Pilot Knob Member is composed predominantly of coarse sand and gravel. Although diamicton beds are locally present in the member, they do not comprise the bulk of the sequence as they do in the Morgan Member.

The sand and gravel sediments comprising the Pilot Knob Member are similar to the fluvial and glaciofluvial sands and gravels of the Noah Creek Formation, but there tends to be greater variability, both laterally and vertically in the Pilot Knob Member. The Pilot Knob Member also occupies a distinct geomorphic position, that being upland hummocks and ridges, whereas the Noah Creek Formation is confined to stream valleys and outwash plains.

Extent and Thickness: The Pilot Knob Member occurs in irregular hummocks and low-sinuosity ridges across the DML. The hummocks are usually a few hundred meters in diameter, and the narrow, sometimes beaded ridges usually extend from 1 to 3 km (1/2 to 1 1/2 mile). Relief on the hummocks and ridges is usually 6 to 13 m (20 to 40 ft), but locally may be greater. The range of thicknesses for the member is uncertain, but is generally greater than 3 m (10 ft). Maximum thicknesses are estimated to be 10 to 15 m (30 to 50 ft).

Origin: Like classic kames and eskers (e.g., Flint, 1971; Banerjee and McDonald, 1975; Saunderson, 1975; Sugden and John, 1976), deposits of the Pilot Knob Member appear to have formed in stagnant-ice environments. The sands and gravels were probably deposited by meltwater flowing in moulins and subglacial and englacial tunnels. Diamicton beds within the member appear to be debris flows into the tunnels as surrounding ice melted. High-angle normal and reversed faults within the Member formed when the sediments collapsed as surrounding ice walls melted away.

NOAH CREEK FORMATION

The Noah Creek Formation is composed predominantly of coarse-grained sand and gravel deposited in present and abandoned stream valleys, and on outwash plains.

Source of name: Noah Creek, a tributary to the Des Moines River near the formation's type section, Boone County.

Type Section: the 8 Hallett-1 Section located on a benched terrace along the west side of the Des Moines Valley in the NW 1/4, NW 1/4, section 36, T. 84 N., R. 27 W., Boone County, Iowa (Bettis et al., 1988).

Description of the Unit: The Noah Creek Formation consists of a thin upper increment of fine-grained sediment usually ranging between 0.3 and 1.5 m (1 to 5 ft) thick overlying thick sand and gravel that typically exceeds 5 m (15 ft) in thickness. Bedding structures in the thick lower sequence of sand and gravel include all of the flow-regime bedforms described by Simons et al. (1965) and the various channel-fill types recognized by Ramos and Sopena (1983). In settings proximal to ice advances, the formation's deposits may exhibit collapse structures related to melt out of ice blocks buried in the outwash sequence. Also, in proximal settings a silt facies is recognized. This unit is best described as a slackwater deposit that consists of a thin, very discontinuous mantle on the oldest Late Wisconsin terraces associated with the Des Moines River valley. Secondary alteration includes soil formation throughout the upper fine-grained sediment, with other pedogenic alterations (such as beta horizons) sometimes extending down

into the upper part of the underlying sand-and-gravel sequence. The sands and gravels are oxidized above the water table and unoxidized below.

Nature of Contacts: On outwash plains, the Noah Creek Formation can conformably or unconformably overlie the Dows Formation. Where the Noah Creek Formation is inset below the uplands in a valley geomorphic position, it unconformably overlies the Dows Formation, older Quaternary sediments, or Paleozoic bedrock into which the stream has incised. It occurs at the land surface of higher stream terraces on the Lobe, and is unconformably buried by the DeForest Formation beneath alluvial fans, low stream terraces, and the modern flood plain.

Differentiation from other Units: The thick, coarse, sand-and-gravel sequences comprising the Noah Creek Formation are unlike any of the other formations on the DML. The Dows Formation occurs in a different geomorphic position, and the Alden and Morgan members are predominantly diamictons rather than sand and gravel. The Lake Mills Member is dominantly fine-grained sediment, and, if present, the basal sand-and-gravel is very thin and generally finer grained than the Noah Creek Formation. The Pilot Knob Member is lithologically similar to the Noah Creek Formation, but differs in geomorphic position (upland hummocks and ridges rather than stream valleys), and tends to have greater variability over short distances. The sand facies of the Peoria Formation (see below) is pebble-free, exhibits better sorting, and has different bedforms than the Noah Creek Formation.

The DeForest Formation differs, being composed primarily of fine-grained alluvium. Sand and gravel in any of the DeForest Formation members is thinner, finer textured, and less laterally extensive than that comprising the Noah Creek Formation.

Extent and Thickness: The Noah Creek Formation occurs on outwash plains and in stream channels that drained the DML, including river valleys and abandoned outwash channels. In river valleys, the Noah Creek Formation underlies terraces and flood plains. Three different terrace morphologies are recognized in the field: cut-off, longitudinal, and point types. Some differences in bedding structures are found in the different terrace types because of stream-flow variations between the terrace types, and there are down-valley differences in both valley morphology and sedimentary sequence as well (Kemmis et al., 1987, 1988; Kemmis, 1991). Most of the terraces are 'benches' cut into the upland with only a veneer of sand and gravel covering them. Thickness of the veneer varies, but commonly is on the order of 6 m (20 ft). The Noah Creek Formation also occurs in abandoned outwash channels at the margin of former ice advances and in associated outwash plains

Origin: The Noah Creek Formation was deposited as outwash or redeposited outwash along stream valleys, outwash channels, and in outwash plains. All major rivers on the DML have their source at the margin of former ice advances (end moraines), and the morphology of their valleys reflects their origins as glacial sluiceways.

Glacial drainage is characterized by extreme variation in streamflow both on annual scales, as conditions change from winter freeze-up to early summer floods when the glacier's snow pack rapidly melts off, and on longer term scales when unusually large flood flows, jokulhlaups, occur (Church and Gilbert, 1975; Smith, 1985). This variability in streamflow is reflected in the wide range of bedding structures and sand-and-gravel textures comprising the Noah Creek Formation. Terraces in the distal part of major rivers on the DML consist of three distinctive increments: a thick, highly variable lower increment that is interpreted to record normal fluctuations in outwash systems on annual scales; a 1 to 2 m (3 to 5 ft) thick middle increment consisting of poorly sorted, planar-bedded cobble gravels extending across the terrace that appears to result from major floods; and a thin veneer of fine-grained sediment capping the terrace that results from waning flow and overbank sedimentation (Kemmis et al., 1987; 1988).

Age: On the DML, the Noah Creek Formation dates from about 14,000 to 11,000 RCYBP. The oldest advance of the DML is dated at about 14,000 RCYBP (Ruhe, 1969; Kemmis et al., 1981) when deposition of the Noah Creek Formation was initiated. Deposition of the Noah Creek Formation ceased by 11,000 RCYBP. Wood from the oldest DeForest Formation alluvium in the Des Moines River valley, which is inset into and therefore younger than the Noah Creek Formation, dates at 11,000 \pm 290 RCYBP (Beta-10882; Bettis and Hoyer, 1986).

PEORIA FORMATION

The Peoria Formation consists of wind-transported sediments and occurs throughout Iowa.

Source of name: the city of Peoria, Peoria County, Illinois.

Type Section: the Tindall School Section, a borrow pit in the west bluff of the Illinois Valley south of Peoria, Peoria County, Illinois, in the SW 1/4, SW 1/4, NE 1/4 of section 31, T. 7 N., R. 6 E. (Willman and Frye, 1970).

Description of Unit: The Peoria Formation includes wind-transported sediments. Two facies are recognized in Iowa, a silt facies (loess) and a sand facies (eolian sand). The sediments are well sorted and the two facies may be interbedded. Textures range from silt loam to medium-to-fine sand. Macroscopic bedding structures are rare and are found primarily in locations proximal to a valley source where the formation's sediments are thick. Where present, bedding structures include planar beds with inverse grading in the silt facies, and planar beds to steep foresets in the sand facies. Where eolian sand overlies sand-and-gravel deposits of the Noah Creek Formation it is included in that formation. On the DML, secondary pedogenic alteration has modified most Peoria Formation deposits.

Nature of Contacts: The Peoria Formation usually occurs at the land surface. It abruptly and unconformably overlies older Quaternary formations and paleosols developed in them. Beneath the DML the silt facies of the formation is buried by Dows Formation glacial diamicton, while the sand facies occurs at the land surface and abruptly and unconformably overlies the Dows Formation. The contact with other units is marked by an abrupt change in texture, sedimentary structures, fossil content, or secondary weathering characteristics.

Differentiation From Other Units: The wind-sorted sediments of the Peoria Formation are generally unlike the deposits of any other formation on the DML. The Lake Mills Member of the Dows Formation consists of fine-grained sediment, but it has greater variability, a higher clay content, and occurs in a different geomorphic setting. The Noah Creek Formation and Pilot Knob Member of the Dows Formation are more poorly sorted and contain coarse sand and gravel. The DeForest Formation contains some sandy sediment, but the bedding structures and sorting of these are distinct from those associated with the Peoria Formation.

Regional Extent and Thickness: The Peoria Formation occurs on uplands and high terraces throughout Iowa. In north-central Iowa, the silt facies of the formation is buried by glacial diamicton of the Dows Formation, except in very restricted, small areas adjacent to major river valleys in the southern part of the lobe. On the DML, the formation is usually restricted to a narrow belt on the upland along major stream valleys.

Thickness varies with respect to distance from the valley source. Proximal to the Missouri Valley in western Iowa, the formation usually is more than thirty meters (90 ft) thick. On the DML the formation ranges from a few centimeters to about three meters (9 ft) in thickness.

Origin: The Peoria Formation consists of wind-deposited sediment. The formation's sediments were derived from wind reworking of valley-train outwash. The sand facies also includes sediments reworked from older eolian sand deposits.

Age: The Peoria Formation is time transgressive. The silt facies was deposited between about 22,000 and 12,500 RCYBP, while the sand facies includes deposits that accumulated contemporaneous with the silt facies, as well as others that accumulated during the Holocene to the present. Most Peoria Formation deposits on the DML accumulated between about 14,000 and 11,000 RCYBP, and have undergone various degrees of wind reworking during the Holocene.

DEFOREST FORMATION

The DeForest Formation consists of fine-grained alluvium, colluvium, and pond sediment in stream valleys, on hillslopes and in closed and semi-closed depressions. The formation was originally defined by Daniels et al. (1963) for a repeatable sequence of alluvial fills in the Loess Hills of western Iowa. Subsequent study of drainage basins across Iowa revealed that a consistent alluvial stratigraphy was present, but its classification required expansion and revision of the formation (Bettis, 1990). The revised DeForest Formation includes the Gunder, Roberts Creek, Camp Creek, and Corrington members, all recognized on the DML (Bettis, 1990; Bettis et al., 1992). These members are not described here for the sake of brevity. These new members are the Flack Member, consisting of colluvium mantling hillslopes, the Woden Member, for sediment fills in semi-closed and closed depressions, and the West Okoboji Member for lake sediment associated with extant lakes.

Source of name: the De Forest Branch of Thompson Creek, Harrison County, Iowa, one of the watersheds originally studied by Daniels et al. (1963).

Type Sections: The original type sections were composed of loess-derived alluvium in a small western Iowa watershed (Daniels et al., 1963). Type sections for the Gunder and Roberts Creek members occur along Roberts Creek, Clayton County, in the Paleozoic Plateau region of northeastern Iowa. The type section for the Camp Creek Member occurs in Woodbury County in the Loess Hills of western Iowa, and the type section of the Corrington Member occurs in Cherokee County along the Little Sioux Valley in the Northwest Iowa Plains region.

Description of Unit: The DeForest Formation consists of fine-grained alluvium, colluvium, and pond sediments. A minor component of most members is sand or pebbly sand which, if present, is usually discontinuous, filling small scour channels at the base of the member or at the base of depositional units within members. Peat and muck occur in the Woden Member and infrequently as thin, local, discontinuous beds within the Gunder, Roberts Creek, and Camp Creek members.

Except where the tops of members have been erosionally truncated, soil profiles are developed in all members of the formation except the West Okoboji Member. Weakly expressed buried soils are locally preserved in all members except the Flack and West Okoboji. These buried soils reflect periods of landscape stability, but they are not widely traceable, even in individual drainage basins. They appear to record only short-lived local conditions. Secondary weathering-zone properties in the members vary with the depth and elevation of the water table.

Nature of Contacts: The DeForest Formation occurs at the land surface. It abruptly and unconformably overlies the Dows, Noah Creek, and any older Quaternary and Paleozoic formations into which it is incised. The contact is marked by an abrupt change in texture, sedimentary structures, and fossil content.

Differentiation from other Units: The alluvium, colluvium, and pond sediments of the DeForest Formation are generally unlike the deposits of any other formation on the DML. The Lake Mills Member of the Dows Formation consists of fine-grained sediment, but it tends to have a higher clay content and occurs in a different geomorphic setting (uplands instead of stream valleys). The Noah Creek Formation and the Pilot Knob Member of the Dows Formation are predominantly coarse sand and gravel. The Alden and Morgan members of the Dows Formation include poorly sorted diamicton deposits, which the DeForest Formation typically lacks. The Peoria Formation occurs on high terraces and uplands and is better sorted than DeForest formation deposits.

Regional Extent and Thickness: The DeForest Formation occurs in stream valleys, closed depressions, and on hillslopes across Iowa, and on the DML it also occurs in linked-depression drainageways. Thickness varies with geomorphic position and local relief. Where present, the formation varies in thickness from a few centimeters (inches) to several meters (greater than 20 feet) thick.

Origin: The DeForest Formation consists of post-glacial alluvium, colluvium, pond deposits, and organic sediment (peat and muck) that were deposited by or in water.

Age: The base of the DeForest Formation is time-transgressive. On the DML it is younger than 11,000 RCYBP in most areas, but is locally as old as 14,000 to 11,000 RCYBP. Deposition of the DeForest

Formation continues to the present. The age of individual members is also time-transgressive, dependent on position in the drainage system and on geomorphic position.

Woden Member

Source of name: Woden Bog, type section for the Woden Member, Hancock County.

Type Section: The type section for the Woden Member is a drill core, 41 Woden Bog W1, located in the NE 1/4, NW 1/4 of section 13, T. 97 N., R. 26 W., Hancock County, Iowa (Walker, 1966). This site is located in the center of a depression that is part of a large linked-depression drainage way associated with the Algona ice margin.

Description of Unit: The Woden Member consists of alternating zones of fine-grained colluvium and organic sediment in semi-closed and closed depressions on the DML. The stratigraphic sequence differs slightly between small and large depressions. Large depressions consist of alternating mineral sediment (colluvium) and organic material. Walker (1966) demonstrated that two successions of these deposits occur in large depressions on the DML, and he informally designated these units as the lower silt, lower muck, upper silt, and upper muck. Thicknesses and textures varied dependent on position in the depression, depth and local relief around the depression, and water table elevation. The units were interpreted to relate to periods of differing hillslope stability during the Holocene caused by changing vegetation and climate. The silt units were related to periods of hillslope instability and the predominant deposition of colluvial deposits, and the muck units related to periods of hillslope stability when organic matter accumulation was greater than colluvial deposition. The "silt" units are often stratified and include silt loam, loam, sandy loam, loamy sand, sand, and pebbly sand textures. The coarsest mineral sediment usually occurs at the base of the depression in the lower silt. The mineral sediment is usually a reduced light gray color at the base, grading upward to black, organic-coated sediment. Thicknesses of the black, organic-coated sediment vary dependent on local drainage-basin history and conditions. The "muck" units include peat, muck, and organic-rich mineral sediment. Because of the historic draining of wetlands, the upper peat and muck at many sites is now degraded.

Smaller depressions have a simpler stratigraphy, usually consisting of only fining upward mineral sediment overlain by organic deposits (Walker and Brush, 1963; Kim, 1986).

Nature of Contacts: The Woden Member unconformably overlies deposits of the Dows or Noah Creek formations. The basal contact is usually marked by an abrupt change in texture, bedding structures, and color. The basal contact is difficult to identify where coarse basal colluvium overlies sand and gravel of the Noah Creek Formation.

In some watersheds, the Woden Member is overlain by thin colluvium of the Camp Creek Member. In these cases, there is an abrupt contact between the stratified, lighter colored, brown sediment of the Camp Creek Member and the massive black peat or muck at the top of the Woden Member.

Differentiation from other Members: The Woden Member differs from other members of the DeForest Formation in geomorphic position and the nature of the stratigraphic sequence. It is restricted to semi-closed and closed depressions, and unlike other members, organic sediments (peat and muck) are common in the sequence, capping depositional units.

Regional Extent and Thickness: On the DML the Woden Member is restricted to semi-closed and closed depressions. Thicknesses vary dependent on the size of the depression, the height and steepness of the surrounding slopes, and the depth of the water table, lake or marsh. The base of the depressions is often uneven, consisting of a series of coalescing basins (Walker, 1966). The thickest Woden Member deposits occur near depression centers. Smaller depressions typically have fills less than 2.5 m (8 ft) thick in the center. Larger depressions have central fills varying from about 4 to 11 m (12 to 35 ft) in thickness.

Origin: Mineral sediment in the Woden Member is primarily colluvium and sheetwash derived from erosion of adjacent slopes. Some of this sediment has subsequently been reworked by various processes in

the wetland depressions. The organic sediment formed during periods when adjacent slopes were relatively stable and organic matter accumulation rates exceeded mineral sediment depositional rates (Walker, 1966).

Age: The base of the Woden Member is time transgressive across the DML, dating from the final wastage of glacial ice from the area (ca. 14,000 RCYBP in central Iowa to ca. 12,000 RCYBP in northern Iowa). Deposition has continued to the present, but depositional rates through the post glacial period (Hudson Episode) varied (Walker, 1966). Where there has been extensive erosion of adjacent slopes during the Historic period, the Woden Member is buried by Camp Creek Member colluvium.

SHELDON CREEK FORMATION

The Sheldon Creek Formation in its type area includes glacial deposits that are overlain by Dows Formation glacial deposits. In northwestern Iowa it outcrops adjacent to the DML and may be overlain by thin mantle of Peoria Formation (silt or sand facies) on uplands. The formation includes glacial deposits, formerly referenced as the “tazewell till”. It is recognized as an undifferentiated unit at this time.

Source of name: Sheldon Creek, Franklin County, Iowa.

Type Section: the Martin-Marietta quarry (formerly Weaver Construction Company Quarry) located in the NE 1/4, NW 1/4, NW 1/4 of section 20, T. 89 N., R. 21 W., Franklin County, Iowa (Kemmis et al., 1981). The type section is located on a moderate relief till plain with aligned ridge forms (formerly classified as “minor moraines”).

Description of Unit: The Sheldon Creek Formation includes glacial deposits at or near the land surface in northwest Iowa and beneath Dows Formation and the Peoria Formation (silt facies) deposits on the Des Moines Lobe. The Sheldon Creek does not appear to be present south of the Altamont I Moraine of the Des Moines Lobe. The Sheldon Creek consists predominantly of massive, dense, clay loam to loam diamicton. At the type section, the Sheldon Creek is overlain by Peoria loess which in turn is overlain by Dows Formation Alden Member diamicton (Kemmis et al., 1981).

Nature of Contacts: The Sheldon Creek Formation unconformably overlies various older stratigraphic units including, diamictons of the Pre-Illinoian Wolf Creek and Alburnett formations, buried soils developed in diamictons of the Pre-Illinoian Wolf Creek and Alburnett formations or undifferentiated alluvial and colluvial deposits overlying these formations, Cretaceous shale, various Pennsylvanian sedimentary rocks, and Mississippian and Devonian carbonate rocks. The formation usually overlies Quaternary sediments. The formation is only at the surface in a several county area in northwest Iowa, and otherwise is overlain by Dows Formation on the DML.

Differentiation from other Units: The Sheldon Creek Formation shares a distinctive clay mineralogy with the Dows Formation. Compared to other formations, the massive diamicton is higher in expandable clay minerals (smectite group) and, unlike other northern-source glacial formations (Wolf Creek, and Alburnett formations), the illite percentages are higher than the kaolinite-plus-chlorite percentages. The clay mineralogy of the Sheldon Creek Formation is similar to the clay mineralogy of the Dows Formation and the Cretaceous Pierre Shale, a distinctive bedrock lithology that was glacially eroded and incorporated into both the Sheldon Creek and Dows Formations. The clay-mineral composition of fifteen Pierre Shale fragments taken from the Dows Formation is 67±3% expandables, 27±3% illite, and 6±2% kaolinite plus chlorite (Kemmis et al., 1981). This compares with the clay mineralogy of the fine-grained matrix of massive Sheldon Creek Formation diamictons of 65±3.5% expandables, 18±1.8% illite, and 18±1.8% kaolinite plus chlorite (Lucas, 1977). Distinctive textural and lithologic signatures aid in deciphering Sheldon Creek Formation from Dows Formation. Dows Formation Alden Member basal till averages 47% sand, 37% silt and 16% clay; a loam diamicton (Lucas, 1977, Kemmis, 1981). The Sheldon Creek Formation diamicton is 32% sand, 37% silt and 32% clay; a clay loam diamicton (Lucas, 1977). Also, Lucas, 1977 reported a noticeably higher percentage of carbonate pebbles in the Sheldon Creek Formation than in Dows Formation diamicton. Other distinguishing characteristics are the possible presence of a weathering zone developed in the former surface sediments of the Sheldon Creek Formation, subaerial

erosion of the former surface sediments; and/or the presence of proglacial outwash sediments associated with DML ice advance overlying the Sheldon Creek Formation.

Regional Extent and Thickness: The Sheldon Creek Formation is continuous across uplands in portions of several counties in northwest Iowa (Buena Vista, Cherokee, Clay, Dickinson, Ida, O'Brien and Osceola.; these counties are adjacent to the DML. In these areas the Sheldon Creek may be mantled with a thin mantle (<2 meters) of Peoria loess. At this time we have limited information on thickness. However, the formation is typically 15 to 55 m (45 to 185 ft) thick across its extent.

Origin: The Sheldon Creek Formation includes all upland glacial deposits west of the Bemis Moraine and east of Mill Creek in northwest Iowa.

Age and Correlation: The Sheldon Creek Formation was deposited by advances of the Wisconsin ice dating from approximately 40,000 to 26,000 radiocarbon years before present (Bettis et al., 1996, Bettis, 1997).

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REFERENCES

- Andrews, W.F. and Dideriksen, R.O., 1981, Soil Survey of Boone County, Iowa: Des Moines, U.S. Department of Agriculture, Soil Conservation Service, 152 p. plus 84 map sheets.
- Baker, R.G., Bettis, E.A. III, Schwert, D.P., Horton, D.G., Chumbley, C.A., Gonzalez, L.A., and Reagan, M.K., Holocene Paleoenvironments of Northeast Iowa, *Ecological Monographs*, Vol. 66, No. 2 May 1996: Ecological Society of America, p. 203-234.
- Banerjee, J. and McDonald, B.C., 1975, Nature of esker sedimentation, *in* Jopling, A.V. and McDonald, B.C., eds., *Glaciofluvial and Glaciolacustrine Sedimentation: Society of Economic Paleontologists and Mineralogists, Special Publication No. 23*, p. 132-154.
- Bettis, E.A. III, 1997, Late-Middle and Early-Late Wisconsin Glaciation in North Central Iowa. *Geological Society of America North-Central Section Meeting Abstracts with Programs* 29 (4):5.
- Bettis, E.A. III, Quade, D.J. and Kemmis, T.J., 1996, *in* Hogs, Bogs, and Logs: Quaternary Deposits and Environmental Geology of the Des Moines Lobe. Edited by: E.A. Bettis, III, D.J. Quade, and T.J. Kemmis. Iowa Department of Natural Resources-Geological Survey Bureau, Guidebook Series No. 18, 170 p.
- Bettis, E.A., III, 1995, The Holocene Stratigraphic Record of Entrenched Stream Systems in Thick Loess Regions of the Mississippi River Basin: University of Iowa Department of Geology, Iowa City, unpublished Ph.D. thesis, 149 p.
- Bettis, E.A., III, Baker, R.G., Green, W., Whelan, M.K., and Benn, D.W., 1992, Late Wisconsinan and Holocene alluvial stratigraphy, paleoecology, and archeological geology of east-central Iowa: Iowa Department of Natural Resources-Geological Survey Bureau Guidebook Series No. 12, 82 p.
- Bettis, E.A., III, 1990a, Holocene alluvial stratigraphy of western Iowa, *in* Bettis, E.A., III, ed., *Holocene alluvial stratigraphy and selected aspects of the Quaternary history of western Iowa: Midwest Friends of the Pleistocene Field Trip Guidebook*, p. 1-72.
- Bettis, E.A., III, 1990b, The DeForest Formation of Western Iowa: Lithologic Properties, Stratigraphy, and Chronology, Iowa Department of Natural Resources Geological Survey Bureau, unpublished report to USDA--Soil Conservation Service; April, 1990. 96 p.
- Bettis, E.A., III, Pearson, J., Edwards, M., Gradwohl, D., Osborn, N., Kemmis, T., and Quade, D., 1988, Natural history of Ledges State Park and the Des Moines Valley in Boone County: Geological Society of Iowa Guidebook 48, 71 p.
- Bettis, E.A., III, and Hoyer, B.E., 1986, Late Wisconsinan and Holocene landscape evolution and alluvial stratigraphy in the Saylorville Lake area, central Des Moines River Valley, Iowa: Iowa Geological Survey Open File Report 86-1, 71 p.
- Boulton, G.S., 1972, Modern Arctic glaciers as depositional models for former ice sheets: *Quart. Jour. of the Geological Society of London*, v. 128, p. 361-393.
- Burras, C.L. and W.H. Scholtes, 1987, Basin properties and postglacial erosion rates of minor moraines in Iowa: *Soil Science Society of America Journal*, v. 51, p. 1541-1547.

- Carney, L.M. and Mooers, H.D., in Patterson, C.J., and Wright H.E. Jr., eds., Contributions to Quaternary studies in Minnesota: Minnesota Geological Survey Report of Investigations 49, p. 85-96.
- Chamberlin, T.C., 1883, Preliminary paper on the terminal moraine of the second glacial epoch: U.S. Geological Survey Third Annual Report, p. 291-402.
- Chamberlin, T.C., 1878, On the extent and significance of the Wisconsin Kettle Moraine: Transactions of the Wisconsin Academy of Sciences, Arts, and Letters, v. 4, p. 201-234.
- Church, M. and Gilbert, R., 1975, Proglacial fluvial and lacustrine environments, in Jopling, A.V., and MacDonald, B.C., eds., Glaciofluvial and Glaciolacustrine Sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication No. 23, p. 22-100.
- Clark, P.U., 1991, Striated clast pavements: products of deforming subglacial sediment?: Geology, v. 19, p. 530-533.
- Clayton, L., Teller, J.T., and Attig, J.W., 1985, Surging of the southwestern part of the Laurentide Ice Sheet: Boreas, v. 14, p. 235-241.
- Clayton, L., Moran, S.R., and Bluemle, J.P., 1980, Explanatory text to accompany the geologic map of North Dakota: North Dakota Geological Survey Report of Investigations, v. 69, 93 p.
- Clayton, L., and Moran, S.R., 1974, A glacial process-form model, in Coates, D.R., ed., Glacial Geomorphology: Binghamton, New York, p. 89-119.
- Croot, D.G., 1978, The depositional landforms and sediments produced by two surging glaciers: University of Aberdeen (Scotland), unpublished Ph.D. thesis, 354 p.
- Daniels, R.B., and Handy, R.L., 1966, Surficial sediments on undulating Cary ground moraine in central Iowa: Iowa State University Engineering Research Institute Technical Report 3, 20 p.
- Daniels, R.B., Rubin, M., and Simonson, G.H., 1963, Alluvial chronology of the Thompson Creek Watershed, Harrison County, Iowa: American Journal of Science, v. 261, p. 473-484.
- Dewitt, T.A., 1984, Soil Survey of Story County, Iowa: Des Moines, U.S. Department of Agriculture, Soil Conservation Service, 149 p. plus 84 map sheets.
- Eyles, N. and Menzies, J., 1983, The subglacial landsystem, in Eyles, N. ed., Glacial geology-An introduction for engineers and earth scientists: Oxford, Pergamon, p. 19-70.
- Flint, R.F., 1971, Glacial and Quaternary Geology: John Wiley & Sons New York, 892 p.
- Flint, R.F., 1959, Glacial map of the United States east of the Rocky Mountains: scale 1:750,000: Geological Society of America: 2 Sheets.
- Fullerton, D.S., 1986, Stratigraphy and correlation of glacial deposits from Indiana to New York and New Jersey, in Richmond, G.M. and Fullerton, D.S., eds., Quaternary Glaciations in the United States of America, in Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary Glaciations in the Northern Hemisphere: Quaternary Science Reviews, v. 5, p 23-37.

- Goldthwait, R.P., 1989, Classification of glacial morphologic features, *in* Goldthwait, R.P., and Matsch, C.L., eds., *Genetic Classification of Glacigenic Deposits*: A.A. Balkema, Rotterdam p. 267-277.
- Goldthwait, R.P., 1975, *Glacial Deposits*: Dowden, Hutchinson & Ross, Stroudsburg, PA, 464 p.
- Graeff, R. W., 1986, *Glaciolacustrine sedimentation in southeastern Winnebago County, Iowa*: University of Iowa Department of Geology, Iowa City, unpublished M.S. thesis, 208 p.
- Gravenor, C.P., and Kupsch, W.O., 1959, Ice-disintegration features in western Canada: *Journal of Geology*, v. 67, p. 48-64.
- Hallberg, G.R. and Kemmis, T.J., 1986, Stratigraphy and correlation of the glacial deposits of the Des Moines and James Lobes and adjacent areas in North Dakota, South Dakota, Minnesota, and Iowa *in* Richmond, G.M. and Fullerton, D.S., eds., *Quaternary Glaciations in the United States of America* *in* V. Sibrava, D.Q. Bowen, and G.M. Richmond, eds., *Quaternary Glaciations of the Northern Hemisphere: Quaternary Science Reviews*, v. 5, p. 11-16.
- Hoyer, B.E., 1980a, The geology of the Cherokee Sewer site, in Anderson, D.C., and Semken, H.A., Jr. eds. *The Cherokee Excavations: Holocene Ecology and Human Adaptions in Northwestern Iowa*: Academic Press, New York, p. 21-66.
- Hoyer, B.E., 1980b, *Geomorphic history of the Little Sioux River Valley*: Geological Society of Iowa Guidebook 34, 94 p.
- Johnson, W.H., Hansel, A.K., Bettis, E.A.III, Karrow, P.F., Larson, G.J., Lowell, T.V. and Schneider, A.F., 1997, Late Quaternary Temporal and Event Classifications, Great Lakes Region, North America: *Quaternary Research*, v. 47, p. 1-12.
- Johnson, W.H., 1986, Stratigraphy and correlation of the glacial deposits of the Lake Michigan Lobe prior to 14 ka BP, *in* Richmond, G.M. and Fullerton, D.S., eds., *Quaternary Glaciations in the United States of America*, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., *Quaternary Glaciations of the Northern Hemisphere: Quaternary Science Reviews*, v. 5, p.17-22.
- Kemmis, T.J, Bettis, E.A. III, and Quade, D.J., 1994, The Des Moines Lobe in Iowa: a surging Wisconsinan glacier: American Quaternary Association, Program and Abstracts, 13th Biennial Meeting, Minneapolis, p. 112.
- Kemmis, T.J., 1991, *Glacial landforms, sedimentology and depositional environments of the Des Moines Lobe, northern Iowa*: University of Iowa Department of Geology, Iowa City, unpublished Ph.D. thesis, 393 p.
- Kemmis, T.J., Quade, D.J., and Bettis, E.A. III, 1988, Part II, Hallet Gravel Pits, *in* Bettis, E.A. III, et al., *Natural history of Ledges State Park and the Des Moines River Valley in Boone County*: Geological Society of Iowa Guidebook 48, p. 37-71.
- Kemmis, T.J., Bettis, E.A., III, and Quade, D.J., 1987, Sedimentary sequences of Wisconsinan-age outwash streams on the Des Moines Lobe in north-central Iowa: Iowa Academy of Science Program Abstracts, 99th Annual Meeting, abstract no. 153.
- Kemmis, T.J. Hallberg, G.R. and Lutengger, A.J., 1981, Depositional environments of glacial sediments and landforms on the Des Moines Lobe, Iowa: Iowa Geological Survey Guidebook No. 6, Iowa City, 132 p.

- Kemmis, T.J., 1981, Glacial sedimentation and the Algona Moraine in Iowa: Geological Society of Iowa Guidebook 35, 45 p.
- Kim, H.K., 1986, Late glacial and Holocene environment in central Iowa: a comparative study on pollen data from four sites: University of Iowa Department of Geology, unpublished Ph.D. thesis, Iowa City (Dissertation Abstract 86-28118).
- Kruger, J., 1979, Structures and textures in till indicating subglacial deposition: *Boreas*, v. 8, p. 323-340.
- Lawson, D.E., 1989, Glacigenic resedimentation: classification concepts and application to mass-movement processes and deposits, *in* Goldthwait, R.P., and Matsch, C.L., eds., *Genetic Classification of Glacigenic Deposits*: A.A. Balkema, Rotterdam, p. 147-169.
- Lawson, D.E., 1979a, Sedimentological analysis of the western terminus region of the Matanuska Glacier, Alaska: CRREL Report 79-9, 112 p.
- Lawson, D.E., 1979b, A comparison of the pebble orientations in ice and deposits of the Matanuska Glacier, Alaska: *Journal of Geology*, v. 87, p. 629-645.
- Lowe, D.R., 1978, Water-escape structures, *in* Fairbridge, R.W., and Bourgeois, J., eds., *The Encyclopedia of Sedimentology*: Dowden, Hutchinson & Ross, p. 864-868.
- Lucas, J.R., 1977, Till Lithology, Landsat Data and Geomorphic Surfaces in Northwestern Iowa, University of Iowa Department of Geology, Iowa City, unpublished Ph.D. thesis, 182 p.
- Macbride, T.H., 1909, Geology of Hamilton and Wright counties: Iowa Geological Survey Annual Report, v. 20, p. 97-149.
- Mathews, W.H., 1974, Surface profile of the Laurentide ice sheet in its marginal areas: *Journal of Glaciology*, v. 13, p. 37-43.
- Matsch, C.L., 1972, Quaternary geology of southwestern Minnesota, *in* Sims, P.K. and Morey, G.B., eds., *Geology of Minnesota: A Centennial Volume*: Minnesota Geological Survey, St. Paul, p. 548-560.
- McDonald, B.C., and Shilts, W.W., 1975, Interpretation of faults in glaciofluvial sediments; *in* Jopling, A.V., and McDonald, B.C., eds., *Glaciofluvial and Glaciolacustrine Sedimentation*, Society of Economic Paleontologists and Mineralogists Special Publication No. 23, p. 123-131.
- Paterson, W.S.B., 1981, *The Physics of Glaciers*, 2nd edition: Pergamon Press Ltd., Oxford, 380 p.
- Quade, D.J., Giglierano, J.D., and Bettis, E.A. III, 2004, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 6: Dickinson and Emmet Counties. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 04-2, 1:100,000 scale map sheet plus report, 26 p.
- Quade, D.J., Giglierano, J.D., Bettis, E.A. III, and Wisner, R.J., 2003, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 5: Polk County. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 03-3, 1:100,000 scale map sheet plus report, 36 p.

- Quade, D.J., Giglierano, J.D., Bettis, E.A. III, and Wisner, R.J., 2002, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 4: Humboldt County. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 02-3, 1:100,000 scale map sheet plus report, 26 p.
- Quade, D.J., Giglierano, J.D., Bettis, E.A. III, and Wisner, R.J., 2002, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 4: Dallas County. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 02-2, 1:100,000 scale map sheet plus report, 36 p.
- Quade, D.J., Giglierano, J.D., Bettis, E.A. III, and Wisner, R.J., 2001, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 3: Boone and Story Counties. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 01-1, 1:100,000 scale map sheet plus report, 25 p.
- Quade, D.J., Giglierano, J.D., Bettis, E.A. III, and Wisner, R.J., 2000, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 2: Hamilton and Webster Counties. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 00-1, 1:100,000 scale map sheet plus report, 22 p.
- Quade, D.J., Giglierano, J.D., Bettis, E.A. III, and Hoyer, B.E., 1999, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 1: Hancock, Kossuth, Winnebago and Wright Counties. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 99-1, 1:100,000 scale map sheet plus report, 22 p.
- Quade, D.J., 1992, Geomorphology, sedimentology and stratigraphy of Late Wisconsinan valley-train terraces along the Iowa River in north-central Iowa: University of Iowa Department of Geology, Iowa City, unpublished M.S. thesis, 85 p.
- Ramos, A., and Sopena, A., 1983, Gravel bars in low-sinuosity streams (Permian and Triassic, central Spain): International Association of Sedimentologists Special Publication No. 6, p. 301-312.
- Ruhe, R.V., 1969, Quaternary Landscapes in Iowa: Iowa State University Press, Ames, IA, 255 p.
- Ruhe, R.V., 1960, Elements of the soil landscape: Transactions of the 7th International Congress of Soil Science, v. 4, p. 165-170.
- Ruhe, R.V., 1956, Geomorphic surfaces and the nature of soils: Soil Science, v. 82, p. 441-455.
- Saunderson, H.C., 1975, Sedimentology of the Brampton Esker and its associated deposits: an empirical test of theory, *in* Jopling, A.V., and McDonald, B.C., eds., Glaciofluvial and Glaciolacustrine Sedimentation, Society of Economic Paleontologists and Mineralogists Special Publication No. 23, p. 155-176.
- Schwert, D.P., 1992, Faunal transitions in response to an ice age: the late Wisconsinan record of Coleoptera in the north-central United States: Coleopterists Bulletin, v. 46, p. 68-94.
- Simons, D.B., Richardson, E.V., and Nordin, C.F., Jr., 1965, Sedimentary structures generated by flow in alluvial channels, *in* Middleton, G.V., ed., Primary Sedimentary Structures and Their Hydrodynamic Interpretation: Society of Economic Paleontologists and Mineralogists Special Publication No. 12, p. 34-52.

- Smith, N.D., 1985, Chapter 3, Proglacial fluvial environment, *in* Ashley, G.M., Shaw, J., and Smith, N.D., eds., *Glacial Sedimentary Environments: Society of Economic Paleontologists and Mineralogists Short Course No. 16*, p. 85-134.
- Steinwand, A.L. and T.E. Fenton. 1995. Landscape evolution and shallow groundwater hydrology of a till landscape in central Iowa: *Soil Science Society of America Journal*, v. 59, p. 1370-1377.
- Sugden, D.E., and John, B.S., 1976, *Glaciers and Landscape*: New York, John Wiley & Sons, 376 p.
- Van Nest, J., and E.A. Bettis, III, 1990, Postglacial response of a stream in central Iowa to changes in climate and drainage basin factors: *Quaternary Research*, v. 33, p. 73-85.
- Van Zant, K., 1979, Late glacial and postglacial pollen and plant macrofossils from West Lake Okoboji, northwestern Iowa: *Quaternary Research*, v. 12, p. 358-380.
- Walker, P.H., 1966, Postglacial environments in relation to landscape evolution on the Cary drift, Iowa: *Iowa State University Agricultural and Home Economic Experiment Station Research Bulletin 549*, p. 838-875.
- Walker, P.H., and Brush, G.S., 1963, Observations on bog and pollen stratigraphy of the Des Moines glacial lobe, Iowa: *Proceedings of the Iowa Academy of Science*, v. 70, p. 253-260.
- Wallace, R.W., and Handy, R.L., 1961, Stone lines on Cary till: *Proceedings of the Iowa Academy of Science*, v. 68, p. 372-379.
- Willman, H.B. and Frye J.C., 1970, Pleistocene stratigraphy of Illinois: *Illinois State Geological Survey Bulletin 94*, 204 p.
- Witzke, B.J., Ludvigson, G.A., Anderson, R.R., Bunker, B.J., Slaughter, M.K., Giglierano, J.D., Pope, J.P., Whitsett, T.M., and Bounk, M.J., 1997, Bedrock geology of northwest Iowa, Digital geologic map of Iowa, Phase 1: Northwest Iowa, Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 97-1, 1:250,000, contract completion report to U.S. Geological Survey for Assistance Award No. 1434-HQ-96-AG-01486, August 1997, plus report, 11 p.