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SURFICIAL GEOLOGIC MAP OF THE DES MOINES LOBE OF IOWA
Phase 4: Dallas County

Iowa Geological Survey
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INTRODUCTION

Phase 4 surficial geologic mapping on the Des Moines Lobe (DML) includes Dallas county. This county covers an area from 41° 29' to 41° 53' N latitude and 94° 18' to 93° 46' 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 Pennsylvanian shale-dominated, coal-bearing cyclotherms with locally thick areas of sandstone and rarer limestone units. (Pope, et. al, 2002). Deposits that overlie bedrock consist of Pre-Illinoian and Wisconsin-age glacial, glaciofluvial sediments and thin wind blown sediments. The extreme southern part of the county is a much older, weathered landscape underlain by Pre-Illinoian glacial tills (greater than 500,000 years old). The Pre-Illinoian till surface is mantled by a Pre-Wisconsin-age loess with a Sangamon Geosol present and in turn overlain by Pisgah Formation Wisconsin-age loess with Farmdale Geosol (basal loess paleosol) developed in loess/pedisediment. Ages on the Pisgah Formation range from 28,000 to 16,500 years before present. The Pisgah Formation appears to have been subjected to hillslope, pedogenic and periglacial processes and is mantled with younger Wisconsin-age Peoria loess (less than 16,000 years old). On major divides in this area loess thickness is approximately 14 to 15 feet thick. Throughout the county the quaternary sediment package ranges in thickness from less than 10 to 225 feet thick.

Previous surficial geologic mapping in the map area consists of the Des Moines 4 o x 6 o 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 and Phase 2: Hamilton and Webster Counties) and Phase 3: Boone and Story Counties has significantly increased our understanding of complex landform sediment assemblages in glaciated terrains (Quade et al., 1999,2000, 2001).

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 margins 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, 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 orgin. 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 indistinguisable on the land surface but are visible from high-altitude imagery. These recessional features are associated with the Clare, Renwick and West Bend moraine complexes. Most likely these features are related to supraglacial as well as proglacial processes. 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 associated with lake plains.

Fifteen 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. Thirty-one cores were collected in the county which represents well over 900 feet of new subsurface information obtained as part of this mapping project. The fifteen units are: Hudson Episode: depressions, alluvium, North and South Raccoon River, Des Moines River and Beaver Creek Valley: low, intermediate, intermediate-high and high terraces; Late Wisconsin Episode: sand dunes and sand sheets, loess, till plain with discontinuous elongated hummocky ridge forms, aligned ridge to discontinuous elongated hummocky ridge forms, aligned ridge forms, till ridge, till plain/buried outwash fan, valley train outwash; Pre Illinoian Episode: glacial till. 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 less than 1 to 5 meters of a 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 hills lopes and in closed depressions. May overlie Dows Formation (Morgan or Alden Mbrs.), Noah Creek Formation, or Pennsylvanian bedrock. Associated with low-relief modern floodplain, closed depressions, modern drainageways or toe slope positions on the landscape. Seasonal high water table and potential for frequent flooding.

Qallt - North and South Raccoon River, Des Moines River and Beaver Creek Valley - Low Terrace (DeForest Formation-Camp Creek Mbr. and Roberts Creek Mbr.)
Variable thickness of less than 1 to 5 meters of very dark gray to brown, noncalcareous, stratified silty clay loam, loam, or clay loam, associated with the modern channel belt of the Des Moines River valley. Overlies Noah Creek Formation. Occupies lowest position on the floodplain ie. modern channel belts. Seasonal high water table and frequent flooding potential.

Qalit - North and South Raccoon River, Des Moines River and Beaver Creek Valley - Intermediate Terrace (DeForest Formation-Camp Creek Mbr., Roberts Mbr. and Gunder Mbr.)
Variable thickness of less than 1 to 5 meters of very dark gray to brown, noncalcareous, stratified silty clay loam to loam that overlies Noah Creek Formation. Occupies low terrace position. Seasonal high water table and frequent flooding potential.

Qali-ht - North and South Raccoon River, Des Moines River and Beaver Creek Valley – Intermediate-High Terrace (DeForest Formation-Gunder Mbr.)
Variable thickness of less than 1 to 5 meters of very dark gray to brown, noncalcareous, silty clay loam to loam alluvium or colluvium that overlies Noah Creek Formation. Occupies terrace and valley margin position 1 to 2 meters above the modern floodplain. Seasonal high water table and low to moderate flooding potential.

Qalht - North and South Raccoon River, Des Moines River and Beaver Creek Valley - High Terrace (DeForest Formation-Gunder and Corrington Mbrs.)
Variable thickness of less than 1 to 7 meters of very dark gray to brown, noncalcareous, silty clay loam, loam alluvium or colluvium. Overlies Noah Creek Formation. Occupies terrace and valley margin position 2 to 3 meters above the modern floodplain. Seasonal high water table and rare flooding potential.

WISCONSIN EPISODE

Landform Sediment Assemblages of Supraglacial 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.

Qps1 - Loess (Peoria Formation-silt facies)
Generally 2 to 4 meters of yellowish to grayish brown, massive, jointed calcareous or noncalcareous silt loam to silty clay loam. Overlies a grayish brown to olive gray silty clay loam to silty clay (Pisgah Formation-eroded Farmdale Geosol) which is less than 1.5 meters thick. The Farmdale Geosol appears to be disturbed by periglacial action and is welded to an older Sangamon Geosol developed in loess. This mapping unit encompasses upland divides, ridge tops and convex side slopes. Well to somewhat poorly drained landscape.

Qtpl - Till Plain with discontinuous elongated hummocky ridge forms (Dows Formation-Morgan Mbr.).
Less than 4 meters of yellowish to grayish brown, calcareous, 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.). The Alden Mbr. in this mapping unit can extend to depths in excess of 30 m and may overlie Peoria Formation-silt facies, Pisgah Formation—Farmdale Geosol or Pre-Illinoian diamicton. Low relief, (less than 3 meters of local relief), slightly undulating plains with irregular surface patterns. **Discontinuous elongated ridge forms** within the unit by less than 8 meters of yellowish brown, often calcareous, 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. Indistinct elongated hummocks are oriented transverse to glacier flow on the till plain with irregular shaped surface patterns. Ridges are predominately low relief (less than 3 meters) with some moderate relief features (3 to 8 meters). Overall landform exhibits swell and swale topography. Seasonal high water table.

Qtpl1 - Aligned ridge to discontinuous elongated hummocky ridge forms (Dows Formation--Morgan Mbr./Pilot Knob Mbr.)
Less than 8 meters of yellowish brown, calcareous, fractured, stratified sand and gravel with interbedded stratified loam diamicton or yellowish to grayish brown, calcareous, fractured, stratified loam to silt loam to sandy loam diamicton; textures can be quite variable. In depressions and sags on upland surfaces, DeForest Fm.-Woden Mbr may bury the sand and gravel. 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 30 meters and may overlie Peoria Formation-silt facies, Pisgah Formation—Farmdale Geosol or Pre-Illinoian diamicton. Low to moderate relief, (less than 8 meters of local relief), slightly undulating plains with irregular surface patterns. **Aligned ridges to discontinuous elongated ridge forms** within the unit by less than 8 meters of yellowish brown, often calcareous, stratified loam to silt loam to sandy loam diamicton; textures can be quite variable. Evidence of shearing is sometimes present. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr. Along the western margin of Beaver Creek, these elongated hummocks consist primarily of sand and gravel and exhibit evidence of syndepositional collapse (Pilot Knob Mbr.). Tracts of faint to distinct aligned ridges to elongated hummocks oriented transverse to glacier flow are prevalent across the till plain. Ridges or aligned hummocks are low to moderate relief features (3 to 8+ meters). Overall landform exhibits swell and swale topography. Seasonal high water table.

Qtpl3 - Aligned ridge forms (Dows Formation-Morgan Mbr.)
Less than 8 meters of yellowish to grayish brown, calcareous, 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.). The Alden Mbr. in this mapping unit can extend to depths in excess of 30 meters and may overlie Peoria Formation-silt facies, Pisgah Formation - Farmdale Geosol or Pre-Illinoian diamicton. Tracts of distinct to well-defined aligned hummocks oriented transverse to glacier flow. Aligned ridges are moderate to high relief features (3 to 8+ meters). Moderate to high relief (3 to 8+ meters) on aligned hummocks. Overall landform exhibits lineated ridge pattern rather than hummocky swell and swale topography. Seasonal high water table.

Qtr - Till ridge (Dows Formation-Pilot Knob Mbr./ 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 can extend to depths in excess of 15 meters and may overlie Peoria Formation-silt facies, Pisgah Formation - Farmdale Geosol or Pre-Illinoian diamicton. Moderate to high relief hummocky landform features exceed 3 to 8 meters of local relief. This landform is associated with the Bemis Moraine in Dallas County. Seasonal high water table.

Landform Sediment Assemblages of Proglacial Origin

Qtpofb - Till Plain/Buried Outwash fan (Dows Formation/Noah Creek Formation)

Less than 2 to 3 meters 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.). The Alden Mbr. in this mapping unit extends to a depth of 4 meters and overlies 8 to 10 meters of yellowish brown to greenish gray coarse-grained sand and gravel (Noah Creek Formation: buried). Overlies greenish gray Pennsylvanian-age shale, most likely Marmaton Group. Low relief, (less than 2 meters of local relief), bench-like feature. The buried fan appears to be an isolated feature located at the toe of the Bemis Moraine. No flooding potential.

Qoch - Valley train outwash (Noah Creek Formation)

Generally 3 to 15 meters of yellowish brown coarse-grained sand and 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 cuspate-shaped point terraces. Outwash terraces associated with the major valleys are predominately benched on a gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). A few are benched on Pennsylvanian bedrock. Primary lithologies are shale, limestone, sandstone and mudstone units associated with the Cherokee, Marmaton and Bronson Groups. No flooding potential.

PRE-ILLINOIS EPISODE

Landform Sediment Assemblage of Glacial Origin

Qwa3 - Till (Wolf Creek or Alburnett Formations)

Generally 10 to 35 meters of very dense, massive, fractured, loamy glacial till of the Wolf Creek or Alburnett Formations with or without a thin loess mantle (Peoria Formation - less than 2 meters) and intervening clayey Farmdale/Sangamon Geosol. This mapping unit encompasses narrowly dissected interfluves and side slopes, and side valley slopes. Drainage is variable from well drained to poorly drained.

DESCRIPTION OF CENTRAL IOWA STRATIGRAPHY

An important aspect of surficial geologic mapping on the DML and the Southern Drift Plain is the development of map units that utilize previously established lithostratigraphic frameworks for Quaternary deposits in Iowa. This stratigraphic framework allows us to better understand the quaternary deposits of central Iowa. Late Wisconsin, Wisconsin, Hudson and Pre-Illinois Episode deposits (Johnson et al., 1997) of the DML and Southern Drift Plain are included in seven formations: Dows and Noah Creek Formations, Peoria and Pisgah Formations (Wisconsin), DeForest Formation (Hudson), and Wolf Creek and Alburnett Formations (Pre-Illinois). The following section provides a description, of formations and members of the DML and Southern Drift Plain sediments.

STRATIGRAPHIC FRAMEWORK FOR CENTRAL IOWA

Surficial and near surface deposits of the DML and the Soutnhern Drift Plain are grouped into seven formations: the Dows, Noah Creek, Peoria, Pisgah, DeForest, Wolf Creek and Alburnett formations. The Dows Formation 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 DeForest Formation includes post-glacial sediments (Hudson Episode) that are primarily fine-grained alluvial, colluvial, and paludal deposits. The Peoria Formation includes wind-blown sediments: two facies are recognized, a silt facies (loess) and a sand facies (eolian sand). The Pisgah Formation originated as eolian silt that has been altered by a combination of colluvial hillslope processes, pedogenic and periglacial processes. Pre-Illinoian glacial deposits in east-central Iowa consist of two formations: the younger Wolf Creek Formation and the Alburnett Formation. The Wolf Creek is divided into the Winthrop, Aurora and Hickory Hills members (oldest to youngest). The Alburnett Formation consists of several "undifferentiated" members. 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 glacigenic 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 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$\pm$4% expandables, 19$\pm$3% illite, and 12$\pm$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.
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 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 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 ± 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.

PISGAH FORMATION

The Pisgah Formation includes both primary eolian silt and eolian silt and related slope sediments that have been altered by a combination of colluvial hillslope processes, pedogenic and periglacial processes.

Source of name: the town of Pisgah, Harrison County, Iowa.
Type Section: the Loveland Paratype Section, cut north of Interstate 680 at intersection with Interstate 29 , Pottawattamie County, Iowa, in the NW1/4, SE ¼, Sec. 3 T77N R44W
Description of Unit: The Pisgah Formation is primary eolian silt (loess) and eolian silt and related hillslope sediments that have been modified by a combination of colluvial hillslope processes, pedogenic and periglacial processes. As a result of various mixing processes most Pisgah Formation deposits have a coarse, gritty silt loam texture. Throughout the state, the unit is usually thin (.15 to 1 m thick), and has been pedogenically altered both at the base, by slow incorporation into the existing Sangamon Geosol, and at the top, from pedogenesis producing the Farmdale Geosol before burial by the Peoria Formation (Kemmis et al., 1992). Typically, the Farmdale Geosol is expressed as a thin, dark grayish brown, weakly developed buried soil consisting of a leached A-C or E-C profile with platy or granular structure and associated charcoal flecks. Where the Pisgah Formation is thin (less than 30cm) the Farmdale Geosol is developed through the entire unit.
Nature of Contacts: The Pisgah Formation is typically buried by the Peoria Formation (silt facies--loess). Beneath the Des Moines Lobe the formation is buried Peoria loess, which in turn is buried by Dows Formation glacial diamicton. A prominent feature at the Peoria/ Pisgah contact is an involuted contact which is attributed to Wisconsin-age periglacial activity. Pisgah deposits typically overlie the Sangamon Geosol that is developed in Loveland or Pre-Wisconsin-age loess(s) or undifferentiated Pre-Illinoian glacial till.
Differentiation From Other Units: The wind-transported and slope reworked sediments of the Pisgah Formation are unlike the deposits of the Dows and Noah Creek formations on the DML. The Lake Mills Member of the Dows Formation consists of fine-grained silty 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 silty sediment, but the bedding structures and sorting of these are distinct from those associated with the Pisgah Formation, and occurs in a different geomorphic setting. The Pisgah Formation is genetically similar to the Peoria Formation, however it has been noticeably altered by pedogenic, colluvial hillslope and periglacial processes. The Pisgah Formation was referred to as the "basal Wisconsin loess" in previous literature (Ruhe, 1969).

Regional Extent and Thickness: The Pisgah Formation is preserved on relatively stable upland surfaces, but is absent on Iowan Erosion Surface of northeastern Iowa and on "Iowan" steps of the stepped erosion surface landscapes associated with the Southern Drift Plain landform region of the state (Hallberg et al., 1978c). Where present on the DML, the formation is buried by Dows Formation glacial till and Peoria Formation loess. Thickness varies with landscape position and distance from the eolian source. In central and eastern Iowa, the formation is commonly only 0.15 to 1 m thick. In extreme western Iowa, adjacent to the Missouri River valley the unit is 3 to 4 m thick. The Pisgah Formation stratigraphic position is equivalent to the Roxana Silt of Illinois and the Gilman Canyon Formation of Nebraska, but lithologic properties are different (Bettis, 1990)
Origin: The Pisgah Formation originated as eolian silt that has been altered by a combination of colluvial hillslope processes, pedogenic and periglacial processes.
Age: The Pisgah Formation is time transgressive. The wind-transported silt was deposited between about 45,000 and 25,500 RCYBP while Peoria loess began to accumulate shortly after 25,0000 RCYBP (Bettis, 1990). Dates from the Farmdale Geosol, developed in the upper part of the Pisgah Formation indicate that ages range from 28,000 to 16,5000 RCYBP with ages decreasing with distance from the Missouri River valley (Ruhe, 1976).

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.

Camp Creek Member

Source of Name: Camp Creek a tributary of Garretson Drainage Ditch, Woodbury County, Iowa.
Type Section: Camp Creek cutbank exposure, Woodbury County, Iowa, NW 1/4, SW1/4 of section 1 T. 87 N., R. 45 W. (Bettis, 1990b).
Description of Unit: Usually a calcareous to noncalerous, very dark gray to brown, stratified (planar-bedded) silt loam to clay loam. Surface soils developed into the Camp Creek Member are Entisols (Typic Udifluvents). These soils consist of an organically enriched surface horizon (A horizon) grading to unaltered parent material. Where this unit is rapidly aggrading, surface soils are absent.
Nature of Contacts: This member is inset into or unconformably overlies the Gunder, Corrington and Roberts Creek members, depending on the local geomorphic setting and history of landuse. This unit often buries pre-settlement soil surface. May grade to sand and gravel in and adjacent to the modern channel belt.
Differentiation From Other Members: The Camp Creek Member differs from other members of the formation, in geomorphic position and nature of the stratigraphic sequence.
Regional Extent and Thickness: Thickness of the Camp Creek member is quite variable ranging from a few centimeters to over five meters (16.4 ft.).
Origin: Camp Creek Member consists of late-Holocene to post-settlement alluvium in and adjacent to modern channel belt, and at the base of steep slopes.
Age: Age is time-transgressive, dependent on drainage system and geomorphic position. In large valleys Camp Creek Member started aggrading as early as 400 B.P. and in small valleys as early as 150 B.P. It is still accumulating at present in both small and large valleys.

Roberts Creek Member

Source of Name: Roberts Creek, Clayton County, Iowa
Type Area: Along Roberts Creek, Clayton County, Iowa, sections 6 and 7, T. 94 N., R. 5 W. (Baker, et.al., 1996).
Description of Unit: Roberts Creek Member consists of dark, clayey, silty and loamy alluvium grading downward to sand and gravel; usually noneffervescent; thick sections are stratified at depth; detrital organic matter in lower part; relatively thick Mollisol (A-C or A-Bw-C profile) developed in the upper part (Bettis et al., 1992). Weakly expressed buried soils have been observed within the Roberts Creek Member, but these are not traceable from one valley to the another. This unit includes the Mullenix and Turton members of Daniels, et al. (1963), which have been redesignated as beds within the Roberts Creek Member in the thick and moderately thick loess areas of western Iowa and adjacent states.
Nature of Contacts: Roberts Creek Member deposits overlie a wide variety of deposits including the Gunder and Corrington members, older alluvium, loess and glacial till.
Differentiation From Other Members: The Roberts Creek Member differs from other members of the formation, in geomorphic position and nature of the stratigraphic sequence. Soils are morphologically less well expressed and have darker B and C horizons than soils developed in the Gunder and Corrington members. The Roberts Creek Member is separated from younger DeForest Formation deposits (Camp

Creek Member) by either a fluvial erosion surface or an unconformity marked by a buried soil (Bettis, 1995).

Regional Extent and Thickness: Roberts Creek deposits are found beneath flood plains of small and large valleys and often overlap Gunder Member deposits in 2nd and 3rd-order valleys. Unit thickness will vary dependent on size of valley. Usually unit thickness will vary from 1.5 to 5 m thick.

Origin: Roberts Creek Member consists of late-Holocene alluvium found in the modern floodplain, parallels the modern channel, also found in fan trenches.

Age: Unit age ranges from 4,000 to 500 B.P.

Gunder Member

Source of Name: Roberts Creek, Clayton County, Iowa

Type Area: Along Roberts Creek, Clayton County, Iowa, sections 6 and 7, T. 94 N., R. 5 W. (Baker, et.al., 1996).

Description of Unit: Gunder Member consists of oxidized brown to yellowish brown to grayish brown silt loam, silty clay loam, or loam grading to sand and gravel at depth. Usually noneffervescent, lower part may be stratified and reduced, detrital organic matter often present in lower coarse-grained part of unit; moderately well to somewhat poorly drained Mollisols and Alfisols developed in upper part. This member includes the Watkins and Hatcher members of Daniels et al. (1963) which have now been redesignated as beds within the Gunder Member. Buried soils are sometimes present within the Gunder Member, but are not traceable on a regional scale.

Nature of Contacts: Gunder Member deposits unconformably overlie loess, glacial till, bedrock, coarse alluvium, or organic-rich fine-grained alluvium. Overlying younger members of the formation are separated from the Gunder Member by a fluvial erosion surface or an unconformity marked by a buried soil.

Differentiation From Other Members: The Gunder Member differs from other members of the formation, in geomorphic position and nature of the stratigraphic sequence. Soils are morphologically better expressed and have lighter B and C horizons than soils developed in the Roberts Creek member.

Regional Extent and Thickness: Gunder deposits usually comprise low terrace that merges with sideslopes in a smooth concave upward profile. Usually unit thickness will vary from .5 to 4 m thick, with thickest deposits associated with Watkins member deposits.

Origin: Gunder Member consists of mid-early Holocene alluvium found low terrace positions merging with sideslopes.

Age: Unit ranges in age from 10,500 to 3000 B.P.

Corrington Member

Source of Name: Corrington alluvial fan, Cherokee, County, Iowa

Type Section: Along the Little Sioux River Valley wall, Cherokee, County, Iowa, W 1/2, SW 1/4, SE 1/4 of section 4, T. 91 N., R. 40 W. (Hallberg, et al., 1974; Hoyer, 1980a, 1980b).

Description of Unit: The Corrington Member is the most internally variable unit of the formation and consists of very dark brown to yellowish brown oxidized loam to clay loam with interbedded lenses of sand and gravel; noneffervescent to effervescent at depth. The unit is stratified and usually contains several buried soils. Surface soils developed into this unit in are thick Mollisols (Cumlic Hapludolls) or Alfisols (Hapludalfs) that have argillic (Bt) horizons (Bettis, 1995).

Nature of Contacts: The Corrington Member buries coarse-grained older alluvium, glacial till, loess, or bedrock, and can grade laterally into Gunder Member deposits.

Differentiation from Other Members: The Camp Creek Member differs from other members of the formation, in geomorphic position and nature of the stratigraphic sequence. The presence of numerous buried soils (paleosols) and several fining-upward sequences often characterize unit.
Regional Extent and Thickness: Corrington Member deposits compose alluvial fans located where small and moderate-size valleys (2nd-and 3rd-order) enter larger valleys. Fans will vary in thickness, typically thicker sections have been measured in western Iowa. At the type section in Cherokee County, section thickness was measured at 11 m (36 ft.).
Origin: Corrington Member is found in alluvial fans and colluvial slopes along the margins of large to moderate-size valley. Deposits are variably textured and accumulated by channeled flow, sheetwash, and debris flow (Hoyer, 1980b).
Age: Unit ranges in age from 9000 to about 2500 B.P

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.
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.

WOLF CREEK FORMATION

The Wolf Creek Formation is subdivided into three members (oldest to youngest): the Winthrop, Aurora and Hickory Hills members. Information on the formation as a whole is presented first, followed by more specific descriptions for individual members.

Source of name: Wolf Creek, northern Tama County, Iowa.

Type Section: the type area for the Wolf Creek Formation is defined from several reference localities in the region around Wolf Creek in Geneseo, Clark, Buckingham, and Grant Townships, in northern Tama County.

Description of Unit: The Wolf Creek Formation is predominantly a massive, uniform, basal till, but may also include fluvial silts, sands and gravels and local fine-textured swale fill deposits and peat. On average the texture is loam, but subtle differences may be used to help distinguish members. The Wolf Creek Formation averages 50-60% expandable clays (slightly lower in the southeastern portion of the state), 16-19% illite, and 22-24% kaolinite plus chlorite (Hallberg et al., 1980).

Nature of Contacts: In areas of southeast Iowa that were glaciated during the Illinoian, the upper boundary of the Wolf Creek Formation is marked by the unconformable contact with deposits of the Glasford Formation. Where Illinoian age deposits are present, the Yarmouth Paleosol is formed in the top of the Wolf Creek Formation. Beyond the reaches of the Illinoian deposits, the Yarmouth-Sangamon Paleosol is developed in the Wolf Creek. The individual till members may be directly overlain by each other or be separated by undifferentiated sediments, glaciofluvial deposits, or paleosols. The Wolf Creek Formation is underlain by either the Alburnett Formation or Paleozoic bedrock.

Differentiation from other Units: The Wolf Creek Formation is distinguished from the Kellerville Member of the Glasford Formation (Illinoian age till) by the relatively low illite and dolomite contents. Additionally, the Kellerville Member exhibits an abundance of Pennsylvanian lithologies in the very coarse sand through cobble size particles (Hallberg 1980b). The Wolf Creek Formation also has a much higher limestone to dolomite ratio (greater than 0.40) than the Kellerville Formation deposits.

Differentiation of the Wolf Creek and Alburnett formation tills is difficult in the field without the assistance of stratigraphic boundaries, but mineralogical characteristics can be used to distinguish them. The most useful characteristic to differentiate between the Wolf Creek and Alburnett formations is the clay mineralogy. The Wolf Creek Formation has a higher expandable clay percentage, averaging around 62%; whereas the Alburnett Formation has lower expandable clay percentages, near 43% (Hallberg et al., 1980a).

Origin: The Wolf Creek Formation consists of three till members associated with several Pre-Illinoian ice advances. Based on the physical properties of the majority of the Wolf Creek Formation deposits (massive structure, high density, uniform texture) they likely represent a basal, or subglacial, till facies.

Age and Correlation: The Wolf Creek Formation represents the youngest of the Pre-Illinoian glaciations. Pre-Illinoian deposits in Iowa range from older than 2.2 million years to approximately 500,000 years ago based on volcanic ash dates in western Iowa (Easterbrook and Boellstorff, 1984; Hallberg, 1986). Paleomagnetic studies of the Wolf Creek Formation in east-central Iowa indicate that these deposits have normal polarity and are therefore younger than 790,000 years (Baker and Stewart, 1984).

Winthrop Member

Source of name: the town of Winthrop, Buchanan County, Iowa.

Type Section: the type area of the Winthrop Till Member consists of a railroad cut and drill-core section approximately 1¼ miles (2 km) west of Winthrop in Buchanan County in the NW1/4 of Section 3, Township 88N, Range 8W. The exposure is about 5 ½ miles (8.8 km) east of Independence and 2 ¼ miles (3.6 km) east of Doris Station.

Description of Unit: The Winthrop Till Member is the oldest and least well-known of the Wolf Creek Formation tills due to poor preservation. The color varies within the weathering profile from a light-yellowish brown to dark gray. Texturally, the Winthrop Till Member is a loam to light clay loam with averages of 25% clay, 41% silt and 34% sand. Generally, it contains more silt than sand. Clay mineral percentages in the Winthrop Till Member average 60% ±4.3 (range 51-68) expandables, 17% ±2.2 (range 10-20) illite, and 24% ±3.8 (range 16-31) kaolinite plus chlorite (Hallberg, 1980a). The Winthrop Till Member tends to have slightly higher values of kaolinite than the other tills of the Wolf Creek Formation. The Winthrop Till Member exhibits a high limestone to dolomite ratio (median and mode >15) and dolomite is commonly absent.

Nature of Contacts: The Winthrop Till Member is overlain by either leached unnamed sediments separating it from the Aurora Till Member, the Aurora Till Member, younger Wolf Creek Formation deposits, or may be exhumed as the surface till where erosion was severe enough to remove the younger deposits.

The lower boundary of the Winthrop Till Member is equally complex, with the contact being marked by the underlying bedrock, sediments of the Alburnett Formation, or in the most complete sections by the top of the Westburg Paleosol. Where present, the Westburg Paleosol occurs below the Winthrop Till Member of the Wolf Creek Formation and is developed in deposits of the Alburnett Formation or older rock units.

Differentiation from other Units: The Winthrop Member is distinguished from the Kellerville Member of the Glasford Formation (Illinoian age till) by the relatively low illite and dolomite contents. The Kellerville aslo exhibits an abundance of Pennsylvanian lithologies in the very coarse sand through cobble size particles and a much lower limestone to dolomite ratio (less than 0.40) (Hallberg, 1980b). All members of the Wolf Creek Formation have average limestone to dolomite ratios greater than 0.40.

Differentiation of the Wolf Creek Formation members and Alburnett Formation materials is difficult in the field without the assistance of stratigraphic boundaries, but mineralogical characteristics can be used to distinguish them. The most useful characteristic to distinguish between the Wolf Creek members and the Alburnett Formation is the clay mineralogy (Hallberg, 1980a). The Wolf Creek Formation has higher expandable clay percentages, averaging around 62%; whereas the Alburnett Formation has lower expandable clay percentages, near 43%.

Clay mineral variation cannot be utilized to differentiate members of the Wolf Creek Formation, and the sand-fraction lithology generally overlaps. However, the limestone to dolomite ratio and grain-size distribution has been useful for discriminating between members (Hallberg, 1980a). Differentiation can be difficult in areas of isolated exposures where only one till is exposed (or the till varies to an end member within its range). Typically, the Hickory Hills member almost always has more sand than silt and has higher values for total carbonate and sedimentary grains than the Aurora or Winthrop members. The Hickory Hills member also has a low limestone to dolomite ratio. Both the Aurora and Winthrop members have more silt than sand, a high limestone to dolomite ratio, and often do not have dolomite. Overall, these similarities between the Aurora and Winthrop members make it difficult to distinguish the two if only one is present. The Winthrop generally has lower values for total carbonates and sedimentary grains.

Regional Extent and Thickness: Due to the limited number of positive identifications, the thickness of the Winthrop Till Member is poorly known and difficult to determine. In the composite Winthrop locality it varies from 2 to about 15 feet (0.6-4.6 m), and has a thickness of 48 feet (14.6 m) in the 4-Mile Creek area.

Origin: The Winthrop Member of the Wolf Creek Formation consists of deposits associated with an advance of Pre-Illinoian ice. Based on the physical properties of these deposits (massive structure, high density, uniform texture) they likely represent a basal, or subglacial, till facies.

Age and Correlation: The Wolf Creek Formation members represent the youngest of the Pre-Illinoian glaciations. Pre-Illinoian deposits in Iowa range from older than 2.2 million years to approximately 500,000 years ago based on volcanic ash dates in western Iowa (Easterbrook and Boellstorff, 1984; Hallberg, 1986). Paleomagnetic studies of the Wolf Creek Formation in east-central Iowa indicate that these deposits have normal polarity and are therefore younger than 790,000 years (Baker and Stewart, 1984).

Aurora Member

Source of name: the town of Aurora, Buchanan County, Iowa.

Type Section: the type area for the Aurora Till Member is the Aurora Transect located approximately 2 miles (3.2 km) southwest of the town of Aurora in northeast Buchanan County, Iowa. The transect consists of core-holes drilled along the axis of the stepped erosion surfaces in the area of the regional divide between the Wapsipinicon and Maquoketa Rivers in the NE1/4 of Section 23, T 90N, R 8W.

Description of Unit: The Aurora Till Member is a basal till with relatively uniform characteristics. The texture of the Aurora Till Member is loam, averaging 22% clay, 40% silt, and 38% sand. The Aurora has a high limestone to dolomite ratio (median and mode >15), and often no dolomite is present. Color varies vertically within the weathering profile from light yellowish-brown to dark gray or dark greenish gray. Clay mineralogy averages 62 % ±3.6 (range 55-70) expandables, 18% ±2.5 (range 13-24) illite, and 21% ±2.3 (range 17-24) kaolinite plus chlorite (Hallberg, 1980a).

Nature of Contacts: The upper boundary of the Aurora Till Member varies in relation to the amount of erosion. In complete sections, this boundary is marked by the contact with the unnamed weathered (leached) sediments, which generally contain the Dysart Paleosol (which is overlain by the Hickory Hills Till Member). Where the Dysart Paleosol has been eroded, the contact may be directly with the Hickory Hills Till Member or a sharp diffuse contact zone including glaciofluvial sediments of the Hickory Hills Till Member. In some places erosion is severe enough that the Aurora Till Member is the surficial till unit and may be overlain by a thin veneer of Wisconsin to Holocene surficial sediments or eolian sand, Wisconsinan loess, or Pre-Wisconsinan sediments.

In complete sections, the lower boundary of the Aurora Till Member may be marked by the contact with leached sediments and weak paleosols separating it from the Winthrop Till Member. In areas where erosion has occurred, the Aurora Member may be in direct contact with the Winthrop Till Member, various sediments of the Alburnett Formation, or bedrock. If either of the last two settings is the case, the Aurora Till Member also marks the base of the Wolf Creek Formation.

Differentiation from other Units: The Wolf Creek Formation tills are distinguished from the Kellerville Member of the Glasford Formation (Illinoian age till) by the relatively low illite and dolomite contents. The Kellerville also exhibits an abundance of Pennsylvanian lithologies in the very coarse sand through cobble size particles (Hallberg 1980b). The Kellerville has a much lower limestone to dolomite ratio (less than 0.40) than the Wolf Creek Formation deposits (95% of which all have limestone to dolomite ratios greater than 0.40).

Differentiation of the Wolf Creek Formation members and Alburnett Formation materials is difficult in the field without the assistance of stratigraphic boundaries, but mineralogical characteristics can be used to distinguish them. The most useful characteristic to distinguish between the Wolf Creek and Alburnett Formations are the clay mineral percentages. The Wolf Creek Formation has higher expandable clay values, averaging around 62%; whereas the Alburnett Formation has lower expandable clay percentages, near 43% (Hallberg, 1980a).

Clay mineral variation cannot be utilized to differentiate members of the Wolf Creek, and the sand-fraction lithology generally overlaps. However, the limestone to dolomite ratio and grain-size distribution has been useful for discriminating between members (Hallberg, 1980a). Differentiation can be difficult in areas of isolated exposures where only one till is exposed (or the till varies to an end member within its range). Typically, the Hickory Hills member almost always has more sand than silt and has higher values for total carbonate and sedimentary grains than the Aurora or Winthrop members. The Hickory Hills member also has a low limestone to dolomite ratio. Both the Aurora and Winthrop members have more silt than sand, a high limestone to dolomite ratio, and often do not have dolomite. Overall, these similarities between the Aurora and Winthrop members make it difficult to distinguish the two if only one is present. The Winthrop generally has lower values for total carbonates and sedimentary grains.

Regional Extent and Thickness: The thickness of the Aurora Member is highly variable. In some areas it has been entirely removed by erosion, and at the 4-Mile Creek locality it may reach 100 feet (31m) in thickness. In most areas it ranges from 20 to 35 feet (6 to 11 m) in thickness.

Origin: The Aurora Member of the Wolf Creek Formation consists of deposits associated with an advance of Pre-Illinoian ice. Based on the physical properties of these deposits (massive structure, high density, uniform texture) they likely represent a basal, or subglacial, till facies.

Age and Correlation: The Wolf Creek Formation members represent the youngest of the Pre-Illinoian glaciations. Pre-Illinoian deposits in Iowa range from older than 2.2 million years to approximately 500,000 years ago based on volcanic ash dates in western Iowa (Easterbrook and Boellstorff, 1984; Hallberg, 1986). Paleomagnetic studies of the Wolf Creek Formation in east-central Iowa indicate that these deposits have normal polarity and are therefore younger than 790,000 years (Baker and Stewart, 1984).

Hickory Hills Member

Source of name: Hickory Hills Park, NW1/4 of the SE1/4 of section 10, T 86N, R 13W (Geneseo Township), Tama County.

Type Section: the type area of the Hickory Hills Till Member is within the vicinity of Hickory Hills Park. Two principal reference localities are described within the type area. The 402 Road cut Section is designated the type locality and section. Casey's Paha East is the principal reference locality. Several other reference localities (the Hayward's Paha Transect and Buckingham Section) are needed to fully describe the upper and lower boundaries.

Description of Unit: Due to weathering, the Hickory Hills Till Member varies vertically in color from light-yellowish brown (10YR 5/6-8) in the oxidized zone to dark greenish gray (5GY 4/1) in the unoxidized zone. Texturally, the Hickory Hills Till Member is a loam, averaging about 22% clay, 34% silt, and 44% sand (Hallberg, 1980a). In thick sections, the till tends to be quite uniform texturally, but where it is thin it tends toward a mixed composition incorporating the material below. The Hickory Hills Member almost always has more sand than silt. The average clay mineral percentages are 63% ±4.5 (range 52-73) expandables, 17% ±3.3 (range 11-23) illite, and 20% ±2.2 (range 14-25) kaolinite plus chlorite (Hallberg, 1980a). The Hickory Hills till has a lower limestone to dolomite ratio than the other Wolf Creek Formation members.

Nature of Contacts: The lower boundary is commonly marked by the contact with the Dysart Paleosol and related unnamed sediments, or where absent it rests directly on the Aurora Till Member. When resting directly on the Aurora, the boundary is often a complex zone of contorted glaciofluvial sediments related to the Hickory Hills Till Member. If pre-Hickory Hills Till erosion was extensive, the Hickory Hills Till Member may lie directly on any older unit from the Winthrop Till Member to Paleozoic bedrock. In some sections the contact with the Dysart Paleosol is not clear due to block inclusions of the Dysart Paleosol that were sheared into the lower portion of the Hickory Hills Till Member. The upper boundary is also complex due to erosion, and it may be overlain by the Yarmouth- Sangamon or Late Sangamon surface, Wisconsinan age sediments or other surficial materials.

Differentiation from other Units: The Wolf Creek Foramtion tills are distinguished from the Kellerville member of the Glasford Formation (Illinoian age till) by the relatively low illite and dolomite contents. The Kellerville also exhibits an abundance of Pennsylvanian lithologies in the very coarse sand through cobble size particles (Hallberg 1980b). The Kellerville has a much lower limestone to dolomite ratio (less than 0.40) than the Wolf Creek Formation tills (95% of which all have limestone to dolomite ratios greater than 0.40).

Differentiation of the Wolf Creek and Alburnett Formation tills is difficult in the field without the assistance of stratigraphic boundaries, but mineralogical characteristics can be used to distinguish them. The most useful characteristic to distinguish between the Wolf Creek and Alburnett Formations is the clay mineralogy (Hallberg, 1980a). The Wolf Creek Formation has higher expandable clay percentages, averaging around 62%; whereas the Alburnett Formation has lower expandable clay percentages, near 43%.

Clay mineral variation cannot be utilized to differentiate members of the Wolf Creek Formation, and the sand-fraction lithology generally overlaps. However, the limestone to dolomite ratio and grain-size distribution has been useful for discriminating between members (Hallberg, 1980a). Differentiation can be difficult in areas of isolated exposures where only one till is exposed (or the till varies to an end member within its range). Typically, the Hickory Hills member almost always has more sand than silt and has higher values for total carbonate and sedimentary grains than the Aurora or Winthrop members. The Hickory Hills member also has a low limestone to dolomite ratio. Both the Aurora and Winthrop members have more silt than sand, a high limestone to dolomite ratio, and often do not have dolomite. Overall, these similarities between the Aurora and Winthrop members make it difficult to distinguish the two if only one is present. The Winthrop generally has lower values for total carbonates and sedimentary grains.

Regional Extent and Thickness: The thickness of the Hickory Hills Till Member is extremely variable. Due to erosion it is absent in some areas, however, in more complete sections the member ranges from 10 to over 50ft (3-15m).

Origin: The Hickory Hills Member of the Wolf Creek Formation consists of deposits associated with an advance of Pre-Illinoian ice. Based on the physical properties of these deposits (massive structure, high density, uniform texture) they likely represent a basal, or subglacial, till facies.

Age and Correlation: The Wolf Creek Formation members represent the youngest of the Pre-Illinoian glaciations. Pre-Illinoian deposits in Iowa range from older than 2.2 million years to approximately 500,000 years ago based on volcanic ash dates in western Iowa (Easterbrook and Boellstorff, 1984; Hallberg, 1986). Paleomagnetic studies of the Wolf Creek Formation in east-central Iowa indicate that these deposits have normal polarity and are therefore younger than 790,000 years (Baker and Stewart, 1984).

ALBURNETT FORMATION

The Alburnett Formation is separated into several "undifferentiated" members. No consistent discriminating characteristics are available for these members, and the only differentiation comes where stratigraphic position allows. Therefore, the following description will be used for all the members.

Source of name: the town of Alburnett, Linn County, Iowa.
Type Section: the region around the town of Alburnett, Otter Creek Township (T 85N, R 7W), Linn County, Iowa.
Description of Unit: The Alburnett Formation is composed of multiple till units, which are "undifferentiated", and a variety of fluvial deposits. Minor paleosols may also be identified within the deposits. Throughout eastern Iowa, these deposits fill and bury the deep bedrock channels. The till is typically a uniform, massive, basal till. The Alburnett Formation ranges in color from light-yellowish brown in the oxidized zone, to dark gray or dark-greenish gray in the unoxidized zone.
The Alburnett Formation is defined by its stratigraphic position and distinctive clay mineralogy. The tills are generally loam textured, but range to light clay loam. On average, the Alburnett Formation consists of 18.7% clay, 36.8% silt, and 44.4% sand. The Alburnett Formation contains 44% expandables, 24% illite, and 32% kaolinte plus chlorite. In comparison with the Wolf Creek Formation, the Alburnett tills have significantly lower percentages of expandable clay minerals and higher kaolinite plus chlorite (Hallberg et al., 1980).
Nature of Contacts: The upper boundary of the Alburnett Formation is an unconformity of variable magnitude. Where the section is complete, the top of the Westburg Paleosol marks the upper boundary and is overlain by the Winthrop Till Member of the Wolf Creek Formation. Where the paleosol is eroded, any member of the Wolf Creek Formation, Wisconsin loess or other surficial sediments may overlie the Alburnett Formation. The lower boundary of the Alburnett Formation is marked by an unconformable contact with the bedrock. Glaciofluvial deposits may also be located at the base of the Alburnett Formation.
Differentiation from other Units: Pre-Illinoian tills are distinguished from the Kellerville Member of the Glasford Formation (Illinoian age till) by the relatively low illite and dolomite contents. The Kellerville also exhibits an abundance of Pennsylvanian lithologies in the very coarse sand through cobble size particles (Hallberg, 1980b). The Alburnett Formation has a much higher limestone to dolomite ratio (almost always greater than 0.40) than the Kellerville Formation.
The differentiation between the Wolf Creek and Alburnett Formation tills is difficult in the field without the assistance of stratigraphic boundaries, but mineralogical characteristics can be used. The most useful characteristic to distinguish between the Wolf Creek and Alburnett formations is the clay mineralogy. The Wolf Creek Formation has higher expandable clay percentages, averaging around 62%; whereas the Alburnett Formation has lower expandable clay percentages, near 43% (Hallberg, 1980a).
Regional Extent and Thickness: The Alburnett Formation has a wide range of thickness. In some areas it is completely absent and in others may reach a substantial thickness where its deposits fill in and bury deep bedrock channels. In these areas it has been identified to reach thicknesses of 220-250 feet.

Origin: The Alburnett Formation consists of multiple undifferentiated members associated with several Pre-Illinoian ice advances. Based on the physical properties of the Alburnett Formation deposits (massive structure, high density, uniform texture) it is likely a basal, or subglacial, till facies.
Age: The Alburnett Formation represents the oldest of the Pre-Illinoian glaciations. Pre-Illinoian deposits in Iowa range from older than 2.2 million years to approximately 500,000 years ago based on volcanic ash dates in western Iowa (Easterbrook and Boellstorff, 1984; Hallberg, 1986). Paleomagnetic studies of the Alburnett Formation in east-central Iowa indicate that these deposits have reversed polarity and are therefore older than 790,000 years (Baker and Stewart, 1984).

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