QUATERNARY LANDFORMS and HYDROGEOLOGY of FENS in CLAY and DICKINSON COUNTIES

or

Mucking About in Northwest Iowa

Trip Leaders:

Carol Thompson
Jean Prior
Deb Quade

Geological Society of Iowa

September 21, 1991 **Guidebook 54**

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ACKNOWLEDGEMENTS

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INTRODUCTION

Glacial Landforms

"The topography of the region before us, for a prairie district, is remarkably varied; we have high mountain-like hills and ridges with corresponding but exceedingly irregular and non-continuous depressions; ... we have long, winding insignificant rivers, moving anon sluggishly in valleys extremely wide and again similar currents hemmed in by precipitous hills through which chance has determined a tortuous and difficult escape... The hills about Diamond Lake, those northwest of Silver Lake, those of Fairview township in Osceola County, simply defy classification or description; they pitch toward every point of the compass, they are of every height and shape, they rise by gradual ascent and fall off by precipices so steep that the most venturesome animal would scarcely attempt descent; they enclose anon high tablelands, anon wide low valleys that open nowhere; they carry lakes on their summits and undrained marshes at their feet; their gentler slopes are beautiful prairies easily amenable to the plough, their crowns are often beds of gravel capped with bowlders and reefs of driven sand."

This description was written by Thomas H. Macbride in his 1899 report on the geology of Osceola and Dickinson counties. Although MacBride did not realize it, he was presenting a vivid description of ice-stagnation topography. The landforms are the result of Wisconsinan glaciation of this area between 14,000 and 12,000 years ago. The Des Moines Lobe is thought to have formed by a surging ice-front well after the period of maximum glacial cold for these latitudes. Clayton and others (1985) have suggested that both advance and retreat occurred very quickly. However, Kemmis (1991) has suggested that regional stagnation occurred rather than active retreat. A thin ice profile has been suggested for the Des Moines Lobe which lends support to such an idea (Mathews, 1974). Deposits in such an environment often consist of complex sedimentary assemblages related to local stagnation conditions rather than the typical end moraine/ground moraine pattern related to active glacial retreat.

The landforms that we will be seeing on this field trip are related to compression along the lateral margins of the ice lobe. Debris normally transported near the base of the glacier is moved up onto the surface of the glacier along shear zones. This material could then be redeposited by meltwater and was subject to slumping and deformation as the underlying ice disintegrated. The result is a jumble of deposits of various textures which can change quickly over short vertical and horizontal distances. The fact that there are two ice advances represented here, with the Altamont overriding the earlier Bemis furthers complicates the sedimentologic picture.

Since few integrated drainage patterns appear in these areas of "knob and kettle topography," the landscape has long been thought to result solely from this collapse-type deposition leaving hummocks as highs on the surrounding till plain. However, recent work Kemmis (1991) has shown that many of the landscape's kettle features and lowland depressions are subtly linked and actually reflect routes of meltwater discharge and outwash deposits. As the stagnant ice wasted away from north-central Iowa following the various surge advances, cavities and tunnels formed within and beneath the ice, some of which were linked to the glacier's surface. These ice-walled conduits served as drainageways for meltwater and glacial debris. The large, deeper portions of this network were probably open throughout the year, while the smaller, upper portions were frozen shut and redeveloped each spring in new locations. In time these drainage systems collapsed and disintegrated; hummocky topography was the result. The larger, more permanent segments of the system became sites of present-day rivers and some of the Lobe's larger lakes. The collapse of smaller segments of this karst-like system in the ice developed into shallower, upland swales and depressions. The irregular concentration of glacial debris that didn't get flushed from these networks resulted in saddle-like ridges which separated segments of the system into kettle-like basins. One of the most significant and unexpected findings to emerge from recent detailed mapping of the maze of landforms and deposits across the Algona advance is this pattern of connected drainage routes.

Figure 1 shows the major glacial advances in relation to the stops on this field trip. Most of the stops will be along the edge of the Des Moines Lobe on either the Altamont or Altamont-Bemis moraine complex, areas where one ice surge has overridden another. Optional stops on Sunday will view some of the landforms associated with the Algona moraine.

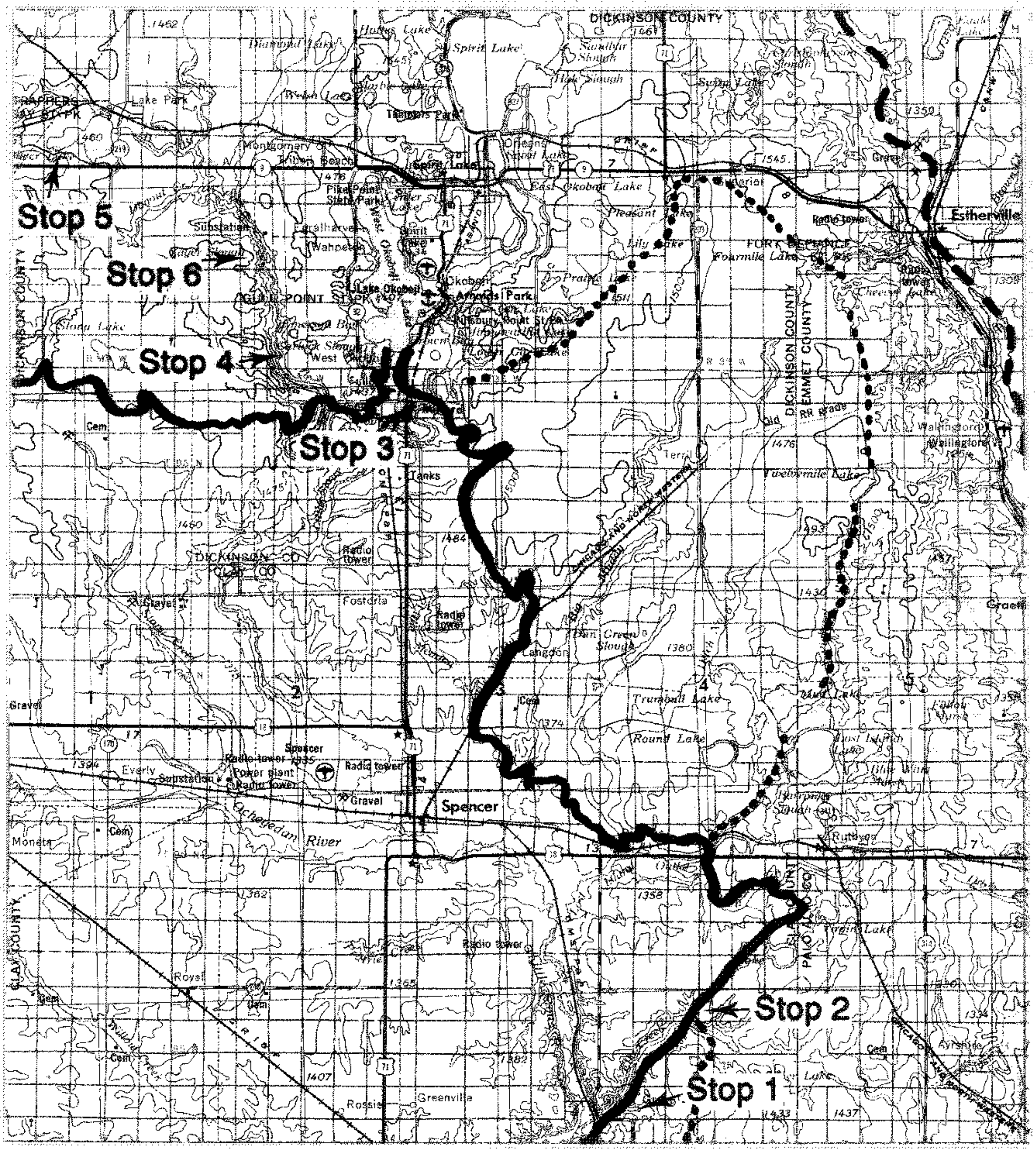

Figure 1. Field trip stops in relation to limits of Des Moines Lobe glacial advances. Solid line-Bemis moraine, dotted line-Altamont moraine, dashed line-Algona moraine. U.S.G.S. Fairmont, NK Series 1:250,00

Fens

On this trip, we will also be examining some of the more unusual wetlands found in Iowa--fens. Fens are a type of peatland which are more commonly thought of as characteristic boreal environments. Peat by definition is a deposit of incompletely decomposed plant remains. Most of the world's peatlands are bogs, from the Celtic word "bocc" meaning "soft." A bog is an acidic peatland which depends entirely on precipitation, leading to nutrient-poor conditions. The minimal decomposition in these environments can lead to the development of very fibrous, woody peats. Fen, from the Anglo-Saxon meaning "mud," is used to describe a type of peatland with a rich nutrient status and a neutral to alkaline pH. This nutrient enrichment is caused by the inflow of groundwater. In these more chemically neutral environments, greater plant decomposition occurs leading to a less fibrous, more mineralized peat or muck.

Fens in Iowa are found in a variety of landscape positions, but the majority occur located on hillslopes. These are wet environments, but standing water is not always present. There are often pools present and biogenic carbonate can be abundant, coating the plant remains. Discharge zones are often recognized by red flocs and "oil" films. They are created as anoxic groundwater discharges from iron-rich sediments. Tufa can be present sometimes forming lenses in the peat body, at some sites the biogenic carbonate is dispersed throughout altering the color of cores.

The peat itself shows a variety of textures. There are several scales available for describing the consistency and texture of peat. The suborders of Histosols are differentiated on the basis of perceived decomposition. Histosols with a fibrous organic matrix and easily identifiable plant remains are called fibrist (Oi), those with intermediate fiber characteristics are called hemist (Oe), and those with completely decomposed remains are saprist (Oa) (Everett, 1983). The International Peat Society also recognizes three categories of decomposition: R1 is spongy, fibrous peat with identifiable plant remains; R2 is amorphous-fibrous with some identifiable remains; and R3 is amorphous composed mainly of humus. One other scale commonly used is the Von Post scale which lists ten (H1-H10) categories based on decomposition. All of the above scales are somewhat subjective. There are also more quantitative methods based on sieve analysis, humic-acid content, or cation-exchange capacity. The majority of peat in Iowa fens is a fairly well-decomposed peat with few identifiable plant remains (Oa, R3, H8-10). In some fens, layers of more fibrous peat (Oe, R2, H6-7) are present, often right above the contact with the underlying sand and gravel or till.

The Preserves and Ecological Services Bureau of the Iowa Department of Natural Resources conducted a state-wide survey of fens, locating over 300 sites in 27 counties. They have ranked these sites based primarily on vascular plant assemblages and in particular the presence of rare species. Of these sites 11 are ranked as very high quality, 18 as high quality, and 34 as medium quality. Unfortunately, several of these sites have been altered, damaged, or destroyed in the past few years. Only seven sites are in public ownership. Iowa's fens are home to more than 200 species of plants, including 24 rare species. Twelve of these rare plants are restricted to fen habitats. As such, fens provide important habitats for preserving Iowa's botanical diversity. Although, in general, wetlands are nitrogen-limited environments, there is still concern over possible agricultural side-effects. Several studies have shown a shift in the species composition as well as lower species diversity as nitrogen inputs increase. Most of these studies were done with large nitrogen increases as in the case with sewage loadings. There is little data available on low-rate loadings. A shift toward more nutrient-tolerant plants could seriously affect survival of many fen-typic species.

In an attempt to better understand the dynamics of Iowa fens, a combined geologic and water chemistry study was started by the DNR - Geological Survey Bureau in 1989. A group of 20 fens located across northern Iowa were chosen for study. At each of these sites, wells were installed upgradient of the fen in sand and gravel. This allowed an evaluation of incoming groundwater quality. In addition, samples were collected from fen outflow. Detailed topographic mapping and coring at the sites allowed us to develop an understanding of the geometry and geology of these sites. Nineteen of the twenty sites have been radiocarbon dated, the first such data on these features in Iowa.

From this work, we have developed a classification for Iowa fens based on landscape position and stratigraphic setting. The categories developed are: 1) fens developed along valley walls where inter-till sand and gravel is exposed (Fig. 2a); 2) fens in hummocky topography on the northwestern margin of the Des Moines Lobe, recharged by sand and gravel buried within glacial till (intra-till, often exhibiting confined flow conditions (Fig. 2b); 3) those located along ridges of exhumed sand and gravel on the Iowan surface (Fig. 2c); 4) fens at the base of benched alluvial terraces or glacial outwash deposits (Fig. 2d); 5) fens recharged by bedrock aquifers (Fig. 2e); and 6) fens occupying abandoned channel areas (Fig. 2f). On this trip we will be making stops at three of these categories: inter-till, intra-till, and outwash. The geology of these sites controls the recharge of the fen and the subsequent water chemistry. Thus, the classification system permits a preliminary assessment of the vulnerability of the fen to possible chemical alterations.

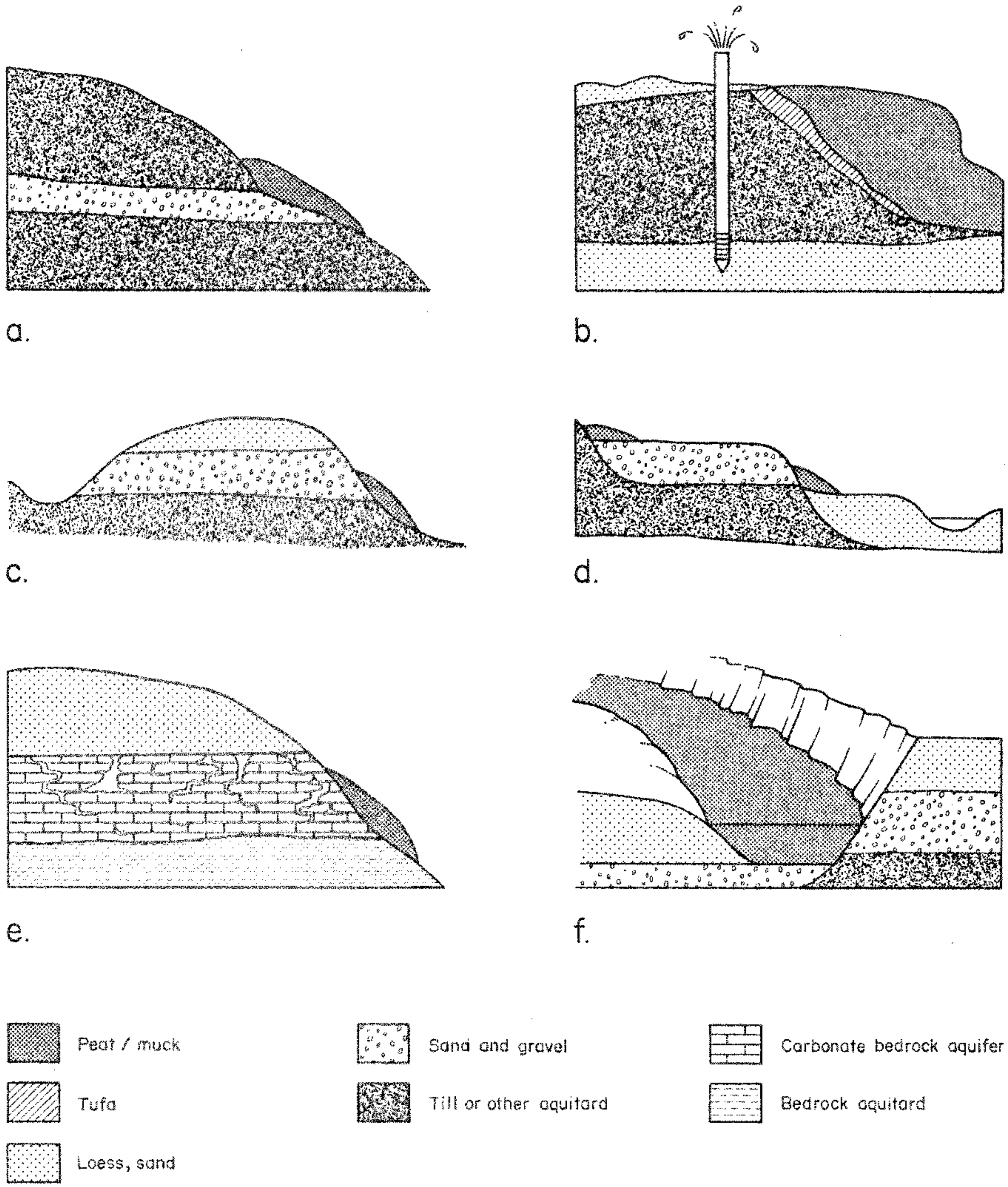

Figure 2. Schematic diagram showing geologic settings of Iowa fens: a) inter-till; b) intra-till; c) gravel ridge; d) terrace, outwash; e) bedrock; and f) abandoned channel.

The water chemistry work has shown interesting results. Western fen sites appear to be different than eastern sites. Concentrations of most common ions are higher in western Iowa than in eastern Iowa, while the reverse is true for nitrate concentrations. These differences can be explained by reference to the weathering characteristics of the surrounding geological materials, which control recharge rate, and the lithologies of the various units. In addition, the regional climatic gradient can lead to accumulation of soluble salts in some western deposits.

Incoming nitrate-nitrogen concentrations at the 20 sites ranged from <0.1 to 26 mg/l, averaging 7.1 mg/l. Samples from the fens showed a similar range, <0.1 to 18 mg/l, but had a significantly lower average, 3.2 mg/l, primarily as a result of denitrification in the fen. Herbicides were detected in wells at 7 of 19 sites and in the fens at 11 of 19 sites. Herbicide concentrations were generally low. Of note was the fact that different herbicides were found in the wells in contrast to the fens. This may indicate that pesticides are entering the fens along pathways other than groundwater flow, or that interactions are occurring within the fens.

Many of these water quality differences can also be related to the geological fen-classification system. Fens where sand and gravel is at the surface such as outwash, alluvial, or gravel ridge settings are more susceptible to surface-derived alteration of their water chemistry. Fens in which the recharge water must first filter through a till sequence would seem to be less susceptible, but there are also differences between eastern and western sites. Variation in weathering profiles and secondary fracture patterns may provide an explanation for these water chemistry differences. The highly weathered, jointed materials around the eastern sites promote rapid flow-through of water to the sand and gravel. In many cases, the water table is within the sand and gravel. Seasonal fluctuations will affect the supply of water; in addition, precipitation effects are rapidly transferred to the aquifer. Less fracturing and shallower weathering profiles around western intra-till and inter-till sites results in slower infiltration rates. Denitrification in western tills also occurs and can reduce the nitrate loads delivered to fen sites.

Although not yet complete, the dating of these sites has provided some interesting data. Radiocarbon dates of basal peat from cores taken in the thickest peat sections range in age from 1240 ± 60 to 10,220 ± 110 RCYBP at the ten western fens. Eastern sites of which four have been dated, range in age from 2130 ± 60 to 8340 ± 80 RCBYP. Only four sites are greater than 5000 years old. Most Iowa fens apparently witnessed either net organic matter decomposition or burning during the middle Holocene

(7000-5000 B.P.). This was a period of extended droughts, expansion of prairie, and frequent fire (Webb et al., 1983; Van Zant, 1979) with many wetland areas receiving significant mineral sedimentation (Walker, 1966).

Management and protection of these sites is becoming more of an issue as the importance of fens is realized. One of the problems is that we still know very little about these environments. The biological diversity of the system is important, yet we have very little information on the many of the components of the system. For instance, different conclusions could be reached about the value of a site based on its vascular plants versus its mosses or snails. As in most ecosystems, the entire system reacts to outside influences making it difficult to manage for specific elements. Fens are dynamic systems and will change in response to erosion and climatic influences. Overall maintenance of the hydrologic system is important. A continued supply of groundwater is necessary for continued existence. The possibility of long-term nutrient alteration needs to be considered. In the short term, other management strategies also have to be considered. Fens are fragile environments and need to be protected from physical alteration. Many sites are surrounded by active pasture and cattle trampling can cause irreversible damage, particularly in drier years when cattle may be forced deeper into the fen in search of water.

The legal status of fens is unclear. Although they technically are covered under Section 404 of the Clean Water Act, the majority of the sites would fall under the nation-wide permits which are issued for sites less than 10 acres. The 1990 Food Security Act has provisions aimed at discouraging wetland conversions, and, in addition, includes provisions for a wetland reserve program. However, the definition of a wetland is still under debate. In the current federal interagency manual, fens are clearly recognized as wetlands as is true in the proposed revisions. Iowa, however, in their wetland protection bill of 1990 uses the old U.S. Fish and Wildlife classification scheme, and the types of wetlands recognized in this bill do not include fens. One law that would apply is the Endangered Species Act which prohibits the taking of endangered or threatened species of either plants or animals. As previously pointed out, there are 23 species of state-endangered or state-threatened plants found in Iowa fens.

However, legal coercion may not be required. Many landowners are interested in these sites and are willing to protect them. Many wildlife and wetland professionals are not even aware of the existence of these sites much less their importance or rarity. A program aimed at education of landowners in addition to wildlife and wetland managers is needed.

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STOP 1. LINDSTROM-SIMONS FEN

Lindstrom-Simons Fen in southeastern Clay County is developed along the sides of a tributary to Elk Creek. This is a fen complex with eight discrete fens totaling about 20 acres. The site (70 acres pasture, 83 acres cropland) was purchased by the Nature Conservancy in 1990 and is currently being transferred to the State of Iowa. Management of the site will be provided by the DNR Wildlife Bureau in conjunction with the Preserves and Ecological Services Bureau. The site is ranked as one of the top fens in Iowa and among the species present are Low Nut Rush which is endangered in Iowa; Capillary Beak Rush, Marsh Arrow Grass, and Small Fringed Gentian which are threatened in Iowa; and Kalm's Lobelia and Grass of Parnassus which are of special concern in Iowa. There are at least 60 native plant species present and 11 of these are uncommon. Frest (1990) lists 17 species of land snails at this site including Hawaiia n. sp. (suggested Iowa and Federal status-endangered) and Vertigo eliator (suggested Iowa and Federal status-threatened).

Land use in the area is primarily row crop; the area immediately surrounding the fen is in pasture. Soils upslope from the fen are loams to sandy loams developed in till and sand and gravel. Elk Creek marks the boundary of the Des Moines Lobe and the fen complex is located on the Bemis morainal surface (Fig. 3). Water is supplied to the fen from an inter-till sand and gravel layer. The thickness and extent of this layer is unknown. Thus in the geological classification schemes developed for Iowa fens, this is the most common type, inter-till.

A portion of the site was mapped and cored in August, 1990. Figures 4 and 5 show fen surface topography, peat thickness, and a cross-section through the fen. A maximum peat thickness of just under 12 feet was found in the lower part of the sedge area. Sand and gravel forms the substrate under the peat along the upper part of the fen. The lower part of the fen rests on till. Cores throughout the fen show that the peat is generally well decomposed (R3 on the International Peat Society Scale), but there are a few layers of non-woody, fine fibrous peat (R2). These especially tend to occur near the bottom of the peat just before contact with the underlying till. There is disseminated carbonate throughout the core. A core taken from the thickest area of peat returned a bottom date of 2720 ± 20 RCYBP. This is in keeping with the dates on other fens in the area and implies that peat development began during the later part of the Holocene during relatively moist conditions.

A well was installed in the sand and gravel near the upslope edge of the fen. Water samples were collected both from the well and from fen discharge on 6/89, 10/89, and 6/90 (Table 1). The

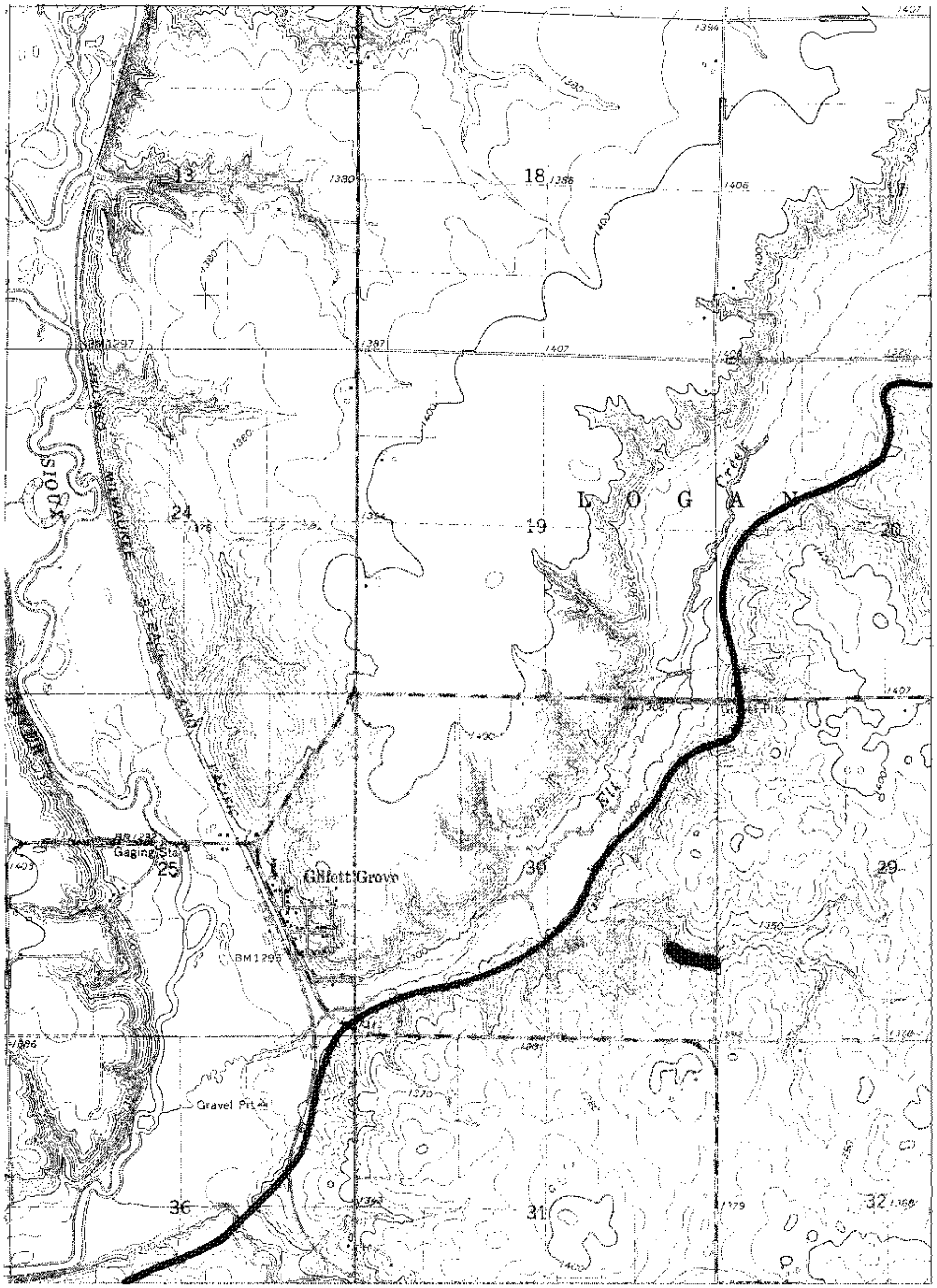

Figure 3. Location of Lindstrom-Simons Fen along the western boundary of the Des Moines Lobe (shown as heavy line). U.S.G.S. Gillett Grove 7.5 minute quad, 1:24,000

LINDSTROM-SIMONS FEN

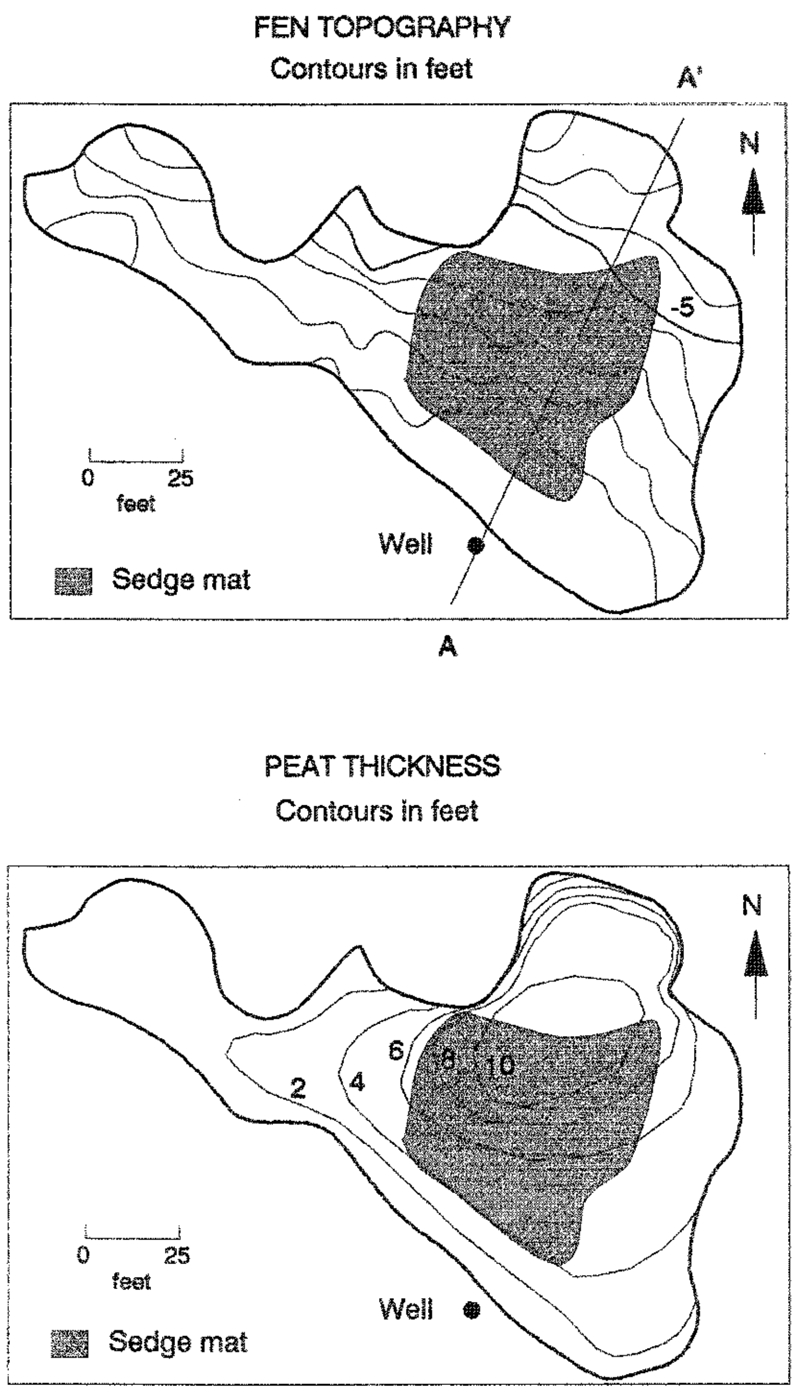

Figure 4. Contour maps of surface topography and peat thickness at Lindstrom-Simons fen.

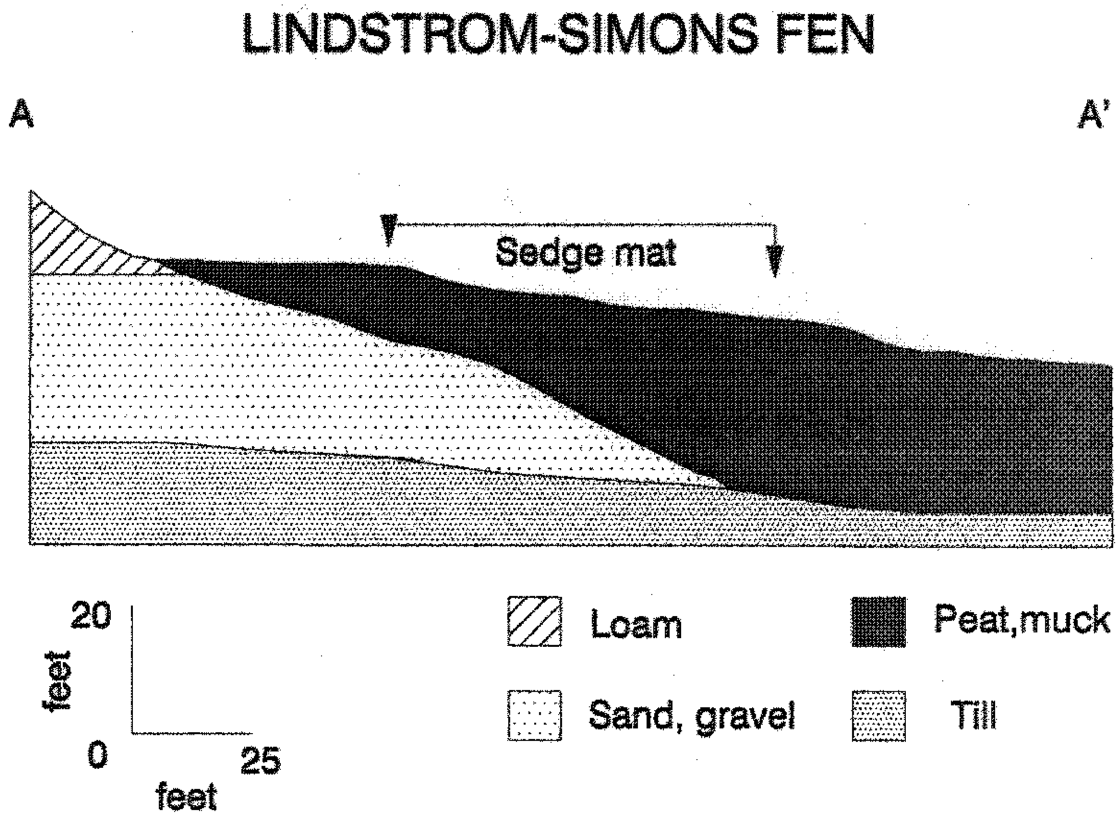

Figure 5. Geologic cross-section of Lindstrom-Simons Fen.

incoming groundwater from the well is a calcium-bicarbonate type. Dissolved oxygen levels were between 5 and 7 mg/l indicating moderately oxygenated water. Conductivity is average for shallow groundwater as are major ions. Nitrate in the incoming groundwater was between 3 and 13 mg/l NO3-N which indicates the water was being affected by agricultural practices in the area.

Water samples from the fen discharge are similar. Nitrate was present in these samples which is surprising in view of the work being done at ISU on nitrate removal in marsh sediments (Tom Isenhart, personal communication). Generally, the process of nitrate removal is very rapid. It is possible that a very short flow path was involved which was very near the interface with the sand and gravel; thus, only incomplete denitrification appears to have occurred. Two herbicides (Lasso and Dual) were detected in the fen sample from 6/89 both in low concentrations (0.12 μg/l). No pesticides were found in the groundwater.

Table 1. Water Chemistry at Lindstrom-Simons Fen
(all measurements in mg/l except for conductivity μhmos/cm)

SITE	DATE	T(C)	pH	D.O.	COND.	ALK.
Lindstrom–Simons well	06/12/89		7.13	6.2	550	358
Lindstrom–Simons well	10/11/89	13.0	7.23	5.0	415	288
Lindstrom–Simons well	06/12/90	13.5	7.05	7.0	490	322
Lindstrom–Simons fen	06/12/89	20.0	7.94	8.0	560	392
Lindstrom–Simons fen	10/11/89	18.0	7.48	8.0	410	288
Lindstrom–Simons fen	06/12/90	21.5	7.32	6.0	530	314

SITE	NA	K	MG	CA	F	CL	SO4	NO3
Lindstrom–Simons well	4.50	2.39	37.97	79.69	0.35	13.53	67.44	8.38
Lindstrom–Simons well								
Lindstrom–Simons well	4.88	5.44	26.58	94.19	0.10	14.21	72.86	12.38
Lindstrom–Simons fen	1.33	0.00	70.58	67.99	0.34	15.67	75.76	3.24
Lindstrom–Simons fen								
Lindstrom–Simons fen	6.08	2.98	27.23	90.69	0.10	14.72	74.71	3.05

References

Frest, T.J., 1990, Final report field survey of Iowa spring fens: unpublished report, 73 p.

STOP 2. BARTON FEN

Barton Fen in southeastern Clay County is developed along a gentle, west-facing slope of a small tributary to Elk Creek. Total acreage is about 10 acres which includes one linear fen with three separate sedge mats and a separate fen in a small side drainage. The site is privately owned. Among the plant species present are: Capillary Beak Rush, Marsh Arrow Grass, and Small Fringed Gentian which are threatened in Iowa; and Kalm's Lobelia and Grass of Parnassus which are of special concern in Iowa. Frest (1990) lists 12 snail species present; but with regard to land snails, he lists the site as highly disturbed.

Land use in the area is primarily row crop similar to that at Lindstrom-Simons Fen. The fen itself is surrounded by active pasture. Soils upslope from the fen loams and fine sandy loams developed in sand and gravel. The site is at the southern end of an extensive outwash terrace deposited by meltwater drainage from the Des Moines Lobe, the western edge of which can be seen about 1/2 mile to the east (Fig. 6). Water is supplied to the fen via this outwash layer and the geological classification is an outwash fen (Fig. 2). All of the known fens in this category are located on or in close proximity to the western edge of the Des Moines Lobe.

The main fen was mapped and cored in August, 1990 (Figs. 7 and 8). Coring at this site revealed some interesting stratigraphy. Much of the material is a well-decomposed peat (R3), although there is some less decomposed, fibrous peat(R2). Biogenic carbonate is evident throughout most of the cores and includes recognizable snails and shell fragments. The overall color of some of the cores tends to a grayish brown as opposed to the dark brown of non-carbonate-rich peats. There are also layers of tufa and/or marl in some locations. Cores in part of the middle sedge area and on the lower terrace show a sub-peat layer of light gray, very fine silt perhaps representing a pond deposit.

The maximum peat thickness found during coring was 15 feet and was just at the edge of the middle sedge mat. It is interesting to note that maximum peat thickness is not coincident with the sedge mat which is often described as a discharge zone. At this site it would appear that the sedge zones have developed upslope of areas of maximum peat accumulation.

The cross-section shows a steeper gradient on the substrate than the current landscape and the position of the silt implies the possible presence of a small pond early in the evolution of this site. Looking at Figure 6 there is a constriction in the valley through which all of the outwash must have passed. This may have acted to reduce flow behind the constriction allowing deeper water to develop. There is also the possibility of backflooding

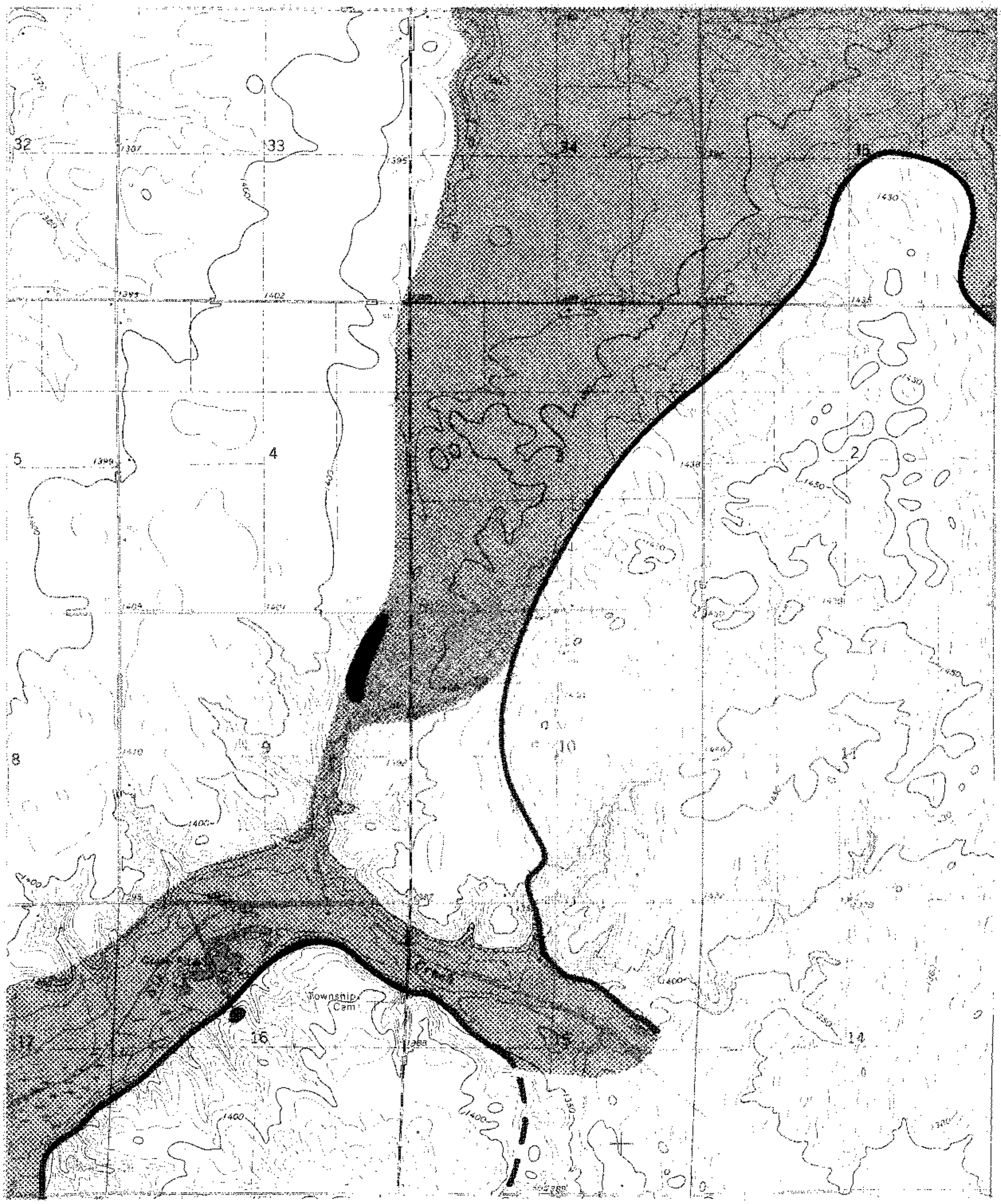

Figure 6. Location of Barton Fen (NE 1/4 section 9) in relation to outwash channels along the western margin of the Des Moines Lobe. Also shown is Evans Fen in the NW section 16. Solid line-Bemis moraine, dashed line-Altamont moraine. U.S.G.S. Silver Lake 7.5 minute quad, 1:24,000

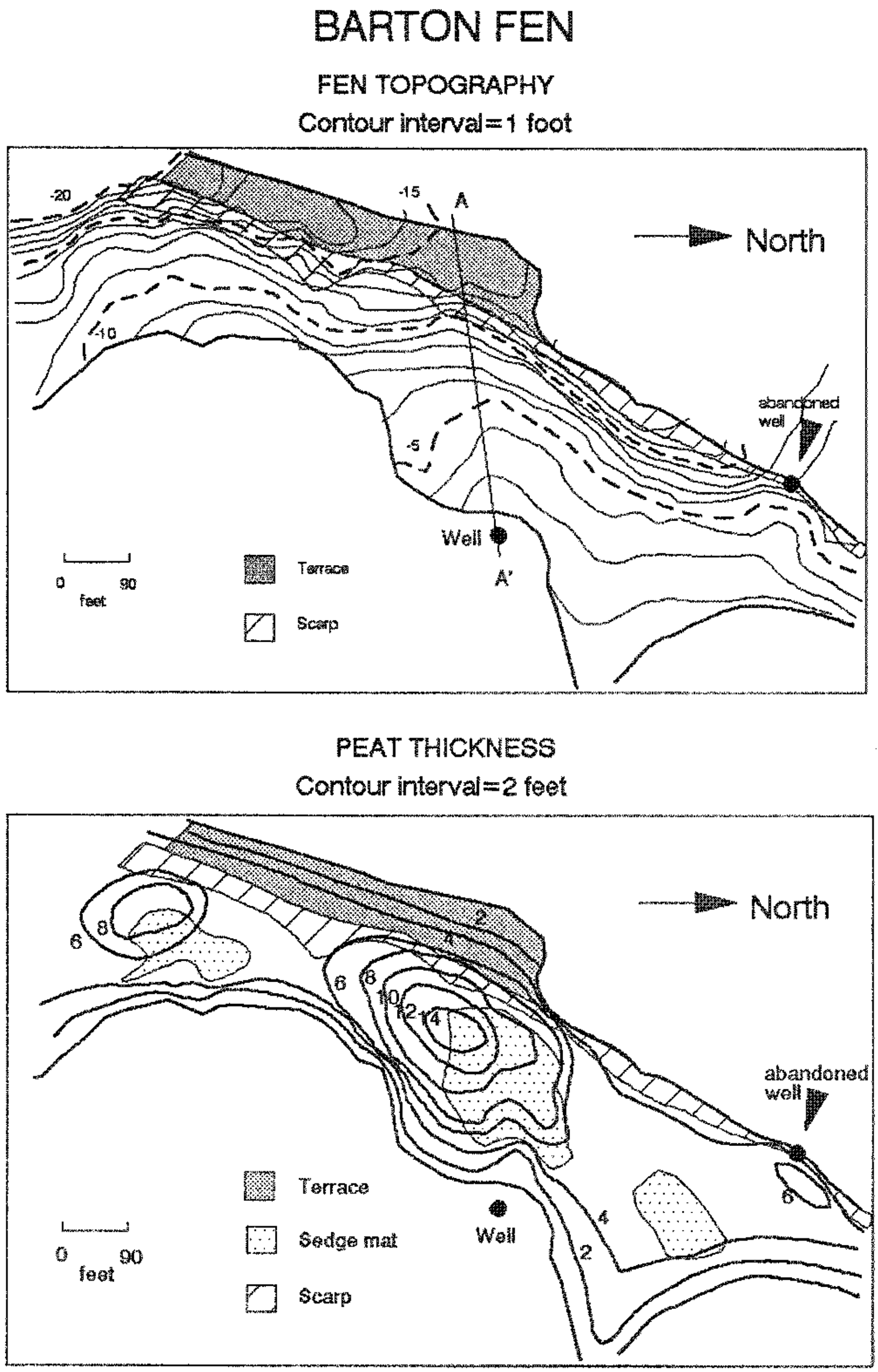

Figure 7. Contour maps of surface topography and peat thickness at Barton Fen.

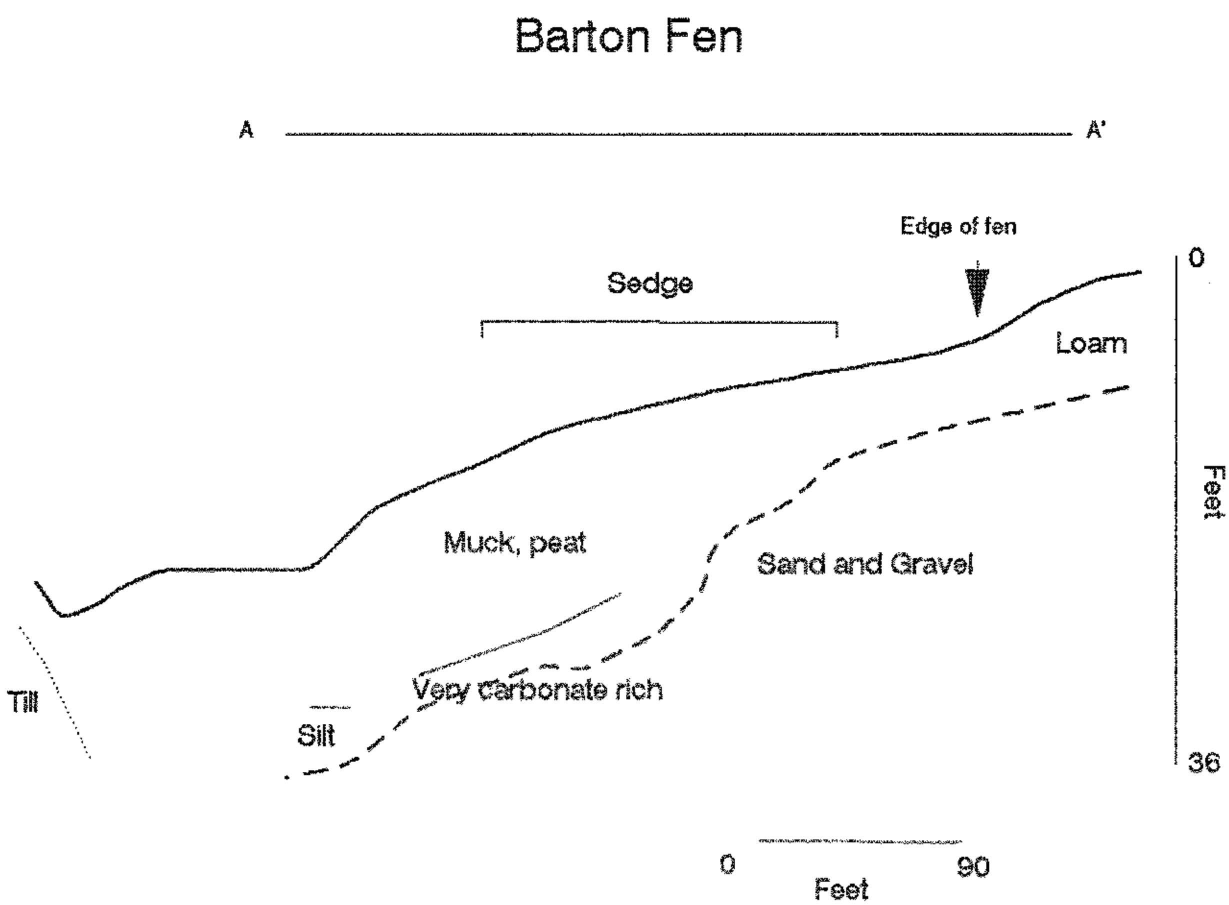

Figure 8. Geologic cross-section of Barton Fen.

from either Elk Creek or even the Little Sioux River discharges during melting of the glacial ice. Such speculation presents interesting avenues for further research in this area.

A core was taken near the edge of the middle sedge mat in the thickest section of peat and was dated at 3390 ± 70 RCYBP. This then would appear to be a site which was not active during the middle Holocene. No evidence of a burned layer at the base was seen.

Water samples collected from the incoming groundwater are typical in most respects to those from the Lindstrom-Simons site (Table 2). The water is a calcium-bicarbonate type with conductivities within expected ranges. Nitrate concentrations have been high ranging from 14 to 46 mg/l NO3-N. Since this fen is fed by outwash sand and gravel which is very susceptible to agricultural contamination, these high nitrate concentrations are not surprising. Nitrate concentrations decrease significantly in the fen, although when incoming nitrate concentrations are very high incomplete denitrification apparently occurs as nitrate is still present in fen outflow. Sulfate concentrations are also interesting: fen outflow has higher concentrations than are present in the groundwater inflow. This is true at several fen sites, but currently there is no adequate explanation. Herbicides were detected in the well and in the fen. Lasso and Sencor were found in the well and Dual in the fen. The concentration of Sencor declined over the summer from an initial 2.7 μg/l to 0.74 μg/l.

This site is one of two (the other is in eastern Iowa in Fayette County) being used in a further study on the hydrology and water chemistry of fens. A total of 11 nested well sets have been installed (6 at Barton Fen) and are being sampled monthly for major ions. Hopefully this work will aid in a better understanding of flow paths and chemical interactions in the fen.

<u>References</u>

Frest, T.J., 1990, Final report field survey of Iowa spring fens: unpublished report, 73 p.

Table 2. Water Chemistry at Barton Fen
(all measurements in mg/l except for conductivity μhmos/cm)

SITE	DATE	T(C)	pH	D.O.	COND.	ALK.
Barton well	06/13/89	17.0	7.52	8.3	535	302
Barton well	10/11/89	12.0	7.43	5.0	420	254
Barton well	06/12/90	12.0	7.25	5.0	515	242
Barton fen	06/13/89	14.0	7.45	3.4	680	312
Barton fen	10/11/89	9.5	7.39	4.0	570	414
Barton fen	06/12/90	20.0	6.86	3.0	465	206

SITE	NA	K	MG	CA	F	CL	SO4	NO3
Barton well	13.55	6.94	38.76	110.18	0.34	29.18	41.33	14.29
Barton well								
Barton well	9.57	3.94	25.71	96.52	0.10	29.17	62.78	46.74
Barton fen	13.99	6.30	51.85	104.56	0.39	34.56	184.89	0.00
Barton fen								
Barton fen	6.13	3.26	25.72	87.89	0.10	24.19	96.64	2.01

STOP 3. TERRACE STRATIGRAPHY AND GEOMORPHOLOGY OF THE OKOBOJI LAKE OUTLET.

Deb Quade, Tim Kemmis, Art Bettis

PLEASE STAND AWAY FROM THE PIT WALLS AT THIS SITE. THEY ARE EXTREMELY UNSTABLE.

Glacial drainage of the Des Moines Lobe was unusual in being concentrated at several distinct outlets rather than fringed by marginal outwash plains. The Okoboji Lake Outlet was an important drainage outlet along the northwestern edge of the lobe (Figure 9). This outlet now drains an interconnected system of lakes and sloughs, including Lower and Upper Gar, East and West Okoboji, Little Spirit, Spirit, Center, Marble, and Hottes lakes.

The geomorphology and stratigraphy of the "Iowa Great Lakes" outlet system are identical to those of much larger streams on the Des Moines Lobe, such as the Iowa and Des Moines rivers, which also originated as meltwater drainageways:

1. The valley has multiple terrace levels, indicating multiple periods of incision and aggradation. Along the Okoboji Lake Outlet, successive terraces are "benched" progressively lower into Des Moines Lobe glacial deposits ("till").

2. The stratigraphic sequences are dominated by coarse sand-and-gravel fluvial sediment deposited from bedload and suspended load; fine-grained overbank deposits occur only as the uppermost veneer.

3. A wide variety of sediment types and structures (facies) indicate significant stream-flow fluctuation as each terrace sequence aggraded.

4. Despite the wide variety of facies, each terrace sequence can be grouped into 3 distinctly different stratigraphic increments. Informally, these are:

   a. a lower increment, dominated by sands and pebbly sands. The thickest of the three increments, it usually also has the widest variety of sedimentary structures. Here at Stop 3, however, the sedimentary structures are mostly different cross-bed types (Figure 10) deposited by dune migration across the former outwash channel floor.

   b. a middle increment, dominated by poorly sorted cobble gravel. This increment unconformably overlies the lower increment, and its base at Stop 3 is marked by a cobble line. At this site, the lower one-half of the increment consists of cobble gravels and coarse pebbly sands in large-scale cross-beds and channel fills. The upper one-half is dominated by very poorly sorted, planar-bedded, cobble gravels. The poor sorting in these gravels indicates a stream with high sediment supply and the simultaneous deposition of both bedload and suspended load. The middle increment of Wisconsinan outwash terraces is typically 1.5 to 2.5 m thick.

c. a thin upper increment of fine-grained sandy loam to loam overbank sediment. In the Okoboji outlet system, this increment is typically 0.3 to 0.7 m thick. It consists of massive to fining upward fine-grained sediment (sandy loam texture).

5. At any given terrace level, there is downstream fining, particularly of middle-increment deposits. For instance, the modal clast diameter in the middle increment at Stop 3 (Site 1, Figure 11) is approximately 20-30 cm; downstream at Site 3 it is 7-10 cm.

6. Modal clast diameters of the middle increment in the lowest, youngest terrace (Site 4; Figure 11) are smaller than those in the older, higher terraces.

Lakes are commonly regarded as sediment "traps" allowing only the finest sediment to escape over the spillway in suspension. Obviously, there were no lakes present in the Okoboji system when the very coarse, poorly sorted sediment of the Okoboji Lake Outlet system was deposited. However, the stratigraphic sequences of terraces in the Okoboji Lake Outlet are typical of glacial outwash streams on the Des Moines Lobe. The coarse sand-and-gravel sequence indicates high input of sediment from a glacial source, and the wide variety of sedimentary structures reflects the highly varying discharge characteristic of glacial meltwater streams.

The multiple terraces, each with a coarse middle increment near the top, also provide clues about terrace development and valley evolution in this type of stream valley (Kemmis et al., 1988). The middle and upper increments are interpreted to have been deposited by a low-frequency, high-discharge flood; the coarse, unconformable middle increment was deposited in the flood channel and the fine-grained upper increment was later deposited from waning flood flow or as overbank deposits. As the middle and upper increments were deposited, portions of the channel were incised to a new, lower level, ultimately leaving portions of the former channel as a terrace when flood flow receded. Valley evolution, then, occurred episodically in a series of widening and deepening events caused by low-frequency, high-discharge meltwater floods.

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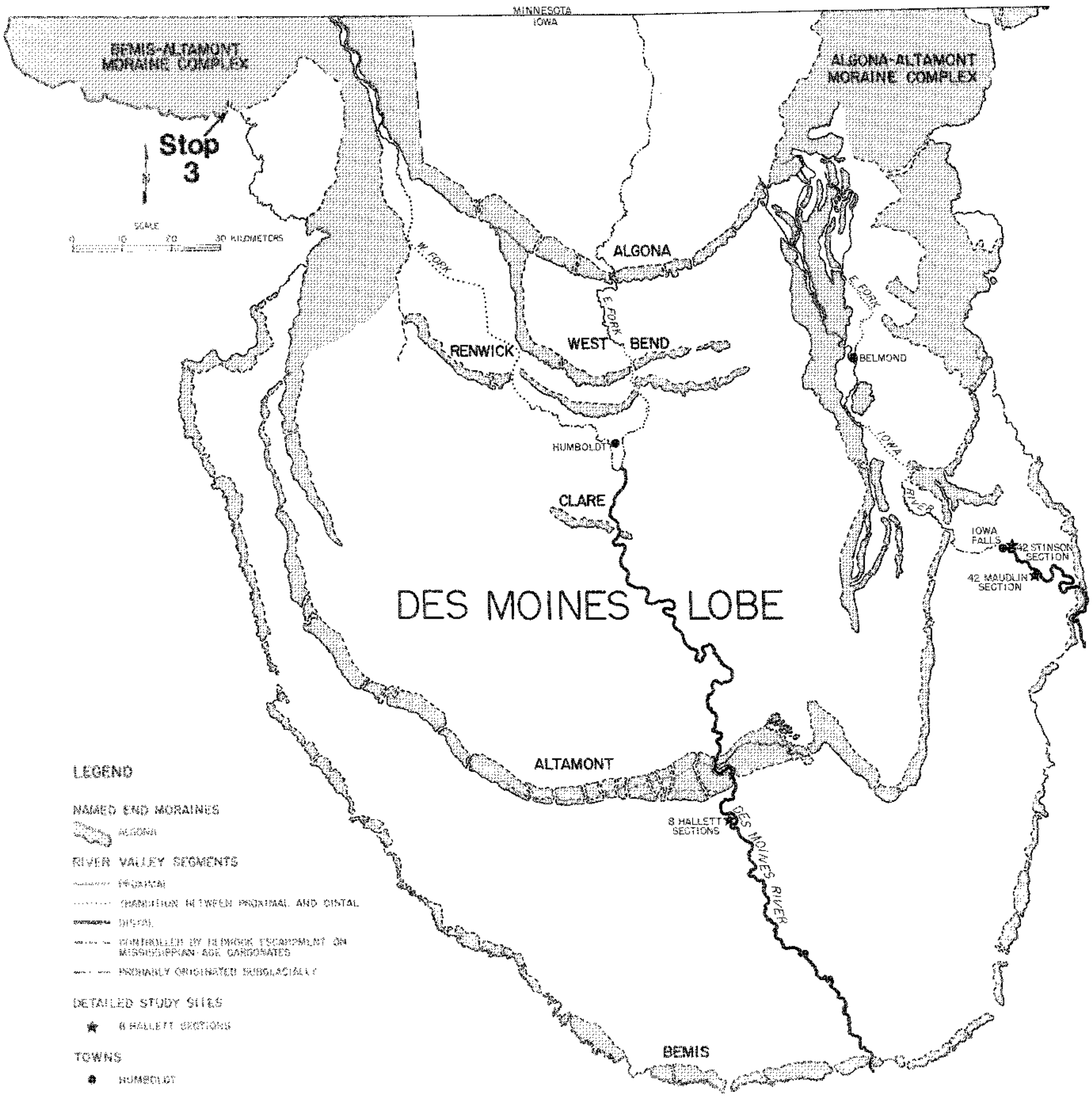

Figure 9. Map of Wisconsin-age Des Moines Lobe showing former ice marginal positions (end moraines) and the location of outwash associated with the Okoboji Lake Outlet (Stop 3).

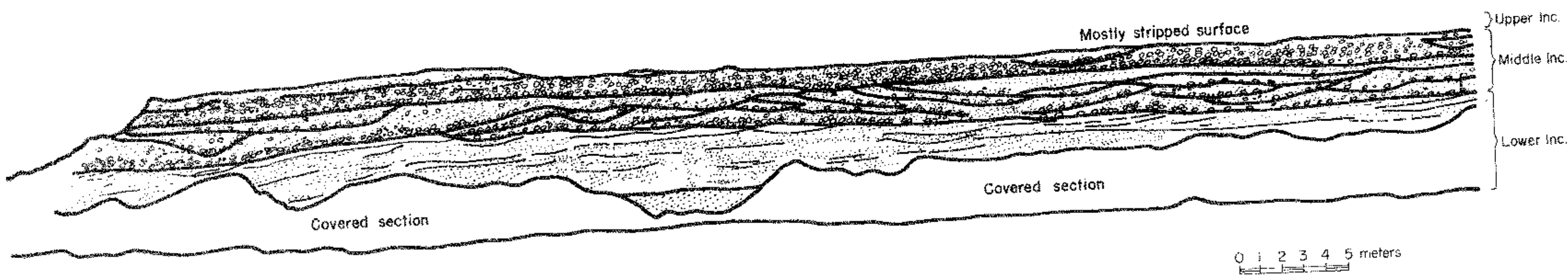

Figure 10. Cross section of Stop 3 showing sedimentary types and structures associated with the various increments of the exposure. Cross section runs from west to east.

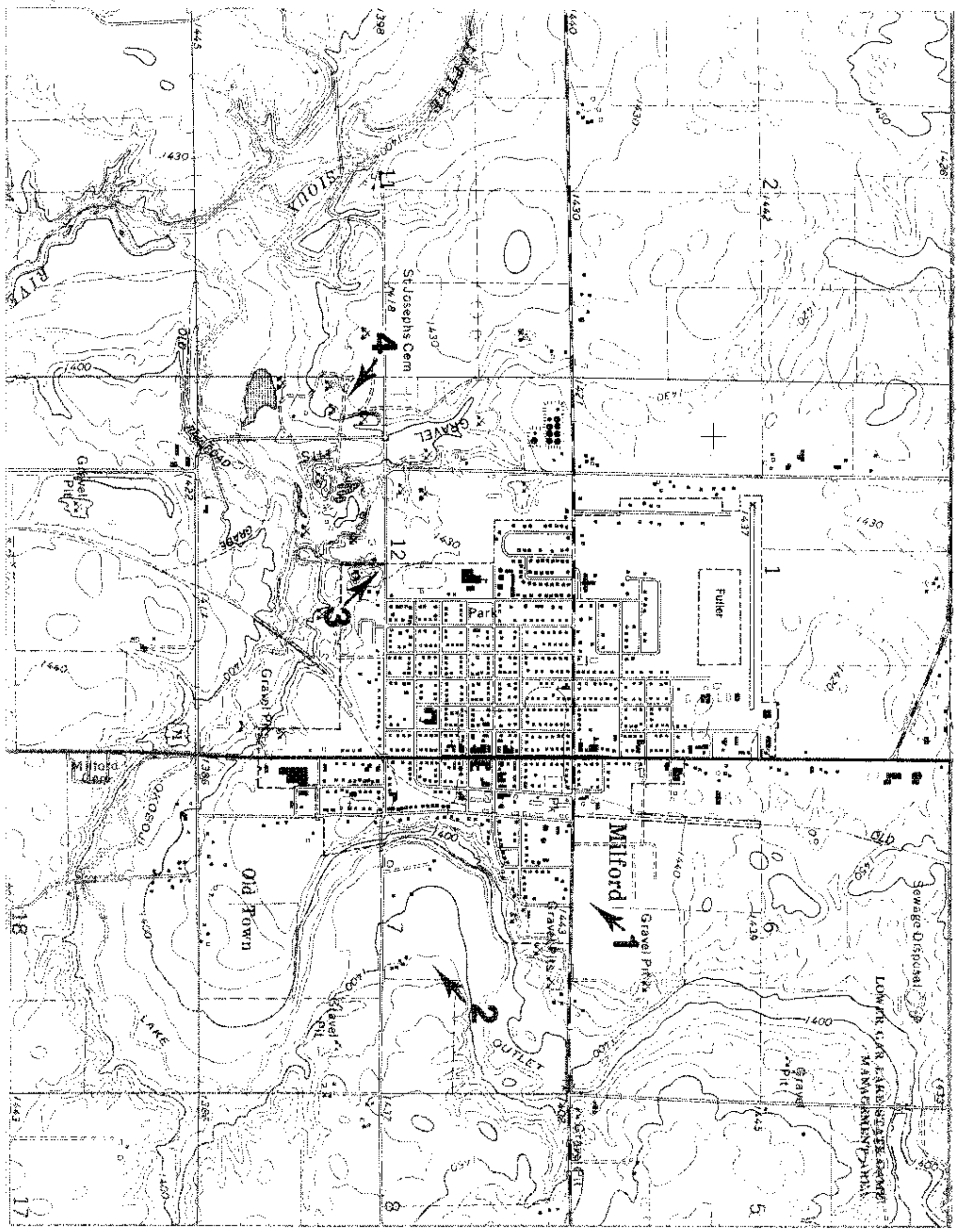

Figure 11. Map of the Okoboji Lake Outlet, showing the location of Stop 3 (site 1), and the location of study sites (2,3,4) in Wisconsin-age terraces associated with the Okoboji drainage outlet (U.S.G.S. Milford 7.5' Quadrangle).

STOP 4. FREDA HAFFNER KETTLEHOLE STATE PRESERVE

Freda Haffner Kettlehole, known for many years as the "Big Kettle Locality" is the largest known glacial kettle in the state. This steep-sided, bowl-shaped depression is located on a high alluvial terrace along the east side of the Little Sioux River valley. The terrace surface is inset just below the upland valley margin seen in the distance to the east. Erosion has partially dissected the terrace surface, contributing to its irregular appearance. Another, smaller kettle is present in the same landscape position about one-quarter mile to the north. This terrace is underlain by coarse sand and gravel deposits, including some very large boulders, as well as finer, unsorted debris-flow material sloughed off the local ice surface (Tim Kemmis, personal communication). Notice the gravel operation just south of the parking area. Soils at the site are well drained Salida gravelly sandy loam and Estherville loam which characteristically occupy stream terraces and glacial outwash areas and are developed in sand and gravel.

The Little Sioux River carried torrents of glacial meltwater through a landscape covered with disintegrating glacial ice along the western margin of the Des Moines Lobe. Salisbury and Knox (1969) have proposed that the Little Sioux was actually a subglacial stream, flowing in a tunnel valley along this portion of its course. It is possible that a large block of relatively clean ice moved down the valley, lodged here, and was quickly surrounded and partially buried by coarse outwash gravels (Tim Kemmis, personal communication). The isolated pocket of ice melted slowly in place, eventually preserving in the landscape this outline of the enclosed ice mass.

The 110-acre site was acquired by The Nature Conservancy in 1972 and was designated as a State Preserve in 1976. Because of the steep sides and steep moisture gradient within the kettle, there is a distinct vertical zonation to the vegetation, and the site has long been an important outdoor laboratory to the state's plant ecologists and taxonomists and their students. The diverse plant community reflects a wide variation in soil moisture from the dry, gravelly rim of the kettle, which contains a number of xeric mosses and lichens, to the marsh in the bottom which supports high populations of blue-green algae (Desmids). Though formerly grazed, the native prairie flora has made a good recovery and over 250 species are known to occur here, including the federally endangered Prairie Bush Clover.

The kettle's steep sides also confine an interesting record of sediments and plant pollen that have been shed from the surrounding hillslopes during the 12,000 to 13,000 years since stagnant glacial ice melted from this area. Salisbury and Knox (1969) report that cores, up to 23 feet deep, taken of the deposits in the bottom of the kettle reveal an interesting record of the sequence of post-glacial vegetation. This begins with coniferous forest in the immediate post-glacial period, yielding to deciduous and finally prairie vegetation as the climate warmed.

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STOP 5. SILVER LAKE FEN STATE PRESERVE

Silver Lake Fen is a 10-acre site located on the southwestern border of Silver Lake in Dickinson County. The fen area and pond have been under state control since 1938 and the site was dedicated as a state preserve in 1972 (Figure 12). There have been several studies on the vegetation of this site, as well as studies on the algae, protozoa, snails, and diatoms. The site contains both Small Water Parsnip and Hooded Ladies Tresses (endangered in Iowa); Small White Ladyslipper, Small Fringed Gentian and Capillary Beak Rush (threatened in Iowa); as well as Grass of Parnassus which is of special concern in Iowa.

Van Der Valk (1975) described a concentric vegetative zonation which consists of a discharge cone, a terraced sedge mat, and a border zone. This concept was developed at Silver Lake and Excelsior fens and while it is not appropriate for all fen sites in Iowa or even in western Iowa, it certainly does describe these two sites. Figure 12 is a map showing the distribution of vegetation zones at the site (Carroll et al., 1984).

This fen is the most unusual in Iowa and in appearance is similar to fens in more boreal regions. There are linear water tracks perpendicular to slope (flarks) separated by peat ridges (strings) (Glaser et al., 1981). These characteristics give rise to a distinctly patterned appearance (described as a terraced sedge mat by Van Der Valk, 1975), and the site is the southernmost known occurrence of a patterned fen (Paul Glaser, personal communication) although the scale is much less than the patterned fens of the northern boreal peatlands. The origin of string and flark complexes is still controversial and current explanations may not apply to its development here.

The site is unusual compared to many as the relief in the area is subtle. Although the site is on the side of a hill, it is not as obviously a sideslope position as the majority of fen sites in Iowa. The aquifer which feeds the fen is a sand and gravel of unknown thickness and extent. Water in the aquifer is under pressure and a well at the site has a head of in excess of 6 feet above land surface. This may imply that the fen is still actively growing. It is unknown what factors are governing this flowing confined system. It would take a network of nested wells to work out the specifics of the flow system at this site. The fact that it is located in an ice-marginal area would only add to the complexities of the flow system. In the fen classification scheme developed for Iowa fens this is an intra-till site. This is one of only two such sites known in Iowa; the other (Excelsior Fen complex) is located about 2 miles south of Silver Lake. The main fen area was mapped and cored in August, 1991. Coring at this site is extremely difficult due to frequent tufa

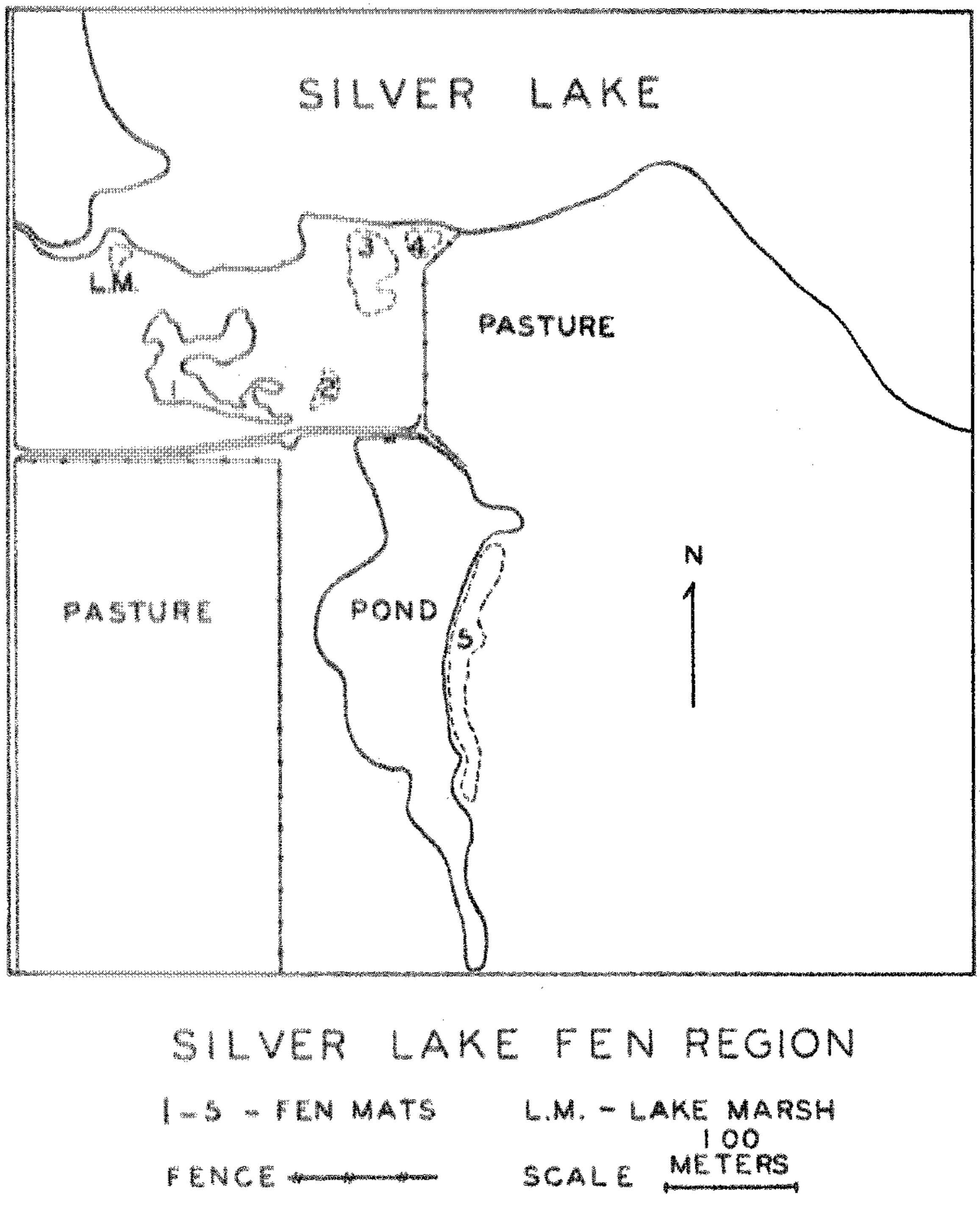

Figure 12. Map showing location of fens at Silver Lake and surrounding land use (from Eickstaedt, 1964).

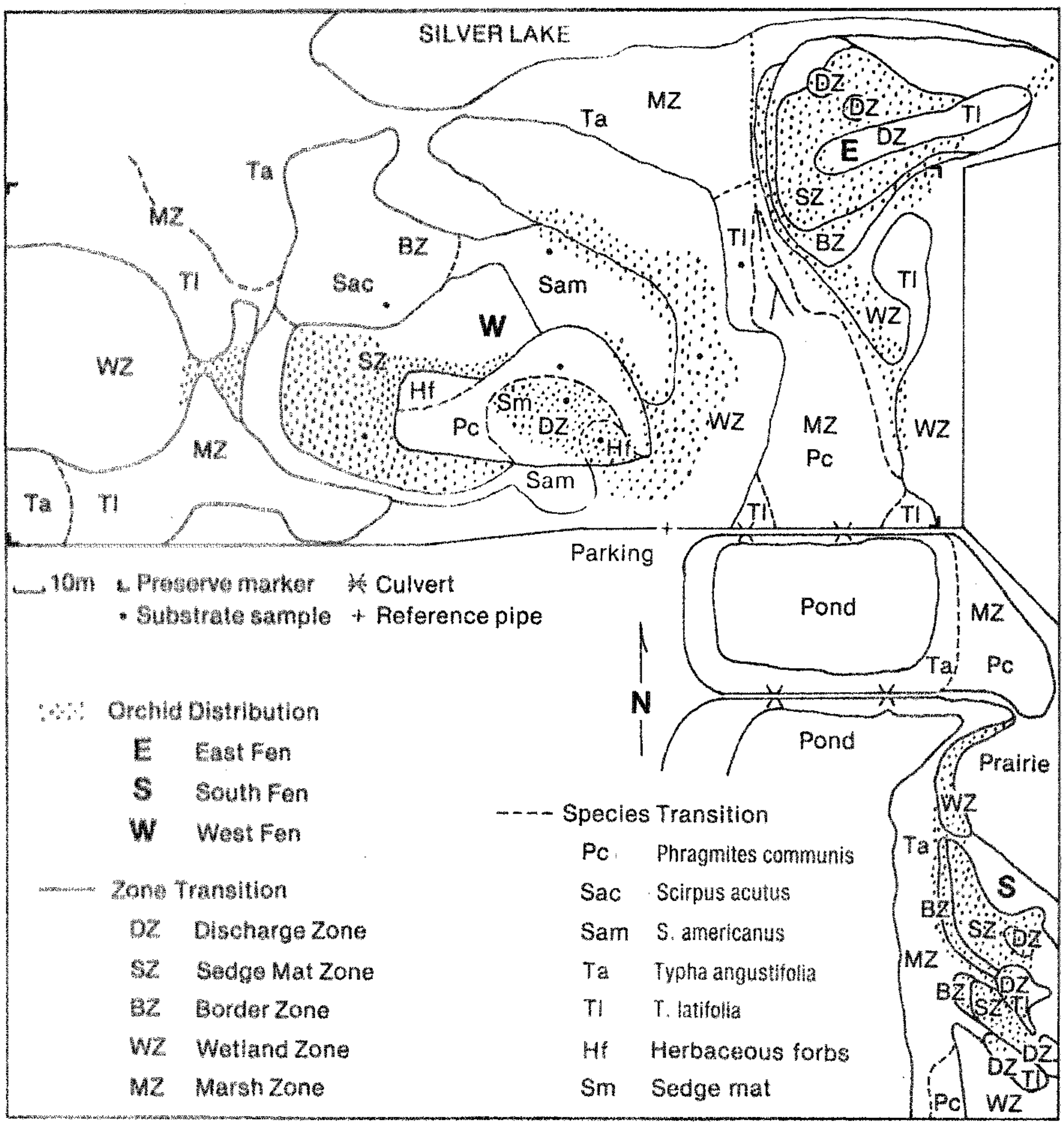

Figure 13. Map of vegetation zones for main fen area (from Carroll et al., 1984).

layers in the peat as well as layers of "bog iron", a hard layer of iron precipitate. Disseminated biogenic carbonate is abundant; almost all cores are light grayish-brown. The thickest peat was on the main peat mound to the northwest of the entrance area where 16.5 feet of very carbonate-rich peat was found. This core was dated at 3750 ± 80 RCYBP. Another date has been obtained from the marsh area to the south of the fen which was 7950 RCYBP (Cornelia Cameron, personal communication). Some cores were taken by Cornelia Cameron in the fen, but those dates were not yet available. The young date was somewhat surprising for it implies a considerable build-up of peat over a relatively short time frame.

Water chemistry at the site is very unusual for shallow groundwater (Table 3). The water has high sulfate concentrations, the origin of which is not completely understood. It has been postulated that these may come from gypsum within the till section (Thompson, 1991, in review). As at Barton, sulfate concentrations are higher in the fen outflow than in the incoming groundwater. The exception to this is the discharge sample taken from the eroded edge of the fen to the northeast of the parking area (fen 4 on Figure 13). Nitrate concentrations are very low to non-detectable and no herbicides were found in the well or the fen.

Some interesting work is being done on metal uptake in peatlands by Cornelia Cameron of the U.S.G.S. out of Reston, Va. Preliminary reports on two cores from Silver Lake Fen show considerable concentration of arsenic, zinc, and nickel in the peat. Arsenic concentrations range from 8.8 at the surface to 440 ppm at 54 inches; zinc shows a corresponding rise going from 17 at the surface to 8191 ppm at 100 in. Similar work is being done at Boston Peak Fen in Colorado (Douglas Owen, personal communication).

Table 3. Water Chemistry at Silver Lake Fen
(all measurements in mg/l except for conductivity μhmos/cm)

SITE	DATE	T(C)	pH	D.O.	COND.	ALK.
Silver Lake well	06/14/89	9.0	7.42	7.9	1650	398
Silver Lake well	10/10/89	11.0	6.89	3.2	1100	384
Silver Lake well	06/14/90	10.0	7.05	4.0	1275	324
Silver Lake fen	06/14/89	18.0	6.92	3.5	2000	386
Silver Lake fen	10/10/89	10.0	7.16	3.0	1200	230
Silver Lake fen	06/14/90	14.5	6.79	6.0	1100	336
Discharge 2	06/14/90		7.00	1.0	1150	350

Table 3. continued.

SITE	NA	K	MG	CA	F	CL	SO4	NO3
Silver Lake well	46.41	12.10	191.99	302.20	0.33	6.82	835.00	1.15
Silver Lake well								
Silver Lake well	35.24	9.16	76.19	153.45	0.10	0.10	788.02	0.10
Silver Lake fen	71.83	9.74	151.53	388.95	0.26	0.83	1305.00	0.00
Silver Lake fen								
Silver Lake fen	50.76	10.26	84.35	330.13	0.10	0.10	1120.25	0.10
Discharge 2	29.52	9.23	70.44	323.55	0.1	0.1	875.35	1.71

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STOP 6. CAYLER PRAIRIE STATE PRESERVE

Cayler Prairie State Preserve is a 160-acre tract of native grassland covering knobs, ridges, and swales characteristic of the Altamont-Bemis moraine complex. It lies along the west margins of the Little Sioux River valley about four miles upstream from the Freda Haffner Kettlehole. The site, one of Iowa's largest remaining virgin prairies, was purchased by the state in 1960. In 1966 the prairie was designated a National Natural Landmark, and in 1971 it was dedicated as a State Preserve. The irregular topography supports dry upland as well as low wetland habitats. Over 265 plant species have been identified, including the rare Poppy Mallow, Prairie Bush Clover, and Prairie Smoke. As with Freda Haffner Kettlehole, this preserve is an important laboratory for continuing field studies of native flora, especially for students and faculty of the nearby Iowa Lakeside Laboratory.

From the entrance ridge at the site, there is an excellent view of the classic knob and kettle topography that is characteristic of this northwestern part of the Des Moines Lobe. These are some of the state's best examples of landscapes developed in contact with glacial ice. The soils are a mix of till-derived (Clarion and Webster) and sand-and-gravel derived (Estherville) loams which represent the often chaotic nature of deposits left in ice-stagnation environments. Soils in topographic depressions on the site are Okoboji silty clay loam or Blue Earth mucky silt loam.

According to Salisbury and Knox (1969), the area contains a notable esker complex. These linear sand and gravel ridges are traces of subglacial meltwater streams, and their stratified deposits and channel shapes are preserved under stagnant ice conditions. The esker complex is split by the course of the Little Sioux River, and the most clearly recognized of these features lies outside the preserve on the east side of the Little Sioux.

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