

SURFICIAL GEOLOGY OF THE FERTILE SE 7.5' QUADRANGLE, WORTH AND CERRO GORDO COUNTIES, IOWA

**Iowa Geological and Water Survey
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prepared by

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PURPOSE

Detailed geologic mapping of Fertile SE 7.5' Quadrangle was completed as part of the Iowa Geological and Water Survey's (IGWS) ongoing participation in the STATEMAP Mapping Program. In particular, mapping of Worth County is part of the Cooperative Mapping with the Natural Resources Conservation Service (NRCS) throughout the State of Iowa. This initial mapping provides basic surficial geologic information which is the basis to further develop derivative datasets and map products for use by local, county and state decision-makers. The STATEMAP component of the National Cooperative Geologic Mapping Program has enhanced the IGWS ability to produce geologic maps. Iowa's mapping program addresses priority state-wide issues with longer term goals in mind. Input from the advisory panel has recommended mapping in areas with environmental concerns, related to groundwater quality and land-use planning issues. IGWS and the advisory panel recognize the need for maps of varying scales to address the complex environmental issues facing urban and rural Iowans. Issues in developing urban areas center around residential and commercial development along major transportation corridors, rapid subdivision expansion on the fringes of urban areas and related problems with septic system siting, aggregate potential (identification and protection of resources), sensitive areas identification, and water quality and quantity issues. In rural areas, issues are focused on the proper siting of animal confinement facilities, water quality, watershed management, nutrient management, wetland delineation and protection and aggregate potential mapping.

INTRODUCTION

The quadrangle-scale map represents the first phase of surficial mapping in conjunction with NRCS and the Iowa Cooperative Soil Survey county updates in Worth County. The Fertile SE 7.5' Quadrangle map covers an area from 43° 15' to 43° 22' 30" N latitude and 93° 15' to 93° 22' 30" W longitude. The mapping area straddles the eastern margin of the Late Wisconsin-age Des Moines Lobe Landform (DML), the most recently glaciated region of the state and the Wisconsin-age Iowan Erosion Surface (IES) Landform Region (Prior and Kohrt, 2006). Generally speaking, in the western portion of the map area, the DML consists of a complex suite of depositional landforms and sediment sequences related to supraglacial, subglacial and proglacial sedimentation. The DML is characterized by hummocky terrain that forms arcuate belts of moraine complexes and undulating plains with thick increments of supraglacial sediment (>3 m). It is now recognized from recent STATEMAP mapping efforts that numerous low-relief recessional moraines are present down the central axis of the DML. These features are not evident on the land surface but are visible on high-altitude imagery. In the map area, these recessional features are not present along the flank of the DML (the Bemis Moraine, the terminal moraine of the DML). Supraglacial and proglacial sediments (coarse-grained glaciofluvial, ice-contact sediments associated with hummocky terrain, outwash fans and channel deposits) encompass a large area of the eastern flank of the DML and are extensively mapped at the former ice margin and in the Winnebago River, Elk Creek and Wharton Creek valleys. The southeastern portion of the map area consists of unnamed loamy sediments (IES materials) of variable thickness overlying Wisconsin-age Sheldon Creek Fm. glacial sediments, Pre-Illinoian glacial sediments or shallow rock. These deposits are regionally extensive. Significant areas of bedrock outcrop or areas with less than 15 feet of loamy material over rock are present, especially along the Winnebago River valley in the extreme southwestern portion of the map area.

Williams (1899) described and mapped the Quaternary and Paleozoic bedrock geology of the county and discussed the stratigraphy of Devonian strata that were exposed at the land surface. He also noted the extreme thinness of the "drift" along the the Winnebago River and nearby Shell Rock River and the remarkable difference in surface features between the eastern and western portions of Worth County. Statewide bedrock geologic maps by Hershey (1969), and most recently, by Witzke, Anderson, and Pope (2010), depict the increased understanding of the complex distribution of geologic units at the bedrock

surface across this region, including Worth County. The only regional surficial map of the area consists of the Des Moines 4° x 6° Quadrangle at a scale of 1:1,000,000 (Hallberg et al., 1991).

REGIONAL SETTING

Early researchers believed there were only two episodes of Pre-Illinoian glaciation in Iowa: Kansan and Nebraskan. Later regional studies determined that at least seven episodes of Pre-Illinoian glaciation occurred in this region between approximately 2.2 million to 500,000 years ago (Boellstorff, 1978a,b; Hallberg, 1980a; 1986). Hallberg (1980a,b; 1986) undertook a regional scale project that involved detailed outcrop and subsurface investigations including extensive laboratory work and synthesis of previous studies. This study led to the abandonment of the classic glacial and interglacial terminology: Kansan, Aftonian and Nebraskan. Hallberg's study marked a shift from use of time-stratigraphic terms to lithostratigraphic classification. The result of Hallberg's study was the development of a lithostratigraphic framework for Pre-Illinoian till. In east-central Iowa, Hallberg formally classified the units into two formations on the basis of differences in clay mineralogy: the Alburnett Formation (several undifferentiated members) and the younger Wolf Creek Formation (including the Winthrop, Aurora and Hickory Hills members). Both formations are composed predominantly of till deposits, but other materials are present. Paleosols are formed in the upper part of these till units. Regionally extensive upland units were not deposited in the map area between 500,000 to 300,000 years ago. During this period several episodes of landscape development resulted in the formation of an integrated drainage network, slope evolution and soil development on stable landsurfaces (Bettis, 1989). Hallberg (1980b) noted that Illinoian-age glacial ice did not advance as far west as the present map area.

In north-central Iowa, the highly eroded and dissected pre-Illinoian upland is overlain by much younger Wisconsin-age glacial sediments. During earlier and mid Wisconsin-age, ice advances dating from approximately 40,000 to 26,000 years before present were deposited throughout the map area. In Iowa, this glacial deposit is formally recognized as the Sheldon Creek Formation (Bettis et al., 1996, Bettis, 1997) and in earlier literature is referred to as the "Tazewell till" (Ruhe, 1950). These sediments are typically buried by loamy erosional sediments associated with the IES. A period of intense cold occurred during the Wisconsin full glacial episode from 21,000 to 16,500 years ago (Bettis, 1989). This cold episode and ensuing upland erosion led to the development of the distinctive landform recognized as the IES (Prior, 1976). A periglacial environment prevailed during this period with intensive freeze-thaw action, solifluction, strong winds and a host of other periglacial processes (Walters, 1996). The result was that surface soils were removed from the IES and the Pre-Illinoian till surface was significantly eroded; resulting in the development of a region-wide colluvial lag deposit referred to as a "stone line". Another common feature are ice-wedge casts which developed in the colluvial sediments and stone lines. The ice wedges are remnants of ice-wedge polygons that formed in frozen sediments (permafrost) during this period of intense cold. Thick packages of stratified loamy and sandy sediments located low in the upland landscape and adjacent to streams are remnants of solifluction lobes dating to this period. Associated with the formation of the IES, thick wedges of sediment were transported downslope. In the map area, along the course of the Winnebago River and Willow Creek, bedrock exposures are common along the valley and alluvial deposits are relatively thin. On slopes near this area, the colluvial cover is the only protection for local groundwater resources.

The depositional history of the IES was under great debate for an extended period of time. Early researchers believed the IES was a separate glaciation occurring sometime between the Illinois and the Wisconsin episodes. Later work disproved this idea and determined that erosional processes controlled the landscape development (Ruhe et al., 1968). Hallberg et al., (1978) revisited the "Iowan Erosion Surface" to further research studies into the mechanisms behind the formation of the erosion surface and to reiterate Ruhe's classic work on stepped erosion surfaces and to illustrate the need for continued research in the area. Beyond the IES, the Peoria Loess continued to accumulate until 13,000 B.P, and in some

parts of the IES a thin increment of loess accumulated as the climate ameliorated approximately 14,000 to 12,000 years ago.

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 glaciations, alluviation, subaerial erosion, and wind-blown transport. To map diverse landscapes at 1:24,000 scale we have selected the most comprehensive mapping strategy- a landform sediment assemblage (LSA) approach. Various landforms are the result of specific processes at work in the geologic system. Landforms typically have similar relief, stratigraphic and sedimentologic characteristics. 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). Bettis and others (1999) found LSA mapping concepts were extremely useful in overcoming the difficulties of mapping in large valleys and noted LSA's provided a unique opportunity to associate landforms with their underlying sediment packages.

Sixteen Quaternary-age landform sediment assemblage units were identified in the map area utilizing orthophotos, topographic expression, digitized soil and existing and new subsurface boring information. Fourteen borings were collected representing 376 feet of new subsurface information obtained as part of this mapping project. The following is a description of each landform sediment assemblage listed in order of episode:

HUDSON EPISODE

Qo - Depressions (DeForest Formation-Woden Mbr.) - Generally 2.5 to 6 m (8-20 ft) 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, loam diamicton (Dows Fm.-Morgan/Alden Mbr.) or Noah Creek Fm. sand and gravel or Sheldon Creek Fm loam diamicton. 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 of less than 1 to 5 m (3-16 ft) of very dark gray to brown, noncalcareous to calcareous, massive to stratified silty clay loam, clay loam, loam to sandy loam alluvium and colluvium in stream valleys, on hillslopes and in closed depressions. May overlie Noah Creek Formation, Wolf Creek or Alburnett formations or fractured Devonian carbonate bedrock. Associated with low-relief modern floodplain, closed depressions, modern drainageways or toeslope positions on the landscape. Seasonal high water table and potential for frequent flooding.

Qalb - Alluvium Shallow to Bedrock (DeForest Formation-Undifferentiated) - Variable thickness of less than 1 to 5 m (3-16 ft) of very dark gray to brown, noncalcareous to calcareous, stratified silty clay loam, clay loam, loam to sandy loam alluvium and colluvium in stream valleys, on hillslopes and in closed depressions. May overlie Noah Creek Formation or Devonian carbonate bedrock. Bedrock surface is within 5 m (16 ft) of the land surface. Associated with low-relief modern floodplain, closed depressions, modern drainageways or toeslope positions on the landscape. Seasonal high water table and potential for frequent flooding.

HUDSON and WISCONSIN EPISODE

Qdsr - Loamy Sediments Shallow to Limestone, Dolomite, and Shale (DeForest-Noah Creek-Shell Rock Formation) - 1 to 2 m (3-7 ft) of yellowish brown to gray, massive to weakly stratified, well to

poorly sorted loamy, sandy and silty alluvial sediment that overlies the Upper Devonian bedrock surface. This formation is the major top bedrock unit in the quad, usually with a thickness of 12 to 18 m (40-60 ft). It is characterized by fossiliferous carbonates with some shale. Layers with abundant subspherical and tabular stromatoporoids, which may be replaced by calcite crystal masses, commonly occur in the lower part of the formation. Around southwest part of the quad, this formation is dominated by argillaceous dolomite and dolomitic limestone, and the thickness can be up to 30 m (100 ft).

Qe - Sand Dunes and Sand Sheets (Peoria Formation-sand facies) - Generally less than 3 m (10 ft) of yellowish brown, massive, calcareous loamy sand to fine sand. It may overlie yellowish-brown coarse-grained sand and gravel (Noah Creek Fm.), or it may overlie yellowish to grayish brown, usually calcareous, stratified loam to silt loam to sandy loam diamicton (Dows Fm.-Morgan Mbr.). Usually restricted to a narrow belt along major river valley bottoms or adjacent uplands on the Des Moines Lobe. Off the Des Moines Lobe this unit is not restricted to dunes along valley areas and may occur as sand stringers overlying unnamed erosion surface loamy sediments.

WISCONSIN EPISODE

Qoch - Valley train outwash (Noah Creek Formation) - Generally less than 8 m (26 ft) of dark gray, dark grayish brown, dark brown to dark yellowish brown medium to coarse sand, gravelly sand to pebbly gravel. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). In valley positions, it is at the land surface of older terraces. On the modern floodplain it is buried by DeForest Fm. alluvium. Low-relief landforms expressed as broad terraces; long, narrow longitudinal terraces or cusate-shaped point terraces. Terraces associated with the major valleys are benched on a gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.).

Qnw - Sand and Gravel (Noah Creek Formation) - 3 m (10 ft) to more than 23 m (75 ft) of yellowish brown to gray, poorly to well sorted, massive to well stratified, coarse to fine feldspathic quartz sand, pebbly sand and gravel. In places mantled with 1 to 3 m (3-10 ft) of fine to medium, well sorted sand derived from wind reworking of the alluvium. This unit encompasses deposits that accumulated in stream valleys during the Wisconsin Episode.

Qnw_T2 - Sand and Gravel, Terrace 2 (Noah Creek Formation) - 3 m (10 ft) to more than 23 m (75 ft) of yellowish brown to gray, poorly to well sorted, massive to well stratified, coarse to fine feldspathic quartz sand, pebbly sand and gravel. In places mantled with 1 to 3 m (3-10 ft) of fine to medium, well sorted sand derived from wind reworking of the alluvium. This unit encompasses deposits that accumulated in stream valleys during the Wisconsin Episode. Terrace 2 is at an elevation approximately 3 m (10 ft) above Terrace 3. This terrace has limited eolian deposits.

Qnw2 - Sand and Gravel (Noah Creek Formation) - 2 to 12 m (7-40 ft) of yellowish brown to gray, poorly to well sorted, massive to well stratified, coarse to fine feldspathic quartz sand, pebbly sand and gravel with few intervening layers of silty clay. Along many valleys a thin mantle of loess, reworked loess, fine-grained alluvium (Qal) may be present. This unit includes silty colluvial deposits derived from the adjacent map units. In places this unit is mantled with 1 to 3 m (3-10 ft) of fine to medium, well sorted medium to fine sand derived from wind reworking of the alluvium. This unit encompasses deposits that accumulated in low-relief stream valleys during the Wisconsin Episode and Hudson Episode. Seasonal high water table and some potential for flooding.

Qnw3 - Sand and Gravel Shallow to Bedrock (Noah Creek Formations) - 1 to 3 m (3-10 ft) of yellowish brown to gray, poorly to well sorted, massive to well stratified, coarse to fine feldspathic quartz sand, pebbly sand and gravel. May be overlain by up to 2 m (7 ft) of silty alluvial material. In places mantled with fine to medium well-sorted feldspathic quartz sand derived from wind reworking of the alluvium.

Fractured carbonate bedrock is less than 5 m (16 ft) below the land surface. The unit encompasses deposits that accumulated in river and stream valleys during the late Wisconsin as well as exhumed Pre-Illinois Episode deposits of the Wolf Creek and Alburnett formations.

Qof - Outwash fan (Noah Creek Formation) - Thickness can be quite variable from 3 to 12 m (10-39 ft) of yellowish-brown coarse-grained sand and gravel. May overlie gray, calcareous, massive, dense loam diamicton (Dows Fm.- Alden Mbr. or Sheldon Creek Fm.). Narrow low-relief apron that gently slopes away from the moraine front. Seasonal high water table.

Qsgc - Supraglacial complex (Dows Formation-Pilot Knob Mbr./ Morgan Mbr.) - Greater than 3 m (10 ft) but less than 15 m (49 ft) of yellowish brown, often calcareous and fractured, stratified sand and gravel with interbedded stratified loam diamicton. Collapse features are usually evident. In depressions and sags on upland surfaces, the sand and gravel may be buried by DeForest Fm.-Woden Mbr. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm. - Alden Mbr.). Moderate to high relief (3 to 8 m) hummocks, beaded ridges, kames and associated linked drainages on upland surfaces.

Qtr_bm - Till ridge (Dows Formation-Morgan Mbr.) - Generally 3 to 5 m (10-16 ft) of yellowish to grayish brown, usually calcareous and fractured, stratified loam to silt loam; stratified sands and gravels to sandy loam diamicton; textures can be quite variable. Overlies gray, calcareous, massive, dense loam diamicton (Dows Fm.-Alden Mbr.). The Alden Mbr. in this mapping unit rarely extends to depths greater than 12 to 15 meters; and overlies the Sheldon Creek Formation diamicton. At the DML margin, this landform may be mantled with a thin layer of Peoria Formation silt. Low to moderate relief hummocky landform features exceed 3 to 5 m (10-16 ft) of local relief. This landform is associated with the Bemis Moraine. The surface pattern is irregularly shaped patterns. Seasonal high water table.

Qsc2 - Loamy Sediments Shallow to Glacial Till (Unnamed erosion surface sediment) - 1 to 3 m (3-10 ft) of yellowish brown to gray, massive to weakly stratified, well to poorly sorted loamy, sandy and silty erosion surface sediment. Map unit includes some areas mantled with less than one meter of Peoria Formation (silt or sand facies). Overlies massive, fractured, slightly firm glacial till of the Sheldon Creek Formation

Qsc - Glacial Till (Sheldon Creek Formation-undiff.) - Generally 3 to 15 m (10-50 ft) of a yellowish brown to gray, calcareous fractured to massive clay loam; at depth this unit can be variably textured and contain significant sand and gravel bodies. It is not uncommon to see Pierre Shale clasts in core samples. This unit overlies Pre-Illinois diamicton and is only shown on the cross-section.

PRE-ILLINOIS EPISODE

Qwa3 - Till (Wolf Creek or Alburnett Formations) - Generally 3 to 23 m (10-75 ft) of very dense, massive, fractured, loamy glacial till of the Wolf Creek or Alburnett formations. This mapping unit can be buried by glacial sediments (Sheldon Creek Fm.), unnamed erosion surface sediments, loess or alluvium and is shown only in the cross-section.

DESCRIPTION OF NORTH-CENTRAL IOWA STRATIGRAPHY

An important aspect of surficial geologic mapping on the IES is the development of map units that utilize previously established lithostratigraphic frameworks for the Hudson, Wisconsin and Pre-Illinoian deposits in Iowa. A stratigraphic framework allows us to better understand the surficial materials of north-central Iowa. Hudson, Wisconsin and Pre-Illinois Episode deposits (Johnson et al., 1997) of the north-central Iowa are included in seven formations: DeForest Formation (Hudson), Noah Creek Formation (Hudson and Wisconsin), Dows Formation (Wisconsin), Peoria Formation (Wisconsin), Sheldon Creek Formation

(Wisconsin), and Wolf Creek and Alburnett Formations (Pre-Illinois). The following section provides a description of formations and members of north-east Iowa deposits.

STRATIGRAPHIC FRAMEWORK FOR NORTH-EASTERN IOWA

Surficial deposits of the map area are composed of seven formations: DeForest, Dows, Noah Creek, Peoria, Sheldon Creek, Wolf Creek, and Alburnett formations as well as unnamed erosion surface sediments. Hudson age deposits associated with fine-grained alluvial, organic and colluvial sediments include the DeForest Formation which is subdivided into the Camp Creek, Roberts Creek, Gunder, Corrington, Flack and Woden members. The Dows Formation consists of upland glacial deposits and is subdivided into the Alden, Lake Mills, Morgan and Pilot Knob Members. The Noah Creek Formation includes coarse sand and gravel associated with outwash from the Des Moines Lobe. The Noah Creek Formation 2 includes coarse to finer grained fluvial deposits associated with local stream and river valleys. Unnamed erosion surface sediments consist of reworked till and slopewash deposits associated with periglacial activity during the Wisconsin ice advance. Areas of Peoria Formation eolian materials are present along the Elk Creek and Winnebago River valleys as well as stringers on the IES surface. Eolian materials may also be intermittently present mantling most other mapping units, and are more abundant near stream valleys. Sheldon Creek Formation glacial deposits are undifferentiated and occur in northwest and north-central Iowa. The full extent of these deposits is still not fully understood. Pre-Illinoian glacial deposits in 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.

Two bedrock mapping units (Devonian Shell Rock and Lithograph City formations) are exposed as outcrop in the map area. Bedrock outcrops occur along the Winnebago River, with some exposures along Willow Creek in the southwest part of the quadrangle. Middle and lower Upper Devonian carbonate rocks of shallow-marine origin comprise the bedrock strata in the mapping area. The strata form the upper part of a thick Devonian carbonate succession within the northern portion of the Iowa Basin. The bedrock strata in the map area are carbonates of Cedar Valley Group; they vary between limestone and dolomite with minor shale. Bedrock is subdivided into the Shell Rock and Lithograph City formations, and is dominated by the Shell Rock Formation. The Shell Rock Formation is characterized by fossiliferous and stromatoporoid-rich carbonates. The underlying Lithograph City Formation is typically composed of laminated lithographic and sublithographic limestone and dolomite. In areas covered by thicker deposits of glacial sediments the bedrock formation distribution is known solely from water well cutting samples.

DEFOREST FORMATION

The DeForest Formation consists of fine-grained alluvium, colluvium, and pond sediment in stream valleys, on hillslopes and in closed and semi-closed depressions. The formation was originally defined by Daniels et al. (1963) for a repeatable sequence of alluvial fills in the Loess Hills of western Iowa. Subsequent study of drainage basins across Iowa revealed that a consistent alluvial stratigraphy was present, but its classification required expansion and revision of the formation (Bettis, 1990). The revised DeForest Formation includes the Gunder, Roberts Creek, Camp Creek, and Corrington members, all recognized on the Des Moines Lobe (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 Okojoji 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, 1990).

Description of Unit: Usually a calcareous to noncalcerous, 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 of-

ten buries the 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: The 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 the 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: The 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 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: The Roberts Creek Member consists of late-Holocene alluvium found in the modern floodplain, parallels the modern channel, and is 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 overlies 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 0.5 to 4 m thick, with thickest deposits associated with Watkins Member deposits.

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

Age: Unit ranges in age from 10,500 to 3,000 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 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: The Corrington Member is found in alluvial fans and colluvial slopes along the margins of large to moderate-size valleys. Deposits are variably textured and accumulated by channeled flow, sheetwash, and debris flow (Hoyer, 1980b).

Age: Unit ranges in age from 9,000 to about 2,500 B.P.

NOAH CREEK FORMATION

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

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

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

Description of the Unit: The Noah Creek Formation consists of a thin upper increment of fine-grained sediment usually ranging between 0.3 and 1.5 m (1 to 5 ft) thick overlying thick sand and gravel that typically exceeds 5 m (15 ft) in thickness. Bedding structures in the thick lower sequence of sand and gravel include all of the flow-regime bedforms described by Simons et al. (1965) and the various channel-fill types recognized by Ramos and Sopena (1983). In settings proximal to ice advances, the formation's deposits may exhibit collapse structures related to melt out of ice blocks buried in the outwash sequence.

Also, in proximal settings a silt facies is recognized. This unit is best described as a slackwater deposit that consists of a thin, very discontinuous mantle on the oldest Late Wisconsin terraces associated with the Des Moines River Valley. Secondary alteration includes soil formation throughout the upper fine-grained sediment, with other pedogenic alterations (such as beta horizons) sometimes extending down into the upper part of the underlying sand-and-gravel sequence. The sands and gravels are oxidized above the water table and unoxidized below.

Off the Des Moines Lobe, the Noah Creek Formation 2 consists of 2 to 18 m (6 to 58 ft) of massive to well stratified coarse to fine feldspathic quartz sand, pebbly sand and gravel with few intervening layers of silty clay or clay.

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 Des Moines Lobe and is unconformably buried by the DeForest Formation beneath alluvial fans, low stream terraces, and the modern flood plain.

Off the Des Moines Lobe, where Noah Creek Formation 2 is inset below the uplands in a valley geomorphic position, it can unconformably overlie undifferentiated Illinoian or Pre-Illinoian till, older Quaternary alluvial sediments, or Paleozoic bedrock into which the stream has incised.

Differentiation from other Units: The thick, coarse, sand-and-gravel sequences comprising the Noah Creek Formation are unlike any of the other formations on the Des Moines Lobe (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.

Off the Des Moines Lobe, the Noah Creek Formation 2 is coarser grained than the DeForest Formation and is more massive and coarser grained than the stratified loam and sand sediment package (unnamed loamy sediments) associated with solifluction lobes on the toeslopes of adjacent uplands.

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

Off the Des Moines Lobe, the Noah Creek Formation 2 occurs as fill in intermediate size valleys and in larger valleys that did not head on the Des Moines Lobe. Thickness of the fill can vary dramatically depending on the size of the valley.

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).

Off the Des Moines Lobe, the Noah Creek Formation 2 occurs as coarse to fine grained alluvial deposits in stream and river valleys.

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).

Off the Des Moines Lobe, the Noah Creek Formation 2 dates from as young as 11,000 RCYBP (Szabo, 1975) to at least as old as 21,000 years before present which was the beginning of the coldest part of the Wisconsin Episode (Baker et al., 1986, 1989, 1991).

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 DML. 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.

DOWS FORMATION

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

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

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

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

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

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

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

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

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

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

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

Alden Member

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

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

Description of the Unit: The bulk of the Alden Member consists of massive, compositionally uniform diamicton. The diamicton is matrix-dominated, with the sand-silt-clay matrix typically comprising 94 to 96% of the diamicton by weight. The matrix texture tends to be uniform both with depth at any one site and regionally from site to site. Several exceptions to this textural uniformity occur locally. At the base of the unit, the texture may vary because of incorporation of local substrate material. Discontinuous pods and lenses of sorted deposits (usually pebbly sands, sands, pebble gravels and silts) are also common at the base of the diamicton. In some cases, block inclusions of intact local substrate occur in the diamicton, but these are rare. Smudges, inclusions of local substrate that have been smeared out in or at the base of the glacier (Kruger, 1979), are also rare. The matrix texture of the diamicton is loam across the Lobe, although there is local variation within the range of sand-silt-clay percentages that comprise the loam textural group. The only systematic variation observed to date occurs south from the latitude of Ames where loess becomes the dominant substrate material below the Dows Formation. Glacial erosion of the loess and its incorporation into the Alden Member diamicton matrix has resulted in a systematic increase in the silt content of the diamicton downglacier to the terminus in Des Moines.

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

diamicton from around the DML are well oriented and show similar consistency between measurement sites at a given location.

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

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

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

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

The upper contact varies. In places, the Alden Member is at the surface. Where buried by the interbedded diamictos 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° and 3.6° C (33.5° to 38.5° F) (Graeff, 1986). The present mean annual temperature in the Lake Mills area is 8° C (46.3° 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.

SHELDON CREEK FORMATION

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

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

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

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

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

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

the Cretaceous Pierre Shale, a distinctive bedrock lithology that was glacially eroded and incorporated into both the Sheldon Creek and Dows Formations. The clay-mineral composition of fifteen Pierre Shale fragments taken from the Dows Formation is 67±3% expandables, 27±3% illite, and 6±2% kaolinite plus chlorite (Kemmis et al., 1981). This compares with the clay mineralogy of the fine-grained matrix of massive Sheldon Creek Formation diamictons of 65±3.5% expandables, 18±1.8% illite, and 18±1.8% kaolinite plus chlorite (Lucas, 1977). Distinctive textural and lithologic signatures aid in deciphering Sheldon Creek Formation from Dows Formation. Dows Formation Alden Member basal till averages 47% sand, 37% silt and 16% clay; a loam diamicton (Lucas, 1977, Kemmis, 1981). The Sheldon Creek Formation diamicton is 32% sand, 37% silt and 32% clay; a clay loam diamicton (Lucas, 1977). Also, Lucas, 1977 reported a noticeably higher percentage of carbonate pebbles in the Sheldon Creek Formation than in Dows Formation diamicton. Other distinguishing characteristics are the possible presence of a weathering zone developed in the former surface sediments of the Sheldon Creek Formation, subaerial erosion of the former surface sediments; and/or the presence of proglacial outwash sediments associated with DML ice advance overlying the Sheldon Creek Formation.

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

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

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

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, 1980a).

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 Formation. 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, 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, Iowa, in the NW¼ 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 Member also 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 dif-

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 0.6 to about 4.6 meters (2 to 15 ft.) and has a thickness of 14.6 meters (48 ft.) 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 % \pm 3.6 (range 55-70) expandables, 18% \pm 2.5 (range 13-24) illite, and 21% \pm 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, Wisconsin 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 Member 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, Iowa.

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 underlying material. The Hickory Hills Member almost always has more sand than silt. The average clay mineral percentages are 63% \pm 4.5 (range 52-73) expandables, 17% \pm 3.3 (range 11-23) illite, and 20% \pm 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 re-

lated 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 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 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 50 feet (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% kaolinite 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 Member 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 Member.

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 to 250 feet (67 to 76 m).

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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