QUATERNARY GEOLOGY OF THE STORM LAKE AREA, IOWA: STORM LAKE OUTLET, DES MOINES LOBE MORAINES, KAMES, VALLEY TRAINS, MINOR MORAINES AND TAZEWELL TILL PLAIN

By Deborah J. Quade and Lynette S. Seigley

Geological Society of Iowa

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cover illustration:
The illustration on the front cover is a map of the extent of Des Moines Lobe advances and end moraines.

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PREFACE

After a nearly 15-year hiatus, the GSI Field Trip returns to Northwest Iowa! The 2006 Spring GSI field trip will be a half-day exploration of the complex assemblage of glacial landforms associated with the western flank of the Des Moines Lobe in the Storm Lake area. Field trip stops will provide an opportunity to examine sediment sequences and landforms associated with the advance and drainage of the Wisconsin-age Des Moines Lobe (DML) ice sheet. The field trip will include stops and a driving tour of the moraines associated with the Bemis, Altamont I, Altamont II, and Altamont Complex, as well as the North Raccoon River valley-train deposits and Bemis till plain. Please check the back of your guidebook for a map of the trip route. For your added information we have included a roadlog, complete with mileage markers so everyone in the field trip caravan has an ample opportunity to view the various landform features as we travel the field trip route.

In the last several decades a number of mapping and hydrogeologic projects have been conducted in several areas on the Des Moines Lobe in Iowa. These studies have significantly increased our understanding of the nature and origin of the Lobe's deposits. This field trip is designed to give the participants a brief overview of DML stratigraphy as well as an opportunity to view the sediment assemblages and glacial landforms associated with the Lobe. The first part of this guidebook will provide an introduction to the Lobe's deposits and landforms. The introductory discussion will be followed by a roadlog and stop descriptions that will provide more in-depth information on the nature of DML deposits and landscapes along the field trip route. The trip crosses three glacial ice margins (moraines) and traverses many of the landform categories found on the Lobe in Iowa.

In addition, Lynette Seigley, Mary Skopec, and Tom Wilton of the Iowa Department of Natural Resources, have made guidebook contributions and will discuss water quality and related issues concerning the North Raccoon River Watershed. Also, we are fortunate to have Mark Anderson, project archaeologist with the Office of State Archaeologist, along on the trip to comment on prehistoric settlement patterns in the area. We have a full afternoon schedule and, if time permits, we will have an optional stop at the end of the day to visit an exposure of the earlier Wisconsin-age Tazewell till (Sheldon Creek Fm.) adjacent to the DML near Sioux Rapids.

INTRODUCTION TO THE DES MOINES LOBE

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The distinctive landform region called the Des Moines Lobe formed from a lobate extension of the last great continental glacier. During the Wisconsinan Episode, 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 (Figure 1).

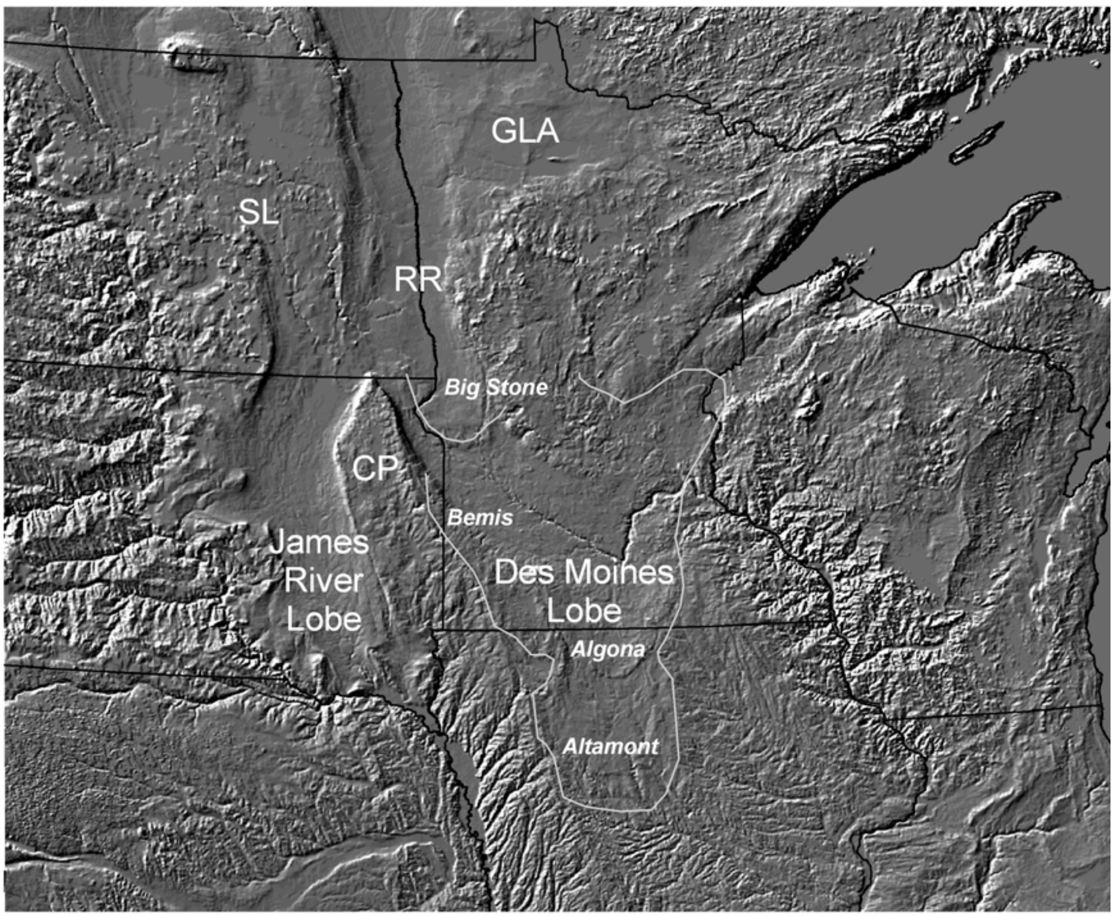

Figure 1. Location of the Des Moines Lobe in the Upper Midwest and the Coteau des Prairies (CP), Glacial Lake Souris (SL), Red River Valley (RR) and Glacial Lake Agassiz (GL).

The age of the Des Moines Lobe is well established by radiocarbon dates (Table 1). The Lobe entered Iowa shortly before 15,000 radiocarbon years before present (RCYBP) and reached the terminal position at Des Moines about 13,800 RCYBP. After reaching its terminus the glacier stagnated. The lobe readvanced to the position of the Altamont ice margin just north of Ames and Boone about 13,500 years ago, then stagnated. Between 13,500 and 12,600 RCYBP, there were three minor readvances marked by the Clare, Renwick, and West Bend moraines. The

Table 1. Radiocarbon ages from the Des Moines Lobe area, Iowa.

Radiocarbon Samples	Laboratory Number	Location	Materials Analyzed	Notes
SAMPLES FROM THE BASE OF THE DOWS FORMATION				
12,790±60	CAMS-24957	55 McGuire Core, Kossuth Co.	wood	collected from lower 30 cm of Alden Mbr. above Dows Fm.? proglacial sediments
13, 440±230	B-10837	National Gypsum, Ft. Dodge, Webster Co.	macrofossils	collected from organic silts of Sheldon Creek Fm. just below Dows Fm.
13,160±150	B-10835	Saylorville Emergency Spillway, Polk Co.	spruce wood	wood from silty alluvium 0.2m below base of Dows Fm.
13,560±90	B-2749	Saylorville Emergency Spillway, Polk Co.	spruce wood	log from base of Dows Fm.
13,800±245	various A-	Saylorville Emergency Spillway, Polk Co.	spruce wood rooted in alluvium	average age of 12 determinations on six different logs -- all 5000 second counts
13,900±400	I-1268	Stratford, Hamilton Co.	wood	at depth of 19.7m in Dows Fm. just above contact with stratified silts and sands
13,910±400	WIS-517	Scranton, Green Co.	wood	tree rooted in place in Peoria Fm. loess
13,930±130	CAMS-17387	National Gypsum, Ft. Dodge, Webster Co.	beetle chitin	collected from organic silts of Sheldon Creek Fm.10-20 cm below Dows Fm.; same location as B-10838
14,042±1000	C-664	Cook's Quarry near Ames, Story Co.	hemlock wood	log from sand and gravel just below Dows Fm.; age determined by carbon-black method
14,200±500	I-1402	Nevada, Story Co.	wood	spruce wood from upper increment of Peoria Fm. loess
14,380±180	I-9765	Weaver Quarry near Alden, Hardin Co.	larch wood	log from contact of Dows Fm. and paleosol in Peoria Fm. loess
14,410±240	B-9877	National Gypsum, Ft. Dodge, Webster Co.	macrofossils	collected from organic silts of Sheldon Creek Fm. just below Dows Fm.
14,470±400	WIS-512	Scranton, Green Co.	spruce wood	wood from top of Peoria Fm. loess; see W-513
14,840±160	CAMS-17383	National Gypsum, Ft. Dodge, Webster Co.	beetle chitin	collected from organic silts of Sheldon Creek Fm. just below Dows Fm.; same location as B-10837
15,140±220	B-9797	National Gypsum, Ft. Dodge, Webster Co.	macrofossils	collected from organic silts of Sheldon Creek Fm. just below Dows Fm.
15,310±180	B-10838	National Gypsum, Ft. Dodge, Webster	wood	collected from organic silts of Sheldon Creek Fm. 10-20 cm

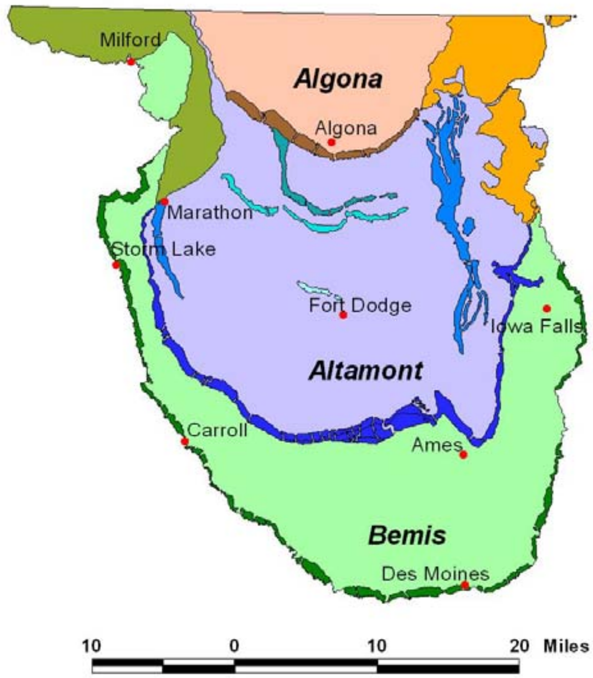

Figure 2. Extent of Des Moines Lobe in Iowa with end moraines

morainic topography associated with these advances is discontinuous, and only the terminal margins are recognized. The final advance into Iowa, the Algona ice margin, occurred about 12,300 RCYBP (Figure 2). This advance also was followed rapidly by stagnation and wastage of the glacier. It was during the Algona advance that the upper Des Moines River, the major axial drainage of the Lobe originated (Bettis and Hoyer, 1986).

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 recostructions 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.

STRATIGRAPHIC FRAMEWORK FOR THE DES MOINES LOBE

Kemmis (1991) noted that glacial landform types and sedimentary sequences of the DML were different than those associated with Lobes in Illinois and Wisconsin. Kemmis and others (1981) developed a classification for DML sediments that grouped sediments by easily recognized properties, readily observed in the field. Upland glacial deposits of the DML were grouped into the Dows Formation. Bettis and others (1996) further refined and described the *lithostratigraphic* framework for the DML to include four formations. Included below is a discussion of the Dows Formation (consists of upland glacial deposits) and its four members from Bettis and others (1996) and a discussion of the Noah Creek Formation (consists of coarse-grained *glaciofluvial* and *fluvial* deposits in stream valleys and on outwash plains). Figure 3 illustrates the lithostratigraphic sequence for the DML.

Dows Formation

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

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

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

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

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

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

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

The distinctive clay mineralogy of the Dows Formation is similar to the clay mineralogy of Cretaceous-age Pierre Shale, a distinctive bedrock lithology that was glacially eroded and incorporated into the Dows Formation. The clay-mineral composition of fifteen Pierre Shale fragments taken from the Dows Formation is $67\pm3\%$ expandables, $27\pm3\%$ illite, and $6\pm2\%$ kaolinite plus chlorite (Kemmis et al., 1981). This compares with the clay mineralogy of the fine-grained matrix of massive Dows Formation diamictons of $69\pm4\%$ expandables, $19\pm3\%$ illite, and $12\pm3\%$ kaolinite plus chlorite.

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

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

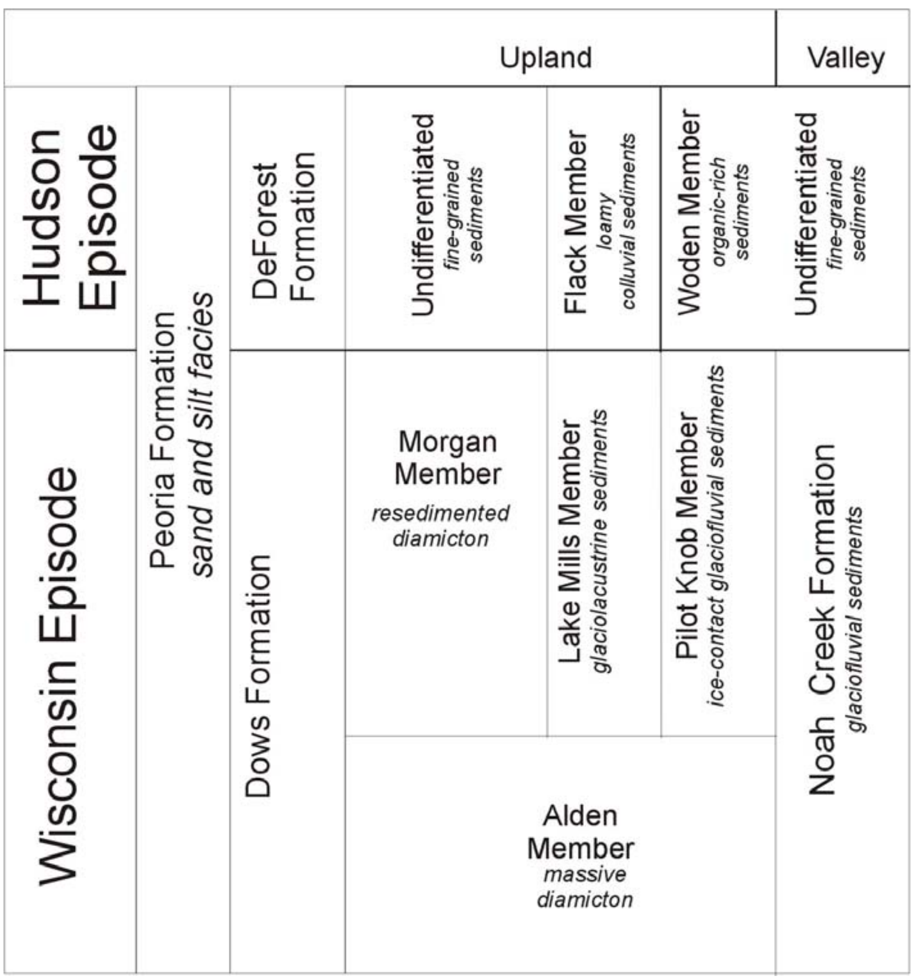

Figure 3. Lithostratigraphy of the Des Moines Lobe region, Iowa.

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

Alden Member

Source of name: the town of Alden, Iowa, near which Alden Member deposits are well exposed in the Martin-Marietta quarry located just southeast of town in the NE 1/4, NW 1/4, NE 1/4 of section 20, T. 89 N., R. 21 W., Hardin County, Iowa.
Type Section: same as that of the Dows Formation; the Martin-Marietta quarry located in the NW 1/4, NE 1/4, SE 1/4 of section 30, T. 91 N., R. 22 W., Franklin County, Iowa.
Description of the Unit: The bulk of the Alden Member consists of massive, compositionally uniform diamicton. The diamicton is matrix-dominated, with the sand-silt-clay matrix typically comprising 94 to 96% of the diamicton by weight. The matrix texture tends to be uniform both with depth at any one site and regionally from site to site (Figure 4). Several exceptions to this textural uniformity occur locally. At the base of the unit, the texture may vary because of incorporation of local substrate material. Discontinuous pods and lenses of sorted deposits (usually pebbly sands, sands, pebble gravels and silts) are also common at the base of the diamicton. In some cases, block inclusions of intact local substrate occur in the diamicton, but these are rare. Smudges, inclusions of local substrate that have been smeared out in or at the base of the glacier (Kruger, 1979), are also rare. The matrix texture of the diamicton is loam across the Lobe, although there is local variation within the range of sand-silt-clay percentages that comprise the loam textural group. The only systematic variation observed to date occurs south from the latitude of Ames where loess becomes the dominant substrate material below the

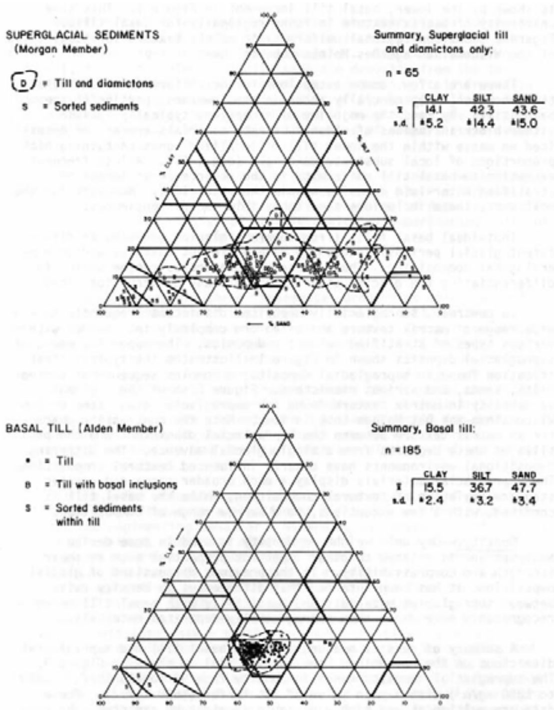

Figure 4. Summary textural data for the Morgan and Alden Members of the Dows Formation. From Kemmis and others, 1981.

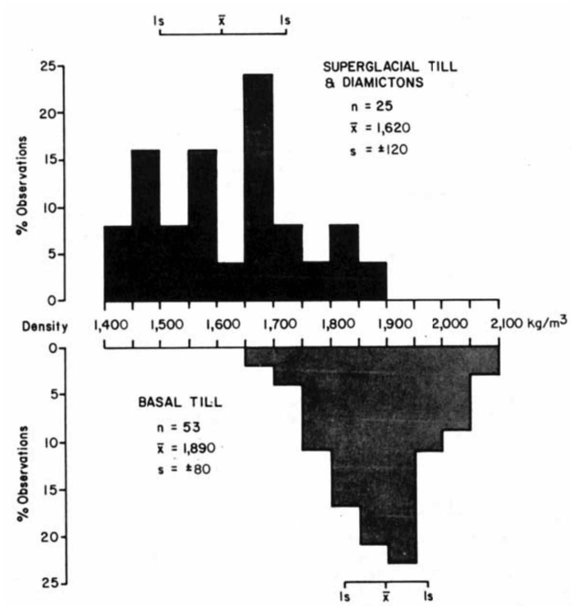

Figure 5. Bulk density data for the Morgan and Alden Members of the Dows Formation. From Kemmis and others, 1981

Dows Formation. Glacial erosion of the loess and its incorporation into the Alden Member diamicton matrix has resulted in a systematic increase in the silt content of the diamicton downglacier to the terminus in Des Moines.

Rod-shaped (prolate) pebbles in the massive diamicton are usually strongly and consistently oriented. The orientations of prolate pebbles in the Alden Member are oriented parallel to the glacial flow direction inferred from ice-margin orientations, and are interpreted to have been oriented by a pervasive subglacial stress field at the base of an actively moving glacier. Pebble fabrics measured in massive Alden Member diamicton from around the Des Moines Lobe are well oriented and show similar consistency between measurement sites at a given location.

Massive diamicton of the Alden Member is usually dense (Figure 5) and "overconsolidated" (compacted to greater densities than possible just by the stress, or weight, of overlying deposits). Densities vary little and have a mean of about 1.9 g/cc. Where unweathered, Alden Member diamicton is unoxidized, very dark gray, and unleached. Various secondary pedogenic and weathering changes may have altered the deposits, depending on the local relief, vegetation, and geomorphic history.

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

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

The substrate underlying the Alden Member is almost always overconsolidated (compacted), the *deformation* resulting in a reduction of pore space, the expulsion of pore water, and an increase in density. Table 3 shows density values of Alden Member diamicton overlying Peoria Formation loess. Here the uppermost loess has been compacted to a density like that of the overlying Alden Member diamicton, while at depth the loess density resembles that which was never overridden by a glacier. This relationship where loess (or other sediment type) has a higher density at the contact with the overlying Alden Member than with depth, is common.

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

The upper contact varies. In places, the Alden Member is at the surface. Where buried by the interbedded diamictons and sorted deposits of the Morgan Member, the contact may vary from gradational to abrupt. Contacts with overlying Lake Mills and Pilot Knob members, and the Noah Creek and Peoria formations are always abrupt. Contacts with overlying sediments of the DeForest Formation are marked by a discontinuous to distinct stone line or a basal zone of coarse sand.

Differentiation from Other Members: The Alden Member differs from other members of the formation primarily in texture and bedding structures. The generally thick, massive diamicton of the Alden Member contrasts with the diamicton of the Morgan Member which usually occurs as beds with sorted sands, silts, and pebbly sands. Diamicton beds in the Morgan Member are usually massive too, but sometimes include various sedimentary structures that indicate resedimentation (detailed in the following section on the Morgan Member). In addition, unlike for the bedded sequence of the Morgan Member, Alden Member diamicton usually shows no evidence for collapse from deposition on or next to stagnant ice.

Diamicton of the Alden Member contrasts with the well sorted fine-grained and sandy deposits of the Lake Mills Member, and the coarse, well to poorly sorted gravels and sands of the Pilot Knob Member.

Extent and Thickness: The Alden Member is the thickest and most extensive member of the formation, underlying nearly all upland sites on the Des Moines Lobe. Thicknesses vary depending on the landform type and topographic position. Typically, massive diamicton of the Alden Member ranges from 10 to 20 m (30 to 60 ft) in thickness. However, near the southern Des Moines Lobe terminus, thicknesses typically range from 4 to 6 m (13 to 20 ft), whereas at or near former ice margins, thicknesses can approach 30 m (100 ft).

Origin: The Alden Member was deposited by various advances of the Des Moines Lobe into Iowa. Its typical lithologic properties (massive structure, poor sorting, overconsolidation, high density, and strongly oriented pebble fabrics) suggest the Alden Member diamicton is usually till formed subglacially by *lodgement*, *melt-out*, or *deformation.*

Morgan Member

Source of name: Morgan Township, Franklin County, the township in which the type section for the Dows Formation is located.

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

Description of the Unit: The Morgan Member consists of interbedded diamicton and sorted sediment. Diamicton beds in this sequence are distinctive. Most are massive, some have basal gravel layers, and others become finer grained upward although these 'normally graded' beds are rare. Matrix textures often fall in the loam category, but there can be variation both within beds and between beds. Individual beds sometimes contain small clasts of sorted sediment, and some beds grade upward to laminae or thin beds of sorted sediment. Overall, there is greater variation in matrix texture for the diamicton beds of the Morgan Member compared to the thick, massive diamictons of the Alden Member (see Figure 4). Bulk densities of diamicton beds in the Morgan Member vary and tend to be lower than those of the massive diamicton comprising the Alden Member (see Figure 5).

Diamicton beds in the Morgan Member vary from 1 centimeter to as much as 2 meters (1/4 inch to 6 ft) in thickness, but most beds are less than 0.7 m (2.5 ft) thick. The beds are discontinuous, occurring either in sheets or pods. From two-dimensional exposures it is difficult to tell the exact extent of these sheets and pods, but individual sheets often extend for several meters, perhaps as much as 15 m (40 to 50 ft). Diamicton pods are less extensive, and commonly range from 0.5 to 5 m (2 to 15 ft) in extent.

Rod-shaped (prolate) pebbles in the diamicton beds are usually not strongly or consistently oriented. Even within an individual bed, orientations may diverge (Figure 9). Contacts between adjacent diamicton beds may be gradational or abrupt, whereas contacts between diamicton beds and beds of sorted sediment are usually abrupt. These contacts are commonly deformed, resembling soft-sediment deformation (Lowe, 1978) that occurs when sediment strength is locally exceeded by increasing weight as overlying sediment successively accumulates.

Sorted sediments in the Morgan Member include a wide range of textures. The fine-grained deposits are usually pebble-free, and include loam, silt loam, clay loam, silty clay loam, and silty clay textures. Coarser-grained deposits include sands, pebbly sands (matrix-supported pebble gravels), and well sorted (clast-supported) pebble gravels. Clasts larger than coarse pebbles are infrequent in the sorted sediments.

The sorted sediments occur in a wide variety of bedding structures, including laminae, massive beds, plane beds, ripple-drift cross-lamination, cross-bed sets, inversely and normally graded beds, and channel fills [(both small-scale individual fills and large-scale fills composed of multiple beds and sedimentary structures--the multi-storey type fills described by Ramos and Sopena (1983)]. Individual beds are usually thin, ranging from lamina to beds 0.5 m (1/10 in. to 1.5 ft) in thickness. The beds occur as sheets or as part of channel fills. Individual sheets are discontinuous. From two-dimensional exposures it is difficult to tell how far individual sheets extend, but they may extend several meters, perhaps as much as 15 m (50 ft). Channel fills tend to be small scale, rarely more than a few meters (5 to 50 ft) in width and usually less than 2 m (6 ft) deep.

Bed contacts are usually abrupt and often contorted. Sometimes conjugate high-angle normal and reverse faults displace the sequence of sorted sediments and diamicton beds in the Morgan Member. The faults appear to have formed as a result of collapse when adjacent or underlying ice melted out (McDonald and Shilts, 1975).

Nature of Contacts: The Morgan Member has always been observed overlying other members of the Dows Formation. It occurs as thin to thick sequences, 0.5 to about 8 m (2 to 25 ft) thick, overlying the Alden Member and as generally thin veneers (less than 3 m--10 ft thick) over Pilot Knob Member sand and gravels. Basal contacts with the Alden Member vary from abrupt to gradational, whereas those with the Pilot Knob Member are typically abrupt.

The Morgan Member often occurs at the present land surface. In places it is overlain by either the Lake Mills Member, or the Noah Creek, Peoria, or DeForest formations. Contacts with these units are abrupt and unconformable.

Differentiation from other Members: The bedded diamictons and sorted sediments of the Morgan Member are distinctly different than other members of the Dows Formation. The Alden Member differs in being composed almost exclusively of massive diamicton. Diamicton beds are extremely rare in the Lake Mills Member; the member usually consists of massive fine-grained sediment overlying a thin increment of sand and pebbly sand. The Pilot Knob Member also consists predominantly of sorted sediments, but the sediments are dominantly coarse sand and gravel. Diamicton beds may occur within the Pilot Knob sequence at some locales, but they are not abundant. The distinction between the Pilot Knob and Morgan members is made on the abundance of diamicton beds. Deposits are classified as Morgan Member when diamicton beds are abundant; in the field, this usually means that diamicton beds constitute 30% or more of the sedimentary sequence.

Extent and Thickness: The Morgan Member varies in both extent and thickness. The member is common in 'hummocky' areas where thicknesses vary from thin, 1 to 3 m (3 to 6 ft) in thickness, to thick, 10 m or more (over 30 ft); often the deposits occur as alluvial-fan like wedges draping and flanking 'hummock' cores. Morgan Member deposits tend to be thin (2-4 m, 6-12 ft) and generally restricted to linked depression systems in low-to-moderate relief areas.

Origin: The geometry and lithologic properties of the bedded diamictons and sorted sediments comprising the Morgan Member suggest the deposits accumulated primarily in ice-marginal (ice-contact) or supraglacial settings where there was repetitive mass-wasting resulting in the deposition of diamicton beds, and in fluvial/lacustrine environments where sorted sediments accumulated (see Lawson, 1979a, 1979b, and 1989 for a discussion of processes in these environments).

Pilot Knob Member

<u>Source of name:</u> Pilot Knob, the prominent glacial hummock in Pilot Knob State Park, located east of Forest City, Winnebago County, Iowa.

<u>Reference Section:</u> Deposits of the Pilot Knob Member are not present at the type section for the Dows Formation, but are well exposed in an excavation at the 98 LaHarv-1 site, located in an east-west trending esker in the NE 1/4, SE 1/4, SE 1/4 of section 30, T. 98 N., R. 22 W., Worth County, Iowa which is designated as the reference section for the member.

<u>Description of the Unit:</u> The Pilot Knob Member consists predominantly of sands and gravels occurring in irregularly shaped hummocks and low-sinuosity ridges in uplands on the Des Moines Lobe. Textures and bedding structures often vary significantly over short distances both laterally and vertically. Bedding structures include all of the flow-regime bedforms described by Simons et al. (1965) and the various channel-fill types recognized by Ramos and Sopena (1983). Beds of virtually pebble-free, fine-grained sediment and diamictons sometimes occur at the top of or within the member, but are uncommon. The diamicton beds tend to occur as isolated, channelized pods. The stratified sequence comprising the member is sometimes offset by high-angle normal and reverse faults resulting from collapse of the sediment when the glacier's supporting ice walls melted away. The modern soil profile is developed in the top of the Pilot Knob Member where it is the surficial deposit. Sands and gravels within the member are oxidized where they occur above the water table and unoxidized below.

<u>Nature of Contacts:</u> The base of the Pilot Knob Member is rarely exposed. It is presumed to be unconformable on underlying diamicton sequences of the Morgan Member or the massive diamicton of the Alden Member. At many sites the Pilot Knob Member occurs at the land surface. At some sites it is overlain unconformably by 3 m (10 ft) or less of interbedded diamictons and sorted sediments of the Morgan Member or by a stoneline and thin colluvium of the Flack Member of the DeForest Formation.

<u>Differentiation from Other Members and Formations:</u> Unlike all other members of the Dows Formation, the Pilot Knob Member is composed predominantly of coarse sand and gravel. Although diamicton beds are locally present in the member, they do not comprise the bulk of the sequence as they do in the Morgan Member.

The sand and gravel sediments comprising the Pilot Knob Member are similar to the fluvial and glaciofluvial sands and gravels of the Noah Creek Formation, but there tends to be greater variability, both laterally and vertically in the Pilot Knob Member. The Pilot Knob Member also occupies a distinct geomorphic position, that being upland hummocks and ridges, whereas the Noah Creek Formation is confined to stream valleys and outwash plains.

<u>Extent and Thickness:</u> The Pilot Knob Member occurs in irregular hummocks and low-sinuosity ridges across the Des Moines Lobe. The hummocks are usually a few hundred meters in diameter, and the narrow, sometimes beaded ridges usually extend from 1 to 3 km (1/2 to 1 1/2 mile). Relief on the hummocks and ridges is usually 6 to 13 m (20 to 40 ft), but locally may be greater. The range of thicknesses for the member is uncertain, but is generally greater than 3 m (10 ft). Maximum thicknesses are estimated to be 10 to 15 m (30 to 50 ft).

<u>Origin:</u> Like classic kames and eskers (e.g., Flint, 1971; Banerjee and McDonald, 1975; Saunderson, 1975; Sugden and John, 1976), deposits of the Pilot Knob Member appear to have formed in stagnant-ice environments. The sands and gravels were probably deposited by meltwater flowing in *moulins* and *subglacial* and *englacial* tunnels. Diamicton beds within the member appear to be debris flows into the tunnels as surrounding ice melted. High-angle normal and reversed faults within the Member formed when the sediments collapsed as surrounding ice walls melted away.

Noah Creek Formation

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

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

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

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

Secondary alteration includes soil formation throughout the upper fine-grained sediment, with other pedogenic alterations (such as beta horizons) sometimes extending down into the upper part of the underlying sand-and-gravel sequence. The sands and gravels are oxidized above the water table and unoxidized below.

Nature of Contacts: On outwash plains, the Noah Creek Formation can conformably or unconformably overlie the Dows Formation. Where the Noah Creek Formation is inset below the uplands in a valley geomorphic position, it unconformably overlies the Dows Formation, older Quaternary sediments, or Paleozoic bedrock into which the stream has incised. It occurs at the land surface of higher stream terraces on the Lobe, and is unconformably buried by the DeForest Formation beneath alluvial fans, low stream terraces, and the modern flood plain.

Differentiation from other Units: The thick, coarse, sand-and-gravel sequences comprising the Noah Creek Formation are unlike any of the other formations on the Des Moines Lobe. The Dows Formation occurs in a different geomorphic position, and the Alden and Morgan members are predominantly diamictons rather than sand and gravel. The Lake Mills Member is dominantly fine-grained sediment, and, if present, the basal sand-and-gravel is very thin and generally finer grained than the Noah Creek Formation. The Pilot Knob Member is lithologically similar to the Noah Creek Formation, but differs in geomorphic position (upland hummocks and ridges rather than stream valleys), and tends to have greater variability over short distances. The sand facies of the Peoria Formation (see below) is pebble-free, exhibits better sorting, and has different bedforms than the Noah Creek Formation.

The DeForest Formation differs, being composed primarily of fine-grained alluvium. Sand and gravel in any of the DeForest Formation members is thinner, finer textured, and less laterally extensive than that comprising the Noah Creek Formation.

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

Origin: The Noah Creek Formation was deposited as outwash or redeposited outwash along stream valleys, outwash channels, and in outwash plains. All major rivers on the Des Moines Lobe have their source at the margin of former ice advances ('end moraines'), and the morphology of their valleys reflects their origins as glacial sluiceways.

Glacial drainage is characterized by extreme variation in streamflow both on annual scales, as conditions change from winter freeze-up to early summer floods when the glacier's snow pack rapidly melts off, and on longer term scales when unusually large flood flows, *jokulhlaups*, occur (Church and Gilbert, 1975; Smith, 1985). This variability in streamflow is reflected in the wide range of bedding structures and sand-and-gravel textures comprising the Noah Creek Formation. Terraces in the distal part of major rivers on the Des Moines Lobe consist of three distinctive increments: a thick, highly variable lower increment that is interpreted to record normal fluctuations in outwash systems on annual scales; a 1 to 2 m (3 to 5 ft) thick middle increment consisting of poorly sorted, planar-bedded cobble gravels extending across the terrace that appears to result from major floods; and a thin veneer of fine-grained sediment capping the terrace that results from waning flow and overbank sedimentation (Kemmis et al., 1987; 1988).

Age: On the Des Moines Lobe, the Noah Creek Formation dates from about 14,000 to 11,000 RCYBP. The oldest advance of the Des Moines Lobe is dated at about 14,000 RCYBP (Ruhe, 1969; Kemmis et al., 1981) when deposition of the Noah Creek Formation was initiated. Deposition of the Noah Creek Formation ceased by 11,000 RCYBP. Wood from the oldest DeForest Formation alluvium in the Des Moines River valley, which is inset into and therefore younger than the Noah Creek Formation, dates at 11,000 ± 290 RCYBP (Beta-10882; Bettis and Hoyer, 1986).

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.

Banerjee, J. and McDonald, B.C., 1975, Nature of esker sedimentation, *in* Jopling, A.V. and McDonald, B.C., eds., Glaciofluvial and Glaciolacustrine Sedimentation: Society of Economic Paleontologists and Mineralogists, Special Publication No. 23, p. 132-154.

Bettis, E.A., III, and Hoyer, B.E., 1986, Late Wisconsinan and Holocene landscape evolution and alluvial stratigraphy in the Saylorvile Lake area, central Des Moines River Valley, Iowa: Iowa Geological Survey Open File Report 86-1, 71 p.

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, Pearson, J., Edwards, M., Gradwohl, D., Osborn, N., Kemmis, T., and Quade, D., 1988, Natural history of Ledges State Park and the Des Moines Valley in Boone County: Geological Society of Iowa Gudiebook 48, 71 p.

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.

Church, M. and Gilbert, R., 1975,Proglacial fluvial and lacustrine environments, *in* Jopling, A.V., and MacDonald, B.C., eds., Glaciofluvial and Glaciolacustrine Sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication No. 23, p. 22-100.

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.

Clark, P.U., 1991, Striated clast pavements: products of deforming subglacial sediment?: Geology, v. 19, p. 530-533.

Flint, R.F., 1971, Glacial and Quaternary Geology: John Wiley & Sons New York, 892 p.

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. and Kemmis, T.J., 1986, Stratigraphy and correlation of the glacial deposits of the Des Moines and James Lobes and adjacent areas in North Dakota, South Dakota, Minnesota, and Iowa *in* Richmond, G.M. and Fullerton, D.S., eds., Quaternary Glaciations in the United States of America *in* V. Sibrava, D.Q. Bowen, and G.M. Richmond, eds., Quaternary Glaciations of the Northern Hemisphere: Quaternary Science Reviews, v. 5, p. 11-16.

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.

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.

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, Minneapolis, p. 112.

Kemmis, T.J. Hallberg, G.R. and Lutengger, A.J., 1981, Depositional environments of glacial sediments and landforms on the Des Moines Lobe, Iowa: Iowa Geological Survey Guidebook No. 6, Iowa City, 132 p.

Kemmis, T.J., 1981, Glacial sedimentation and the Algona Moraine in Iowa: Geological Society of Iowa Guidebook 35, 45 p.

Kemmis, T.J., 1991, Glacial landforms, sedimentology and depositional environments of the Des Moines Lobe, northern Iowa: University of Iowa Department of Geology, Iowa City, unpublished Ph.D. thesis, 393 p.

Kemmis, T.J., Bettis, E.A., III, and Quade, D.J., 1987, Sedimentary sequences of Wisconsinan-age outwash streams on the Des Moines Lobe in north-central Iowa: Iowa Academy of Science Program Abstracts, 99th Annual Meeting, abstract no. 153.

Kemmis, T.J., Quade, D.J., and Bettis, E.A. III, 1988, Part II, Hallet Gravel Pits, *in* Bettis, E.A. III, et al., Natural history of Ledges State Park and the Des Moines River Valley in Boone County: Geological Society of Iowa Guidebook 48, p. 37-71.

Kruger, J., 1979, Structures and textures in till indicating subglacial deposition: Boreas, v. 8, p. 323-340.

Lawson, D.E., 1979a, Sedimentological analysis of the western terminus region of the Matanuska Glacier, Alaska: CRREL Report 79-9, 112 p.

Lawson, D.E., 1979b, A comparison of the pebble orientations in ice and deposits of the Matanuska Glacier, Alaska: Journal of Geology, v. 87, p. 629-645.

Lawson, D.E., 1989, Glacigenic resedimentation: classification concepts and application to mass-movement processes and deposits, *in* Goldthwait, R.P., and Matsch, C.L., eds., Genetic Classification of Glacigenic Deposits: A.A. Balkema, Rotterdam, p. 147-169.

Lowe, D.R., 1978, Water-escape structures, *in* Fairbridge, R.W., and Bourgeois, J., eds., The Encyclopedia of Sedimentology: Dowden, Huchinson & Ross, p. 864-868.

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

Matsch, C.L., 1972, Quaternary geology of southwestern Minnesota, *in* Sims, P.K. and Morey, G.B., eds., Geology of Minnesota: A Centennial Volume: Minnesota Geological Survey, St. Paul, p. 548-560.

McDonald, B.C., and Shilts, W.W., 1975, Interpretation of faults in glaciofluvial sediments; *in* Jopling, A.V., and McDonald, B.C., eds., Glaciofluvial and Glaciolacustrine Sedimentation, Society of Economic Paleontologists and Mineralogists Special Publication No. 23, p. 123-131.

Ramos, A., and Sopena, A., 1983, Gravel bars in low-sinuosity streams (Permian and Triassic, central Spain): International Association of Sedimentologists Special Publication No. 6, p. 301-312.

Ruhe, R.V., 1969, Quaternary Landscapes in Iowa: Iowa State University Press, Ames, IA, 255 p.

Saunderson, H.C., 1975, Sedimentology of the Brampton Esker and its associated deposits: an empercal test of theory, *in* Jopling, A.V., and McDonald, B.C., eds., Glaciofluvial and Glaciolacustrine Sedimentation, Society of Economic Paleontologists and Mineralogists Special Publication No. 23, p. 155-176.

Simons, D.B., Richardson, E.V., and Nordin, C.F., Jr., 1965, Sedimentary structures generated by flow in alluvial channels, *in* Middleton, G.V., ed., Primary Sedimentary Structures and Their Hydrodynamic Interpretation: Society of Economic Paleontologists and Mineralogists Special Publication No. 12, p. 34-52.

Smith, N.D., 1985, Chapter 3, Proglacial fluvial environment, *in* Ashley, G.M., Shaw, J., and Smith, N.D., eds., Glacial Sedimentary Environments: Society of Economic Paleontologists and Mineralogists Short Course No. 16, p. 85-134.

Sugden, D.E., and John, B.S., 1976, Glaciers and Landscape: New York, John Wiley & Sons, 376 p.

GLOSSARY

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

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

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

Deformation (till)--weak rock or unlithified sediment that has been detached from its source beneath a moving glacier, the primary sedimentary structures distorted or destroyed, and some foreign material admixed

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

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

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

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

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

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

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

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

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

Jokulhlaups –outburst flood event of glacial origin.

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

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

Lodgement (till)--diamicton deposited by plastering of glacial debris from the sliding base of a moving glacier by pressure melting and/or other mechanical processes. Lodgement till is characterized by being massive and dense, with a pebble fabric oriented parallel to the direction of glacier flow.

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

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

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

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

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

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

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

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

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

IMPACT OF TOTAL DISSOLVED SOLIDS AND CHLORIDE FROM WASTEWATER FACILITIES ON IOWA STREAMS

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INTRODUCTION

The Iowa Department of Natural Resources (DNR) is currently developing/revising total dissolved solids (TDS) and chloride water quality standards for streams. These revised numerical criteria are due by April 2007. TDS measures all constituents dissolved in water, including chloride. Elevated levels of chloride and TDS in streams can be harmful to aquatic life, and elevated TDS levels can be a concern for livestock use.

In order to establish realistic criteria, the Iowa DNR, in conjunction with the Iowa Water Pollution Control Association and wastewater facilities across Iowa, conducted a study in 2005 to measure TDS and chloride concentrations from 100 wastewater facilities (Figure 1) and the impact of those levels on their respective receiving streams under low-flow conditions. The City of Storm Lake and Storm Lake Tyson wastewater facilities both participated in this study.

Figure 1. Location of wastewater facilities participating in the TDS/chloride full study in August/September 2005. The City of Storm Lake and Tyson facilities are located in Buena Vista County.

CURRENT WATER QUALITY STANDARDS

Currently, acceptable levels of TDS and constituent cations and anions (including chloride) are established on a site-specific basis (Chapter 61, Water Quality Standards, Iowa Administrative Code). Prior to 2004, TDS concentrations could not exceed 750 mg/L in any waterbody with a flow rate equal to or greater than three times the flow rate of any upstream point source discharges. The Iowa DNR's current development/revision to TDS and chloride water quality standards due April 2007 will also include an economic analysis of the impact of proposed standards on wastewater facilities in Iowa. Current TDS and chloride levels being considered by the Iowa DNR are TDS of 1,000 mg/L and chloride of 860 mg/L for general use streams (streams that are not designated for drinking water, aquatic life, or recreational uses); whereas for streams designated for aquatic life uses, a TDS of 1,000 mg/L (acute and chronic effect) and chloride levels of 860 (acute effect) and 230 mg/L (chronic effect) are being considered. The levels for preventing chronic toxicity effect would need to be met at the end of the mixing zone, and the levels for preventing acute toxicity effect would need to be met at the end of the zone of initial dilution. A mixing zone and zone of initial dilution in a stream are the areas where pollutants from discharges are mixed with receiving waters to dilute their concentration in the water. The zone of initial dilution is a smaller area in the mixing zone where the acute guideline values may be exceeded. A mixing zone is the area where chronic guideline values may be exceeded. Outside the mixing zone boundary, both the acute and chronic guideline values need to be met.

BACKGROUND TDS/CHLORIDE LEVELS IN IOWA STREAMS

Since 2000, the Iowa DNR has monitored a network of 85 streams statewide on a monthly basis as part of its Water Monitoring Program. Data collected from 2000 through 2005 as part of this network show that TDS levels in Iowa streams range from 25 to 1,640 milligrams per liter (mg/L) with a median concentration of 360 mg/L and most concentrations falling between 300 and 440 mg/L. Chloride concentrations vary from 2.2 to 170 mg/L with a median of 23 mg/L and the majority of concentrations between 16 and 31 mg/L. Regional differences in TDS concentrations exist, with higher concentrations generally occurring in northwest and north-central Iowa, the areas represented by the Des Moines Lobe and Northwest Iowa Plains landform regions. Chloride also exhibits higher concentrations in these two landform regions.

So what process causes the elevated TDS and chloride concentrations in streams on the Des Moines Lobe and Northwest Iowa Plains landform regions? Recent conversations with Bill Simpkins, Professor of Hydrogeology in the Geological and Atmospheric Sciences Department at Iowa State University, have generated the following ideas. Is it caused by differences in weathering rates of geologic deposits or the length of time the deposits have been on the landscape? Are sulfate concentrations lower on the Des Moines Lobe relative to the Northwest Iowa Plains because much of the sulfate is reduced in the carbon-rich till and bound with iron sulfide there, whereas sulfate in the older, more oxidized glacial tills of the Northwest Iowa Plains may be more mobile, thus contributing higher sulfate concentrations to streams on the Northwest Iowa Plains, as well as to the overall TDS concentrations, relative to the Des Moines Lobe? Or are processes other than geologic weathering (i.e., elevated concentrations of nitrate, phosphate, and chloride from agricultural inputs) causing the higher TDS values? Could these sources of anions be a greater contribution on the Des Moines Lobe relative to the Northwest Iowa Plains? Are there more contributing CAFO (confined animal feeding operation) sources on the Des Moines Lobe than the Northwest Iowa Plains? And does the higher density of tile drains, especially on the Des Moines Lobe, provide a more efficient delivery mechanism for anions to nearby streams, thus raising their concentrations? These potential relationships, as well as others, will be explored as the data continue to be analyzed.

TDS/CHLORIDE STUDY

There were two phases to the TDS/chloride study: a low-flow, late winter pilot study of 21 wastewater facilities conducted from February 21 through March 6, 2005, and a low-flow, late summer-early fall full study of 100 wastewater facilities across Iowa from August 22 through September 28, 2005. Both phases of the study were conducted under low-flow conditions in order to evaluate the worst case scenario of any proposed standards. Low-flow conditions are the time of year when there is the least amount of dilution of wastewater effluent occurring in the receiving stream and the time when wastewater facilities would most likely exceed any proposed standards for TDS and chloride. As part of the pilot study, wastewater facilities sampled from 1 to 14 times (no more than once a day). For the full study, the majority of facilities sampled one time.

Each participating wastewater facility collected samples from five locations: receiving stream, upstream of the wastewater facility; city tap water; final wastewater effluent grab; final effluent composite (24 hour); and the receiving stream, downstream of the wastewater facility discharge, ideally below the mixing zone. Some of the wastewater facilities participating in the study are controlled discharge lagoons that do not continuously discharge, rather they discharge two times a year in the spring and fall. For controlled discharge lagoons, only one stream sample was collected along with the final wastewater effluent grab and the city tap water. A city tap water sample was included, because depending on the aquifer(s) used by each city, depth of its well(s), and type of water treatment, the city tap water may be a significant source of the resulting chloride and TDS levels in the city's wastewater effluent.

As part of this study, the City of Storm Lake and Tyson wastewater facilities collected samples on September 21, 2005. Both facilities are located southeast of Storm Lake on the south side of 630th St. (C65) next to Outlet Creek. We drove by both facilities at mile 5 of the field trip road log. Figure 2 shows the results from the full TDS/chloride study for the five sampling locations, as well as the results for the City of Storm Lake and Tyson wastewater facilities. Both the City of Storm Lake and Tyson wastewater facilities are activiated sludge facilities.

Figure 2 shows that the Outlet Creek downstream sampling location was below 230 mg/L for chloride and slightly above 1,000 mg/L for TDS. The chloride concentration from the City of Storm Lake wastewater facility was slightly higher than the level from the Tyson facility, whereas TDS was higher in the Tyson facility relative to the City of Storm Lake facility.

WHAT'S NEXT

The Iowa DNR Water Quality Standards Section will develop/revise TDS/chloride numerical criteria based on available toxicity data and considering data collected as part of the TDS/chloride study. Once these criteria have been established, an economic analysis will be completed to determine the cost for municipalities and other wastewater facilities to meet the proposed criteria based on the data collected as part of the TDS/chloride study. Stakehold and Technical Advisory meetings will be held to gather input and comments on the proposed criteria, after which the information will be taken before the Iowa Environmental Protection Commission for approval.

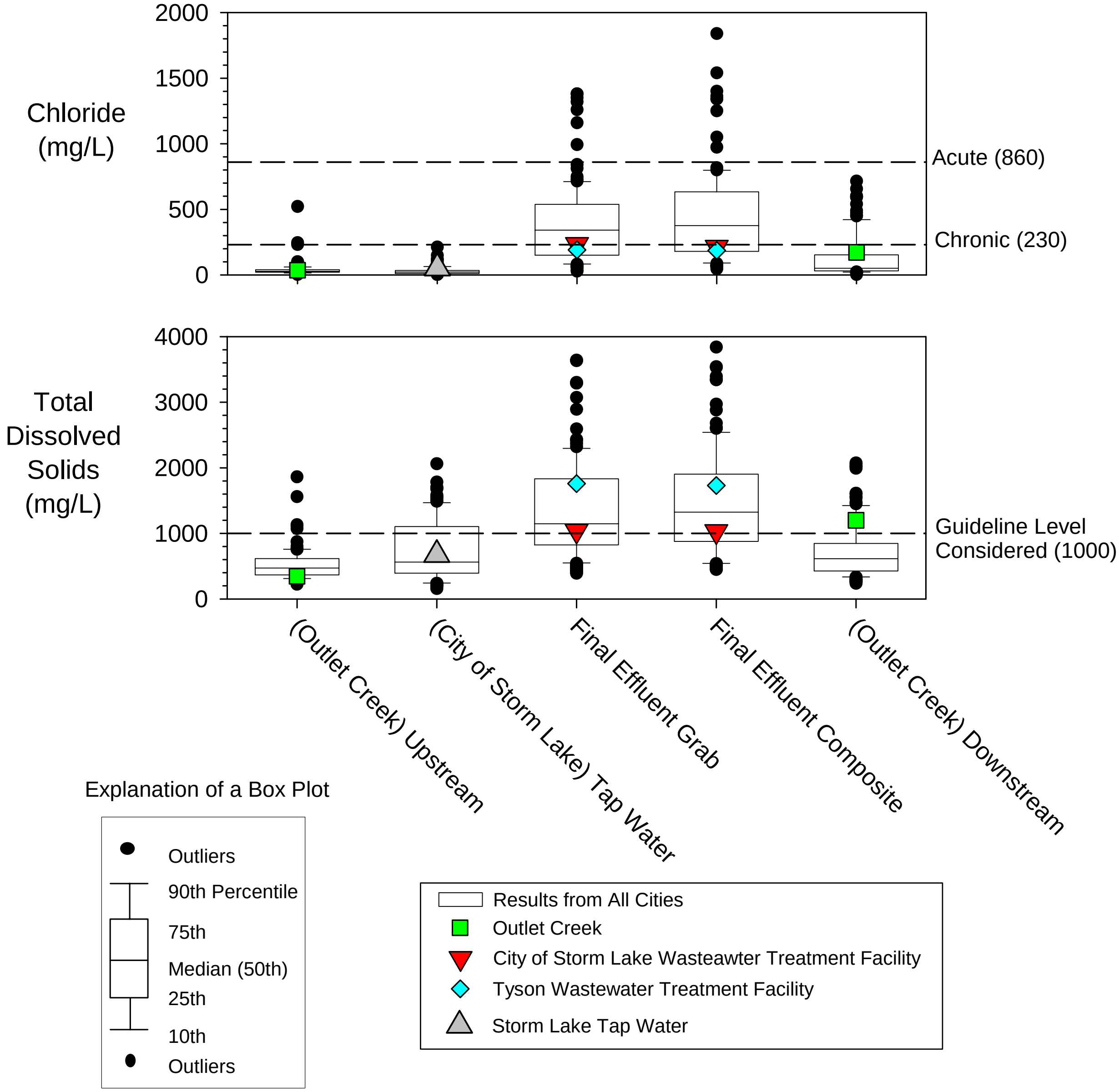

Figure 2. Results from the 100 wastewater facilities participating in the TDS/chloride full study in August/September 2005. Dashed lines represent guidelines being considered.

WATER QUALITY IN THE NORTH RACCOON RIVER WATERSHED

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INTRODUCTION

Water quality is a reflection of a stream's watershed and the land use within it. The headwaters of the North Raccoon River originated as drainage associated with the western edge of the Altamont Moraine Complex. The beginning of the North Raccoon River is located approximately ½ mile south of the town of Leverett in northeast Buena Vista County. All but a small portion of the watershed is located on the Des Moines Lobe landform region; the watershed area that flows directly into Storm Lake (except for the east side of the lake) and Little Storm Lake drains land located in the Northwest Iowa Plains landform region. The North Raccoon River watershed drains 2,469 square miles before joining the South Raccoon River near Van Meter in Dallas County to become the Raccoon River. Land use within the watershed is dominated by corn and soybean production (Table 1).

Table 1. 2002 land use for the North Raccoon River watershed.

Land Use Type	Percent of Watershed	Land Use Type	Percent of Watershed
Water	<1%	Alfalfa	1%
Wetland	<1%	Corn	43.9%
Bottomland Hardwoods	<1%	Soybeans	34.8%
Coniferous Forest	<1%	Other Rowcrop	<1%
Deciduous Forest	2.8%	Roads	1.2%
Ungrazed Grassland	8.6%	Commercial / Industrial	<1%
Grazed Grassland	2.9%	Residential	1%
Conservation Reserve Program (CRP)	1.2%	Barren	<1%

WATER CHEMISTRY OF THE NORTH RACCOON RIVER WATERSHED

Since 2000, the Iowa DNR has monitored a network of streams statewide to assess ambient stream water quality conditions, identify regional differences, and determine trends in water quality. Three of the currently monitored sites are located in the North Raccoon River watershed (Figure 1): North Raccoon River upstream of Sac City, North Raccoon River downstream of Sac City, and the North Raccoon River near Jefferson.

Elevated concentrations of nitrate and *E. coli* bacteria are water quality concerns within the North Raccoon River watershed. Monthly monitoring of nitrate concentrations in the North Raccoon River downstream of Sac City shows an increasing trend in nitrate levels since 1986 (Figure 2). Data show a seasonal trend, with higher concentrations during the late spring/early summer followed by a decline in late summer/early fall. Variability in nitrate is also dependent on rainfall conditions. Data from the statewide network of 85 streams monitored monthly show a relationship between median nitrate+nitrite-N concentrations and percent of land use in row crop (Figure 3). The three sites in the North Raccoon River watershed have some of the highest median nitrate+nitrite-N concentrations, and these levels correspond to a high percentage of the watershed being in row crop. For all three sites, more than 80% of the respective watershed is in row crop. Due to the watershed being located on the Des Moines Lobe, extensive tiling is present throughout the watershed. This tiling enhances the delivery of nitrate, a water soluble compound, to nearby streams.

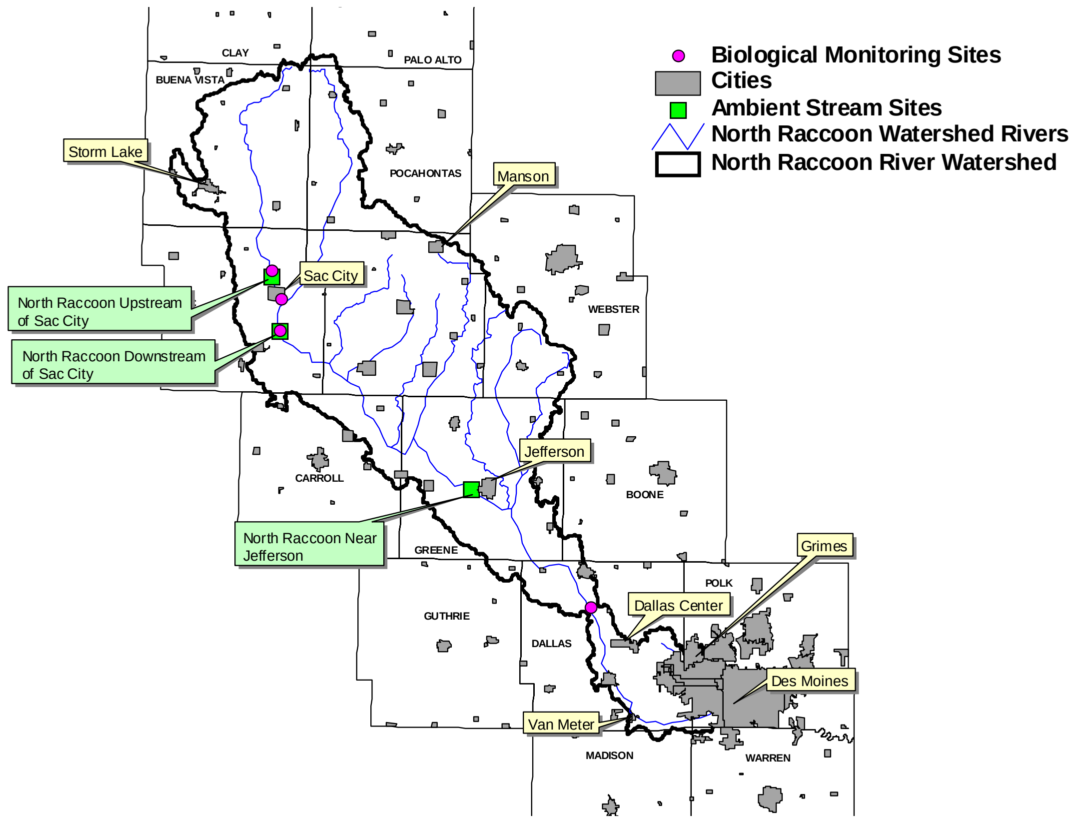

Figure 1. Location of currently monitored stream sites in the North Raccoon River watershed. Labels identify only the three sites monitored monthly for water chemistry.

The North Raccoon River joins the South Raccoon River near Van Meter to become the Raccoon River. The elevated nitrate concentrations in the North Raccoon River, as well as in the South Raccoon, pose problems for users downstream, including Des Moines Water Works, a public water utility which provides drinking water to the City of Des Moines and the surrounding metropolitan area. Des Moines Water Works utilizes surface water from both the Raccoon and Des Moines rivers, as well as an infiltration gallery of shallow groundwater wells along the Raccoon River. Increasing nitrate concentrations over time have resulted in Des Moines Water Works constructing the world's largest nitrate removal facility. During certain times of the year, Des Moines Water Works activates their nitrate removal facility to decrease nitrate levels below the drinking water standard of 10 mg/L as nitrate-N.

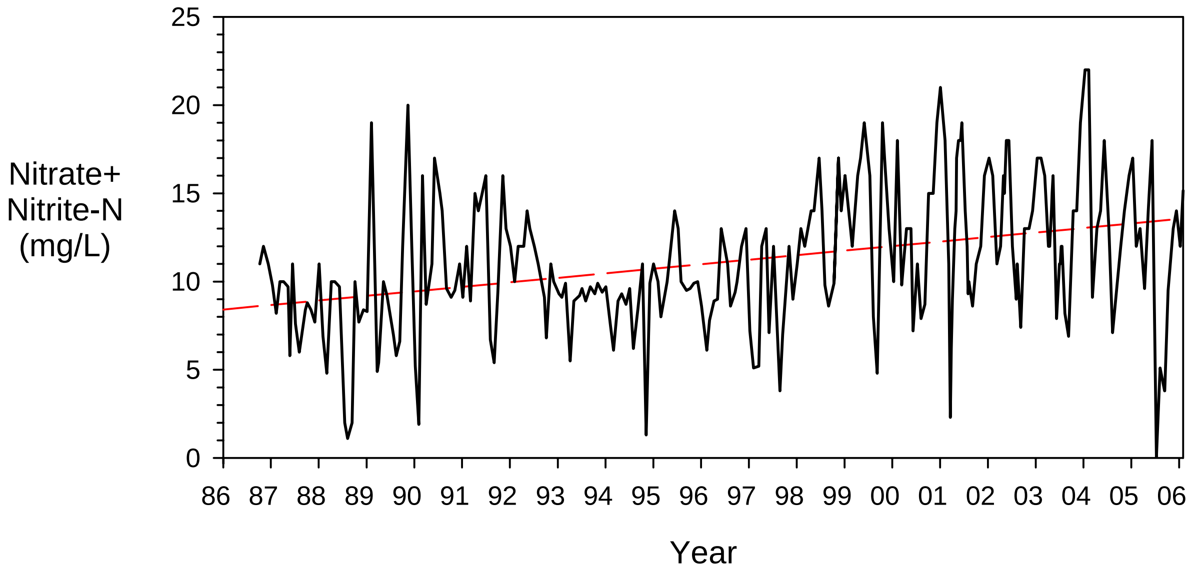

Figure 2. The North Raccoon River downstram of Sac City is one of 16 stream sites statewide that has been monitored monthly since 1986. The linear regression line (dashed) indicates an increasing trend in nitrate+nitrite-N concentrations during the past 20 years.

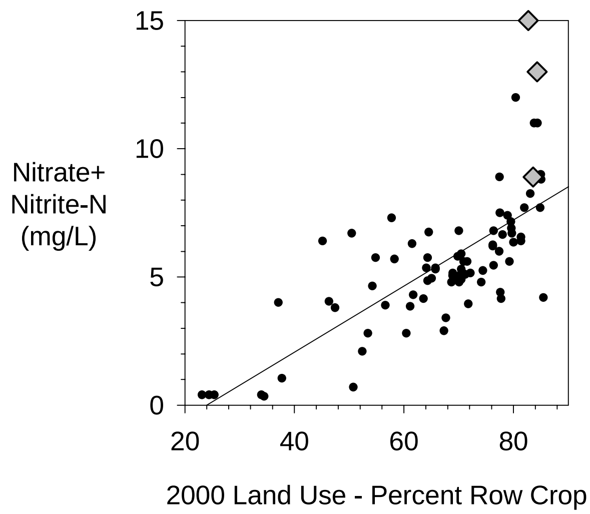

Figure 3. The relationship between median nitrate+nitrite-N concentrations (2000-2005) and the percent row crop in the associated watershed for 85 stream sites monitored as part of Iowa's Water Monitoring Program. Linear regression line has an R^2 of 0.53. Diamonds represent the three monitoring sites in the North Raccoon River watershed.

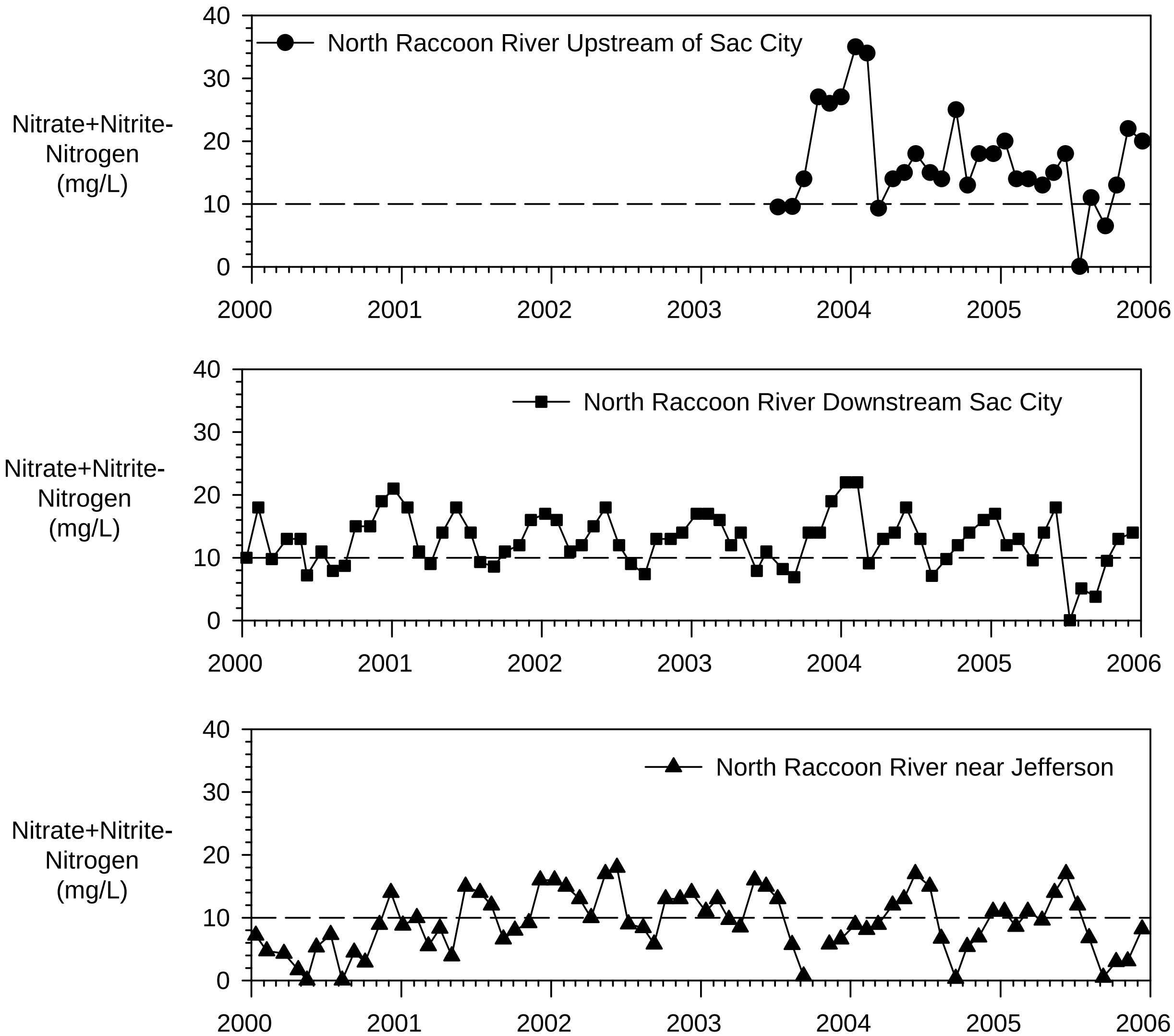

Figure 4. Nitrate+nitrite-N concentrations for the three monthly stream sites on the North Raccoon River. Dashed line represents the U.S. Environmental Protection Agency's drinking water standard of 10 mg/L.

Much of the North Raccoon River from Sac City south to its confluence with the South Raccoon River is designated for primary contact recreational use. With such a designation, an *E. coli* bacteria water quality standard of 235 Colony Forming Units per 100 ml (CFU/100 ml) applies. Figure 5 shows the *E. coli* bacteria levels for the three sites along the North Raccoon River. Bacteria levels are extremely variable, ranging from 10 to 380,000 CFU/100 ml. Levels tend to be higher during late spring/early summer and spikes tend to be related to rainfall events. Currently, three segments along the North Raccoon River are impaired for bacteria, meaning that water quality data from these sites indicate elevated bacteria levels exceeding the state's bacteria water quality standard (see Iowa's 2004 list of impaired waters - http://www.iowadnr.com/water/tmdlwqa/wqa/303d.html#2004).

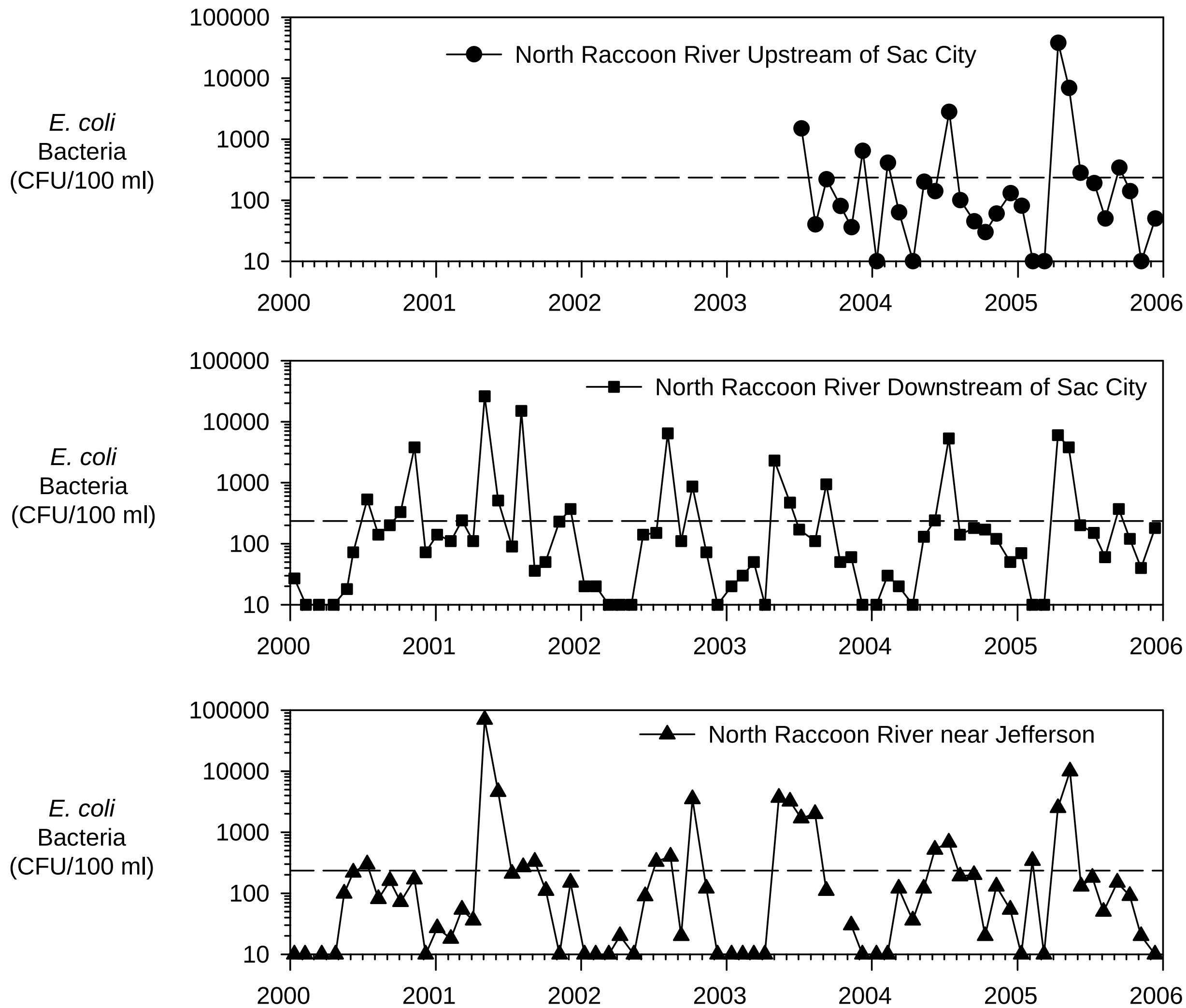

Figure 5. *E. coli* bacteria levels for the three monthly stream sites on the North Raccoon River. Dashed line represents the State of Iowa *E. coli* bacteria standard of 235 Colony Forming Units per 100 ml (CFU/100 ml) for streams designated for primary contact recreation (i.e., swimming) or childrens recreation (i.e., wading).

BIOLOGICAL QUALITY OF THE NORTH RACCOON RIVER WATERSHED

In addition to water chemistry, the aquatic organisms inhabiting a stream serve as indicators of stream health. Figures 6 and 7 show results of biological assessments conducted by the Iowa DNR and University Hygienic Laboratory from streams statewide, including four sites located in the North Raccoon River watershed (Figure 1). Indexes of biotic integrity (IBIs) are calculated for a site based on the number and types of benthic macroinvertebrate and fish species sampled. Benthic macroinvertebrates consist of aquatic insects or other spineless organisms such as clams, crustaceans, leeches, snails, and worms that large enough to be seen without magnification.

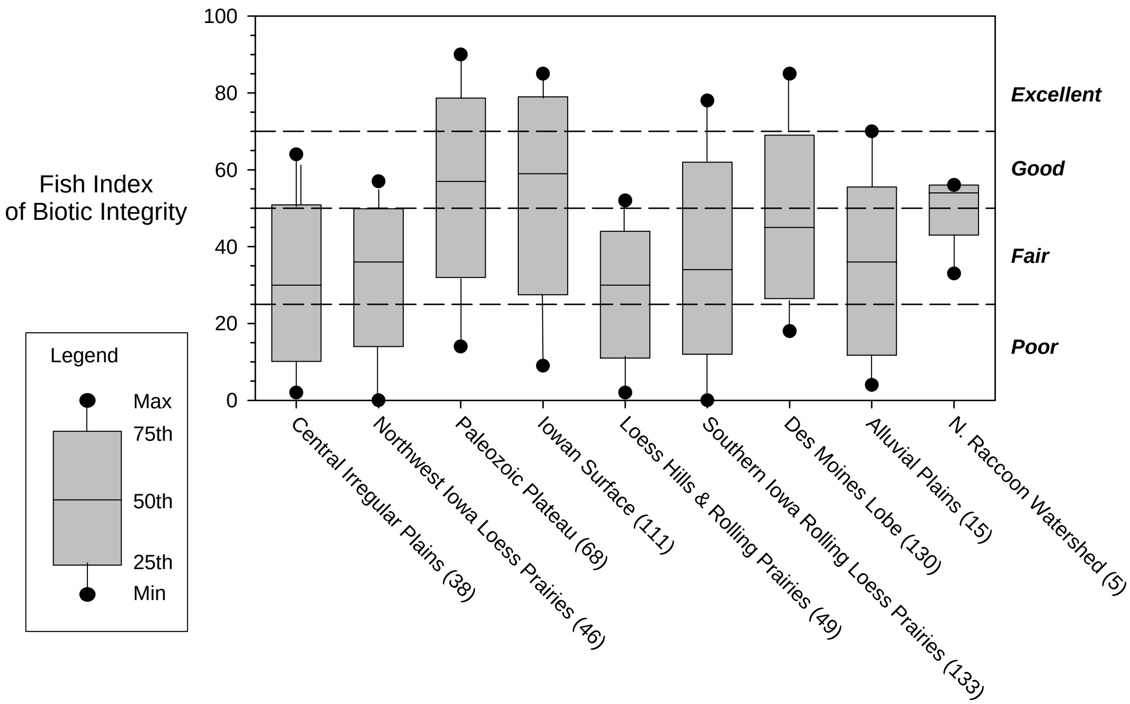

Figure 6. Fish index of biotic integrity data for streams sampled across the various ecoregions for comparison to sites sampled in the North Raccoon River watershed. X axis represents the various ecoregions, and the number in parentheses represents the number of samples.

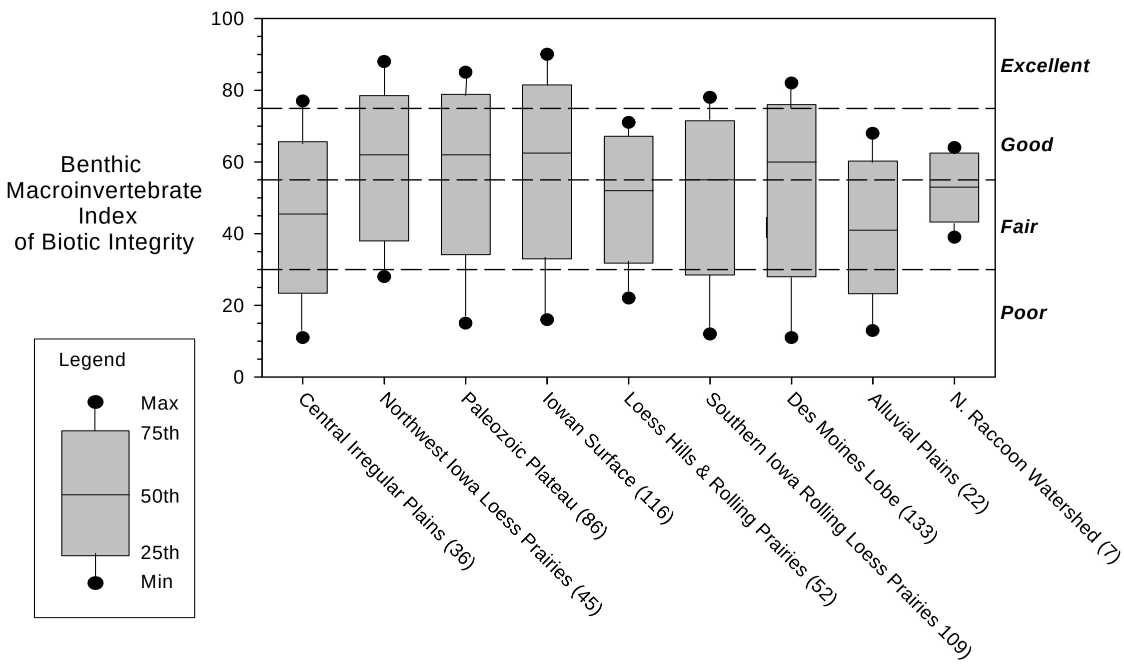

Figure 7. Benthic macroinvertebrate index of biotic integrity data for streams sampled across the various ecoregions for comparison to sites sampled in the North Raccoon River watershed. X axis represents the various ecoregions, and the number in parentheses represents the number of samples.

Generally, benthic macroinvertebrate and fish IBI scores from sites in the North Raccoon River watershed fall within typical ranges of IBI scores for streams in the Des Moines Lobe ecoregion. Fish IBI scores ranged from 33 (fair) to 61 (good), and the median score (54) was higher than the median level for all sampling sites in the ecoregion (Figure 6). Benthic macroinvertebrate index scores ranged from 39 (fair) to 64 (good), and the median score (50) was lower than the ecoregion median (Figure 7).

Due to varying sample years and uneven distribution of bioassessment sites in the watershed, an analysis of biological trends is impractical. The range of biological conditions found at North Raccoon River sampling sites is generally marked by moderate decreases from optimal levels of species diversity, losses or reductions in sensitive species, and increased dominance of tolerant organisms. The highest-ranking IBI scores were found at the two sites located upstream from the confluence with Cedar Creek in Sac County. The lowest IBI scores were obtained from the Dallas County sample site.

CRITICAL HABITAT FOR THE TOPEKA SHINER

It should be noted that 19 stream segments within the North Raccoon River watershed are designated as critical habitat for the federally endangered Topeka shiner (*Notropis Topeka*) (Federal Register, 2004). The Topeka shiner was listed as an endangered species on December 15, 1998 (Federal Register, 1998). The Topeka shiner is a small, stout minnow characteristic of small, low order (headwater) prairie streams of the central prairie regions of the U.S. (including Iowa) with good water quality and cool-to-moderate water temperatures. Historically, the Topeka shiner was widespread and abundant throughout these prairie streams, including streams within the Des Moines, Raccoon, Boone, Missouri, Big Sioux, Cedar, Shell Rock, Rock, and Iowa watersheds in Iowa. Topeka shiner populations have been reduced by about 80 percent with half of this decline occurring during the past 25 years (Federal Register, 1998). Causes for the population decline and continued threats to the Topeka shiner include sedimentation, eutrophication (nutrient enrichment causing decreased dissolved oxygen concentrations), intensive land-use practices, maintenance of altered waterways, dewatering of streams, and channelizations (Federal Register 2004).

In 2002, the U.S. Fish and Wildlife Service proposed designating critical habitat for the Topeka shiner in the central prairie regions of the U.S. This designation included 225 miles of streams in Iowa (Federal Register, 2004). Critical habitat designates areas that contain habitat essential for the conservation of a threatened or endangered species and which may require special management considerations. Nineteen stream segments within the North Raccoon River watershed (these segments are tributary streams to the North Raccoon River and off-channel pool habitats; none of these are located along the mainstem of the North Raccoon River) have been identified as critical habitat for the Topeka shiner. Primary threats to the Topeka shiner in the North Raccoon River watershed include agricultural practices and channelization that increase sedimentation and other water quality impacts. Grass waterways and terracing to reduce erosion, as well as implementation of best management practices for ditch maintenance are identified management practices that would help preserve these critical areas for the Topeka shiner (Federal Register, 2004). Other watersheds in Iowa designated as having critical habitat for the Topeka shiner include the Boone River and Rock River watersheds.

REFERENCES

Federal Register, 1998, 50 CFR Part 17, Final Rule to List the Topeka Shiner as Endangered, Vol. 63, No. 240, December 15, 1998, p. 69008-69021.

Federal Register, 2004, 50 CFR Part 17, Final Designation of Critical Habitat for the Topeka Shiner, Vol. 69, No. 143, July 27, 2004, p. 44736-44770.

Road Log

by
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Field Trip Stop Descriptions

by
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Road Log for Spring 2006 GSI Field Trip completed April 5, 2006 (distance in miles)

Mileage	Roadlog
0	Begin at parking lot E on the Buena Vista University campus, Storm Lake. Turn north (left) out of parking lot onto Early St. Turn east (right) onto West 4th.
0.2	Turn south (right) on College.
0.5	Turn east (left) on West Lakeshore. Drive along the north edge of Storm Lake.
0.8	West Lakeshore becomes East Lakeshore. At Sail Inn, look south (right) across Storm Lake to see Bemis Moraine. Also note the dredging equipment on Storm Lake. Storm Lake has been dredged twice before. This time, the dredging project was preceded by a watershed protection project to reduce future sediment inputs to Storm Lake and Little Storm Lake, located west of Storm Lake. Storm Lake was previously dredged in the 1960s. In 2000, prior to the current dredging project, much of Storm Lake was only 2 feet deep.
1.8	Note Destination Park construction to the south (right).
2.4	Turn south (right) on 120th Avenue. Bemis Moraine is present along east edge of Storm Lake, to your left as you drive south.
3.1	Enter City of Lakeside. Driving across outwash. This outwash is most likely related to the drainage of the Bemis Moraine rather than the drainage of Storm Lake. Note more undulating topography off to the east (left). This topography represents the Bemis Moraine.
4.0	Cross over Outlet Creek, the drainage outlet for the 3,000-acre Storm Lake and 190-acre Little Storm Lake.
4.4	Turn east (left) on 630th St. (C65). Continue to drive across the Bemis Moraine.
4.6	Cross over Outlet Creek. To the south (right) note the high terrace located along Outlet Creek.
4.8	City of Storm Lake Wastewater Treatment facility located to the south (right). The facility discharges into Outlet Creek.
5.0	Tyson Wastewater Treatment facility located to the south (right). It also discharges into Outlet Creek. During the fall of 2005, both the City of Storm Lake and Tyson were two of 100 wastewater facilities across Iowa that participated in a study to evaluate the impact of total dissolved solids and chloride from wastewater facilities on their receiving streams. Results from this study the Iowa Department of Natural Resources in developing proposed stream water quality standards for total dissolved solids and/or chloride in the spring of 2007.
5.2	To north (left) is former weigh station section – A 15 ft. section of gravelly loamy sand overlying laminated silts and sands. See Stop 1.
5.3	Cross over Highway 71 and drive east on Highway 7.
5.6	Cross over unnamed drainage into Outlet Creek. Turn north (left) into Oatman's Pit. The thickness of sand and gravel at this site could be as much as 45 feet of sand and gravel here. **Stop 1**. Notice the presence of shale clasts in the pit.
6.1	Leave Oatman's Pit, turn east (left) on Highway 7.

Mileage	Roadlog
6.4	Buena Vista County Landfill to the south (right). This site is a former sand and gravel pit. Crest of Bemis Moraine at this location.
7.5	Cross over Outlet Creek.
7.8	Cross over Outlet Creek. We are now off the Bemis Moraine.
8.2	To the north (left) is an isolated knob on the Bemis Till Plain. This knob is kame-like. More likely it is a crevasse fill on the till plain surface.
8.6	Cross over Outlet Creek.
9.2	Look to the north and south (left and right, respectively). Aligned hummock features (ridges) present. Early settlers located their houses and farms on this higher ground on the till plain.
11.2	Cross over the North Raccoon River. Note differences in land management practices along the river.
11.6	Begin ascent onto Altamont 1. Note moderate to high relief hummocky topography which is classic terrain of the Altamont.
11.9	Turn south (right) on 190th.
12.2	Note kame behind farm at 10 o'clock approximately 1 mile in the distance. The kame we will be visiting for Stop 2 is located behind the trees. Out in the foreground are a few other kame-like features.
12.5	Note farmstead on the west (right) side of the road. Water tower located on north side of the Bodholdt's farmstead is made out of glacial erratics.
12.7	On the east (left) side of the road, note the lighter textured soil on hummocks on the top of the knobs. Few cobbles/boulders on slopes.
12.9	Turn east (left) on 640th St. To the southwest is the Raccoon River valley. To the south are the remains of a kame and our Stop 2. Note cobbles in the road ditches which were removed from the adjacent farm fields.
13.0	**Stop 2**. Turn south (right) into the Anderson farmstead (abandoned; 1912 640th St.). Walk along west side of kame. Note the presence of shale clasts. Note Bemis Moraine in the distance to the west. Note prominent kame to the southeast.
13.2	Leave Anderson farmstead. Turn west (left) on 640th . Note Bemis Moraine in the distance.
13.4	Turn north (right) onto 190th. Note lighter textured soil on hummocks on the east (right) side of the road.
14.4	Turn west (left) onto Highway 7. It was not uncommon for early settlers to build their farms on knobs or kames. These features were good sources of foundation material and represented topographically higher ground that remained dry.
15.0	Cross over the North Raccoon River. Note subtle meander scars to the north (right) along the North Raccoon River valley. How suitable might some of these areas be for wetland restoration or non-rowcrop land uses?
15.3	Turn north (right) on 180th. We are now driving on the Bemis Till Plain. To the west (left) are hummocks representing minor moraine features running north-south.

Mileage	**Roadlog**
16.1	Cross over railroad tracks. Note Sioux Quartzite used as railroad ballast.
16.3	Turn east (right) on 620th St.
16.5	Note sand and gravel at land surface. Aligned hummock (crevasse fill).
16.6	Begin descent into the North Raccoon River valley. Again, note difference in land use for areas adjacent to the river.
16.8	Cross over the North Raccoon River.
16.9	Turn south (right) into Sturchler County Park. We are now back on the toe of Altamont 1. The lake at this site is a former sand and gravel pit.
17.1	Driving adjacent to the North Raccoon River.
17.3	**Stop 3**. Arrive at parking lot. Unisex pit toilet available for use.
17.8	Leave Sturchler Park. Turn east (right) on 620th. Driving up onto Altamont 1.
18.2	Turn north (left) on 190th. To the south of this intersection at the edge of the cornfield is where the Sturchler-1core was collected. Drive north on Altamont 1. To the east (right), the landscape drops off to the Altamont Till Plain. In the distance to the east (right), the western edge of Altamont 2 is visible.
19.1	At the intersection of 610th and 190th, begin descent off Altamont 1. Turn east (right) on 610th . Driving off of Altamont 1 and onto Altamont Till Plain.
20.1	Driving across Altamont Till Plain. Altamont 2 is visible to the east. Turn north (left) on 200th Avenue.
21.5	Note radio tower to the northeast at approximately 2 o'clock. The radio tower is located on Altamont 2. To the west (left) is a ridge in the distance. This is Altamont 1. The tree line in the distance marks the North Raccoon River. Beyond both the Altamont 2 and the North Raccoon River is another ridge which is the Bemis Moraine.
22.1	Turn east (right) on 200th Avenue (C49).
22.3	Cross over Drainage Ditch 18. This drainage is a linked depression sytem. Turkey farm on right.
22.9	Approaching Grau Wildlife Area to the north (left). The Grau Wildlife Area is located on the toe of Altamont 2.
23.1	Turn north (left) on 210th St. (M54). Continue driving north on Altamont 2.
23.5	Radio tower to the east (right) is located on Altamont 2. Often radio towers are on topographically high points and mark glacial moraines.
25.5	Radio tower to the west (left) on Altamont 1. Next ridge to the west beyond Altamont 1 is Bemis Moraine.
29.0	Intersection of Highway 3 and 210th Avenue. For the next four miles, we will be driving just off of Altamont 2 in the sag behind the moraine.
29.2	Cross over Lateral No. 2 This stream drains the backside of the Altamont and then empties into the North Raccoon River. Lateral No. 2 drains the high area off to the east.
30.4	Driving on Altamont Till Plain. Albert City to the east (right).
32.2	Altamont 2 to the west (left) is getting closer.

Mileage	Roadlog
33.3	Drive back up onto Altamont 2.
35.1	Altamont 1 to the northwest. Note kame-like features.
36.0	Turn west (left) onto Highway 10. The ridge in the distance to the west is Altamont 1. To the north (right), Altamont 1 and 2 are not distinguishable, hence they are mapped as the Altamont Complex.
37.0	Turn north (right) on 200th Avenue. To the left is Buena Vista County Goldsmith Pit. Directly in front is the North Raccoon River valley.
37.3	**Stop 4**. Cross over the North Raccoon River. Turn west (left) into the Goldsmith Pit (4567 200th Avenue). To the south is Altamont 1. On the east side of the road along the North Raccoon River is the City of Marathon's wastewater treatment facility.
37.5	Leave Goldsmith Pit. Turn south (right) onto 200th Avenue.
37.8	Turn west (right) on Highway 10.
38.4	Cross over the North Raccoon River.
38.7	The ridge off in the distance to the south is Altamont 1.
39.8	Bemis Till Plain. Note low area to the south (left). This is North Raccoon River outwash.
40.3	Cross over unnamed drainage ditch.
40.9	Minor moraines or aligned hummocks present on the Bemis Till Plain.
42.0	**Stop 5**. Duane Magnuson Pit. Crevasse fill on the Bemis Till Plain.
43.0	The backside of the Bemis Moraine, as it trends east to west, is visible in front of us. To the south (left) is the Bemis Till Plain.
43.6	To the south on 140th is a large animal confinement situated above a low area with an irrigation rig to the north. Irrigation rig for manure?
44.7	Bemis Moraine is to the north as we approach the intersection of Highways 71 and 10. Turn north (right) onto Highways 71 and 10.
45.6	Ascending the Bemis Moraine. As you drive north, you cross over the watershed divide between the Mississippi and Missouri River watersheds. To the south are the headwaters of the North Raccoon River which flows toward the Mississippi River and the drainage to the north flows into the Little Sioux River, eventually emptying into the Missouri River.
46.0	Off in the distance to the west (left) are wind turbines located just off the Des Moines Lobe onto the Northwest Iowa Plains landform region.
47.1	Begin descent into the Little Sioux River valley as we enter the City of Sioux Rapids. Little Sioux River located to the west (left).
47.9	Cross over the Little Sioux River.
48.3	Turn east (right) onto North River Road. Drive along the Little Sioux River valley. Along the north (left) valley wall is the Tazewell Till Plain, glacial deposits associated with earlier glacial advances during the Wisconsinan.
48.8	Note the City of Sioux Rapids water tower to the south (right). The tower is located on the Bemis Moraine.

Mileage	Roadlog
48.9	**Stop 6**. Tazewell exposure.
49.0	Leave Tazewell site.
49.6	Turn south (left) onto Highways 71 and 10.
49.8	Note the Late Wisconsinan terrace to the west (right).
50.0	Cross over the Little Sioux River.
50.2	The City of Sioux Rapids is situated on several Late Wisconsinan terraces.
50.7	Ascend the Little Sioux River valley up onto the Bemis Moraine.
52.5	Descending off the Bemis Moraine.
53.1	Intersection with Highway 10.
53.4	Aligned hummocks or minor moraines present to east (left) and west (right).
56.6	Altamont 1 ridge is visible to the east (left).
58.4	Wind turbines visible in distance to the west (right). Wind turbines are located off the Des Moines Lobe. Ridge in front of wind turbines is the Bemis Moraine.
60.1	Junction of Highways 3 and 71.
61.4	Buena Vista Restoration trumpeter swan pond to the east (left).
64.5	Radio tower to west (right) is located on the Bemis Moraine.
66.2	Ascend onto the Bemis Moraine.
68.0	Turn west (right) onto Highway 7 at the lighthouse. At stop light in Storm Lake, continue straight and drive along the north edge of Storm Lake.
71.0	Turn north (right) on College Avenue.
71.3	Turn west (left) onto West 4th.
71.5	Turn south (left) on Early St.
71.6	Turn west (left) into parking lot E on Buena Vista University. This concludes our field trip. Have a safe drive home.

STOP 1 — OATMAN'S PIT—BEMIS MORAINE ENGLACIAL CHANNEL LOCATION: LAKESIDE QUAD, T.90N., R.36W., SEC 18 SW¼ SE¼

At this site, we are standing on the Bemis Moraine, the terminal moraine of the Des Moines Lobe Landform (Figure 1, Introduction). It exhibits the classic morphology of Des Moines Lobe (DML) end moraines, which are curved, concentric ridges of hummocky terrain outlining the maximum extent of active ice advance and stationary margins of ice wastage during the Late Wisconsin ice advance (15,000 to 12,000 RYBP in Iowa).

Glacial drainage of the DML was unusual that it was concentrated as valley trains along major river valleys and at distinct outlets associated with moraine margins rather than marginal outwash plains. During our last GSI fieldtrip (Guidebook 54) in northwest Iowa, we visited the Okoboji Lake Outlet channel. That outlet served as a major drainage outlet for a complex of lakes along the northwestern edge of the Lobe. Today we are viewing a pit that has been mentioned as outwash associated with the Storm Lake outlet channel. However, on closer inspection it appears this sediment package is most likely related to deposition in an englacial tunnel in wasting ice along the Bemis Moraine rather than in an ice marginal stream serving as an outlet for Storm Lake (Figure 1).

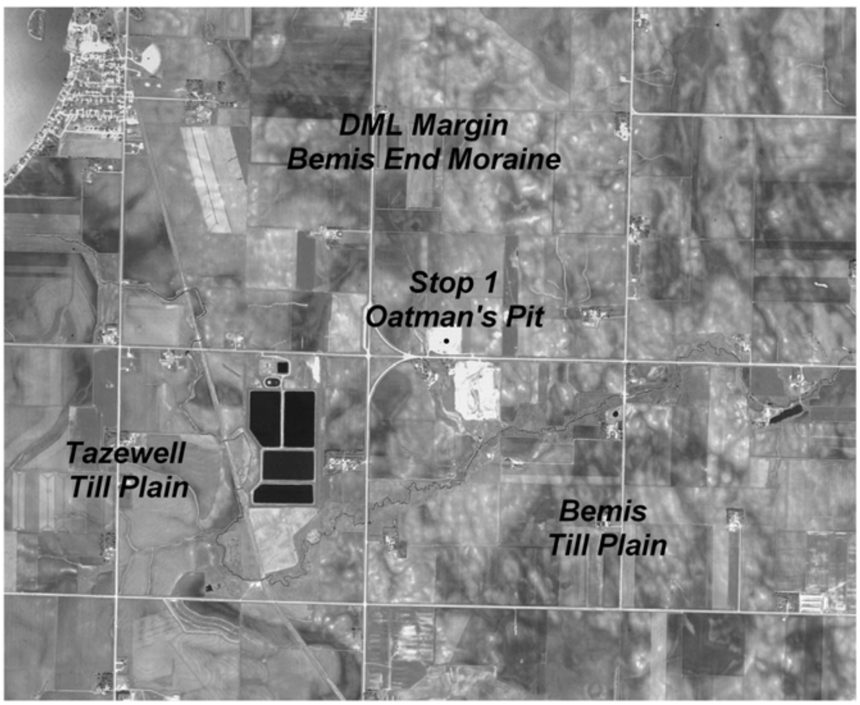

Figure 1. Location of Oatman's Pit on the Bemis End Moraine. Storm Lake is located in the upper left.

Several features have led to the conclusion that this deposit is englacial rather than ice-marginal. First, the morphology and landscape position of the Oatman's Pit Section does not fit the morphology and landscape position of valley-train deposits on the DML. At this location (which is considerably north of Outlet Creek) we do not see benched terrace levels; rather, the pit is located in an upland position. Also, the stratigraphy of the sediment package is quite different than described at the Okoboji Outlet, and at numerous valley-train terrace sites along the Des Moines and Iowa Rivers. All of the above mentioned deposits originated as ice marginal meltwater drainageways to the Lobe.

In ice marginal streams, the stratigraphic sequence is dominated by a three-increment deposit characterized by a thin veneer of fine-grained deposits, overlying a massive very cobble gravel to pebble gravel package that was deposited primarily as bedload during high magnitude flood events, with a thicker package of cross-bedded sands and pebble gravel at the base of the sequence . In contrast, at this site we see a sediment package that is more related to the internal drainage of debris-rich ice sheet: loamy sandy diamicton above deformed silts and fine sands which in turn overlie cross-bedded sand and gravel. Therefore this section would be mapped as Dows Formation Pilot Knob Member based on its morphology and lithostratigraphy (see Introduction).

Oatman's Pit Section Description
Dows Formation—Pilot Knob Member

A complete section is not well exposed at this time. However, if you look around the pit you will see there are several levels that have been excavated within the pit that exhibit a variety of sediment types and structures indicating significant changes sediment type and flow regime as the deposit aggraded. Due to slumping and accessibility issues the measurements for this section are approximate.

0-15 ft-- Uppermost section of the pit (north wall). Stripped surface. Massive to planar bedded gravelly loamy sand to gravelly sandy loam diamicton with occasional large boulders and cobbles (Figure 2).

15-35 ft-- In places, approximately 5 feet of planar-bedded loamy PGms (matrix-supported pebble gravel). These sands overlie channel fills of laminated silts and interbedded very fine sand that are in places deformed; Fe stains along bedding planes and cross bedded PGms (matrix-supported pebble gravel (Figure 3). Slumped section.

35-45 ft-- Reported by pit workers as a very coarse gravel in a test hole directly north of Hwy 7.

Also, as noted in the trip log we looked at the stripped section directly west of this pit on the west side of Hwy 71. At that site we saw a similar sequence in the upper 15 feet of exposed section.

Hwy 71 Weigh Station Section Description
Dows Formation—Pilot Knob Member

0- 3 ft-- Stripped surface.

3-10 ft-- Massive to planar bedded gravelly loamy sand; pebbles up to 3-5" diameter (Figure 4).

10-12 ft-- Laminated silts and interbedded very fine sand. Soft sediment deformation and collapse features present (Figure 5).

12-13 ft-- Cross bedded medium to fine sand.

13-15 ft-- Channel fills of laminated and ripple drift cross laminated silts and interbedded very fine sand; Fe stains along bedding planes.

Figure 2. Plane bedded sandy diamicton with occasional large pebbles and cobbles.

Figure 3 Matrix-supported pebble gravel overlying channel fills of laminated deformed silts and fine sand. Shovel placed at contact.

Figure 4. Massive to plane bedded loamy sand to sandy diamicton overlying deformed silts.

Figure 5. Deformed laminated silts and very fine sand overlying cross-bedded sands.

STOP 2 — ANDERSEN-BODHOLDT KAME
LOCATION: NEWELL WEST QUAD, T.90N., R.35W., SEC 30 NW¼ NW¼ NW¼

We are standing on a narrow belt of high relief hummocky terrain associated with the Altamont Moraine I advance (Figure 1). The Altamont Moraine represents a readvance of the Des Moines Lobe (DML) ice that occurred approximately 13,500 YBP. The Altamont is characterized by moderate to high relief hummocky topography as well as numerous ice-collapse features, namely kames, eskers and ice-walled lake features (in areas further north). Along the flanks of the DML the Altamont Moraine is a relatively narrow 1.5 mi (2.4 km) north-south curvilinear ridge. Kames are usually conical mound-shaped landforms composed primarily of sand and gravel; more uncommonly kames are stratified diamicton and silts (Bettis et al., 1996). Kames often show evidence of collapse (steep faulting beds as well as variably textured juxtaposed deposits). One model for kame formation is shown in Figure 2 and involves the deposition of debris-rich meltwater and flow tills into lower elevation depressions on the former ice surface. Eventual filling of the depressions in conjunction with the melting of the underlying ice would result in the present day mounds comprised of a chaotic mixture of collapsed deposits. It is also therorized that kames may have formed as sand and gravel was deposited at the base of moulins, vertical shafts in the ice that shunted meltwater to the bed of the glacier (Figure 3). It is unlikely that this occurred and more plausible that kames on the DML are related to supraglacial or possibly englacial deposition, from either holes or cavities in the ice. In Iowa, kames are becoming an endangered land feature, as they are valued as potential sand and gravel resources for many landowners. These deposits comprise the Pilot Knob Member of the Dows Formation (see Introduction).

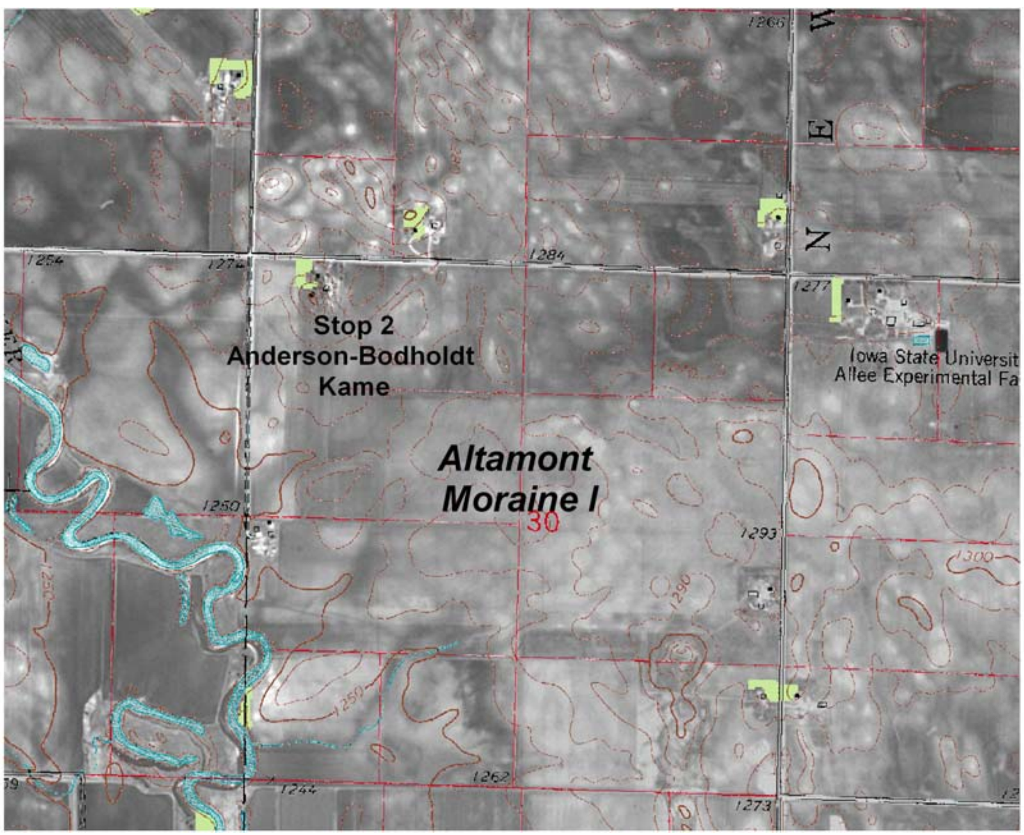

Figure 1. Location of Anderson-Bodholdt Kame on Altamont Moraine I. Iowa State University Allee Research Farm located just off the moraine on till plain (note vague aligned hummock tract north of Allee Farm).

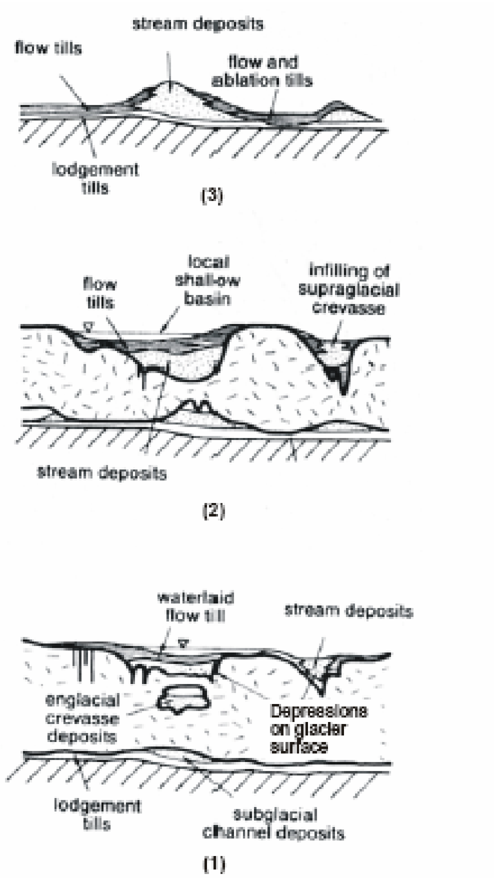

Figure 2. Model for kame formation modified from Benn and Evans (1998).

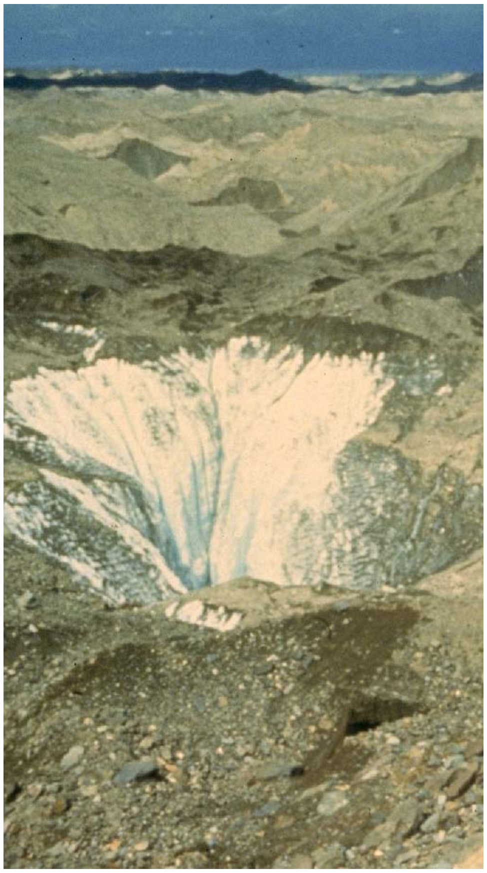

Figure 3. Moulin on Klutlan Glacier, Alaska. Photo by Herb Wright.

Figure 4. Partial view of Anderson-Bodholdt kame mined for sand and gravel potential. Note large boulders, originating from the kame, that are now present in front of the kame exposure.

Anderson-Bodholdt Kame Description
Dows Formation-Pilot Knob Member

At this site, we will view a partially exposed section located in the barnyard of an abandoned farmstead (Figure 4). The exposed sediment package is typical of what one would find in any of the numerous kames in this vicinity. This section was first visited and described nearly 25 years ago. Figure 5 is a drawing by Tim Kemmis, former geologist at the Iowa Geological Survey, documenting the chaotic mix of sandy diamicton, sand and gravel, as well as fine sand and silts deposits associated with this kame. In his description, Kemmis noted graben-like structures and several infillings consisting of large boulders up to 3 ft (1 m) in dimension within the sandy diamicton. The sediment package is consistent with what is commonly described in kames throughout the mid-continent.

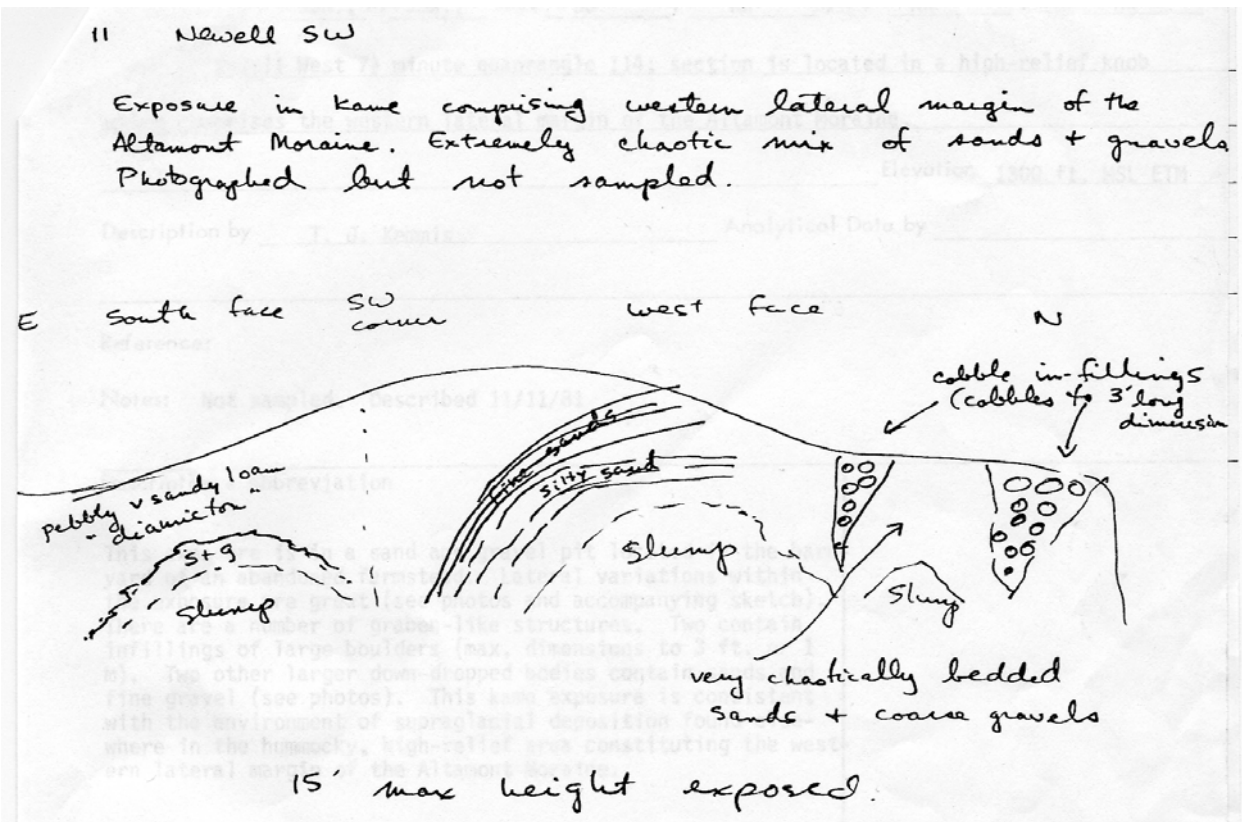

Figure 5. Cross-section of Anderson-Bodholdt kame. Description and sketch completed in November, 1981 by Tim Kemmis. Section is now overgrown.

REFERENCES

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.

Benn, B.J. and D.J.A., Evans, 1998. Glaciers and Glaciation, Oxford, London.

STOP 3 — STURCHLER PIT COUNTY PARK-ALTAMONT MORAINE I

The Altamont Moraine represents a readvance of the Des Moines Lobe (DML) ice sheet that occurred approximately 13,500 RYBP. The Altamont extends across much of the DML landform and is characterized by several curvilinear belts of moderate to high relief hummocky terrain with intervening linked depressions. The Altamont II moraine is a more complex branching moraine system that is present only on the inner flanks of the DML, and most likely represents a fairly quick readvance of ice after the Altamont I advance (see front cover). Moderate to high relief hummocky topography and ice collapse features such as kames (stop 2), eskers and ice-walled lakes are common on the Altamont landforms. Kemmis (1991) proposed a model for the development of hummocky topography and linked depression systems on the DML and attributed the hummocks and related depressions to the development of a glacial karst system in debris-rich wasting ice (Figure 1). Later, Bettis and others (1996) proposed a model for the development of linked depression systems on DML till plains in Iowa (Figure 2). Both models illustrate how meltwater percolating through DML ice would contribute to the collapse of debris-rich ice and form a system of widespread linked depression systems that are mantled with supraglacial material. One implication of the the linked depression system models is that they account for the deposition of supraglacial materials pervasively across the DML landscape.

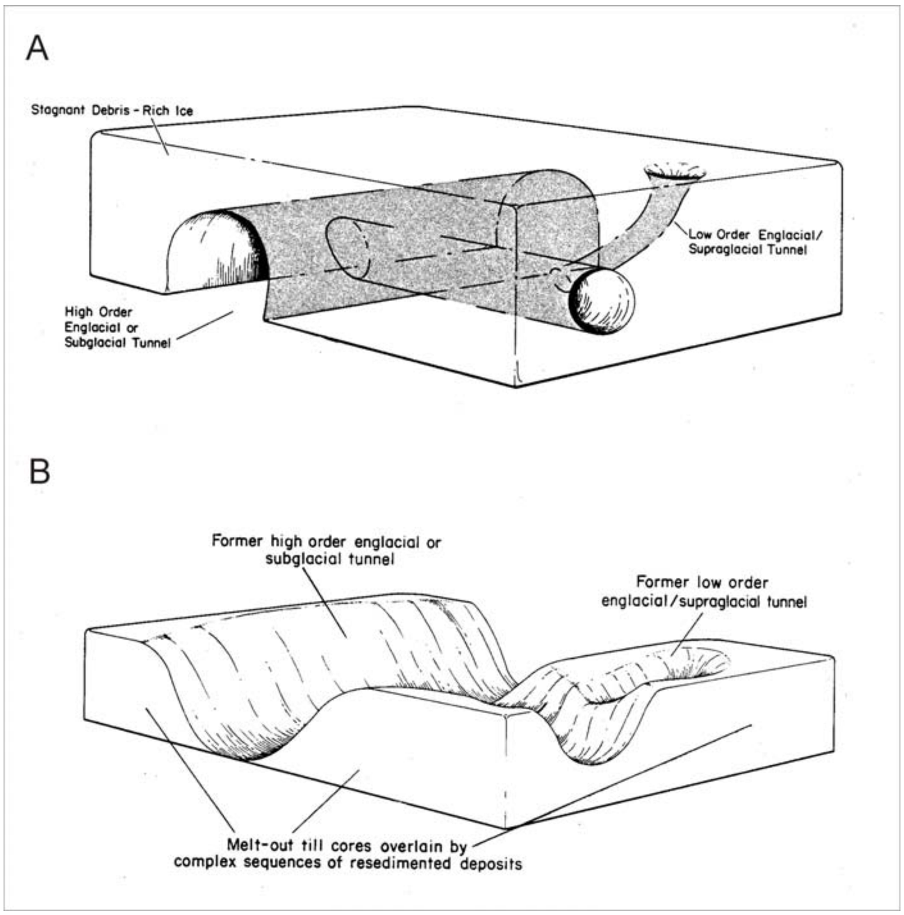

Figure 1. A model for the development of present-day Des Moines Lobe hummocky topography. The glacial karst system with low-order (smaller) tunnels connecting to high-order (larger) tunnels within and at the base of the stagnant glacier (Kemmis, 1991).

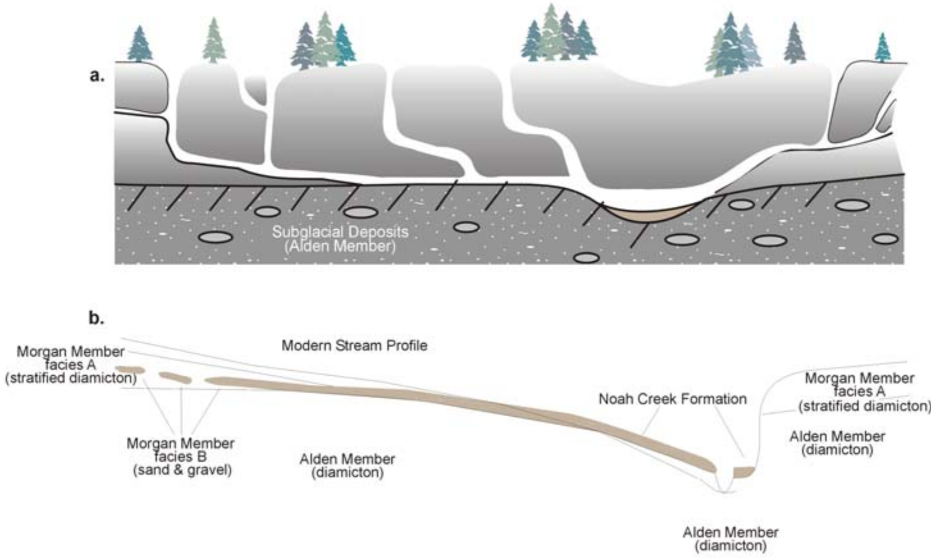

Figure 2. a) A cross-section through the stagnant Des Moines Lobe glacier illustrates a glacial karst system and drainage to a central drainage tunnel. b) Idealized profile along a linked depression system illustrating the distribution of sand and gravel within the former glacial karst system (Bettis et al., 1996).

At this site we have included descriptions of two cores, one taken directly east of here on the Altamont I (Sturchler 1) and another core (Allee-1) taken on the Altamont I till plain approximately 3.5 miles southeast from here on ISU Alley Research Farm near Newell (Figure 3). Note the thickness of supraglacial diamicton (Morgan Mbr.) in each core.

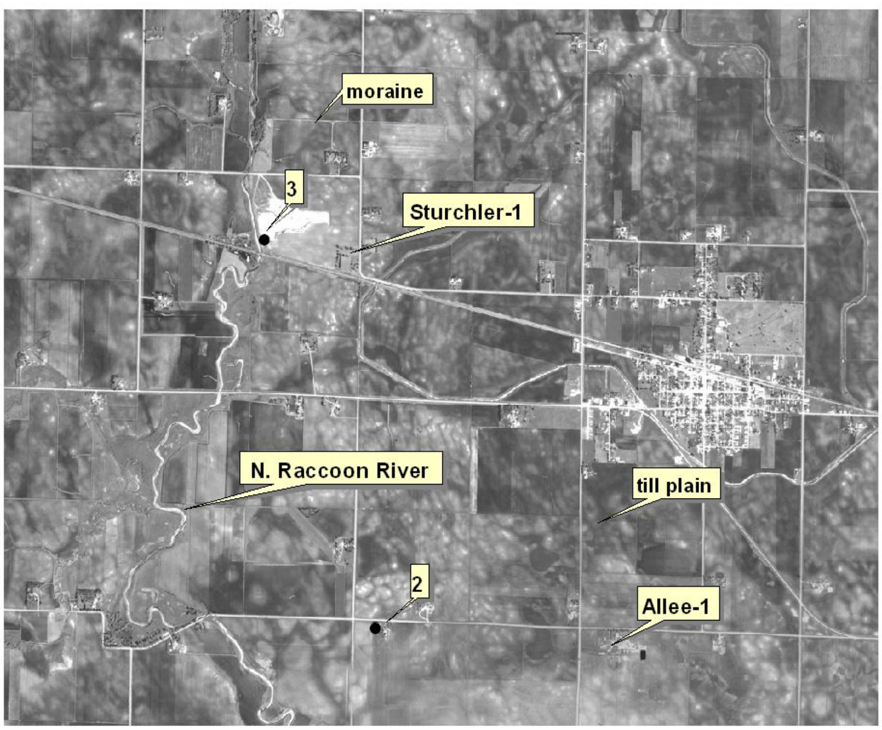

Figure 3. Location of Sturchler County Park in relationship to Sturchler-1 and Allee-1 core sites.

Unfortunately, due to time and logistical constraints we will not be able to view cores at the field trip stop. Rather we will use this time to discuss water quality and land use practices in the watershed.

Sturchler Pit Area (Altamont I) Core Description
Altamont I Location: Newell West Quad, T.90N., R.36W., Sec 13 NE1/4SE1/4
11Sturchler-1
Landscape Position: Altamont I Moraine
Parent Material: diamicton
Soil: Clarion
Vegetation: grass
Date: 4/12/06
Described by: IGS-Deb Quade, Stephanie Tassier-Surine and NRCS-Julie McMicheal
Driller: Bob Rowden

Depth (ft.)	***Horizon***	***Solum***
0-0.7	Ap	10YR 3/1 very dark gray loam, weak fine to medium granular, very friable, noneffervescent, clear boundary
0.7-1.2	Bw1	10YR 3/2 very dark grayish brown and 10YR4/3 brown sandy loam, weak fine subangular blocky, very friable, noneffervescent, clear boundary
1.2-4.0	Bw2	10YR5/4 yellowish brown sandy loam to loam, moderate fine subangular blocky, very friable, strongly effervescent, strongly effervescent, clear boundary
4.0-4.9	BC	10YR5/4 yellowish brown loam, weak fine subangular blocky, friable, strongly effervescent, clear boundary
		Dows Formation—Morgan Mbr.
4.9-5.1	OU	10YR5/4 yellowish loam diamicton and 10YR6/2 light brownish gray, vaguely stratified, violently effervescent, friable, commoncalcium carbonate concentrations, clear boundary
5.1-6.7	OU	10YR5/6 yellowish brown sandy loam diamicton, resedimented, friable, strongly effervescent, clear boundary
6.7-17.1	OU	2.5Y5/4-5/6 yellowish brown sandy loam diamicton with interbedded lenses of laminated silt and fine sand as well as pebbly sand, vaguely stratified to laminated, friable to very friable, strongly effervescent, clear boundary
17.1-19.1	OU	2.5Y5/4 light olive brown silt and fine sand, laminated with interbedded sand, coarsening with depth, strongly effervescent, abrupt boundary
19.1-20.3	OU	2.5Y5/4-5/3 light olive brown sandy loam diamicton, resedimented, friable, Fe stains along bedding planes, strongly effervescent, abrupt boundary
20.3-21.8	OU	2.5Y5/4-5/3 light olive brown coarse silt, fine sand, and sandy loam diamicton, stratified, friable, strongly effervescent, abrupt boundary
21.8-22.0	OU	10YR5/4 and 5/6 yellowish brown fine to medium sand, loose, strongly effervescent

Alley Research Farm (Altamont I till plain) Core Description
Altamont I Till Plain Location: Newell West Quad, T.90N., R36W., Sec 13 NE1/4SE1/4

11Allee-1
Landscape Position: Altamont I till plain
Parent Material: diamicton
Soil: Nicollet
Vegetation: grass
Date: 4/12/06
Described by: IGS-Deb Quade, Stephanie Tassier-Surine and NRCS-Julie McMicheal
Driller: Bob Rowden

Depth (ft.)	*Horizon*	*Solum*
0-1.1	Ap	10YR2/1 black loam weak fine subangular blocky parting to weak fine granular, friable, noneffervescent, clear boundary
1.1-1.9	A1	10YR 3/1 very dark gray loam, weak fine subangular blocky, friable, noneffervescent, clear boundary
1.9-3.1	Bt1	2.5Y4/3 olive brown and 2.5Y4/1 dark gray silty clay loam, moderate fine subangular blocky, few faint 2.5Y4/4 mottles, friable, noneffervescent, clear boundary
3.1-3.8	Bt2	2.5Y4/2 dark grayish brown silty clay loam, moderate medium prismatic, friable,noneffervescent, clear boundary
3.8-6.0	BC	2.5Y5/4 light olive brown sandy clay loam, weak moderate prismatic, common medium 2.5Y5/2 grayish brown mottles, common calcium carbonate concentrations from 4.7-6.0 ft., strongly effervescent, friable, clear boundary
		Dows Formation—Morgan Mbr.
6.0-9.1	MOU	10YR5/6 yellowish brown loam diamicton, common medium 2.5Y5/2 dark grayish brown mottles, resedimented, friable, lower 0.5 ft is a gravelly sandy loam lag deposit, strongly effervescent, slough from 8 to 9.1 ft in tube
9.1-12.8	OJU	2.5Y5/4-5/3 light olive brown loam diamicton, resedimented, common coarse joints with 7.5YR4/6 strong brown Fe stains on joint faces, strongly effervescent, clear boundary, firm, slough from 12 to 12.8 ft in tube
12.8-17.7	OJU	2.5Y5/4-5/3 light olive brown sandy loam and loam diamicton, resedimented, common coarse joints with 7.5YR4/6 strong brown Fe stains on joint faces, few thin beds of medium sand throughout unit, firm, strongly effervescent, slough from 16 to 17.7 ft in tube, clear boundary
17.7-18.9	OJU	2.5Y5/3 light olive brown loam diamicton, resedimented, common coarse joints with 7.5YR4/6 strong brown Fe stains on joint faces, firm, strongly effervescent, abrupt boundary

		Dows Formation—Alden Mbr.
18.9-20.0	UU	5Y3/1 very dark gray loam diamicton, firm, dense, strongly effervescent

REFERENCES

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.

Kemmis, T.J., 1991, Glacial landforms, sedimentology and depositional environments of the Des Moines Lobe, northern Iowa: University of Iowa Department of Geology, Iowa City, unpublished Ph.D. thesis, 393 p.

STOP 4 — GOLDSMITH PIT—PROXIMAL OUTWASH (NORTH RACCOON RIVER) LOCATION: SIOUX RAPIDS SE QUAD, T.90N., R.35W., SEC 19 SE¼ SW¼

Several studies have provided insight into the evolution and the development of Late Wisconsinan (LW) terraces associated with the Des Moines Lobe (DML) (Kemmis et al., 1987; Kemmis, 1991; and Quade, 1992). These studies are the basis for a regional framework for the Noah Creek Fm. showing that: 1) there is a repetitive stratigraphy associated with LW valley-train terraces; 2) river valleys can be separated into four geomorphic segments: proximal, transitional, bedrock-controlled, and distal segments, where flow regime and depositional environment varied and; 3) there are three terrace types and each possess a distinct stratigraphy: a longitudinal type, a point type, and a cut-off type.

The multiple terraces, each with a coarse middle increment near the top, provide clues about terrace development and valley evolution on the DML (Kemmis et al., 1987, Quade, 1992). Middle increment deposits are significantly coarser, and overlie an abrupt unconformity on the lower-increment sediments. Middle increment deposits are dominated by two facies: very poorly sorted, massive to crudely planar-bedded cobble gravels, and coarse-grained, low-amplitude channel fills. Middle increment deposits show a significant change of scale from the meso- and micro-forms of the lower increment to large-scale, terrace-wide (valley-wide?) deposition. The very poorly sorted cobble gravels of this increment indicate a stream with a very high sediment load, and simultaneous deposition of bed and suspended load (Harms et al., 1975). On the continuum of flow conditions and processes, the middle-increment deposits probably represent very concentrated fluid-flow conditions approaching those of hyper-concentrated flow, and are most likely related to infrequent, very high magnitude floods that are responsible for the middle and upper increments of LW terraces of the DML. Such flood deposits may be related “glacier bursts” or “jokulhlaups,” similar to those described by Church and Gilbert (1975), Haeberli (1983), and Sturm and others (1987), among others. It is unlikely that we will ever know for certain what caused these jokulhlaups in major river basins associated with the DML since the ice is long since gone, and the discontinuous terrace record downstream prohibits any full historical reconstruction. There are, however, several possibilities, including catastrophic drainage of supraglacial, subglacial, or proglacial lakes, or perhaps even seasons of extremely high melt rates. Geomorphic and stratigraphic evidence, as well as radiocarbon dates, suggest that advances of the DML were rapid, followed by general stagnation of large areas of the lobe (Kemmis, 1991). This kind of glacial behavior is similar to that of surge-type glaciers which release large volumes of meltwater just prior to and in the early stages of surging. It is thus possible that some glacial floods may be related to such meltwater releases as the Des Moines Lobe surged to the Altamont Moraine position.

GOLDSMITH PIT DESCRIPTION

As we enter the pit we are walking along a small ditch which is the North Raccoon River. At this location Altamont I and II have coalesced and are indistinguishable as individual moraines. They are referred to as the Altamont Moraine Complex (Figure 1). The headwaters of the North Raccoon are located approximately 3 miles northeast of the Goldsmith Pit. At this site the North Raccoon doesn’t have a well-defined valley and appears to be nestled in the moraine. Table 1 provides a comprehensive comparison of LW proximal and distal terraces associated with the Des Moines Lobe. Proximal and distal terrace deposits associated with the DML have consistent coarse-grained stratigraphic sequences composed of the Noah Creek Fm. which are grouped into three units: lower, middle and upper increments. The sedimentology and stratigraphy of these increments indicate that they were deposited in aggrading braided streams that carried glacial meltwater from ice-marginal sources.

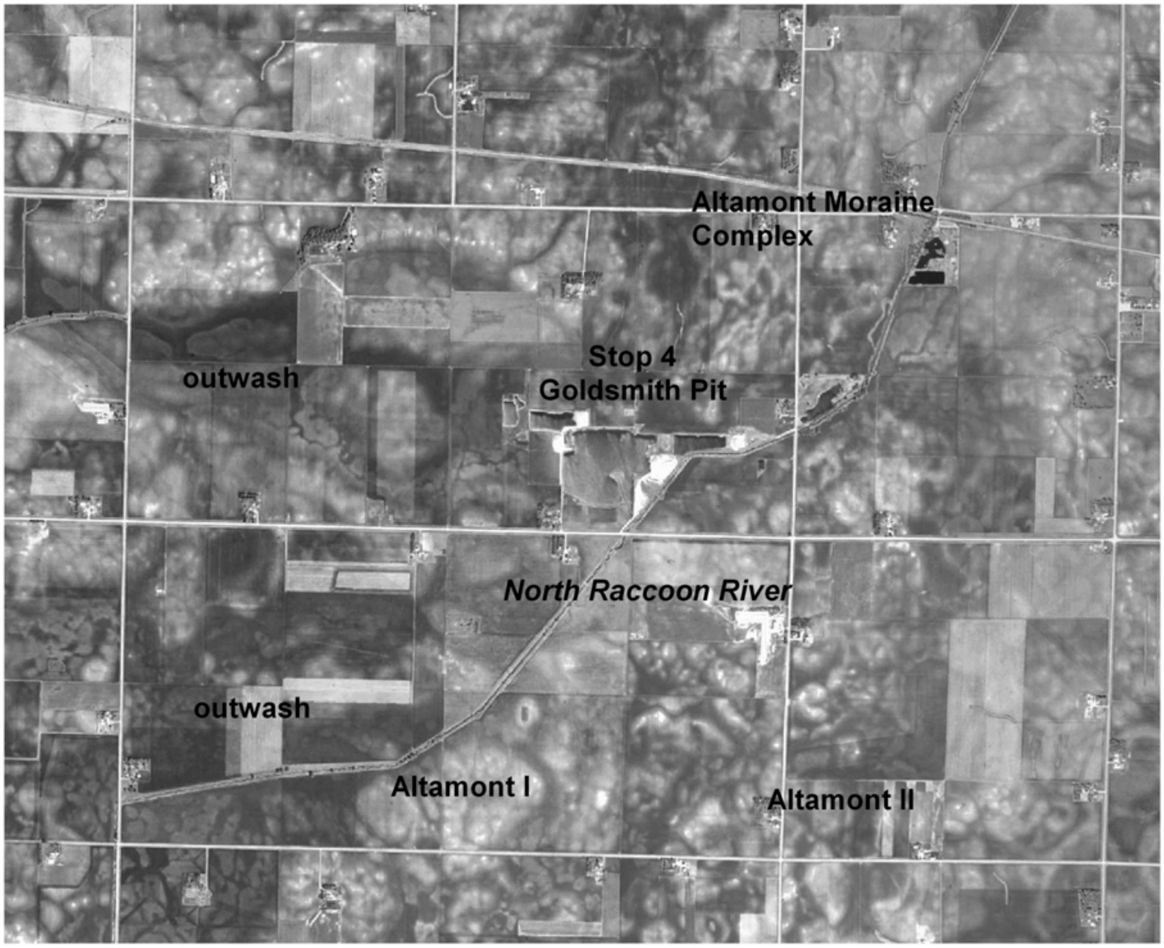

Figure 1. Location of Goldsmith Pit and proximity to Altamont Moraines I, II and Altamont Moraine Complex. The North Raccoon River is proximal to the Altamont Moraine Complex.

The distribution of these three increments is illustrated in Figure 2, a photo from the Goldsmith Pit. Below is a generalized description of the sediment package found at Goldsmith Pit. The Buena Vista county engineer said the pit was pumped down and deposits dredged 4 months ago. It is unfortunate we did not know about the pumping as he indicated they only do it every ten years. According to county records there is approximately 28 feet (8.5 m) of sand and gravel at this location and about 10-12 feet of exposed section.

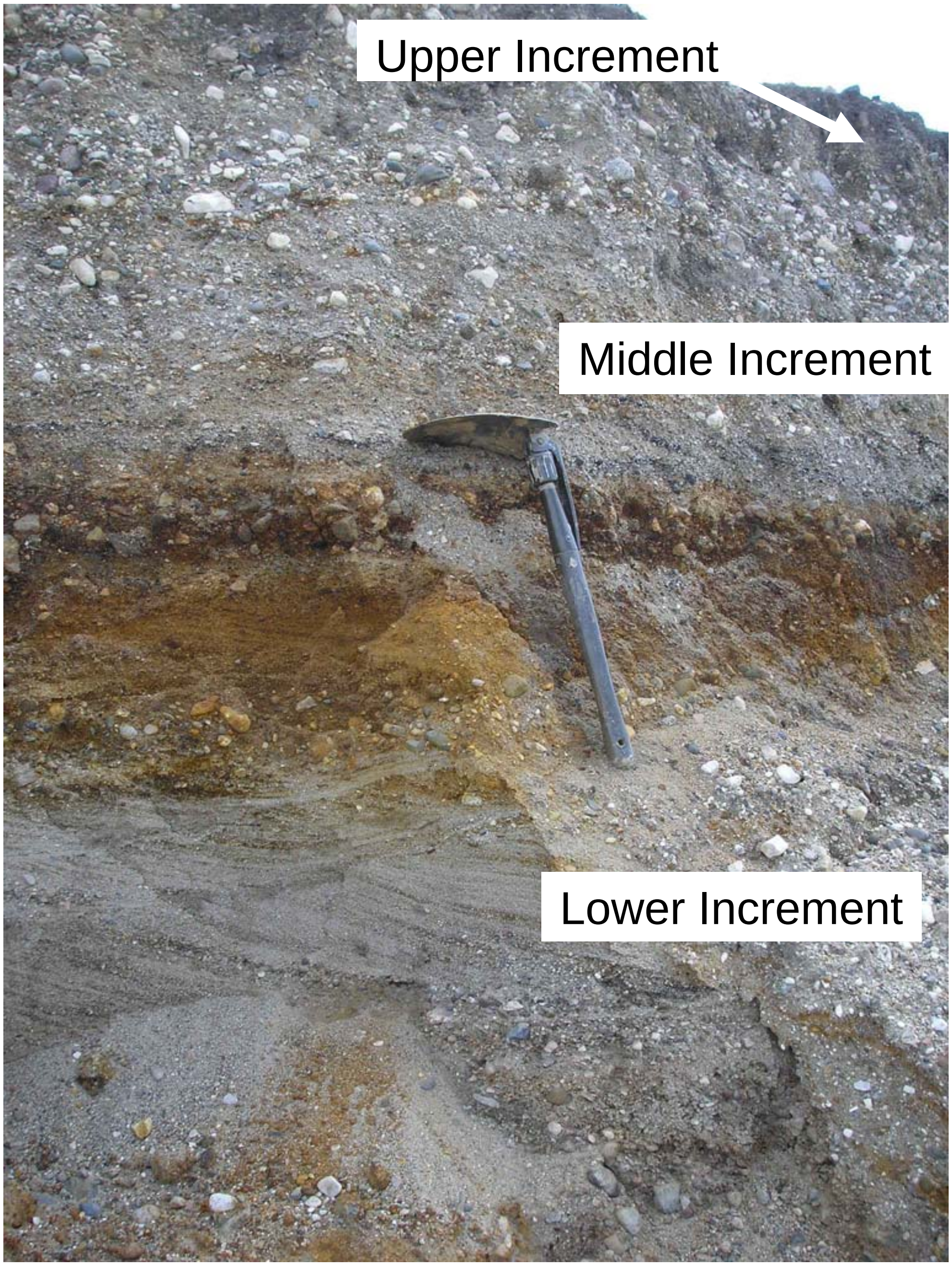

Figure 2. Proximal outwash package at Goldsmith Pit. Photo shows sediment types and structures associated with the various increments of the Noah Creek Formation.

Lower Increment

The lower increment is the thickest of the three increments, generally 16 to 18 feet (5.0-5.5 m). It has the widest variety of sedimentary structures, consisting of various complex crossbed types, dominantly medium-scale complex crossbeds composed of sand and matrix-supported pebble gravel. The upper and lower contacts are complex; the upper and lower boundaries are undulatory and appear to mimic former channel floors. Grain size is variable ranging from medium to coarse sand, to matrix-supported pebble gravel. Occasionally, pebble gravels occur at the lower bounding surface of the larger scale crossbeds or as bedded stringers in the unit. At the Goldsmith Pit, the sedimentary structures appear to be mostly different cross-bed types deposited by dune migration across the former outwash channel floor.

Middle Increment

The middle increment is typically 5 to 8 feet (1.5 to 2.5 m) thick and consists of a massive clast-to-matrix supported cobble gravel to pebble gravel. This increment unconformably overlies the lower increment; this contact is marked by a cobble line. At this site, the middle increment is dominated by massive to plane-bedded cobble gravel with several diamicton (till balls) deposited as a lag in places (Figure 3). The poor sorting in these gravels indicates a stream with high sediment supply and the simultaneous deposition of both bedload and suspended load during a high-magnitude flood event, possibly related to meltwater releases during rapid ice advance or subglacial or supraglacial lake drainage.

Upper Increment

The upper increment consists of a thin veneer of fine-grained sandy loam to loam overbank sediment. At this site, this increment is typically 1 to 2 feet (0.3 to 0.6 m) thick and consists of massive upward-fining sandy loam to loam.

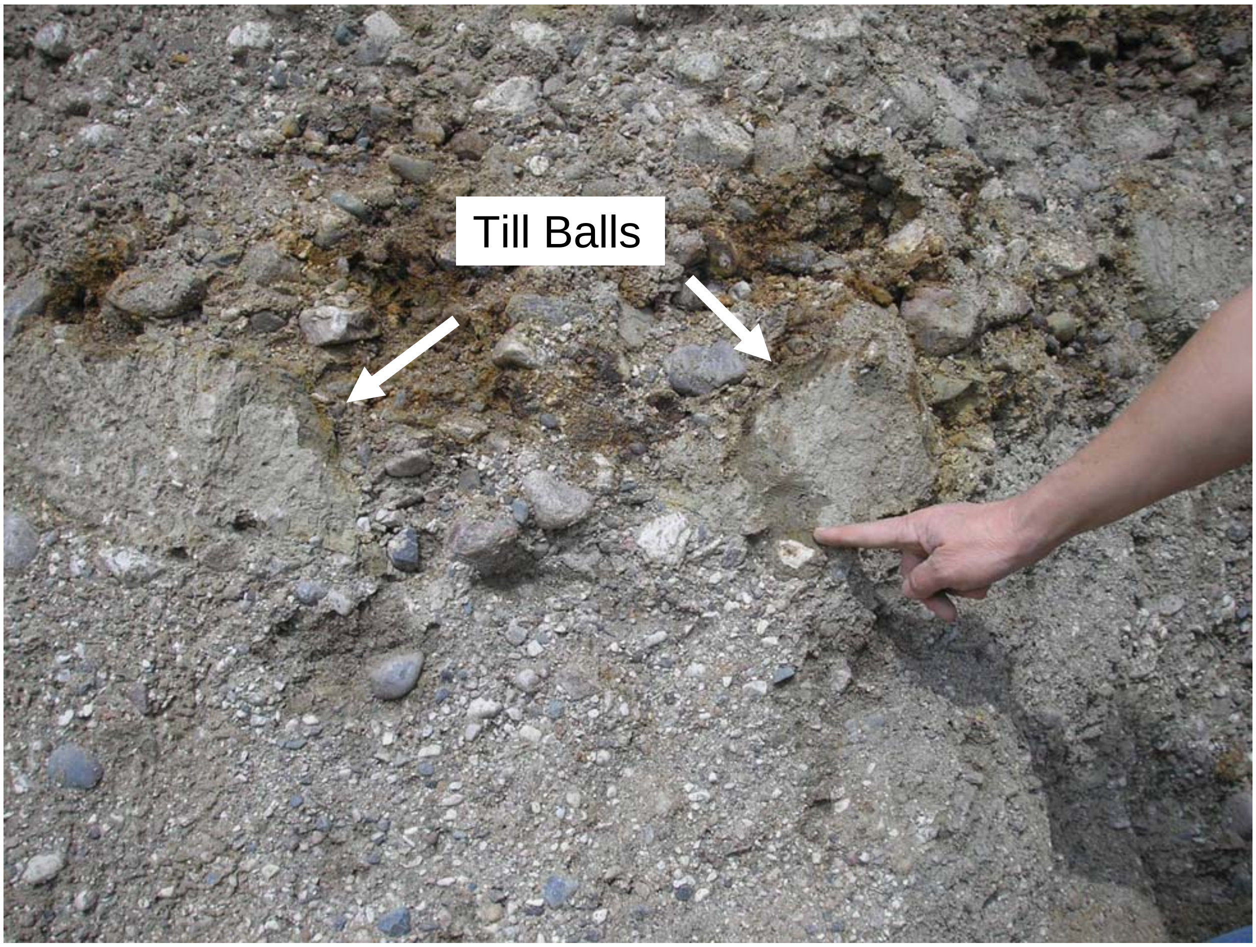

Figure 3. Middle increment. Massive to plane bedded matrix supported pebble to cobble gravel with several till balls near the base of the increment. The till balls are indicative of a proximal setting.

REFERENCES

Church, M. and Gilbert, R., 1975, Proglacial fluvial and lacustrine environments, *in* Jopling, A.V., and MacDonald, B.C., eds., Glaciofluvial and glaciolacustrine sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 23, p. 22-100.

Haeberli, W., 1983, Frequency and characteristics of glacier floods in the Swiss Alps: Annals of Glaciology, v. 4, p. 85-90.

Harms, J.C., Southard, J.B., Spearing, D.R., and Walker, R.G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists Short Course No. 2 Lecture Notes, 161 p.

Kemmis, T.J., 1991, Glacial landforms, sedimentology and depositional environments of the Des Moines Lobe, northern Iowa: Iowa City, University of Iowa Department of Geology, unpublished Ph.D. thesis, 393 p.

Kemmis, T.J., Bettis, E.A., III, and Quade, D.J., 1987, Sedimentary sequences of Wisconsinan-age outwash streams on the Des Moines Lobe in north-central Iowa: Iowa Academy of Science Program Abstracts, 99th Annual Meeting, abstract no. 153.

Quade, D.J., 1992, Geomorphology, sedimentology and stratigraphy of Late Wisconsinan valley-train terraces along the Iowa River in north-central, Iowa, Unpublished Master's Thesis, University of Iowa, 85 p.

Sturm, M., Beget, J., and Benson, C., 1987, Observations of jokulhlaups from ice-dammed Strandline Lake, Alaska: implications for paleohydrology, *in* Mayer, L. and Nash, D., eds., Catastrophic Flooding: The Binghamton Symposia in Geomorphology: International Series, no. 18, p. 79-94.

STOP 5 — MAGNUSON PIT-BEMIS TILL PLAIN "MINOR MORAINES"
LOCATION: SIOUX RAPIDS SE QUAD, T.90N.,R. 36W., SEC 21 SE¼ SE¼

At this site, we are standing on the Bemis Till Plain. On the drive from Stop 4 you may have noticed that inset onto the broader plain are small, low to moderate relief curvilinear ridges which are generally 1 to 3 m in relief (Figure 1). These features have historically been referred to as "swell and swale topography" and "minor moraines" by geologists for a number of decades (Gwynne, 1942, 1951, Kemmis et al., 1981, and Stewart et al., 1988). More recently, Colgan (1996) suggested that these features should more appropriately be referred to as transversely aligned hummocks or elongated hummocks, given that many of these landforms are not found at the ice margin but behind the end moraine. This author agrees with Colgan that the name "minor moraine" is misleading to some and that most of these features did not form at the terminus.

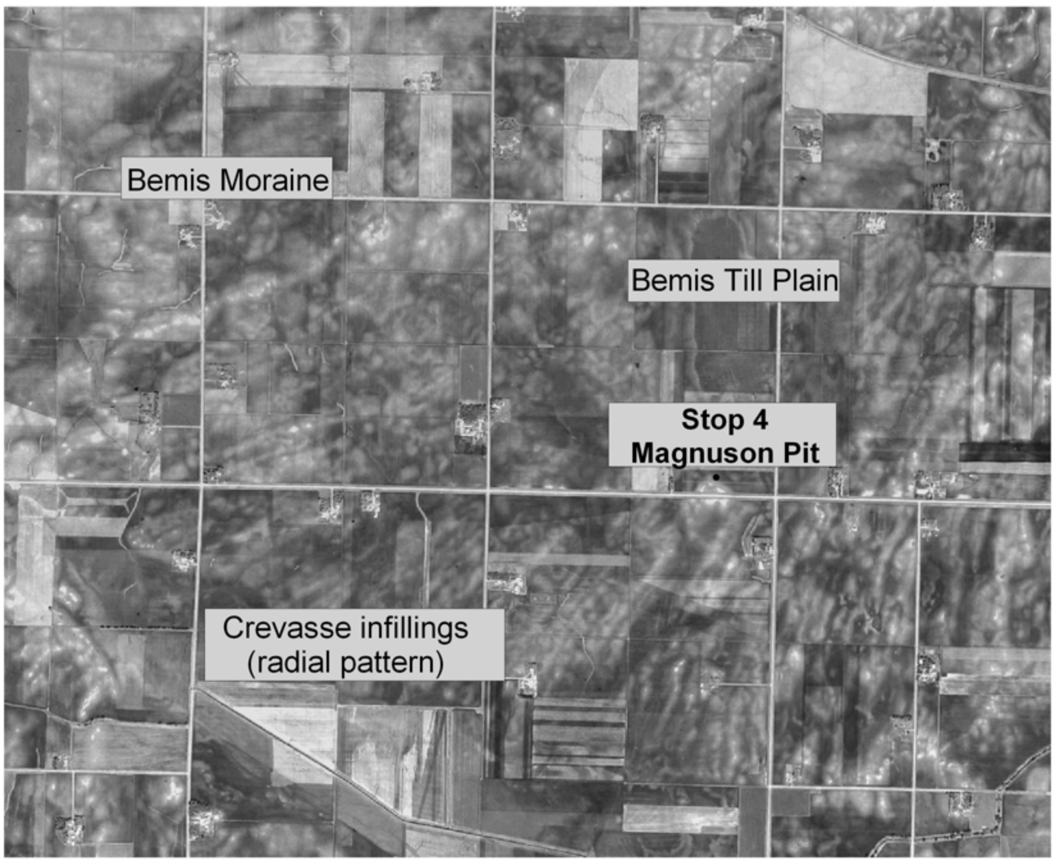

Figure 1. Location of Magnuson Pit in tract of aligned hummocks (crevasse infillings) associated with the Bemis Till Plain. The radial pattern of the hummock tract may be related to the bend in the Bemis Moraine just to the north.

To date, most agree that tracts of aligned hummocks most likely are the result of crevasses forming on the ice sheet due to extensive flow pressure. Iverson (2005) noted that a rapidly sliding ice sheet would be somewhat analogous to the extensive flow of modern day ice shelves (West Antartica) which have large associated crevasse fields. Crevasses are simply defined as cracks in the surface of a glacier or ice sheet caused by extensive stress within the ice and form when the ice sheet is stretched past its breaking point (Figure 2). In this area it appears that we are seeing tracts of former transverse crevasses that formed across the region of the glacier where the speed of the flow of the glacier is increasing. This caused stretching in the direction of the flow of the glacier. Also, it appears we have radial crevasses that form where the glacier begins to turn a corner. The ice on the outside of the corner has to travel faster than the ice on the inside of the corner (note radial pattern in Figure 1). This radial pattern is most likely associated with the curve in the Bemis Moraine directly north of this site (see field trip map).

Beyond the agreement on crevasses as the origin of aligned hummocks there is still discussion concerning if these features are supraglacial, englacial or subglacial in nature. Kemmis and others (1981) and Stewart and others (1988) attributed “minor moraine” formation to crevasses that opened in basal ice with deposition of basal till and glaciofluvial sediment. Iverson (2005) countered that it would be difficult for crevasses to open in basal ice due to tensile stresses that would have to be very high to overcome basal confining pressures that usually squeeze crevasses shut. Iverson (2005) did offer a solution that crevasses could open under a combination of high basal water pressure and water flow, noting that the high water flow could hold basal cavities open and promote ice melting. Several aligned hummocks associated with the Bemis till plain have been cored as part of the STATEMAP Mapping Project. Some of those features had 20 to 30 feet of glaciofluvial material overlying subglacial till. Still others had extremely thick packages of glaciofluvial material (approaching 70 to 80 feet) which may be more indicative of supraglacial/englacial formation rather than subglacial origin. These findings would be in agreement with observations by Carrie Jennings, University of Minnesota, whose work on the DML indicates that most crevasse fills are supraglacial/englacial in nature (Figure 3). However, that said, there is still much to learn about the origin, genesis and nature of aligned hummocks behind the various advances across the extent of the DML.

Figure 2. Modern day crevasse developing on glacier in Iceland. Photo by K. Blake.

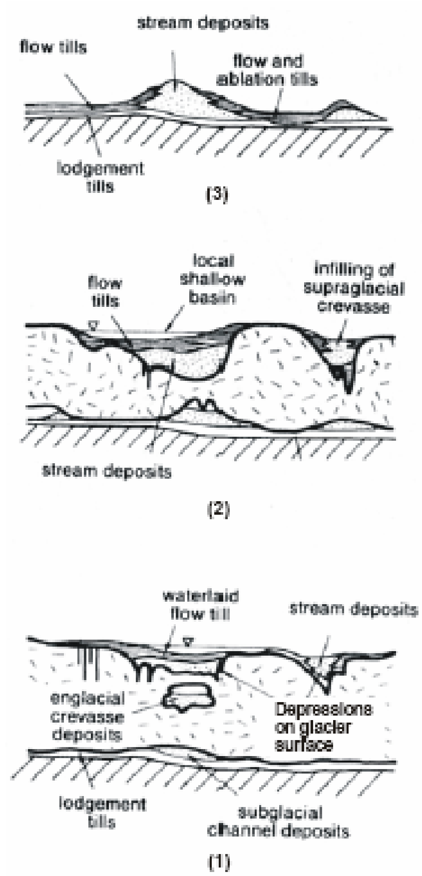

Figure 3. Model for crevasse formation modified from Benn and Evans (1998).

Magnuson Farm Pit (Transverse Crevasse Infill) Generalized Description
Dows Formation—Pilot Knob Member (Figure 4)

0-5 ft -Partially overgrown and covered upper section. Solum developed in cross bedded sand.
5-8 ft - Cross bedded loamy medium to coarse sand which grades down into a gravelly loamy sand with numerous pebbles.
8-10 ft - Cross bedded medium sand with numerous thin beds of interbedded silt.
10-12 ft - Clean fine to medium sand with few thin beds of silt and Fe stains along possible bedding planes.

Figure 4. Cross bedded loamy pebbly sand with interbedded silts. These deposits represent crevasse fills on aligned hummocks associated with the Bemis Till Plain.

REFERENCES

Benn, B.I., and Evans, D.J.A., 1998, Glaciers and Glaciation, Oxford, London.

Colgan, P.M., 1996, The Green Bay and Des Moines Lobes of the Laurentide Ice Sheet: Evidence for the Stable and Unstable Glacier Dynamics 18,000 to 12,000 BP: University of Wisconsin-Madison Department of Geology, Madison, unpublished Ph.D. thesis, 274 p.

Gwynne, C.S., 1942, Swell and swale pattern of the Mankato Lobe of the Wisconsin drift plain in Iowa: Journ. Geol., v. 50, p. 200-208.

Gwynne, C.S., 1951, Minor moraines in South Dakota and Minnesota: Geol. Soc. Amer. Bulletin., v. 62, p. 233-250.

Iverson, N.R., 2005, Tills, Moraines, and Dynamics of the Des Moines Lobe, 66th Annual Tri-State Geological Field Conference Guidebook, Iowa State University, Ames, Iowa, p. 3-11.

Kemmis, T.J., Hallberg, G.R., and Lutengger, A.J., 1981, Depositional environments of glacial sediments and landforms on the Des Moines Lobe, Iowa: Iowa Geological Survey Guidebook No. 6, Iowa City, 132 p.

Stewart, R. A., Bryant, D., and Sweat, M.J., 1988, Nature and origin of corrugated ground moraine of the Des Moines Lobe, Story County, Iowa. Geomorphology, v. 1, p. 111-130.

STOP 6 — SALTS SECTION (TAZEWELL TILL PLAIN)

Due to the weathered exposure at this site we have included a summary of the history of Pleistocene geology of northwest Iowa and the Tazewell till. Also, more recently the Tazewell till has been formally recognized as the Sheldon Creek Formation (Bettis, 1997). The interpretation of the Pleistocene landscapes of northwestern Iowa has changed over time. Lucas (1977) provided a lengthy synopsis on the changing Pleistocene stratigraphy over nearly 75 years. The following is a short synopsis of his discussion of the Pleistocene in northwest Iowa. As early as 1881, Upham was mapping in northwest Iowa. His work was incorporated into the work of Chamberlin (1883, 1894) who assigned the northwest Iowa drift sheet as younger than Kansan (Pre-Illinoian) but older than Wisconsinan. Bain (1897, 1899) waffled with his interpretations. First indicating the drift sheet was either Illinoian or Iowan age, not Kansan. However, by 1899 he mapped the area as two types of Kansan drift: one leached and highly weathered while the other was atypical, as it had unweathered till in its upper portions (near the land surface). Later Calvin (1901, 1904) influenced by the mapping of Frank Leverett, in Minnesota, produced maps designating large areas of northwestern Iowa as Wisconsinan ground moraine. Carman (1917), noting the lack of agreement in previous reports, revisited the study of the Pleistocene in northwestern Iowa. In his 1917 report he again landed on the interpretation that all of northwestern Iowa west of the DML was Kansan in age, but not without much consternation. In 1925, Leverett, Kay and others found an intermediate till in O'Brien County. This prompted restudy of the area again by Carman (1931) that recognized two drift regions, the Iowan and the Kansan regions. Later Smith and Riecken (1947) proposed a southern limit for the Iowan drift region in northwestern Iowa, which greatly extended the reach of the Iowan in northwestern Iowa (Figure 2). They based the new Iowan drift plain boundary from the Kansan on the basis of: 1) lack of a buried soil on the uplands, 2) less dissection and relief on the landscape, and 3) thin loess thickness. Their Iowa drift plain is now referred to as the Northwest Iowa Plains Landform Region (Prior, 1991). It was Ruhe (1950) that reclassified Carmen's Iowan drift as Tazewell and recognized the drift west of the Tazewell and north of the Smith and Reicken line as Iowan (Figure 3). Also, it was Ruhe (1969) that demonstrated that the Iowan was an erosion surface developed in Pre-Illinoian till in eastern Iowa, rather than a separate stage of glaciation. Ruhe's work in northwestern Iowa noted that all of northwestern Iowa had been subjected to erosion from 29,000 to 14,000 years ago, including the Tazewell surface.

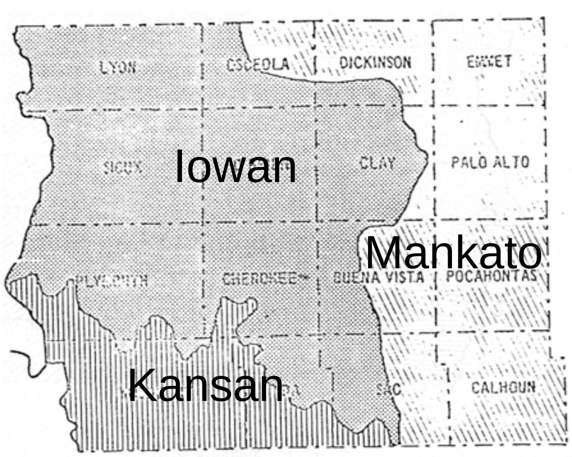

Figure 1. Iowan drift border of northwest Iowa (Smith and Riecken, 1947).

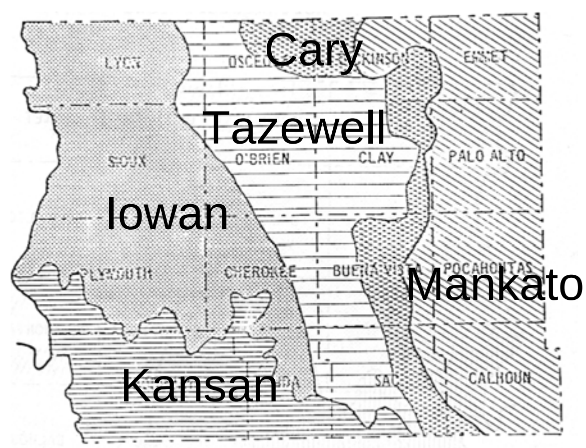

Figure 2. Glacial drifts of northwestern Iowa as identified by Ruhe (1950).

SALT SECTION OVERVIEW

Stop 6 is located just off the Des Moines Lobe (DML) and north of the Little Sioux River on the Tazewell Till plain (Figure 3).

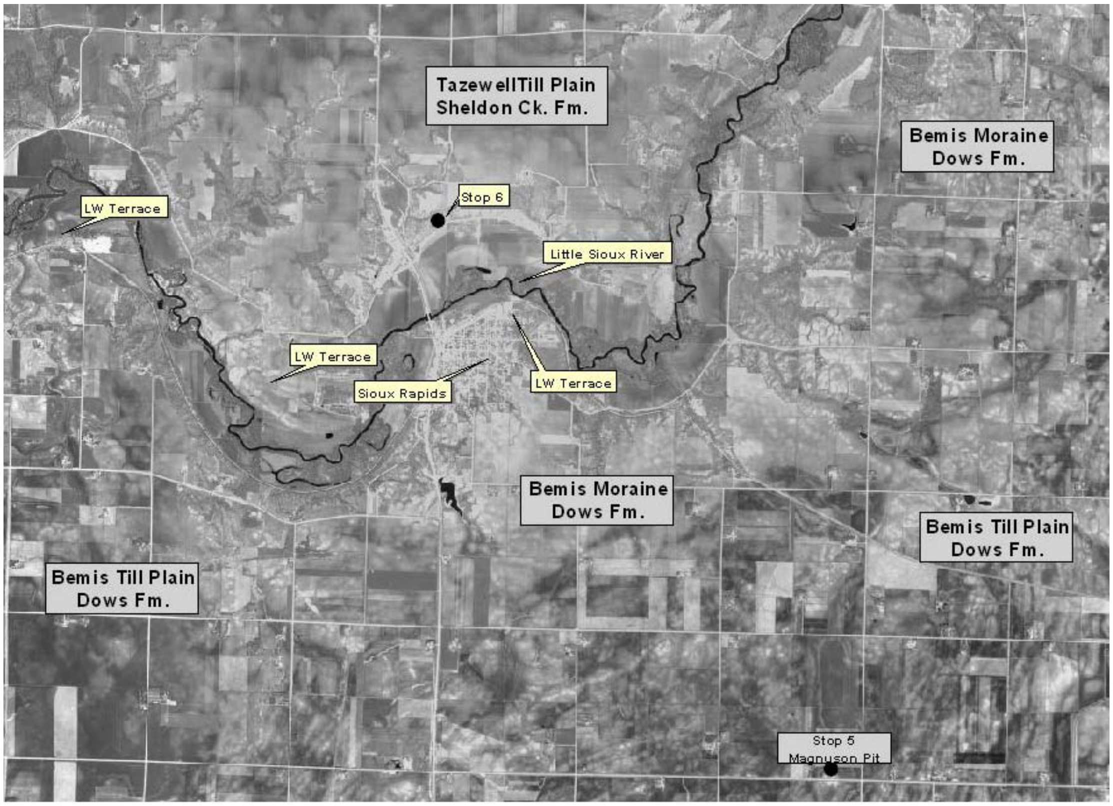

Figure 3. Location of Stop 6 in relationship to the Tazewell Till Plain, the Des Moines Lobe advance, the Little Sioux River valley and Sioux Rapids, Iowa. Note Sioux Rapids is located on a Late Wisconsinan (LW) terrace surface.

At this site there is approximately 30 feet of section behind a house under construction. During our last visit, the section was very dry and appeared to be fairly weathered making it difficult to expose a fresh section. Out of respect for the landowner, we ask trip participants to not use shovels or picks on this section.

The section appears to be approximately 30 ft of unleached, oxidized, jointed clay loam diamicton. It is difficult to access the uppermost section but it appears the upper 3 to 4 feet is loamy sediments overlying the clay loam diamicton. Also, in the upper 7 to 9 feet of the section it appears there are some signs of periglacial activity (solifluction) which gives it a unique structure. As mentioned earlier, Ruhe noted that the Tazewell surface was subjected to erosion processes. Mapping by Quade and others (2004a, 2004b, 2005) confirms the presence of an erosion surface in northwestern Iowa. The clay mineralogy of the Sheldon Creek Formation "Tazewell till" is similar to Des Moines Lobe Dows Formation till (Alden Member) given both formations contain Pierre shale clasts (high in expandable "smectitic" clays). Also, Sheldon Creek Formation deposits usually texture as clay loam diamicton as opposed to a loam texture for Dows Formation Alden Member diamicton. Both formations have distinctive signatures for texture and clay mineralogy that are outlined in detail in the following formal stratigraphic description for the Sheldon Creek Formation.

SHELDON CREEK FORMATION

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

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

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

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

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

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

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

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

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

REFERENCES

Bain, H.F., 1899, Geology of Carroll County: Iowa Geological Survey Annual Report, v. 6, p. 429-476.

Bain, H.F., 1897, Relations of the Wisconsin and Kansan drift sheets in central Iowa and related phenomena: Iowa Geological Survey Annual Report, v. 9, p. 49-107.

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.

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.

Calvin, S., et al., 1901 Preliminary outline map of the drift sheets of Iowa: Iowa Geological Survey Annual Report, v. 11, Plate II.

Calvin, S., et al., 1904 Preliminary outline map of the drift sheets of Iowa: Iowa Geological Survey Annual Report, v. 14, Plate III.

Carman, J.E., 1917, The Pleistocene geology of northwestern Iowa: Iowa Geological Survey Annual Report, v. 26, p. 233-245.

Carman, J.E., 1931, Further studies on the Pleistocene geology of northwestern Iowa: Iowa Geological Survey Annual Report, v. 35, p. 15-194.

Chamberlin, T.C., 1883, Preliminary paper on the terminal moraine of the second glacial epoch: U.S. Geological Survey Third Annual Report, p. 291-402.

Chamberlin, T.C., 1894, Glacial phenomena of North America, in Geikie, James, The great ice age and its relation to the antiquity of man: New York, D. Appleton and Co., p. 724-775 (3rd ed.), p. 724-775.

Kemmis, T.J. Hallberg, G.R. and Lutengger, A.J., 1981, Depositional environments of glacial sediments and landforms on the Des Moines Lobe, Iowa: Iowa Geological Survey Guidebook No. 6, Iowa City, 132 p.

Lucas, J.R., 1977, Till Lithology, Landsat Data, and Geomorphic Surfaces in Northwestern Iowa, University of Iowa Department of Geology, Iowa City, unpublished Ph.D. thesis, 182 p.

Quade, D.J., Giglierano, J.D., and Bettis, E.A. III, 2004a, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 7: Osceola County. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 05-3, 1:100,000 scale map sheet plus report, 25 p.

Quade, D.J., Giglierano, J.D., and Bettis, E.A. III, 2004b, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 6: Dickinson and Emmet Counties. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 04-2, 1:100,000 scale map sheet plus report, 26 p.

Quade, D.J., Giglierano, J.D., and Bettis, E.A. III, 2005, Overview of the Surficial Geologic Map of the Des Moines Lobe of Iowa, Phase 7: Clay County. Iowa Department of Natural Resources-Geological Survey Bureau, Open File Map 05-2, 1:100,000 scale map sheet plus report, 25 p.

Prior, J.C., 1991, Landforms of Iowa, University of Iowa Press, Iowa City, 153 p.

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.

Ruhe, R.V., 1969, Quaternary landscapes in Iowa: Iowa State University Press, Ames, 255 p.

Smith, G.D., and Riecken, F.F., 1947, The Iowan drift border of northwestern Iowa: American Journal of Science, v. 245, p. 706-713.

Upham, W., 1881, Glacial drift and its terminal moraines, in Winchell, N. H., Annual report for the year 1880, 9th: Minnesota Geological Natural History Survey, 392 p.

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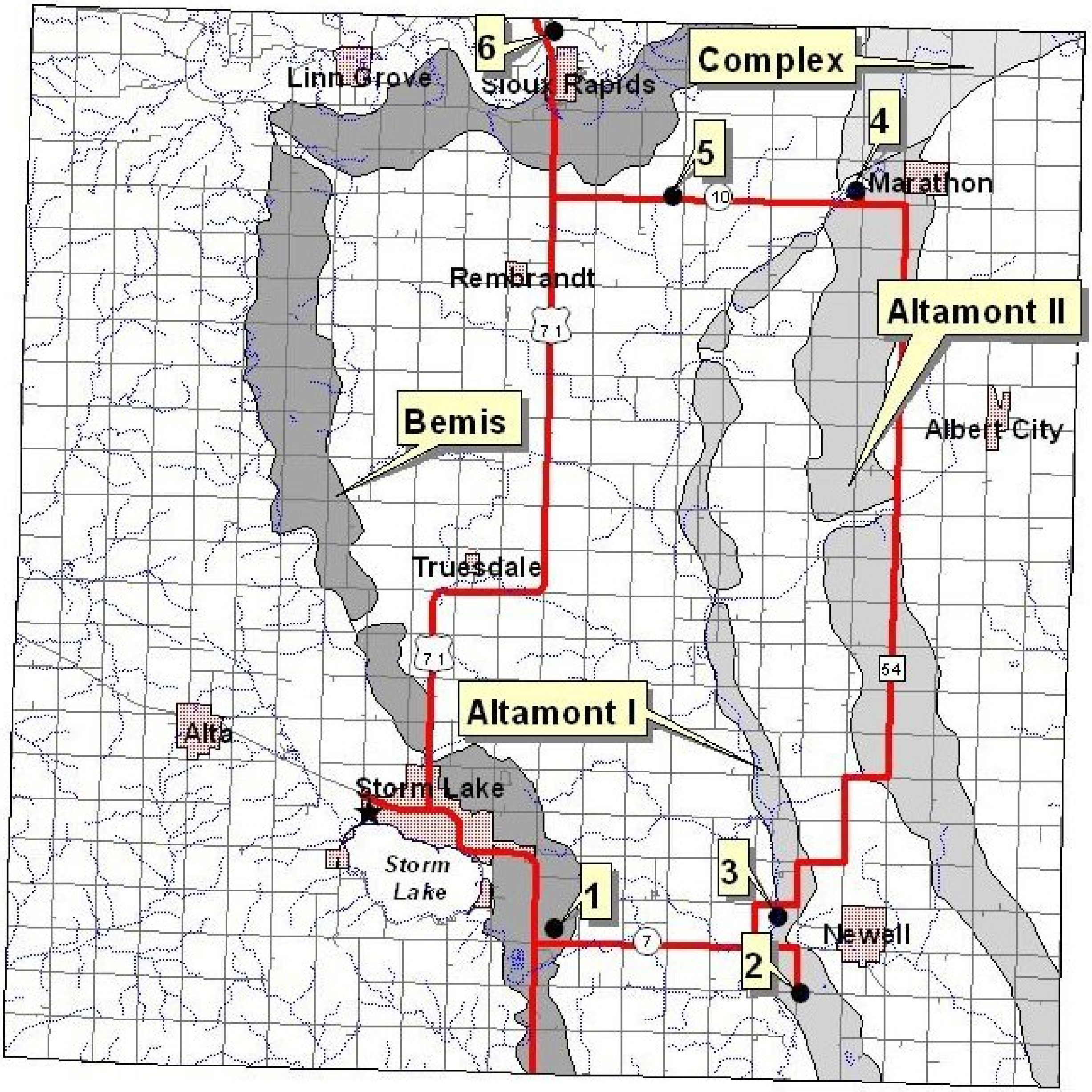

Field Trip Route and Stop Locations

Geological Society of Iowa Field Trip #78

QUATERNARY GEOLOGY OF THE STORM LAKE AREA, IOWA: STORM LAKE OUTLET, DES MOINES LOBE MORAINES, KAMES, VALLEY TRAINS, MINOR MORAINES AND TAZEWELL TILL PLAIN