COOPERATIVE MAPPING WITH THE NATURAL RESOURCES CONSERVATION SERVICE (NRCS) SURFICIAL GEOLOGIC MAPS OF THE STANWOOD AND CEDAR BLUFF 1:24,000 QUADRANGLES
Phase 2

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PURPOSE

Detailed geologic mapping of the Cedar Bluff and Stanwood Quadrangle was completed as part of the Iowa Geological Survey's (IGS) ongoing participation in the STATEMAP Mapping Program. In particular, mapping of these quadrangles is part of 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 Iowa Geological Survey's (IGS) 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. IGS 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 subdivison 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

Surficial mapping in conjunction with NRCS and Iowa Cooperative Soil Survey county updates has continued in Cedar County and into southern Jones County with the completion of the Cedar Bluff and Stanwood Quadrangles. The Cedar Bluff quadrangle covers an area from 41° 45' N latitude to 41° 52' 30" and 91° 22' 30" to 91° 15' 00" W longitude The Stanwood Quadrangle covers an area from 41° 52' 30" to 42° 00' N latitude and 91° 15' 00" to 91° 07' 30" W longitude. The mapping area is primarily concentrated on the Iowan Erosion Surface Landform Region with the southwestern portion of Cedar Bluff Quadrangle on the Southern Iowa Drift Plain Landform Region. Both regions have been subjected to periods of multiple Quaternary glaciations and subaerial erosion. Episodic erosion during the last 500,000 years has led to the development of an integrated drainage network and the destruction of pre-existing glacial landforms associated with Pre-Illinoian glaciations. Generally speaking, the southern part of the map area consists of Wisconsin age loess mantling Pre-Illinoian glacial sediments of variable thickness and the northern part of the map area consists of unnamed loamy sediments of variable thickness overlying Pre-Illinoian glacial sediments. These deposits are regionally extensive.

Previous surficial geologic mapping of the map area consists of the Des Moines 4° x 6° Quadrangle at a scale of 1:1,000,000 (Hallberg et al., 1991). Additional surficial geologic mapping near the project area includes previous STATEMAP map products for Linn County (1:24,000 scale): Surficial geologic materials of the Cedar Rapids North Quadrangle, Iowa and Surficial geologic materials of the Marion Quadrangle, Iowa (Bettis et al., 1995a,b); Surficial geologic materials of the Cedar Rapids South Quadrangle, Iowa and Surficial geologic materials of the Central City Quadrangle, Iowa (Bettis et al., 1996a,b); Surficial geologic materials of the Bertram Quadrangle, Iowa (Bettis et al., 1998). Quadrangle mapping of Linn County culminated in the production of the 1:100,000 scale Surficial geologic materials of Linn County (Quade et al., 1998). More recent STATEMAP projects include Surficial geologic materials of Johnson County (Tassier-Surine et al., 2004) and Cooperative Mapping with the NRCS Surficial Geology of the Rochester and Bennett Quadrangles in Cedar County (Tassier-Surine et al., 2006).

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 from 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 lithostratigaphic 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 eastern Iowa, the highly eroded and dissected pre-Illinoian upland and older terraces are mantled by Wisconsin loesses of variable thickness (Ruhe, 1969; Prior, 1976). These sediments are the youngest regionally extensive Quaternary deposits and were deposited between 30,000 and 12,000 years ago. Loess is thickest in the region near the Iowan Erosion Surface (IES) boundary and near local sources (Cedar River valley). Two loess units were deposited across eastern Iowa, the older Pisgah Formation and the younger Peoria Loess. The Pisgah is thin and includes loess and related slope sediments that have been altered by colluvial hillslope processes, pedogenic and periglacial processes. The unit is characterized by the presence of a weakly developed soil recognized as the Farmdale Geosol. It is not uncommon to see the Farmdale developed throughout the Pisgah and incorporated into the underlying older Sangamon Geosol. Most likely the Pisgah loess was deposited on the eastern Iowa landscape from 30,000 to 24,000 years ago (Bettis, 1989). The Pisgah Formation is typically buried by Peoria Formation loess. The Peoria Formation loess accumulated on stable landsurfaces in eastern Iowa from 25,000 to 21,000 years ago and was followed by a period of intense cold during the Wisconsin full glacial episode from 21,000 to 16,500 years ago (Bettis, 1989). This period of intense cold and ensuing upland erosion led to the development of the distinctive landform recognized at the Iowan Erosion Surface (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 Iowan Erosion surface 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". Other common features of this region are isolated and uneroded topographic highs of loess mantled Pre-Illinoian till. These elongated or elliptical shaped ridges have a directional orientation from northwest to southeast east and exist as erosional outliers of the once higher and older landscape. Another common feature is 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. The depositional history of the Iowan Surface was under great debate for an extended period of time. Early researchers believed the Iowan Surface 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 Iowa Erosion Surface, 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.

Esling (1984) undertook a regional study to document extensive post Illinoian-age alluvial deposits that had accumulated in major valleys in eastern Iowa. He identified three major terrace assemblages with differing stratigraphy and age: Early Phase High Terrace (EPHT), Late Phase High Terrace (LPHT) and Low Terrace (LT). EPHT are characterzied by the presence of Peoria and Pisgah Formation sediments overlying a Sangamon Geosol in the underlying alluvium. Esling theorized that these terraces are older than 40,000 years B.P. but younger than the Illinoian sediments in eastern Iowa (Bettis, 1989). LPHT deposits are characterized by the presence of Peoria Formation loess grading down into underlying alluvium with no paleosol. These terraces developed prior to 25,000 years ago and were buried by loess before 12,500 years ago. The LPHT terraces are typically inset into EPHT deposits. The LT is the youngest terrace and is not buried by Peoria loess. In the map area, eolian dunes (Peoria Formation—sand facies) are present on the terrace surface and indicate this terrace surface was deposited during Late Wisconsin through early Holocene time (12,500 to 10,000 years ago). Anderson (1986) conducted an extensive geoarcheology study of the Hawkeye Wildlife area along the Iowa River valley in adjacent Johnson County. He identified a Woodfordian age high terrace which is correlative with Esling's LT, and Holocene-age Low and Intermediate terraces. Anderson's intermediate terrace was an active floodplain throughout the early and mid-Holocene. During late Holocene time the alluvial history of the Iowa River valley has been dominated by lateral stream migration and channel belt formation. A similar alluvial history appears to be the case for the Cedar River valley in Cedar County.

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.

Fifteen landform sediment assemblage units were identified in the map area utilizing orthophotos, topographic expression, digitized soil and existing and new subsurface boring information. Forty borings were collected in both quadrangles which represents well over 1218 feet of new subsurface information obtained as part of this mapping project. Previous boring and stratigraphic information for Cedar County (Szabo, 1975; Miller, 1974) proved very useful in mapping the extent of fluvial deposits and loess thickness in the map area. The following is a description of each landform sediment assemblage listed in order of episode.

HUDSON EPISODE

Qo – Depressions and Fens (DeForest Formation-Woden Mbr.)
Generally 2.5 to 6 meters (8 to 16.5 feet) 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 Noah Creek Fm. sand and gravel in larger stream valleys or may be associated with seeps and springs along valley walls Usually, associated with stream valley side slopes and areas of exhumed inter-till gravels. Supports wetland vegetation and can be permanently covered by water. High water table.

Qal - Alluvium (De Forest Formation) One to four meters (3.3 to 13 feet) of massive to weakly stratified, grayish brown to brown loam, silt loam, clay loam, or loamy sand overlying less than three meters of poorly to moderately well sorted, massive to moderately well stratified, coarse to fine feldspathic quartz sand, pebbly sand, and gravel and more than three meters of pre-Wisconsin or late Wisconsin Noah Creek Formation sand and gravel. Unit also includes colluvial deposits derived from adjacent map units. Seasonally high water tables occur in this map unit.

Qal2 - Stream Valley Thick Alluvium (DeForest Formation-Undifferentiated) Variable thickness of 2 to 6 meters (6.6 to 20 feet) of very dark gray to brown, noncalcareous, massive to stratified silty clay loam, loam, sandy loam alluvium and colluvium associated with Pioneer and Walnut Creek stream valleys. Alluvium overlies an unusually thick, from 6 to 18 m (20 to 60 ft) sequence of medium sand to pebbly sand outwash of the Noah Creek Formation. Occupies low-relief modern floodplain. Seasonal high water table and potential for frequent flooding.

Qallt - Cedar River Valley- Low Terrace/Modern Channel Belt (DeForest Formation-Camp Creek Mbr. and Roberts Creek Mbr.) Variable thickness of less than one to 5 meters (3 to 16 feet) of very dark gray to brown, noncalcareous, stratified silty clay loam, loam, or clay loam, associated with the Holocene channel belt of the Cedar River valley. Overlies Noah Creek Formation sand and gravel. Ox-bow lakes and meander scars are common features associated with this terrace level. Post settlement alluvium thickness varies from 1.5 feet in higher areas to 6 feet along the river course and in lower lying areas. Seasonal high water table and frequent flooding potential.

HUDSON and WISCONSIN EPISODE

Qe - Sand Dunes and Sand Sheets (Peoria Formation-sand facies) Generally less than 6 meters (20 feet) of yellowish brown, massive, calcareous loamy sand to fine sand. It may overlie yellowish-brown sand and gravel (Noah Creek Fm.), or reworked unnamed loamy sediments associated with the Iowan Erosion Surface and/or it may overlie yellowish to grayish brown, often calcareous and fractured clay loam to loam diamicton; (Wolf Creek and Alburnett Formations)

Qnw2 – Sand and Gravel (Noah Creek Formation) Two to eighteen meters (6.6 to 60 feet) 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 Pioneer and Walnut Creek valleys a thin mantle of loess, reworked loess, fine-grained alluvium (Qal2) may be present. This unit includes silty colluvial deposits derived from the adjacent map units. In places this unit is mantled with one to three meters 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.

WISCONSIN EPISODE

Qnw- Sand and Gravel (Noah Creek Formation) More than three meters (10 feet) 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 one to three meters 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.

Qptlp - Late Phase High Terrace (LPHT) (Peoria Formation-silt and/or sand facies) Generally two to eight meters (6 to 26 feet) of yellowish brown to gray, massive, jointed, calcareous or noncalcareous, silt loam and intercalated fine to medium, well sorted, sand. Grades downward to poorly to moderately well sorted, moderately to well stratified, coarse to fine feldspathic quartz sand, loam, or silt loam alluvium.

Qptep – Early Phase High Terrace (EPHT) (Peoria Formation-silt and/or sand facies) Generally two to twelve meters (6 to 39 feet) of yellowish brown to gray, massive, jointed, calcareous or noncalcareous, silt loam and intercalated fine to medium, well sorted, sand. The Peoria deposits overlie a Farmdale Geosol developed in Roxanna Silt which in turn overlies a well-expressed Sangamon Geosol developed in poorly to moderately well sorted, moderately to well stratified, coarse to fine sand, loam, or silt loam alluvium.

Qps1 - Loess and Intercalated Eolian Sand (Peoria Formation-silt facies) Two to ten meters (6.6 to 33 feet) of yellowish brown to gray, massive, fractured, noncalcareous grading downward to calcareous silt loam and intercalated fine to medium, well sorted, sand. Sand is most abundant in lower part of the eolian package. Overlies massive, fractured, loamy glacial till of the Wolf Creek or Alburnett formations with or without intervening clayey Farmdale/Sangamon Geosol.

Qps1b - Thick Loess and Intercalated Eolian Sand (Peoria Formation-silt facies) Five to fifteen meters (16 to 50 feet) of yellowish brown to gray, massive, noncalcareous grading downward to calcareous silt loam and intercalated fine to medium, well sorted, sand. Minimum thickness of five meters on uplands. Maximum thickness of two to seven meters (6.6 to 23 feet) of loess occurs on adjacent slopes. Overlies massive, fractured, loamy glacial till of the Wolf Creek or Alburnett formations with or without intervening clayey Farmdale /Sangamon Geosol.

Qps2 - Eolian Sand and Intercalated Silt (Peoria Formation-sand facies) Five to fifteen meters (16 to 50 feet) of yellowish brown to gray, moderately to well stratified noncalcareous or calcareous, fine to medium, well sorted, eolian sand. May contain interbeds of yellowish brown to gray, massive, silt loam loess. Overlies eroded, massive, fractured, loamy glacial till of the Wolf Creek or Alburnett formations or fractured Devonian- age carbonate bedrock.

Qwa1 - Sand and Gravel Shallow to Till (Unnamed erosion surface sediment) One to three meters (3.3 to 10 feet) of yellowish brown to pale brown, massive to weakly stratified, noncalcareous, medium to coarse, poorly sorted pebbly to cobbly sand with intercalated gravel and loam. Overlies massive, fractured, firm, loamy glacial till of the Wolf Creek or Alburnett formations. Deposits in this mapping unit are derived primarily from erosion of glacial till in the adjacent drainage basin. Seasonally high water table may occur in this map unit. Moderate flood potential.

Qwa2 - Loamy and Sandy Sediment Shallow to Glacial Till (Unnamed erosion surface sediment) One to six meters (3.3 to 20 feet) 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 two meters of Peoria Silt (loess). Overlies massive, fractured, firm glacial till of the Wolf Creek and Alburnett formations. Seasonally high water table may occur in this map unit.

PRE-ILLINOIS EPISODE

Qwa3 – Till (Wolf Creek or Alburnett Formations) Generally 3 to 55 meters (10 to 180 feet) of very dense, massive, fractured, loamy glacial till of the Wolf Creek or Alburnett Formations with or without a thin loess mantle (Peoria Formation—less than 2 meters or 6.6 feet) or thin loamy sediment mantle (unamed erosion surface sediment) may overlie intervening clayey Farmdale/ Sangamon Geosol. This mapping unit can be buried by unnamed erosion surface sediments, loess or alluvium and is shown only in the cross-section.

DESCRIPTION OF EAST-CENTRAL IOWA STRATIGRAPHY

An important aspect of surficial geologic mapping on the Iowan Erosion Surface and the Southern Iowa Drift Plain 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 east-central Iowa. Hudson, Wisconsin and Pre-Illinois Episode deposits (Johnson et al., 1997) of the east-central Iowa are included in six formations: DeForest Formation (Hudson), Noah Creek Formation 2 (Hudson and Wisconsin), Peoria and Pisgah Formations (Wisconsin), and Wolf Creek and Alburnett Formations (Pre-Illinois). The following section provides a description, of formations and members of east-central Iowa deposits.

STRATIGRAPHIC FRAMEWORK FOR EAST-CENTRAL IOWA

Surficial deposits of the map area are composed of six formations: DeForest, Noah Creek Peoria, Pisgah, Wolf Creek, and Alburnett formations. Hudson age deposits associated with fine-grained alluvial and colluvial sediments include the DeForest Formation which is subdivided into the Camp Creek, Roberts Creek, Gunder and Corrington members. The Noah Creek Formation 2 includes coarse to finer grained fluvial deposits associated with stream and river valleys. The Peoria Formation includes wind-blown sediments: two facies are recognized, a silt facies (loess) and a sand facies (eolian sand). The Pisgah Formation originated as eolian silt that has been altered by a combination of colluvial hillslope processes, pedogenic and periglacial processes. Pre-Illinoian glacial deposits in east-central Iowa consist of two formations: the younger Wolf Creek Formation and the Alburnett Formation. The Wolf Creek is divided into the Winthrop, Aurora and Hickory Hills members (oldest to youngest). The Alburnett Formation consists of several “undifferentiated” members.

DEFOREST FORMATION

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

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

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

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

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

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

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

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

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

Age: The base of the DeForest Formation is time-transgressive. On the DML it is younger than 11,000 RCYBP in most areas, but is locally as old as 14,000 to 11,000 RCYBP. Deposition of the DeForest Formation continues to the present. The age of individual members is also time-transgressive, dependent on position in the drainage system and on geomorphic position.

Camp Creek Member

Source of Name: Camp Creek a tributary of Garretson Drainage Ditch, Woodbury County, Iowa.

Type Section: Camp Creek cutbank exposure, Woodbury County, Iowa, NW 1/4, SW1/4 of section 1 T. 87 N., R. 45 W. (Bettis, 1990).

Description of Unit: Usually a calcareous to noncalerous, very dark gray to brown, stratified (planar-bedded) silt loam to clay loam. Surface soils developed into the Camp Creek Member are Entisols (Typic Udifluvents). These soils consist of an organically enriched surface horizon (A horizon) grading to unaltered parent material. Where this unit is rapidly aggrading, surface soils are absent.

Nature of Contacts: This member is inset into or unconformably overlies the Gunder, Corrington and Roberts Creek members, depending on the local geomorphic setting and history of landuse. This unit often buries pre-settlement soil surface. May grade to sand and gravel in and adjacent to the modern channel belt.

Differentiation From Other Members: The Camp Creek Member differs from other members of the formation, in geomorphic position and nature of the stratigraphic sequence.

Regional Extent and Thickness: Thickness of the Camp Creek member is quite variable ranging from a few centimeters to over five meters (16.4 ft.).

Origin: Camp Creek Member consists of late-Holocene to post-settlement alluvium in and adjacent to modern channel belt, and at the base of steep slopes.

Age: Age is time-transgressive, dependent on drainage system and geomorphic position. In large valleys Camp Creek Member started aggrading as early as 400 B.P. and in small valleys as early as 150 B.P. It is still accumulating at present in both small and large valleys.

Roberts Creek Member

Source of Name: Roberts Creek, Clayton County, Iowa
Type Area: Along Roberts Creek, Clayton County, Iowa, sections 6 and 7, T. 94 N., R. 5 W. (Baker, et.al., 1996).
Description of Unit: Roberts Creek Member consists of dark, clayey, silty and loamy alluvium grading downward to sand and gravel; usually noneffervescent; thick sections are stratified at depth; detrital organic matter in lower part; relatively thick Mollisol (A-C or A-Bw-C profile) developed in the upper part (Bettis et al., 1992). Weakly expressed buried soils have been observed within the Roberts Creek Member, but these are not traceable from one valley to another. This unit includes the Mullenix and Turton members of Daniels, et al. (1963), which have been redesignated as beds within the Roberts Creek Member in the thick and moderately thick loess areas of western Iowa and adjacent states.
Nature of Contacts: Roberts Creek Member deposits overlie a wide variety of deposits including the Gunder and Corrington members, older alluvium, loess and glacial till.
Differentiation From Other Members: The Roberts Creek Member differs from other members of the formation, in geomorphic position and nature of the stratigraphic sequence. Soils are morphologically less well expressed and have darker B and C horizons than soils developed in the Gunder and Corrington members. The Roberts Creek Member is separated from younger DeForest Formation deposits (Camp Creek Member) by either a fluvial erosion surface or an unconformity marked by a buried soil (Bettis, 1995).
Regional Extent and Thickness: Roberts Creek deposits are found beneath flood plains of small and large valleys and often overlap Gunder Member deposits in 2nd and 3rd-order valleys. Unit thickness will vary dependent on size of valley. Usually unit thickness will vary from 1.5 to 5 m thick.
Origin: Roberts Creek Member consists of late-Holocene alluvium found in the modern floodplain, parallels the modern channel, also found in fan trenches.
Age: Unit age ranges from 4,000 to 500 B.P.

Gunder Member

Source of Name: Roberts Creek, Clayton County, Iowa
Type Area: Along Roberts Creek, Clayton County, Iowa, sections 6 and 7, T. 94 N., R. 5 W. (Baker, et al., 1996).
Description of Unit: Gunder Member consists of oxidized brown to yellowish brown to grayish brown silt loam, silty clay loam, or loam grading to sand and gravel at depth. Usually noneffervescent, lower part may be stratified and reduced, detrital organic matter often present in lower coarse-grained part of unit; moderately well to somewhat poorly drained Mollisols and Alfisols developed in upper part. This member includes the Watkins and Hatcher members of Daniels et al. (1963) which have now been redesignated as beds within the Gunder Member. Buried soils are sometimes present within the Gunder Member, but are not traceable on a regional scale.
Nature of Contacts: Gunder Member deposits unconformably overlie loess, glacial till, bedrock, coarse alluvium, or organic-rich fine-grained alluvium. Overlying younger members of the formation are separated from the Gunder Member by a fluvial erosion surface or an unconformity marked by a buried soil.
Differentiation From Other Members: The Gunder Member differs from other members of the formation, in geomorphic position and nature of the stratigraphic sequence. Soils are morphologically better expressed and have lighter B and C horizons than soils developed in the Roberts Creek member.

Regional Extent and Thickness: Gunder deposits usually comprise low terrace that merges with sideslopes in a smooth concave upward profile. Usually unit thickness will vary from .5 to 4 m thick, with thickest deposits associated with Watkins member deposits.
Origin: Gunder Member consists of mid-early Holocene alluvium found low terrace positions merging with sideslopes.
Age: Unit ranges in age from 10,500 to 3000 B.P.

Corrington Member

Source of Name: Corrington alluvial fan, Cherokee, County, Iowa
Type Section: Along the Little Sioux River Valley wall, Cherokee, County, Iowa, W 1/2, SW 1/4, SE 1/4 of section 4, T. 91 N., R. 40 W. (Hallberg, et al., 1974; Hoyer, 1980a, 1980b).
Description of Unit: The Corrington Member is the most internally variable unit of the formation and consists of very dark brown to yellowish brown oxidized loam to clay loam with interbedded lenses of sand and gravel; noneffervescent to effervescent at depth. The unit is stratified and usually contains several buried soils. Surface soils developed into this unit in are thick Mollisols (Cumlic Hapludolls) or Alfisols (Hapludalfs) that have argillic (Bt) horizons (Bettis, 1995).
Nature of Contacts: The Corrington Member buries coarse-grained older alluvium, glacial till, loess, or bedrock, and can grade laterally into Gunder Member deposits.
Differentiation from Other Members: The Camp Creek Member differs from other members of the formation, in geomorphic position and nature of the stratigraphic sequence. The presence of numerous buried soils (paleosols) and several fining-upward sequences often characterize unit.
Regional Extent and Thickness: Corrington Member deposits compose alluvial fans located where small and moderate-size valleys (2nd-and 3rd-order) enter larger valleys. Fans will vary in thickness, typically thicker sections have been measured in western Iowa. At the type section in Cherokee County, section thickness was measured at 11 m (36 ft.).
Origin: Corrington Member is found in alluvial fans and colluvial slopes along the margins of large to moderate-size valley. Deposits are variably textured and accumulated by channeled flow, sheetwash, and debris flow (Hoyer, 1980b).
Age: Unit ranges in age from 9000 to about 2500 B.P

NOAH CREEK FORMATION *(2)*

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 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 e. 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 lobe. On the DML, the formation is usually restricted to a narrow belt on the upland along major stream valleys.

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

Origin: The Peoria Formation consists of wind-deposited sediment. The formation's sediments were derived from wind reworking of valley-train outwash. The sand facies also includes sediments reworked from older eolian sand deposits.
Age: The Peoria Formation is time transgressive. The silt facies was deposited between about 22,000 and 12,500 RCYBP, while the sand facies includes deposits that accumulated contemporaneous with the silt facies, as well as others that accumulated during the Holocene to the present. Most Peoria Formation deposits on the DML accumulated between about 14,000 and 11,000 RCYBP, and have undergone various degrees of wind reworking during the Holocene.

PISGAH FORMATION

The Pisgah Formation includes both primary eolian silt and eolian silt and related slope sediments that have been altered by a combination of colluvial hillslope processes, pedogenic and periglacial processes.
Source of name: the town of Pisgah, Harrison County, Iowa.
Type Section: the Loveland Paratype Section, cut north of Interstate 680 at intersection with Interstate 29 , Pottawattamie County, Iowa, in the NW1/4, SE ¼, Sec. 3 T77N R44W
Description of Unit: The Pisgah Formation is primary eolian silt (loess) and eolian silt and related hillslope sediments that have been modified by a combination of colluvial hillslope processes, pedogenic and periglacial processes. As a result of various mixing processes most Pisgah Formation deposits have a coarse, gritty silt loam texture. Throughout the state, the unit is usually thin (.15 to 1 m thick), and has been pedogenically altered both at the base, by slow incorporation into the existing Sangamon Geosol, and at the top, from pedogenesis producing the Farmdale Geosol before burial by the Peoria Formation (Kemmis et al., 1992). Typically, the Farmdale Geosol is expressed as a thin, dark grayish brown, weakly developed buried soil consisting of a leached A-C or E-C profile with platy or granular structure and associated charcoal flecks. Where the Pisgah Formation is thin (<30cm) the Farmdale Geosol is developed through the entire unit.
Nature of Contacts: The Pisgah Formation is typically buried by the Peoria Formation (silt facies--loess). Beneath the Des Moines Lobe the formation is buried Peoria loess, which in turn is buried by Dows Formation glacial diamicton. A prominent feature at the Peoria/ Pisgah contact is an involuted contact which is attributed to Wisconsin-age periglacial activity. Pisgah deposits typically overlie the Sangamon Geosol that is developed in Loveland or Pre-Wisconsin-age loess(s) or undifferentiated Pre-Illinoian glacial till.
Differentiation From Other Units: The wind-transported and slope reworked sediments of the Pisgah Formation are unlike the deposits of the Dows and Noah Creek formations on the DML. The Lake Mills Member of the Dows Formation consists of fine-grained silty sediment, but it has greater variability, higher clay content, and occurs in a different geomorphic setting. The Noah Creek Formation and Pilot Knob Member of the Dows Formation are more poorly sorted and contain coarse sand and gravel. The DeForest Formation contains some silty sediment, but the bedding structures and sorting of these are distinct from those associated with the Pisgah Formation, and occurs in a different geomorphic setting. The Pisgah Formation is genetically similar to the Peoria Formation, however it has been noticeably altered by pedogenic, colluvial hillslope and periglacial processes. The Pisgah Formation was referred to as the "basal Wisconsin loess" in previous literature (Ruhe, 1969).
Regional Extent and Thickness: The Pisgah Formation is preserved on relatively stable upland surfaces, but is absent on Iowan Erosion Surface of northeastern Iowa and on "Iowan" steps of the stepped erosion surface landscapes associated with the Southern Drift Plain landform region of the state (Hallberg et al., 1978). Where present on the DML, the formation is buried by Dows Formation glacial till and Peoria Formation loess. Thickness varies with landscape position and distance from the eolian source. In central and eastern Iowa, the formation is commonly only 0.15 to 1 m thick. In extreme western Iowa, adjacent to the Missouri River valley the unit is 3 to 4 m thick. The Pisgah Formation stratigraphic posi-

tion is equivalent to the Roxana Silt of Illinois and the Gilman Canyon Formation of Nebraska, but lithologic properties are different (Bettis, 1990)

Origin: The Pisgah Formation originated as eolian silt that has been altered by a combination of colluvial hillslope processes, pedogenic and periglacial processes.

Age: The Pisgah Formation is time transgressive. The wind-transported silt was deposited between about 45,000 and 25,500 RCYBP while Peoria loess began to accumulate shortly after 25,0000 RCYBP (Bettis, 1990). Dates from the Farmdale Geosol, developed in the upper part of the Pisgah Formation indicate that ages range from 28,000 to 16,5000 RCYBP with ages decreasing with distance from the Missouri River valley (Ruhe, 1969).

WOLF CREEK FORMATION

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

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

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

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

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

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

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

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

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

Winthrop Member

Source of name: the town of Winthrop, Buchanan County, Iowa.
Type Section: the type area of the Winthrop Till Member consists of a railroad cut and drill-core section approximately 1¼ miles (2 km) west of Winthrop in Buchanan County in the NW1/4 of Section 3, Township 88N, Range 8W. The exposure is about 5 ½ miles (8.8 km) east of Independence and 2 ¼ miles (3.6 km) east of Doris Station.
Description of Unit: The Winthrop Till Member is the oldest and least well-known of the Wolf Creek Formation tills due to poor preservation. The color varies within the weathering profile from a light-yellowish brown to dark gray. Texturally, the Winthrop Till Member is a loam to light clay loam with averages of 25% clay, 41% silt and 34% sand. Generally, it contains more silt than sand. Clay mineral percentages in the Winthrop Till Member average 60% ±4.3 (range 51-68) expandables, 17% ±2.2 (range 10-20) illite, and 24% ±3.8 (range 16-31) kaolinite plus chlorite (Hallberg, 1980a). The Winthrop Till Member tends to have slightly higher values of kaolinite than the other tills of the Wolf Creek Formation. The Winthrop Till Member exhibits a high limestone to dolomite ratio (median and mode >15) and dolomite is commonly absent.
Nature of Contacts: The Winthrop Till Member is overlain by either leached unnamed sediments separating it from the Aurora Till Member, the Aurora Till Member, younger Wolf Creek Formation deposits, or may be exhumed as the surface till where erosion was severe enough to remove the younger deposits.
The lower boundary of the Winthrop Till Member is equally complex, with the contact being marked by the underlying bedrock, sediments of the Alburnett Formation, or in the most complete sections by the top of the Westburg Paleosol. Where present, the Westburg Paleosol occurs below the Winthrop Till Member of the Wolf Creek Formation and is developed in deposits of the Alburnett Formation or older rock units.
Differentiation from other Units: The Winthrop Member is distinguished from the Kellerville Member of the Glasford Formation (Illinoian age till) by the relatively low illite and dolomite contents. The Kellerville aslo exhibits an abundance of Pennsylvanian lithologies in the very coarse sand through cobble size particles and a much lower limestone to dolomite ratio (less than 0.40) (Hallberg, 1980b). All members of the Wolf Creek Formation have average limestone to dolomite ratios greater than 0.40.
Differentiation of the Wolf Creek Formation members and Alburnett Formation materials is difficult in the field without the assistance of stratigraphic boundaries, but mineralogical characteristics can be used to distinguish them. The most useful characteristic to distinguish between the Wolf Creek members and the Alburnett Formation is the clay mineralogy (Hallberg, 1980a). The Wolf Creek Formation has higher expandable clay percentages, averaging around 62%; whereas the Alburnett Formation has lower expandable clay percentages, near 43%.
Clay mineral variation cannot be utilized to differentiate members of the Wolf Creek Formation, and the sand-fraction lithology generally overlaps. However, the limestone to dolomite ratio and grain-size distribution has been useful for discriminating between members (Hallberg, 1980a). Differentiation can be difficult in areas of isolated exposures where only one till is exposed (or the till varies to an end member within its range). Typically, the Hickory Hills member almost always has more sand than silt and has higher values for total carbonate and sedimentary grains than the Aurora or Winthrop members. The Hickory Hills member also has a low limestone to dolomite ratio. Both the Aurora and Winthrop members have more silt than sand, a high limestone to dolomite ratio, and often do not have dolomite. Overall, these similarities between the Aurora and Winthrop members make it difficult to distinguish the two if only one is present. The Winthrop generally has lower values for total carbonates and sedimentary grains.
Regional Extent and Thickness: Due to the limited number of positive identifications, the thickness of the Winthrop Till Member is poorly known and difficult to determine. In the composite Winthrop locality it varies from 2 to about 15 feet (0.6-4.6 m), and has a thickness of 48 feet (14.6 m) in the 4-Mile Creek area.
Origin: The Winthrop Member of the Wolf Creek Formation consists of deposits associated with an advance of Pre-Illinoian ice. Based on the physical properties of these deposits (massive structure, high density, uniform texture) they likely represent a basal, or subglacial, till facies.

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

Aurora Member

Source of name: the town of Aurora, Buchanan County, Iowa.
Type Section: the type area for the Aurora Till Member is the Aurora Transect located approximately 2 miles (3.2 km) southwest of the town of Aurora in northeast Buchanan County, Iowa. The transect consists of core-holes drilled along the axis of the stepped erosion surfaces in the area of the regional divide between the Wapsipinicon and Maquoketa Rivers in the NE1/4 of Section 23, T 90N, R 8W.
Description of Unit: The Aurora Till Member is a basal till with relatively uniform characteristics. The texture of the Aurora Till Member is loam, averaging 22% clay, 40% silt, and 38% sand. The Aurora has a high limestone to dolomite ratio (median and mode >15), and often no dolomite is present. Color varies vertically within the weathering profile from light yellowish-brown to dark gray or dark greenish gray. Clay mineralogy averages 62 % ±3.6 (range 55-70) expandables, 18% ±2.5 (range 13-24) illite, and 21% ±2.3 (range 17-24) kaolinite plus chlorite (Hallberg, 1980a).
Nature of Contacts: The upper boundary of the Aurora Till Member varies in relation to the amount of erosion. In complete sections, this boundary is marked by the contact with the unnamed weathered (leached) sediments, which generally contain the Dysart Paleosol (which is overlain by the Hickory Hills Till Member). Where the Dysart Paleosol has been eroded, the contact may be directly with the Hickory Hills Till Member or a sharp diffuse contact zone including glaciofluvial sediments of the Hickory Hills Till Member. In some places erosion is severe enough that the Aurora Till Member is the surficial till unit and may be overlain by a thin veneer of Wisconsin to Holocene surficial sediments or eolian sand, Wisconsinan loess, or Pre-Wisconsinan sediments.
In complete sections, the lower boundary of the Aurora Till Member may be marked by the contact with leached sediments and weak paleosols separating it from the Winthrop Till Member. In areas where erosion has occurred, the Aurora Member may be in direct contact with the Winthrop Till Member, various sediments of the Alburnett Formation, or bedrock. If either of the last two settings is the case, the Aurora Till Member also marks the base of the Wolf Creek Formation.
Differentiation from other Units: The Wolf Creek Formation tills are distinguished from the Kellerville Member of the Glasford Formation (Illinoian age till) by the relatively low illite and dolomite contents. The Kellerville also exhibits an abundance of Pennsylvanian lithologies in the very coarse sand through cobble size particles (Hallberg 1980b). The Kellerville has a much lower limestone to dolomite ratio (less than 0.40) than the Wolf Creek Formation deposits (95% of which all have limestone to dolomite ratios greater than 0.40).
Differentiation of the Wolf Creek Formation members and Alburnett Formation materials is difficult in the field without the assistance of stratigraphic boundaries, but mineralogical characteristics can be used to distinguish them. The most useful characteristic to distinguish between the Wolf Creek and Alburnett Formations are the clay mineral percentages. The Wolf Creek Formation has higher expandable clay values, averaging around 62%; whereas the Alburnett Formation has lower expandable clay percentages, near 43% (Hallberg, 1980a).
Clay mineral variation cannot be utilized to differentiate members of the Wolf Creek, and the sand-fraction lithology generally overlaps. However, the limestone to dolomite ratio and grain-size distribution has been useful for discriminating between members (Hallberg, 1980a). Differentiation can be difficult in areas of isolated exposures where only one till is exposed (or the till varies to an end member within its range). Typically, the Hickory Hills member almost always has more sand than silt and has higher values for total carbonate and sedimentary grains than the Aurora or Winthrop members. The Hickory Hills member also has a low limestone to dolomite ratio. Both the Aurora and Winthrop members have more

silt than sand, a high limestone to dolomite ratio, and often do not have dolomite. Overall, these similarities between the Aurora and Winthrop members make it difficult to distinguish the two if only one is present. The Winthrop generally has lower values for total carbonates and sedimentary grains.

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

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

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

Hickory Hills Member

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

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

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

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

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

Differentiation of the Wolf Creek and Alburnett Formation tills is difficult in the field without the assistance of stratigraphic boundaries, but mineralogical characteristics can be used to distinguish them. The most useful characteristic to distinguish between the Wolf Creek and Alburnett Formations is the clay

mineralogy (Hallberg, 1980a). The Wolf Creek Formation has higher expandable clay percentages, averaging around 62%; whereas the Alburnett Formation has lower expandable clay percentages, near 43%.
Clay mineral variation cannot be utilized to differentiate members of the Wolf Creek Formation, and the sand-fraction lithology generally overlaps. However, the limestone to dolomite ratio and grain-size distribution has been useful for discriminating between members (Hallberg, 1980a). Differentiation can be difficult in areas of isolated exposures where only one till is exposed (or the till varies to an end member within its range). Typically, the Hickory Hills member almost always has more sand than silt and has higher values for total carbonate and sedimentary grains than the Aurora or Winthrop members. The Hickory Hills member also has a low limestone to dolomite ratio. Both the Aurora and Winthrop members have more silt than sand, a high limestone to dolomite ratio, and often do not have dolomite. Overall, these similarities between the Aurora and Winthrop members make it difficult to distinguish the two if only one is present. The Winthrop generally has lower values for total carbonates and sedimentary grains.
Regional Extent and Thickness: The thickness of the Hickory Hills Till Member is extremely variable. Due to erosion it is absent in some areas, however, in more complete sections the member ranges from 10 to over 50ft (3-15m).
Origin: The Hickory Hills Member of the Wolf Creek Formation consists of deposits associated with an advance of Pre-Illinoian ice. Based on the physical properties of these deposits (massive structure, high density, uniform texture) they likely represent a basal, or subglacial, till facies.
Age and Correlation: The Wolf Creek Formation members represent the youngest of the Pre-Illinoian glaciations. Pre-Illinoian deposits in Iowa range from older than 2.2 million years to approximately 500,000 years ago based on volcanic ash dates in western Iowa (Easterbrook and Boellstorff, 1984; Hallberg, 1986). Paleomagnetic studies of the Wolf Creek Formation in east-central Iowa indicate that these deposits have normal polarity and are therefore younger than 790,000 years (Baker and Stewart, 1984).

ALBURNETT FORMATION

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

Source of name: the town of Alburnett, Linn County, Iowa.
Type Section: the region around the town of Alburnett, Otter Creek Township (T 85N, R 7W), Linn County, Iowa.
Description of Unit: The Alburnett Formation is composed of multiple till units, which are "undifferentiated", and a variety of fluvial deposits. Minor paleosols may also be identified within the deposits. Throughout eastern Iowa, these deposits fill and bury the deep bedrock channels. The till is typically a uniform, massive, basal till. The Alburnett Formation ranges in color from light-yellowish brown in the oxidized zone, to dark gray or dark-greenish gray in the unoxidized zone.
The Alburnett Formation is defined by its stratigraphic position and distinctive clay mineralogy. The tills are generally loam textured, but range to light clay loam. On average, the Alburnett Formation consists of 18.7% clay, 36.8% silt, and 44.4% sand. The Alburnett Formation contains 44% expandables, 24% illite, and 32% kaolinte plus chlorite. In comparison with the Wolf Creek Formation, the Alburnett tills have significantly lower percentages of expandable clay minerals and higher kaolinite plus chlorite (Hallberg et al., 1980).
Nature of Contacts: The upper boundary of the Alburnett Formation is an unconformity of variable magnitude. Where the section is complete, the top of the Westburg Paleosol marks the upper boundary and is overlain by the Winthrop Till Member of the Wolf Creek Formation. Where the paleosol is eroded, any member of the Wolf Creek Formation, Wisconsin loess or other surficial sediments may overlie the Alburnett Formation. The lower boundary of the Alburnett Formation is marked by an unconformable contact with the bedrock. Glaciofluvial deposits may also be located at the base of the Alburnett Formation.

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

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

Regional Extent and Thickness: The Alburnett Formation has a wide range of thickness. In some areas it is completely absent and in others may reach a substantial thickness where its deposits fill in and bury deep bedrock channels. In these areas it has been identified to reach thicknesses of 220-250 feet.

Origin: The Alburnett Formation consists of multiple undifferentiated members associated with several Pre-Illinoian ice advances. Based on the physical properties of the Alburnett Formation deposits (massive structure, high density, uniform texture) it is likely a basal, or subglacial, till facies.

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

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