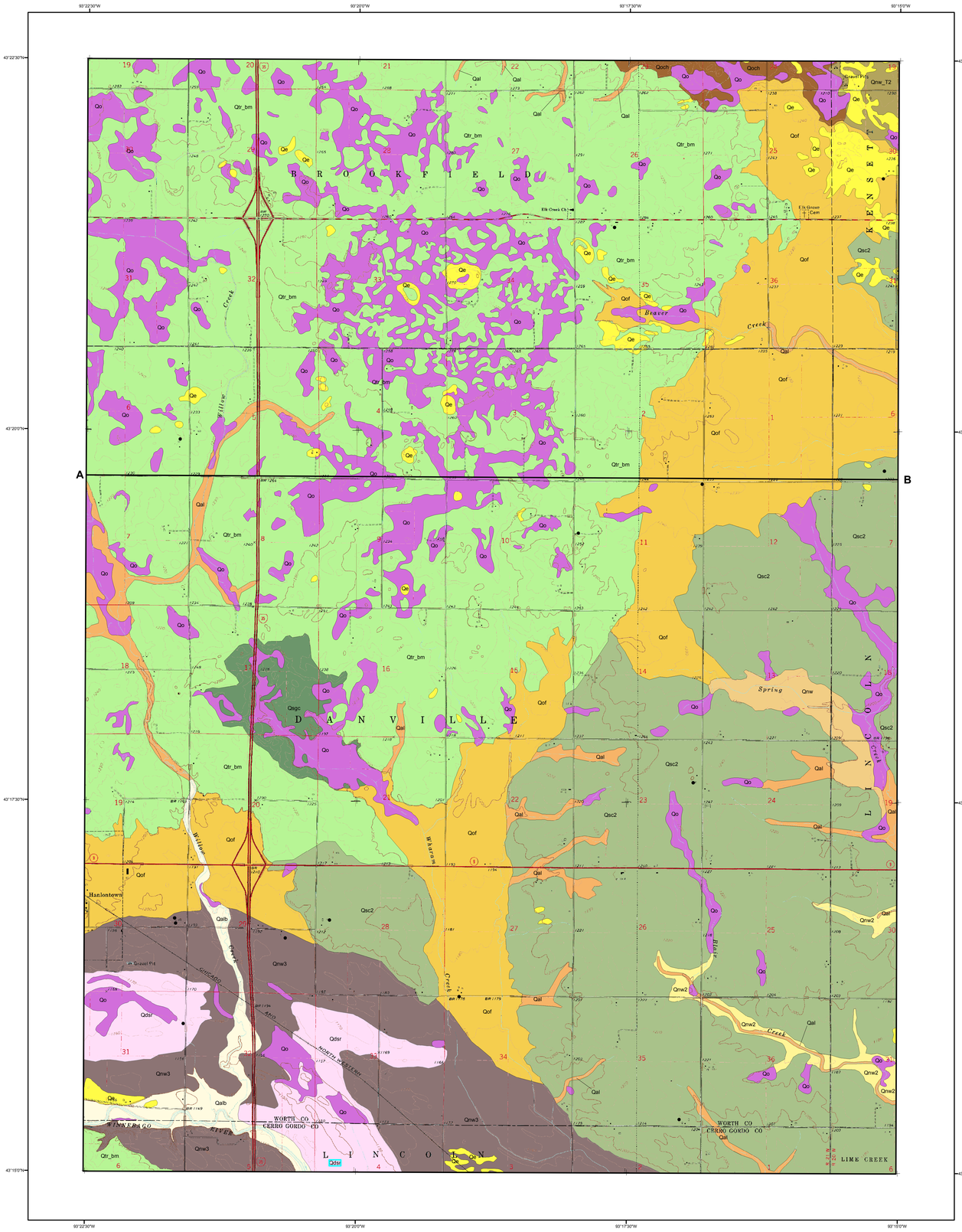
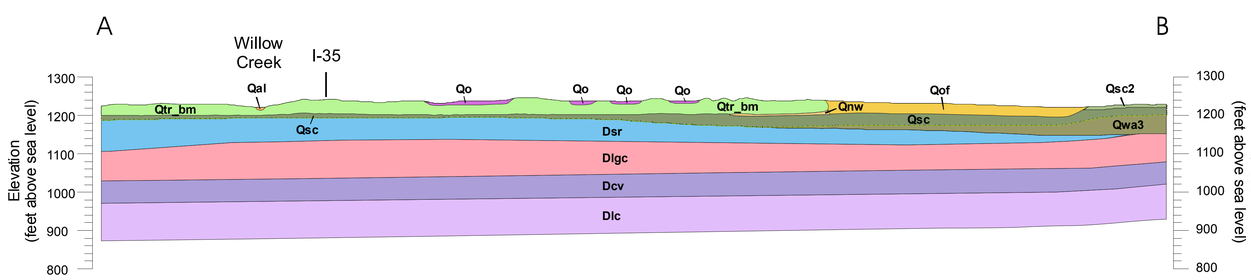
# Surficial Geology of the Fertile SE (Iowa) 7.5' Quadrangle




## GEOLOGIC CROSS-SECTION A-B




## LEGEND

### CENOZOIC

### QUATERNARY SYSTEM

#### 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 cuspate-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.

### PALEOZOIC

### DEVONIAN SYSTEM

**Dsr - Limestone, Dolomite, and Shale** (Shell Rock Formation) Upper Devonian. 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).

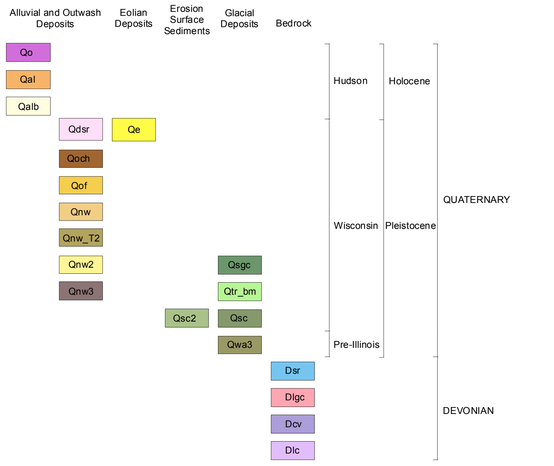
**Dlgc - Dolomite, Limestone, and Shale** (Lithograph City Formation) Middle to Upper Devonian. Maximum thickness of this map unit is up to 30 m (100 ft), consisting of dolomite and dolomitic limestone, partially characterized by interbeds of unfossiliferous to sparsely fossiliferous laminated lithographic and sublithographic limestone and dolomitic limestone, in part argillaceous or with slight shale. "Birdseye" carbonate fabric is common in some layers. This unit is shown only on cross-section, not on map.

**Dcv - Limestone and Dolomite** (Coralville Formation) Middle Devonian. Thickness of this formation varies between 10 and 18 m (35-60 ft), and is dominated by limestone, dolomitic limestone, and dolomite, in part laminated and argillaceous. Brachiopods and corals usually occur in the limestone facies. This unit is shown only on cross-section, not on map.

**Dlc - Dolomite and Limestone** (Little Cedar Formation) Middle Devonian. Thickness of this formation ranges from 27 to 36 m (90-120 ft) in this area. It is dominated by slightly argillaceous to argillaceous dolomite and dolomitic limestone, usually vuggy and partially laminated and/or cherty. This unit is commonly fossiliferous and brachiopods are especially abundant in lower portion. This unit is shown only on cross-section, not on map.

**Drill Holes**

### Correlation of Map Units




### Location Map

Base map from USGS Fertile SE 7.5' Digital Raster Graphic (IGS GIS file DRGC28.TIF) which was scanned from the Fertile SE 7.5' Topographic Quadrangle map, published by US Geological Survey in 1972
Topographic contours and land features based on 1971 aerial photography, field checked in 1972
Land elevation contours (10' interval).

Iowa Geological Survey digital cartographic file FertileSE_Surf_2010.mxd, version 10/04/'10 (ArcGIS 9.2)
Map projection and coordinate system based on Universal Transverse Mercator (UTM) Zone 15, datum NAD83.

The map and cross section are based on interpretations of the best available information at the time of mapping. Map interpretations are not a substitute for detailed site specific studies.

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


**Iowa Geological and Water Survey**
**Open File Map OFM-10-6**
**September 2010**



*prepared by*

Deborah Quade, Stephanie Tassier-Surine, Huaibao Liu, Robert M. McKay, and James D. Giglierano

Iowa Geological and Water Survey, Iowa City, Iowa

Iowa Department of Natural Resources, Patricia Boddy, Interim Director
Iowa Geological and Water Survey, Robert D. Libra, State Geologist



Supported in part by the U.S. Geological Survey
Cooperative Agreement Number G09AC00190
National Cooperative Geologic Mapping Program (STATEMAP)

**ACKNOWLEDGMENTS**

Recognized for contributions to map's production: Andrew Asell, Chris Kahle, Brian Witzke, Ray Anderson, Bill Bunker, Mary Pat Heitman, and Lois Bair. New subsurface geologic data was generated by the University of Iowa student Kyle Bracken who produced descriptive logs of water well drill samples. Jason Vogelgesang prepared well samples for stratigraphic logging. Drilling was provided under contract with Aquadrill of Swisher, Iowa and Cahoy Well and Pump Service of Fredericksburg, Iowa. Special thanks to drillers Dennis Auld and Mark Claassen. Assistance with field work during drilling was provided by Bob Rowden and Jason Vogelgesang. Special thanks to all landowners who graciously allowed access to their land for drilling: Stan Bachaus, Ken Benjegerdes, Bil Blanchard Dan Brunsvold, Dianna Brunsvold, Margueirte Brunsvold, Patty Edenfield, Steve Jennings, Amil Johnson, LeRoy Luecht, David Meyer, Arden Midgaard, Arlen Midgaard, and Brian Tweeten. Robin Wisner, Kathy Woida, Leland Camp, Neil Sass, and Elizabeth Swanberg assisted with field work and describing cores as part of the mapping update for the Iowa Cooperative Soil Survey Update for Worth County. Dean Mueller of the Worth County Conservation Board assisted with finding drilling locations on public lands. Shane Buenzow, Worth County Sanitarian, assisted with acquiring well drillers records.


## INTRODUCTION

The Fertile Quadrangle is located in Worth County and Cerro Gordo County in north-central Iowa. 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, 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 Des Moines Lobe 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).

The map area has a rich and complex geologic history punctuated by at least seven periods of glaciation between 2.2 million to 500,000 years ago. (Boellstorff, 1978a,b; Hallberg, 1980, 1986) In this area, Pre-Illinoian Episode glacial deposits and associated buried soils are overlain by much younger Wisconsin-age glacial deposits. 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). 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 Sheldon Creek and Pre-Illinoian till surface was significantly eroded; resulting in the development of a region-wide colluvial lag deposit referred to as a "stone line". Shortly, following the IES formation the southern edge of the Laurentide Ice Sheet split into several lobes that each flowed down regional topographic lows. The Des Moines Lobe extended from central Canada through the Dakotas and Minnesota into Iowa, terminating at what is now the City of Des Moines. The Des Moines Lobe was active in Iowa between about 15,000 and 12,000 RCYBP, about 5,000 to 8,000 years later than glacial lobes to the east made their southernmost maximum advance (Johnson, 1986; Fullerton, 1986). The Lobe advance occurred well into a period of regional warming and was thus climatically out of equilibrium (Kemmis et al., 1994). Ice thickness reconstructions indicate that the lobe was probably thin and gently sloping (Mathews, 1974; Clark, 1992; Brevik, 2000; Hooyer and Iverson, 2002). Clark (1992) reconstructed the Lobe's thickness near Ames, Iowa, at ~80 m. More recently, ice reconstructions by Hooyer and Iverson (2000) were based on a model assuming the Bemis Moraine was ice-cored, which yielded ice thickness estimates of ~250 m. Despite these variations, all agree that the Des Moines Lobe ice sheet was extremely thin and gently sloping. This ice advance was rapid and episodic, and was most likely fueled by basal lubrication; in other words, a warm-based, non-deforming bed glacier. These assumptions are backed up by evidence of numerous plants (Baker et al., 1986) and trees (Bettis et al., 1996) found near the base of the DML package. Furthermore, the complex landform sediment assemblages found on the DML in Iowa seem more indicative and explained by regional stagnation, by a surging-type glacier, not rapid recession.

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 valley and east along the Shell Rock river valley 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) are exposed as outcrop in the map area. Bedrock outcrops occur along the Shell Rock River, with some exposures along Beaver Creek in the southeast 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, typically composed of laminated lithographic and sublithographic limestone and dolomite, occurs along the Shell Rock River and in a subsurface valley in the western part of the quad. In areas covered by thicker deposits of glacial sediments the bedrock formation distribution is known solely know from water well cutting samples.

### References


Baker, R.G., Rhodes, R.S. II, Schwert, D.P., Ashworth, A.C., Frest, T.J., Hallberg, G.R., and Janssens, J.A., 1986, A full-glacial biota from southwestern Iowa, USA: Journal of Quaternary Science, v.1, p. 91-107.

Bettis, E.A., III, 1989, Late Quaternary history of the Iowa River Valley in the Coralville Lake area *in* Plocher, O.W., Geologic Reconnaissance of the Coralville Lake area: Geological Society of Iowa Guidebook 51, p. 93-109.

Bettis, E.A. III, Quade, D.J., and Kemmis, T.J., 1996, *in* Hogs, Bogs, and Logs: Quaternary Deposits and Environmental Geology of the Des Moines Lobe. Edited by: E.A. Bettis, III, D.J Quade, and T.J Kemmis. Iowa Department of Natural Resources-Geological Survey Bureau, Guidebook Series No. 18, 170 p.

Bettis, E.A. III, 1997, Late-Middle and Early-Late Wisconsin Glaciation in North Central Iowa**.** Geological Society of America North-Central Section Meeting Abstracts with Programs 29 (4):5.

Brevik, E., 2000. Limits of ice thickness in Iowa during the Late Wisconsian: Journal of the Iowa Academy of Science, v.107, p. 46-50.

Boellstorff, J., 1978a, North American Pleistocene Stages reconsidered in light of probable Pliocene-Pleistocene continental glaciation: Science, v. 202 p.305-307.

Boellstorff, J., 1978b, Chronology of some late Cenozoic deposits from the central United States and the ice ages: Transactions of the Nebraska Academy of Science, v. 6, p. 35-49.

Calvin, S., et al., 1901 Preliminary outline map of the drift sheets of Iowa: Iowa

Clark, P.U., 1992, Surface form of the southern Laurentide Ice Sheet and its implications to ice-sheet dynamics. Geological Society of America Bulletin, v. 104, p. 595-605.

Fullerton, D.S., 1986, Stratigraphy and correlation of glacial deposits from Indiana to New York and New Jersey, *in* Richmond, G.M. and Fullerton, D.S., eds., Quaternary Glaciations in the United States of America, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary Glaciations in the Northern Hemisphere: Quaternary Science Reviews, v. 5, p.23-37.

Hallberg, G.R., 1980, Pleistocene stratigraphy in east-central Iowa: Iowa Geological Survey Technical Information Series 10, 168p.

Hallberg, G.R., 1986, Pre-Wisconsin glacial stratigraphy of the central plains region in Iowa, Nebraska, Kansas, and Missouri: *in* Richmond, G.M. and Fullerton, D.S., eds., Quaternary Glaciations in the United States of America, Report of the International Correlation Programme-Project 24: in Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary Science Reviews, Quaternary Glaciations in the Northern Hemisphere, v. 5, p. 11-15.

Hallberg, G.R., Lineback, J.A., Mickelson, D.M., Knox, J.C., Goebel, J.E., Hobbs, H.C., Whitfield, J.W., Ward, R.A., Boellstorf, J.D., and Swinehart, J.B., 1991, Quaternary geologic map of the Des Moines 4° x 6° quadrangle, United States: U.S. Geological Survey, Miscellaneous Investigations Series, Map I-1420, 1:100,000 scale map sheet.

Hershey, H. G., 1969, Geologic map of Iowa, Iowa Geological Survey, scale 1:500,000 (out of print).

Hooyer, T.S. and Iverson, N.R., 2000, Clast-fabric development in a shearing granular material: Implications for subglacial till and fault gouge. Geol. Soc. Am Bull., 112(5), 683-692.

Hooyer, T.S. and Iverson, N.R., 2002, Flow mechanism of the Des Moines lobe of the Laurentide ice sheet, J. Glaciol., 48(163), 575-586.

Johnson, W.H., 1986, Stratigraphy and correlation of the glacial deposits of the Lake Michigan Lobe prior to 14 ka BP, *in* Richmond, G.M. and Fullerton, D.S., eds., Quaternary Glaciations in the United States of America, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary Glaciations of the Northern Hemisphere: Quaternary Science Reviews, v. 5, p.17-22.

Kemmis, T.J, Bettis, E.A. III, and Quade, D.J., 1994, The Des Moines Lobe in Iowa: a surging Wisconsinan glacier: American Quaternary Association, Program and Abstracts, 13th Biennial Meeting,

Mathews, W.H., 1974, Surface profile of the Laurentide ice sheet in its marginal areas: Journal of Glaciology, v. 13, p. 37-43. Minneapolis, p. 112.

Prior, J.C., 1976, Landforms of Iowa: Iowa City, University of Iowa Press, 154p.

Prior, J.C. and Korht, C.J., 2006, The Landform Regions of Iowa, Iowa Geological Survey, digital map, available on IDNR GIS Library-http://www.igsb.uiowa.edu/nrgislibx/

Ruhe, R.V., 1950, Reclassification and correlation of the glacial drifts of northwestern Iowa and adjacent areas: University of Iowa Department of Geology, Iowa City, unpublished Ph.D. thesis, 124 p.

Walters, J.C., 1996, General and Environmental Geology of the Cedar Falls/Waterloo Area, The Iowan Surface, in General and Environmental Geolgoy of Cedar Falls/Waterloo and Surrounding Area, Northeast Iowa, Iowa Geological Survey Guidebook Series No. 22, p.7-9.

Williams, I. A., 1899, Geology of Worth County: Iowa Geological Survey, Annual Report, v. 10, p. 315-378.

Witzke, B.J., Anderson, R.R. and Pope, J.P., 2010, Bedrock Geologic Map of Iowa, scale: 1:500,000, Iowa Geological and Water Survey, Open File Digital Map OFM-10-1.