OVERVIEW OF THE SURFICIAL GEOLOGIC MAP OF CAMP DODGE, POLK COUNTY, IOWA

prepared by

E. Arthur Bettis III[1], Deborah J. Quade[2], and James D. Giglierano[2]

[1] Geoscience Department, University of Iowa, 121 Trowbridge Hall, Iowa City, IA 52242

[2] Iowa Department of Natural Resources, Geological Survey Bureau
109 Trowbridge Hall, Iowa City, IA 52242-1319

Introduction

This report is intended to accompany the Surficial Geologic Map for Camp Dodge, Polk County, Iowa. Camp Dodge, a 4,400-acre Iowa National Guard facility is located near the southern terminus of the Des Moines Lobe (Figure 1). The Des Moines Lobe (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 Pennsylvanian-age marine carbonates, and non-marine deltaic, and fluvial sediments that comprise the Swede Hollow and Floris Formations, respectively. Deposits that overlie bedrock consist of Pre-Illinoian and Wisconsin-age glacial and glaciofluvial sediments that range from less than 20 to 100 feet thick.

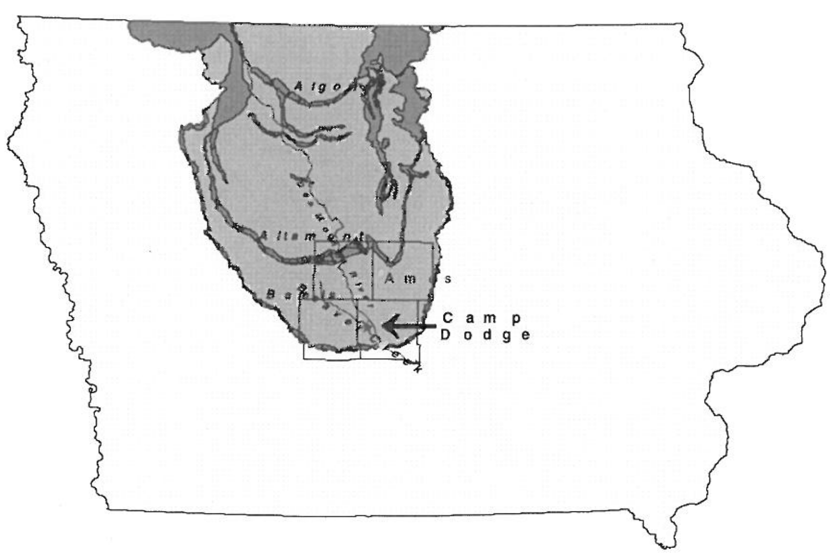

Figure 1 - Camp Dodge with respect to former ice margins on the Des Moines Lobe.

The project is supported by a U.S. Department of Defense LEGACY grant. The purpose of this project was to map the distribution of geologic materials in the upper five meters for the entire Camp Dodge base installation. The 1:12,000-scale mapping was accomplished on screen by integrating geologic information obtained through research drilling, trenching, existing water well and engineering boring records with digital soils and elevation data using Geographic Information System (GIS) tools.

Geologic Setting

Camp Dodge is a Iowa National Guard training facility located about nine miles north of the Des Moines Lobe (DML) terminus in central Iowa. The facility encompasses a narrow divide separating the Des Moines and Beaver Creek valleys, and portions of Beaver Creek valley. Beaver Creek occupies the northwest-southeast trending pre-late Wisconsin Des Moines Valley that was buried by advance of the DML around 13,900 years before present (YBP). By 13,500 YBP the Des Moines Lobe glacier was north of this area at the position marked by the Altamont Moraine. At that time Beaver Creek valley served as an outwash channel carrying water and sediment from the ice margin to the pre-Wisconsin Des Moines Valley south of the DML terminus.

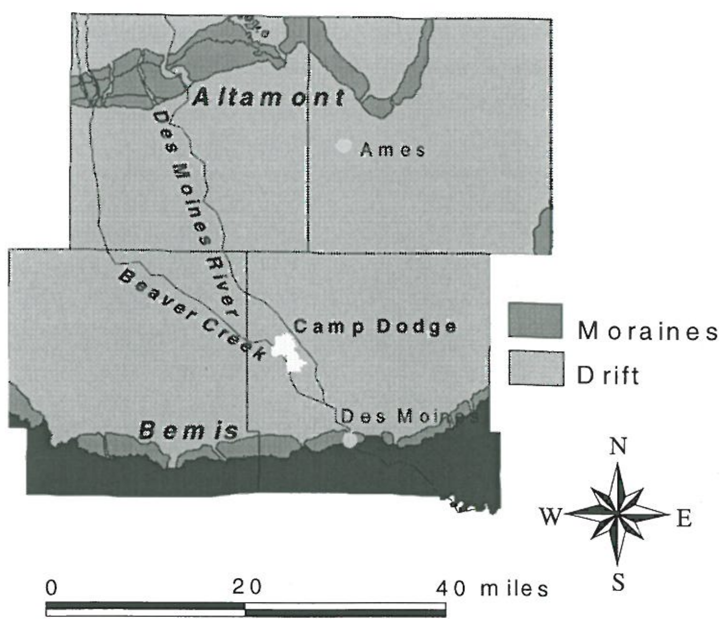

Figure 2 - Location map of the surrounding area.

The project area encompasses a tributary of the Des Moines River that flows through a multi-channel, late-glacial outwash system and its adjacent uplands. The uplands *exhibit hummocky topography*, a linked-depression system, and other ice-contact landforms. Stratified diamictons of the Dows Formation, Morgan Member are relatively thick and continuous across the uplands and sideslopes, and interfinger with glaciofluvial sediments, Pilot Knob Member (in the uplands) and interfinger with the Noah Creek Formation along former outwash channel margins (present day Beaver Creek valley). Wetlands and restored wetlands are associated with the outwash channels and linked-depression systems. The project was undertaken to provide facility managers with detailed geologic information and a geologic framework that will improve land use and natural resource management decisions. The project is also providing a unique opportunity for intensive geologic study of DML deposits and hydrogeology, a critical need for addressing environmental management decisions in north-central Iowa.

Description of Stack 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 small area for local planning purposes a stack unit map is especially useful for land-use planning purposes. A stack-unit maps show the thickness and distribution of geologic materials from the land surface to a specified depth, in this case 25 feet for the 4,400 acre Camp Dodge Facility. This map represents three-dimensional geologic units on a two-dimensional map.

Thirteen map units were identified in the map area. These units were developed by utilizing subsurface boring information, low and high altitude aerial photography, topographic expression, and digitized soil information The thirteen units comprise: Wisconsin Episode glacial till, complex upland and valley glaciofluvial sediments, lake sediments and eolian sediments; and Hudson Episode muck, peat, lake sediments and alluvium. The following is a description of each stack-unit listed by episode.

Stack-Units- Wisconsin Episode

Dows Formation

Dm/a-- Dows Formation, Morgan Member over Alden Member: two to four meters of calcareous, mostly oxidized, stratified to weakly bedded friable loam diamicton with sandy loam and loamy sand interbeds (Morgan Member), over dense, calcareous, unoxidized massive diamicton (Alden Member). The Alden Member in this mapping unit extends to depths in excess of five meters and overlies a variety of Quaternary and bedrock materials.

Dm/Pp--Dows Formation Morgan Member over Pennsylvanian bedrock (Cherokee Group): Two to four meters of calcareous, mostly oxidized, stratified to weakly bedded friable loam diamicton with sandy loam and loamy sand interbeds (Morgan Member), over dense Pennsylvanian bedrock consisting primarily of siltstone and mudstone but also including thin sandstone and limestone strata. These rocks underlie all the Quaternary sediments in the Camp Dodge area, but are within four meters or less of the land surface in this mapping unit.

Dpk/a--Dows Formation Pilot Knob Member over Alden Member: Two to five meters of stratified, calcareous, oxidized, usually unsaturated pebbly sand to cobble gravel (Pilot Knob

Member) over dense, calcareous, unoxidized massive diamicton (Alden Member). The upper meter of the unit may be wind-reworked and consist of fine to medium sand. This map unit occurs on isolated upland ridges that formed as subglacial and ice-contact channel fills (eskers and kames).

Dlm/a--Dows Formation Lake Mills Member over Alden Member: Two to three meters of oxidized, calcareous laminated silt loam, fine sand and silty clay (Lake Mills Member) over dense, calcareous, unoxidized massive diamicton (Alden Member). This map unit occurs on isolated upland ridges and is associated with the Pilot Knob Member. This relationship suggests that these Lake Mills Member deposits accumulated either in subglacial channels or in ice-contact settings (eskers and kames).

Noah Creek Formation

NC/Da--Noah Creek Formation over Dows Formation Morgan or Alden Member: Two to four meters of oxidized, calcareous pebbly sand to cobble gravel (Noah Creek Formation) over calcareous, reduced to unoxidized stratified to weakly bedded friable loam diamicton with sandy loam and loamy sand interbeds (Morgan Member), or dense, calcareous, unoxidized massive diamicton (Alden Member). The upper one to one and a half meters of the Noah Creek Formation may be wind reworked and consist of fine to medium sand. The lower two to three meters of the Noah Creek Formation is usually saturated. This unit occurs on outwash terraces along Beaver Creek Valley.

NC/Pp--Noah Creek Formation over Pennsylvanian bedrock: Two to four meters of oxidized, calcareous pebbly sand to cobble gravel (Noah Creek Formation) over dense Pennsylvanian bedrock consisting primarily of siltstone and mudstone. The upper one to one and a half meters of the Noah Creek Formation may be wind reworked and consist of fine to medium sand. The lower two to three meters of the Noah Creek Formation is usually saturated.

Peoria Formation

P/Dm-- Peoria Formation (sand facies) over Dows Formation Morgan Member: One to two meters of oxidized, generally non-calcareous fine to medium sand or loamy sand (Peoria Formation) over calcareous, reduced to unoxidized stratified to weakly bedded friable loam diamicton with sandy loam and loamy sand interbeds (Morgan Member). A few small areas of silty material (loess) occur within this mapping unit. The Peoria Formation deposits are eolian (wind blown) in origin.

Stack-Units Hudson Episode

DF/Dm--DeForest Formation undifferentiated over Dows Formation Morgan Member: One to three meters of weakly stratified to massive, calcareous to non-calcareous loam, clay loam and sandy loam alluvium, often with a thin basal pebbly sand zone (DeForest Formation undifferentiated) over calcareous, reduced to unoxidized stratified to weakly bedded friable loam diamicton with sandy loam and loamy sand interbeds (Morgan Member). Where this mapping unit passes through the Dm/Pp mapping unit Pennsylvanian bedrock may occur within 5 meters of the land surface.

DFf/NC--DeForest Formation undifferentiated over Noah Creek Formation: one to three meters of weakly stratified to massive, calcareous to non-calcareous loam, clay loam and sandy loam alluvium (DeForest Formation undifferentiated) over oxidized, calcareous pebbly sand to cobble gravel (Noah Creek Formation). The Noah Creek Formation usually overlies Dows Formation glacial diamicton (Morgan or Alden Member) within three to four meters of the land surface in this mapping unit.

DFp-- DeForest Formation undifferentiated – floodplain: One to three meters of weakly stratified to massive, calcareous to non-calcareous loam, clay loam and sandy loam alluvium (DeForest Formation undifferentiated) over oxidized, calcareous pebbly sand to cobble gravel (Noah Creek Formation). The Noah Creek Formation usually overlies Dows Formation glacial diamicton (Morgan or Alden Member) within three to four meters of the land surface in this mapping unit. This mapping unit occurs along the floodplain of Beaver Creek. This area is prone to frequent flooding and is covered by variable amounts of post-settlement alluvium (Camp Creek Member of the DeForest Formation).

DFt--DeForest Formation undifferentiated – terrace: One to three meters of weakly stratified to massive, calcareous to non-calcareous loam, clay loam and sandy loam alluvium (DeForest Formation undifferentiated) over oxidized, calcareous pebbly sand to cobble gravel (Noah Creek Formation). The Noah Creek Formation usually overlies Dows Formation glacial diamicton (Morgan or Alden Member) within three to four meters of the land surface in this mapping unit. This mapping unit occupies a low terrace along Beaver Creek Valley and contains prehistoric alluvium (Roberts Creek and Gunder members of the Deforest Formation).

Dw--DeForest Formation Woden Member: Two to six meters of stratified peat, muck, and organic-rich silt, clay and sand. This mapping unit is seasonally to permanently covered by water and supports wetland vegetation.

Do--DeForest Formation Okoboji Member: Two to three meters of stratified organic-rich silt, clay, loam, and sand. Contains significant amounts of post-settlement alluvium and is flooded seasonally.

Description of Des Moines Lobe Stratigraphy

An important aspect of surficial geologic mapping on the Des Moines Lobe (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 and understand the surficial materials of the DML. Wisconsin and Hudson Episode deposits (Johnson et al., 1997) of the DML are included in four formations: Dows, Peoria and Noah Creek Formations (Late Wisconsin) and DeForest Formation (Hudson). The following section provides includes a description of formations and members for DML sediments.

Stratigraphic Framework For The Des Moines Lobe

Surficial deposits of the DML are grouped into three formations: the Dows, Peoria, Noah Creek, and DeForest formations. The Dows Formation consists of upland glacial deposits. The Peoria Formation consists primarily of loess beneath the southern part of the Des Moines Lobe, and *eolian sand* locally blanketing the surface of the Lobe. The Noah Creek Formation is composed predominantly of coarse-grained *glaciofluvial* and *fluvial* deposits in stream valleys and on outwash plains. 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 Des Moines Lobe. 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 *glacigenic* deposits on the Des Moines Lobe 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 diamictons 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 $67\pm3\%$ expandables, $27\pm3\%$ illite, and $6\pm2\%$ kaolinite plus chlorite (Kemmis et al., 1981). This compares with the clay mineralogy of the fine-grained matrix of massive Dows Formation diamictons of $69\pm4\%$ expandables, $19\pm3\%$ illite, and $12\pm3\%$ kaolinite plus chlorite.

Regional Extent and Thickness: The Dows Formation is continuous across uplands on the Des Moines Lobe 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 Des Moines Lobe. 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 Des Moines Lobe 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 Des Moines Lobe 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 Des Moines Lobe 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 Des Moines Lobe. 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

Des Moines Lobe 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 Des Moines Lobe 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, 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 (Figure 10). 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 Des Moines Lobe. 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 Des Moines Lobe. 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.

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 Des Moines Lobe, 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 Des Moines Lobe 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 Des Moines Lobe. 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 Des Moines Lobe, 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 Des Moines Lobe 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 Hudson Episode to the present. Most Peoria Formation deposits on the Des Moines Lobe accumulated between about 14,000 and 11,000 RCYBP, and have undergone various degrees of wind reworking during the Hudson Episode.

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.

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 Des Moines Lobe. 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 Des Moines Lobe, 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 downvalley 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 Des Moines Lobe 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 Des Moines Lobe 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 Des Moines Lobe, the Noah Creek Formation dates from about 14,000 to 11,000 RCYBP. The oldest advance of the Des Moines Lobe 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 ± 290 RCYBP (Beta-10882; Bettis and Hoyer, 1986).

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 Des Moines Lobe (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 Des Moines Lobe. 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 Des Moines Lobe 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 Des Moines Lobe 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.

Flack Member

Source of name: the Flack farm on which the type section is located, Story County.
Type Section: The type section is the 85 Flack Section, an east-west trending stream cut exposing a hillslope descending to East Indian Creek in the NE 1/4, NE 1/4, NW 1/4 of section 2, T. 83 N., R. 22 W., Story County, Iowa (Figure 13).
Description of Unit: The Flack Member comprises colluvium on and at the base of hillslopes. Where present, the base of the Member is commonly marked by a stoneline that is discontinuous on upper slopes, gradually becoming continuous downslope. The lower part of the member usually consists of pebbly loam in which the pebbles become finer and less abundant upward. This gradation and distribution of pebbles is different than that of the diamictons comprising the Dows Formation. This lower portion of the member thickens and becomes slightly coarser in footslope positions. The pebbly lower portion of the member often grades to pebble-free loam in the upper part. The modern soil has developed in the upper part of the member, and morphologic characteristics vary with local slope, vegetation, and drainage conditions.
Nature of Contacts: The Flack Member unconformably overlies the Dows Formation and any older formations into which the member has incised. The basal contact is usually marked by a stoneline (Ruhe, 1956), a gravel lag left from the erosion of diamicton sediments. The stoneline

is often discontinuous on the upper part of hillslopes, grading to continuous downslope. On the lower portions of hillslopes, the Flack Member may be overlain by thin colluvium of the Camp Creek Member. The contact is usually marked by an abrupt change in color between the dark soil A horizon developed in the Flack Member and the lighter colored Camp Creek Member, and by a change in structure.

Differentiation from other Members: The Flack Member is composed primarily of fine-grained sediment with a coarser increment at the base like other members of the DeForest Formation. However, it is usually more poorly sorted, thinner than other members, and it only occurs on and at the base of slopes. It grades downslope to the Gunder, Corrington, Roberts Creek, and Woden members, and may locally interfinger with the Gunder, Corrington, and Roberts Creek members at the base of steep slopes.

Extent and Thickness: On the Des Moines Lobe, the Flack Member discontinuously mantles upland hillslopes. It usually thickens downslope, but rarely exceeds 1 m (3.5 ft) in thickness.

Origin: The Flack Member consists of thin colluvium resulting from sheetwash, rill erosion, and mass movement on upland hillslopes.

Age: The Flack Member is Holocene in age. Deposition was time-transgressive, dependent on landscape position and factors affecting local hillslope stability.

Previous usage: This is the first time the Flack Member has been used. Wallace and Handy (1961) previously recognized stonelines on the Des Moines Lobe, and correlative sediment has informally been referred to as 'hillside surficial sediment' and 'hillside surficials' by Walker (1966) and as 'surficial sediment' and 'surficials' by Daniels and Handy (1966).

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 drainageway associated with the Algona ice margin (Figure 14).

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 Des Moines Lobe. 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 Des Moines Lobe, 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 Des Moines Lobe 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 Des Moines Lobe, 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 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.

West Okoboji Member

Source of Name: Lake West Okoboji, Dickinson County, the location of the Type section.
Type Section: Little Millers Bay core, collected in two meters of water in the northernmost portion of Millers Bay, a western projection of Lake West Okoboji, SW 1/4 SW 1/4, NE 1/4 of section 23, T. 99 N., R. 37 W., Dickinson County, Iowa (Van Zant, 1979; Figure 15). This is within the Bemis/Altamont ice margin complex.

Description of Unit: The West Okoboji Member comprises lake sediment associated with extant lakes on the Des Moines Lobe. The lower part of the member usually consists of organic-rich silt, and the remainder of the unit is dominantly *gyttja*, sometimes with lenses of silt, sand, and pebbles. Shells and plant macrofossils are common.

Nature of Contacts: The West Okoboji Member abruptly and unconformably overlies glacial diamicton of the Dows Formation. Laterally the Okoboji Member may interfinger with sediments of the Woden Member, or unnamed sandy and gravely sediments of ice-push ridges. In most cases the member is overlain by lake water.

Differentiation From Other Members: The West Okoboji Member differs from other members of the formation, except the Woden Member, in geomorphic position and nature of the stratigraphic sequence. The West Okoboji Member differs from the Woden Member in that it does not contain peat or muck, generally lacks root traces, and is covered by more than one meter of standing water.

Regional Extent and Thickness: The West Okoboji Member is restricted to extant lake basins on the Des Moines Lobe. Thicknesses vary depending on the size of the lake and the topography of the pre-West Okoboji surface in the lake basin. The thickest sections occur in depressions in the lake basin and near the location of surface drainage inlets. At the type section the member is 11.7 m thick.

Origin: Sediment in the West Okoboji Member is primarily mineral and organic sediment that was deposited from suspension. Minor amounts of fine-grained mineral sediment and sand and pebbles in the member were deposited by *turbidity currents*, ice rafting, and by ice-pushing during periods of low lake levels.

Age: The West Okoboji Member dates from the time of the final wastage of glacial ice from the Des Moines Lobe. Deposition has continued to the present, but depositional rates have varied (Van Zant, 1979).

Description of Derivative Maps

Potential for Buried Prehistoric Cultural Resources*
Camp Dodge, Polk County, Iowa

Map Unit	Potential
Low local	low potential, local landscape positions of limited extent may contain prehistoric cultural resources that have been buried by slopewash
Low local – wind	low potential, local landscape positions of limited extent may contain prehistoric cultural resources that have been buried by wind-transported sand
Low-moderate wind	low to moderate potential, local landscape positions may contain prehistoric cultural resources that have been buried by wind-transported sand and slopewash
Moderate	moderate potential, wetland areas poorly drained but old enough to contain buried prehistoric cultural resources. This mapping unit may contain environmental records (pollen, plant macrofossils, diatoms, etc) that may be valuable in reconstructing prehistoric and historic environments
Moderate wind	moderate to high potential, may contain prehistoric cultural resources that have been buried by wind-deposited sediments and slopewash. Depth of burial should not exceed 1.5 meters.
Moderate to high	moderate to high potential, may contain prehistoric cultural resources that have been buried by alluvium or slopewash. Depth of burial should not exceed 1.0 meters
Moderate to high - young	moderate to high potential, may contain cultural resources less than 1000 years old buried by alluvium. Some of this mapping unit consists of post-settlement alluvium that is too young to contain in-situ prehistoric cultural resources. Post-settlement alluvium buries all prehistoric surfaces to variable depths in this mapping unit. Maximum depth of burial of in-situ cultural resources is estimated to be between 1.5 and 2.0 meters in this mapping unit.
High	High potential, may contain cultural resources buried by alluvium. Unit is underlain by alluvium ranging from about 8500 to 500 years in age. Thin post-settlement may mantle the prehistoric surface in this mapping unit. Maximum depth of burial of in-situ cultural resources is estimated to be between 1.5 and 2.0 meters in this mapping unit.

* Potential is based on age and depositional environment of the sediments comprising the mapping unit and assumes all surfaces have been cultivated. Cultural preferences and settlement patterns are not considered in this assessment.

Aggregate Resources
Camp Dodge, Polk County, Iowa

2-5 meters pebbly sand to cobble gravel--Dows Formation Pilot Knob Member over Alden Member: Two to five meters of stratified, calcareous, oxidized, usually unsaturated pebbly sand to cobble gravel (Pilot Knob Member) over dense, calcareous, unoxidized massive diamicton (Alden Member). The upper meter of the unit may be wind-reworked and consist of fine to medium sand. This map unit occurs on isolated upland ridges that formed as subglacial and ice-contact channel fills (eskers and kames).

2-4 meters of pebbly sand w/ basal sand--Noah Creek Formation over Dows Formation or Pennslyvanian Cherokee Grp.bedrock: Two to four meters of oxidized, calcareous pebbly sand to cobble gravel (Noah Creek Formation) over calcareous, reduced to unoxidized stratified to weakly bedded friable loam diamicton with sandy loam and loamy sand interbeds (Morgan Member), or dense, calcareous, unoxidized massive diamicton (Alden Member), or over dense Pennsylvanian bedrock consisting primarily of siltstone and mudstone. . The upper one to one and a half meters of the Noah Creek Formation may be wind reworked and consist of fine to medium sand. The lower two to three meters of the Noah Creek Formation is usually saturated. This unit occurs on outwash terraces along Beaver Creek Valley.

2-3 meters buried pebbly sand--DeForest Formation undifferentiated over Noah Creek Formation: one to three meters of weakly stratified to massive, calcareous to non-calcareous loam, clay loam and sandy loam alluvium (DeForest Formation undifferentiated) over oxidized, calcareous pebbly sand to cobble gravel (Noah Creek Formation). The Noah Creek Formation usually overlies Dows Formation glacial diamicton (Morgan or Alden Member) within three to four meters of the land surface in this mapping unit.

modern floodplain 2-3 meters buried pebbly sand-- DeForest Formation undifferentiated – floodplain: One to three meters of weakly stratified to massive, calcareous to non-calcareous loam, clay loam and sandy loam alluvium (DeForest Formation undifferentiated) over oxidized, calcareous pebbly sand to cobble gravel (Noah Creek Formation). The Noah Creek Formation usually overlies Dows Formation glacial diamicton (Morgan or Alden Member) within three to four meters of the land surface in this mapping unit. This mapping unit occurs along the floodplain of Beaver Creek. This area is prone to frequent flooding and is covered by variable amounts of post-settlement alluvium (Camp Creek Member of the DeForest Formation).

muck and peat--DeForest Formation Woden Member: Two to six meters of stratified peat, muck, and organic-rich silt, clay and sand. This mapping unit is seasonally to permanently covered by water and supports wetland vegetation.

Quaternary Materials Thickness (Depth to Bedrock) Map
Camp Dodge, Polk County, Iowa

The topography on the bedrock surface at Camp Dodge, Polk County, Iowa varies considerably from the action of water and glacial ice. Erosion of the bedrock surface is likely associated with the numerous advances of Pre-Illinoian glaciers from approximately 1.5 million to 500,000 years ago. The topography of the bedrock surface in the project area varies from five to twenty-five feet below the land surface on the slopes of the eastern margin to well over 120 feet below the land surface in the far southeastern portion of Camp Dodge. The variability in bedrock topography is probably associated with lithologic differences in the Middle Pennsylvanian-age Cherokee Group (300 million years ago) strata. The Pennsylvanian sequence in this area is characterized by older rocks that represent non-marine fluvial-deltaic depositional environments such as siltstones, mudstones, sandstone and some fossilferous limestone beds that transgress to near-marine and marine environments represented by coal seams, shales, and more resistant limestone units.

The thick Pennsylvanian-age bedrock sequence is overlain by Pre-Illinoian age Wolf Creek Formation glacial till and/or alluvium; which in turn is overlain by Late Wisconsin-age Dows Formation glacial till, glaciofluvial sediments, lake sediments or Noah Creek Formation outwash.

The quaternary materials thickness map was generated from existing bedrock topography maps and from some depth to bedrock data from several approximately ten GSB borings, engineering borings and water well logs. Map units consist of the following intervals: *0 – 25 feet, 25 – 50 feet, 50 – 100 feet and 100 – 150 feet to bedrock.*

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Appendix A

GLOSSARY

Alluvial--sediments deposited in stream valleys by the action of running water. Also pertains to valley geomorphic settings.

Colluvial--sediments deposited by a number of subareal, nonchannel processes including sheetwash, rainsplash, creep, debris flow, and sediment gravity flow. Colluvial sediments are usually found on at the base of hillslopes.

Conformable--strata lying one upon the other in unbroken and parallel order are said to be conformable.

Diamicton--a descriptive term for poorly sorted deposits. In Iowa, diamictons consist of mixtures of sand, silt, clay, pebbles, cobbles, and boulders. Most Iowa diamictons are 'matrix-supported;' that is, finer grained matrix material constitutes the greatest volume and surrounds individual pebbles or larger size rock fragments in the diamicton.

End moraine--a moraine that marks the greatest extent of a glacial advance. A moraine is a ridge or escarpment composed of drift deposited chiefly by direct glacial action, and having constructional topography independent of control by the surface on which the drift lies.

Englacial--contained, embedded, or carried within the body of a glacier.

Eolian sand--sand deposited by wind action. Eolian sand is well sorted and usually dominated by the fine sand fraction. In Iowa eolian sand is included in the Peoria Formation when it occurs on valley slopes and uplands, and in the Noah Creek or Henry formations when it overlies valley train outwash.

Esker--an elongate, often serpentine ridge composed of stratified and deformed sand and gravel, sometimes with minor mounts of diamicton beds. Eskers accumulated in englacial and subglacial tunnels through the action of meltwater. Deposits comprising eskers in Iowa are included in the Pilot Knob Member of the Dows Formation.

Fluvial--of or pertaining to streams, produced by river action.

Glacigenic--a term indicating a relationship to glaciation. For example, sand-and-gravel outwash deposited in streams draining a glacier are not glacial deposits *per se* because they are not deposited directly from the glacier. They are glacigenic, however, because it is glacier meltwater and, in large part, glacier sediment supply that result in their formation.

Glaciofluvial--pertaining to meltwater streams flowing from the margins of glaciers or to the alluvial deposits and landforms formed by such streams.

Ground moraine--an accumulation of till after it has been deposited or released from the ice during ablation, to form an extensive area of low relief

Gyttja--a sapropelic (originating as an aquatic ooze) black mud in which organic matter is more or less determinable.

Hummocky topography--topography consisting of randomly arranged knobs (hummocks) that are separated and defined by intervening low-lying areas that are part of linked-depression systems.

Ice marginal--geomorphic settings at or near the margin of a former glacier.

Kame--a short ridge composed of stratified and deformed sand and gravel, sometimes with minor amounts of diamicton beds, deposited, usually as a steep alluvial fan, against the edge of a glacier by debauching streams of sediment-laden meltwater. Sediments comprising kames in Iowa are included in the Pilot Knob Member of the Dows Formation.

Kettle--a depression in drift formed by the melting away of a detached block of ice that was wholly or partially buried in the drift

Lithostratigraphic--referring to a stratigraphic classification that is based on observable rock characteristics including: chemical and mineralogical composition, texture, grain size, bedding structures, color, fossil content, or other organic content

Loess--wind-blown sediment dominated by grains in the silt size fraction. In Iowa most loess originated from wind deflation of valley train outwash.

Melt-out (till)--diamicton deposited by a slow release of glacial debris from ice that is not sliding or deforming internally. Melt-out till is similar to lodgement till, but may contain debris banding and clasts of unlithified sediments.

Moulin--a depression on the surface of a melting glacier into which meltwater funnels. Moulins are the surface inlets of a glacial karst system.

Paleosol--a former soil; usually buried by younger deposits.

Paludal--pertaining to fen, bog, and marsh wetlands and to the sediments deposited in them.

Pothole--a closed or semi-closed depression

Striated clast pavement--clasts of rock (cobbles, boulders, and pebbles) concentrated at the basal contact of a glacial diamicton that have been striated (scraped and etched) by rock fragments carried at the base of an overriding glacier.

Subglacial--formed or accumulated in or by the bottom parts of a glacier or ice sheet. Pertaining to the area immediately beneath a glacier.

Supraglacial--on the surface of a glacier. Also refers to diamictons that accumulated in a supraglacial environment through a variety of processes (also know as flowtills). Supraglacial sediment has usually undergone a series of resedimentation events producing various degrees of sorting, deformation (from both meltout of underlying ice and sediment loading), and a wide range of bedding structures. The Morgan member of the Dows Formation is interpreted as supraglacial sediment.

Till--sediment released directly from the glacial ice that has not undergone subsequent disaggregation and resedimentation. Till can form by several different glacial processes, including lodgement, melt-out, and deformation. Till on the Des Moines Lobe is usually massive, dense diamicton without any fissility (subhorizontal partings) or other recognizable deformation structures.

Turbidity current--a highly turbid and dense current which moves along the bottom slope of a standing body of water (also called a density current).

Varve couplets--a pair of contrasting laminae representing seasonal sedimentation in a lake where thermal stratification and turnover occurs. Usually the part of the couplet deposited during the summer is light colored and the winter part of the couplet is darker.