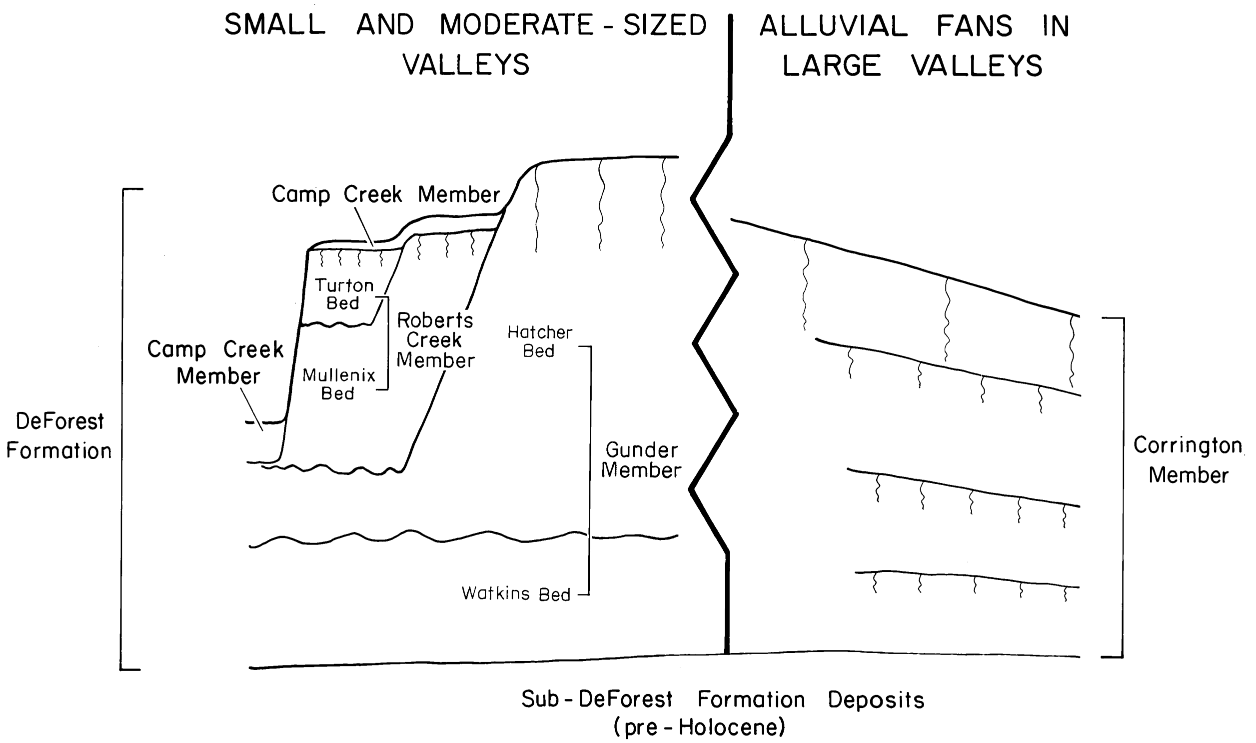
HOLOCENE ALLUVIAL STRATIGRAPHY
and
SELECTED ASPECTS of the QUATERNARY HISTORY of WESTERN IOWA

GEOLOGICAL SURVEY BUREAU
Guidebook Series No. 9



Midwest Friends of the Pleistocene

37th Field Conference
May 12-13, 1990

HOLOCENE ALLUVIAL STRATIGRAPHY AND SELECTED ASPECTS OF THE QUATERNARY HISTORY OF WESTERN IOWA

GEOLOGICAL SURVEY BUREAU
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Modified from original guidebook used at field trip.

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Midwest Friends of the Pleistocene 37th Field Conference
May 12-13, 1990, Council Bluffs, Iowa

Iowa Quaternary Studies Group Contribution No. 36

MEETINGS OF THE MIDWEST FRIENDS OF THE PLEISTOCENE

		Location	Leaders
1	1950	Eastern Wisconsin	S. Judson
2	1951	Southeastern Minnesota	H.E. Wright, Jr. and R.V. Ruhe
3	1952	Western Illinois and Eastern Iowa	P.R. Shaffer and W.H. Scholtes
U	1952	Southwestern Ohio	R.P.Goldthwait
U	1953	Northeastern Wisconsin	F.T. Thwaites
U	1954	Central Minnesota	H.E. Wright, Jr. and A.F. Schneider
6	1955	Southwestern Iowa	R.V. Ruhe
U	1956	Northwestern Lower Michigan	J.H. Zumberge and others
8	1957	South-central Indiana	W.D. Thornbury and W.J. Wayne
9	1958	Eastern North Dakota	W.M. Laird and others
10	1959	Western Wisconsin	R.F. Black
11	1960	Eastern South Dakota	A.G. Agnew and others
12	1961	Eastern Alberta	C.P. Gravenor and others
13	1962	Eastern Ohio	R.P. Goldthwait
14	1963	Western Illinois	J.C. Frye and H.B. Willman
15	1964	Eastern Minnesota	H.E. Wright, Jr. and E.J. Cushing
16	1965	Northeastern Iowa	R.V. Ruhe and others
17	1966	Eastern Nebraska	E.C. Reed and others
18	1967	South-central North Dakota	L. Clayton and T.F. Freers
19	1969	Cyprus Hills, Saskatchewan and Alberta	W.O. Kupsch
20	1971	Kansas-Missouri Border	C.K. Bayne and others
21	1972	East-central Illinois	W.H. Johnson and others
22	1973	Lake Michigan Basin	E.B. Evenson and others
23	1975	Western Missouri	W.H. Allen and others
24	1976	Meade County, Kansas	C.K. Bayne and others
25	1978	Southwestern Indiana	R.V. Ruhe and C.G. Olsen
26	1979	Central Illinois	L.R. Follmer and others
27	1980	Yarmouth, Iowa	G.R. Hallberg and others
28	1981	Northeastern Lower Michigan	W.A. Burgis and D.F. Eschman
29	1982	Driftless Area, Wisconsin	J.C. Knox and others
30	1983	Wabash Valley, Indiana	N.K. Bleuer and others
31	1984	West-central Wisconsin	R.W. Baker
32	1985	North-central Illinois	R.C. Berg and others
33	1986	Northeastern Kansas	W.C. Johnson and others
34	1987	North-central Ohio	S.M. Totten and J.P. Szabo
35	1988	Southwestern Michigan	G.J. Larson and G.W. Monaghan
36	1989	Northeastern South Dakota	J.P. Gilbertson
37	1990	Southwestern Iowa	E.A. Bettis III and others

U -Unnumbered

ACKNOWLEDGEMENTS

Many people have contributed to the investigation of western Iowa alluvium and other aspects of the geology discussed on this trip. I would especially like to acknowledge Dean Thompson for his efforts in establishing the cooperative agreement under which much of the work reported herein was performed. Dean also was a co-investigator in many of the areas and his discussions in the field and over beers helped formulate many ideas. Tom Fenton, Gerry Miller, and George Hallberg provided many insights and thoughtful discussions concerning the alluvial fill sequence and the associated soils. George also managed to help me find excuses to continue my work in the area under the auspices of the IDNR. Dave Benn gave me my first opportunity to study alluvium at the Rainbow site, and we have both been wide-eyed since. Stan Riggle saw the potential payoffs of geologic studies for cultural resource management and turned me loose on western Iowa in the summer of 1979. I am indebted to Ray Daniels for recognizing that there is stratigraphy in fine-grained alluvium and for establishing the framework of the DeForest Formation. The SCS Planning Staff, Des Moines has been very supportive of studies of the alluvial stratigraphy of western Iowa and have shared data and personnel. Tim Kemmis, Russ Shepherd, and Rolfe Mandel have provided many hours of insightful discussions, experiences from elsewhere, and, at times, some healthy disagreements. Several people including, Bill Efflan, Aaron Steinwand, Tim Kemmis, Deb Quade, and Vern Souders provided field assistance preparing sections for the trip and assisting with descriptions of some sections. Monty Storm and Harlan Lightwine of the Desoto Bend National Wildlife Refuge spent a hot day in June backhoeing the Loveland Paratype. Several staff of the Iowa Department of Natural Resources contributed great effort helping prepare this guidebook. Hats off to Brenda Nations, Pat Lohman, Kay Irelan, Mary Pat Heitman, Deb Quade, Greg Ludvigson, Lynette Siegley, Tim Kemmis, and Warren Lofgren. We are indebted to the many landowners and quarry operators who have let us work on their property and who have agreed to let this group cross fields and examine outcrops. Finally, I would like to thank Brenda for her patience, understanding, and for being there.

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HOLOCENE ALLUVIAL STRATIGRAPHY OF WESTERN IOWA

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INTRODUCTION

The western Iowa fluvial system has been extremely dynamic during the Holocene. As a result of the co-occurrence of easily eroded materials and great local relief the western Iowa fluvial system has displayed dramatic, region-wide episodes of entrenchment and sediment transport followed by longer periods of sediment storage. These episodes occur at scales ranging from individual runoff events to long-term responses spanning the Holocene. The focus of this trip is the longer-term behavior of the system; that which occurs over periods of thousands of years, leaving imprints in the stratigraphic record traceable across the area. At this scale changes in the locus of sediment transport and storage can be documented and related to some of the factors operating on the longer-term in the fluvial system. This leads to an appreciation for the dynamic and extremely responsive nature of the western Iowa fluvial system, and helps to place its Historic behavior in geological perspective. This framework for fluvial system behavior can also be adapted, with some modification, to other midwestern fluvial systems where channel processes differ from those of the entrenched stream systems characteristic of western Iowa.

Several aspects of the western Iowa fluvial system will be discussed during the first day of the trip. We will examine large and small valleys in order to see some of the similarities and differences in the processes operative in various parts of the fluvial system. These present entrenched channel processes provide a framework for interpretation of the longer-term processes resulting in the geometry and distribution of Holocene alluvial stratigraphic units. We will focus on the alluvial stratigraphy of western Iowa tributary valleys, and emphasize that there is a distinctive, easily recognized sequence of alluvial fills (the DeForest Fm.) that can be traced from valley to valley across the region. We will demonstrate that the units comprising the DeForest Fm. are distinguishable on the basis of gross lithologic characteristics, and that unconformities between units, although aiding in interpretation of the units, are not necessary in order to distinguish the stratigraphic units. We will also demonstrate that the chronology of the stratigraphic units varies in different parts of the drainage network, and discuss what this tells us about long-term behavior of the system and the relative importance of intrinsic and extrinsic factors influencing the system's behavior.

This framework of long-term behavior of the western Iowa fluvial system will provide a springboard for discussions of the archaeology and vertebrate paleontology of western Iowa. At the final stop of the day we will examine a probable Plio-Pleistocene, western-source alluvial fill buried beneath pre-Illinoian till that pre-dates the origin of Missouri River Valley.

Day 2 will feature visits to the Loveland Loess Paratype Section and the County Line Ash site (Kraft Locality). The Loveland stop will focus on new age determinations on the Loveland and overlying Wisconsinan loesses and how these relate to the established chronology of Midcontinent loesses. The stop at the County Line Ash site will provide the group with a good look at the Lava Creek B ash at a locality that has been discussed extensively, but studied little. Discussions at this locality will focus on complexities in the interpretation of the depositional environment of the exposed deposits, and the relationship of supra-ash deposits at the Kraft Locality to those at the Shimek and Yard localities located to the south along the bluff line. This stop will also feature interpretations of faunas associated with deposits above and below the ash, and amino-acid ratios from gastropods associated with these deposits. The field trip route and stop locations for Day 1 are shown on the back cover. The route and stop locations for Day 2 are shown on the inside of the back cover. A roadlog is included only for Day 2 when we will be traveling by car caravan.

In the descriptions standard pedologic terminology and horizon nomenclature are used for soils and paleosols (see Soil Survey Staff, 1975, 1981). Weathering zone terminology (Hallberg et al., 1978) is applied to Quaternary materials beneath the solum. Modified U.S.D.A.-S.C.S. textural classes and standard terms are also used (see Walter et al., 1978). Particle-size analysis was performed using the pipette method outlined in Walter et al. (1978). Clay mineralogy was determined by the procedure outlined in Hallberg et al. (1978), a modification of the technique developed by Dr. H. D. Glass, now retired from the Illinois State Geological Survey. Several clay mineralogy analyses were also determined at the Illinois State Geological Survey by Brandon Curry. Matrix carbonates were evaluated with the Chittick apparatus at the Iowa State University Agronomy Laboratory using the procedure of Walter and Hallberg (1978).

PREVIOUS INVESTIGATIONS OF HOLOCENE ALLUVIUM IN WESTERN IOWA

Early geological investigations recognized the potential importance of the alluvial stratigraphic record in western Iowa tributary valleys:

> "The alluvium is by no means the least interesting and important of the surface deposits... But while the alluvial deposits of the great valley excel in magnitude and extent, they are in many respects less satisfactory for study than those which in some places border the valley along the bases of the bluffs, or follow the numerous tributaries into the region in which uplands predominate."
>
> B. Shimek, Geology of Harrison and Monona Counties. IA. Geol. Survey, Annual Report XX, 1909: 405-406.

Despite these early suggestions, prior to the late 1950s geologic studies generally ignored the alluvial fill of small valleys in western Iowa and adjacent parts of Nebraska. Scattered observations on small valley alluvial fills were made by archaeologists, most notably Champe (1949) who suggested that a repeatable sequence of alluvial fills and associated archaeological manifestations could be observed in the thick loess region of eastern Nebraska.

From 1957 to 1960 Ray Daniels and co-workers undertook a detailed study of landscapes, soils, entrenched streams, and gullies in parts of Harrison County under the auspices of the Soil Survey Investigations, Soil Conservation Service (Daniels et al., 1963; Daniels and Jordan, 1966). This seminal study identified and defined the DeForest Formation which encompassed the fine-grained alluvial fill in the Willow River, Thompson Creek, and Magnolia Watershed areas of Harrison County. Six lithologically distinct alluvial fills (five ranked as members) were recognized in the formation and bounding radiocarbon ages were provided. An extensive drilling program was used to map the subsurface distribution of the members of the formation and to relate the alluvial fills to erosion surfaces on the valley slopes. This study demonstrated that lithologically distinct alluvial fills could be identified in the fine-grained alluvial fill of western Iowa valleys, and that these alluvial fills were mappable and occupied predictable geomorphic and stratigraphic positions.

Stratigraphic information, historical observations, and assessment of documented bed-and-bank changes along straightened reaches of the Willow River were analyzed to assess the mechanisms involved in the development of entrenched streams and gullies (Daniels and Jordan, 1966; Daniels, 1960). This information was used to reconstruct the history of Holocene landscape development and to make predictions concerning the future behavior of western Iowa fluvial systems. This work set the standard for future studies in the area and provided a sound stratigraphic framework for mapping the Holocene alluvial fill of small to moderate-size valleys in the thick-loess areas of the middle Missouri Drainage. In addition, Daniels' analysis of entrenched-stream processes and predictions of future response are still some of the best available in the literature.

In 1964 a report on the Geology of the Omaha-Council Bluffs area appeared in U.S.G.S. Professional Paper 472 (Miller, 1964). The report dealt with the exposed geology of the area including Holocene (Recent) alluvium in tributary valleys. This study of the Holocene alluvial sequence was confined to natural outcrops and quarries. The alluvium in tributary valleys was separated into five units on the basis of lithologic characteristics and topographic/geomorphic position: 1) slope wash (also called colluvium), 2) alluvial fans, 3) older Recent alluvium (pale, yellowish-brown silt), 4) younger Recent alluvium (dark yellowish-brown humic silt), and 5) floodplain alluvium. Although the work of Daniels and co-workers was not cited, cross-sections and distribution maps of Holocene alluvium in Miller's report show similar relationships to those studied by Daniels and others to the northeast in Harrison County. By the mid-1960s it was apparent that a regionally extensive sequence of alluvial fills with distinctive lithology and geomorphic relationships was present in the small valleys of southwestern Iowa and southeastern Nebraska.

W. H. Allen studied soil formation and landscape evolution in the Treynor Watershed of south-central Pottawattamie County for his doctoral dissertation (Allen, 1971). Part of his study was concerned with the stratigraphy and properties of Holocene alluvium in a small watershed in the upper part of the drainage network. He recognized the same sequence of alluvial fills Daniels and co-workers had described in Harrison County, further strengthening the idea that the DeForest Fm. was wide-spred.

In the mid-1970s a formerly unstudied part of western Iowa's fluvial system was the focus of geologic studies at the Cherokee Sewer site and other areas along the Little Sioux Valley. These studies were concerned with the stratigraphy, sedimentology, and chronology of alluvial fans as well as late-glacial events that greatly influenced the geometry and valley wall stratigraphy of upper and middle reaches of the valley (Hallberg et al., 1974; Hoyer, 1980a and b). Hoyer concluded that alluvial fans in the valley developed during the early and middle Holocene by episodic transport of sediment from small contributory basins punctuated by intervening periods of fan stability and soil development. He pointed to a link between sediment transport and storage in tributaries and sedimentation and pedogenesis on alluvial fans. Aggradation of fans occurred during sediment transport out of contributory basins, while periods of fan stability and soil formation were coincident with sediment storage in contributory basins. This linkage implied that depositional records spanning the period of alluvial-fan aggradation might be absent from the small valleys tributary to the fans.

In 1978 Bettis studied the alluvial stratigraphy of a small valley in northwest Iowa as part of archaeological investigations at the Rainbow site (Benn ed., 1990). About midway through the investigation it was realized that the stratigraphic sequence in this northwestern Iowa valley was the same as described by Daniels and co-workers in Harrison County about 100 miles to the south. The possibility of a repeatable Holocene stratigraphic sequence in small and moderate-size valleys throughout western Iowa prompted the U.S.D.A.-S.C.S. to fund a cooperative project with the Iowa State University Agronomy Department to investigate the alluvial stratigraphy of several western Iowa watersheds where flood-control and soil-conservation measures were being planned. The purpose of these investigations was to document and radiocarbon date the Holocene alluvial-fill sequence and use this information as part of the assessment of cultural resources in and around areas to be impacted by soil-conservation measures (Thompson and Bettis, 1980; 1981; Bettis and Thompson, 1981). These investigations provided the groundwork for the stratigraphic framework and valley history presented in this guidebook. A picture of the Holocene behavior of the entire western Iowa fluvial system began to emerge as a result of these investigations. Figure 1 shows the locations of some of the watersheds where detailed subsurface investigations have been conducted, as well as the locations of type sections, reference sections, and reference areas for the DeForest Fm.

Short-term (less than 30 years) gully evolution studies have been conducted over the last three decades at the U.S.D.A.-A.R.S. Treynor Watershed research area (now the Deep Loess Research Station) in south-central Pottawattamie County. Several small instrumented watersheds with various soil-conservation and cropping practices are included in the area. Relationships among runoff, throughflow, and the stability of headwalls and channel banks have been studied, and several factors important in the growth, widening, and eventual stabilization of entrenched channels have been identified. Bradford and others (1978) suggest that the sequence of events during headwall advance in loess-derived alluvium consists of development of alcoves or popouts, followed by column failure, and cleanout of debris entering the channel. The transport (cleanout) process seems to be the limiting factor for continued advance of the headwall. Data from instrumented watersheds at Treynor show that sediment discharge peaks soon after runoff begins in gullies but declines sharply

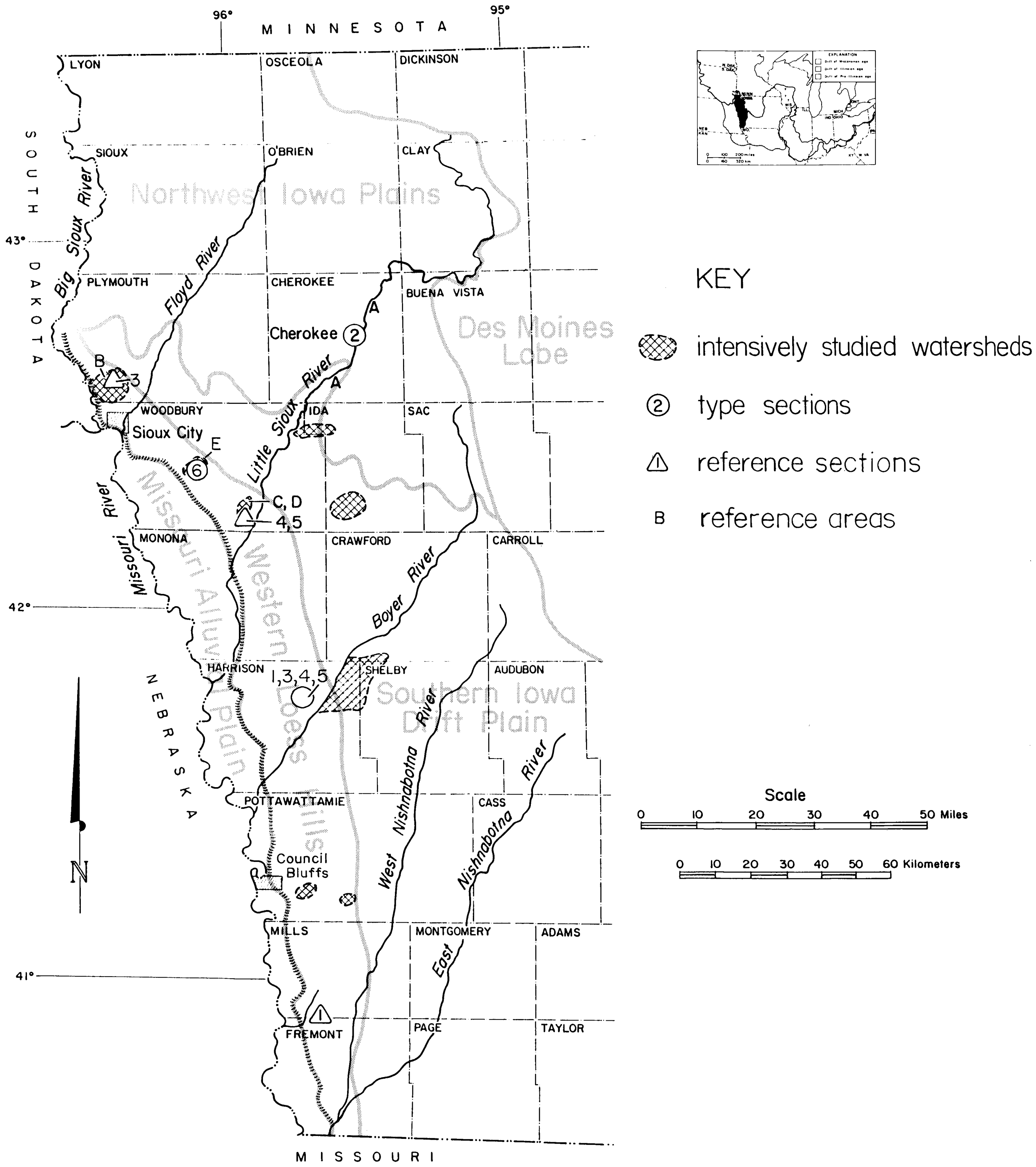


Figure 1. Map of western Iowa showing landform regions (after Prior, 1976), the location of some of the watersheds where detailed subsurface investigations of the Holocene alluvial stratigraphy have been conducted, and the locations of type sections, reference sections, and reference areas for the DeForest Fm. Type and reference sections: 1-Watkins Bed, 2-Corrington Mbr., 3-Hatcher Bed, 4-Mullenix Bed, 5-Turton Bed, 6-Camp Creek Mbr. Reference areas: A-Corrington Mbr., B-Hatcher Bed, C-Mullenix Bed, D-Turton Bed, E-Camp Creek Mbr.

during subsequent periods of high discharge (Bradford et al., 1978; see contributed paper). This indicates that tractive forces of runoff along the channel boundary do not play a major role in gully erosion. The source of most sediment removed from entrenched streams in the area is debris from channel wall failure. These studies provide us with a processural framework for interpreting the stratigraphic record of entrenched stream systems.

STRATIGRAPHIC FRAMEWORK FOR WESTERN IOWA

The generalized Pleistocene stratigraphic framework for western Iowa is presented in Figure 2. The first day of the trip will focus on Holocene deposits with a final stop to look at deposits from the bottom of the column. The following discussion focuses on the Holocene stratigraphic framework. See Hallberg (1986) for a discussion of the complex pre-Illinoian sequence and the second day of this trip for a discussion of the Illinoian and Wisconsinan sequence.

The dominant surficial deposit across western Iowa is Peoria Loess. Kay and Graham (1943) referred to this unit as Peorian loess, but since 1950 the unit has been called Wisconsin or Wisconsinan loess (Daniels and Handy, 1959; Ruhe, 1969; Ruhe et al., 1971; Olson and Ruhe, 1980). The name Peoria Loess is used here because the upper Wisconsinan loess unit of western Iowa is in the same stratigraphic position and imperceptibly merges with the Peoria Loess of Illinois. In addition, many properties of the loess are similar across the region. The Peoria Loess thins systematically away from the Missouri River source. The loess is exceptionally thick, generally in excess of 80 feet (24.4 m), and depths of 150 to 200 feet (47 to 62 m) have been recorded. Loess thicknesses of this magnitude are unmatched on a regional scale elsewhere in the Midcontinent. Exceptional loess thickness and deep entrenchment of the drainage network impart unique characteristics, such as a deep watertable, and very xeric topographically controlled microclimates to the area. At the eastern-most location on this field trip (11 mi. from the bluff line), Peoria Loess thickness is 35 to 40 feet (10.7 to 12.2 m) on primary divides.

DeForest Fm.

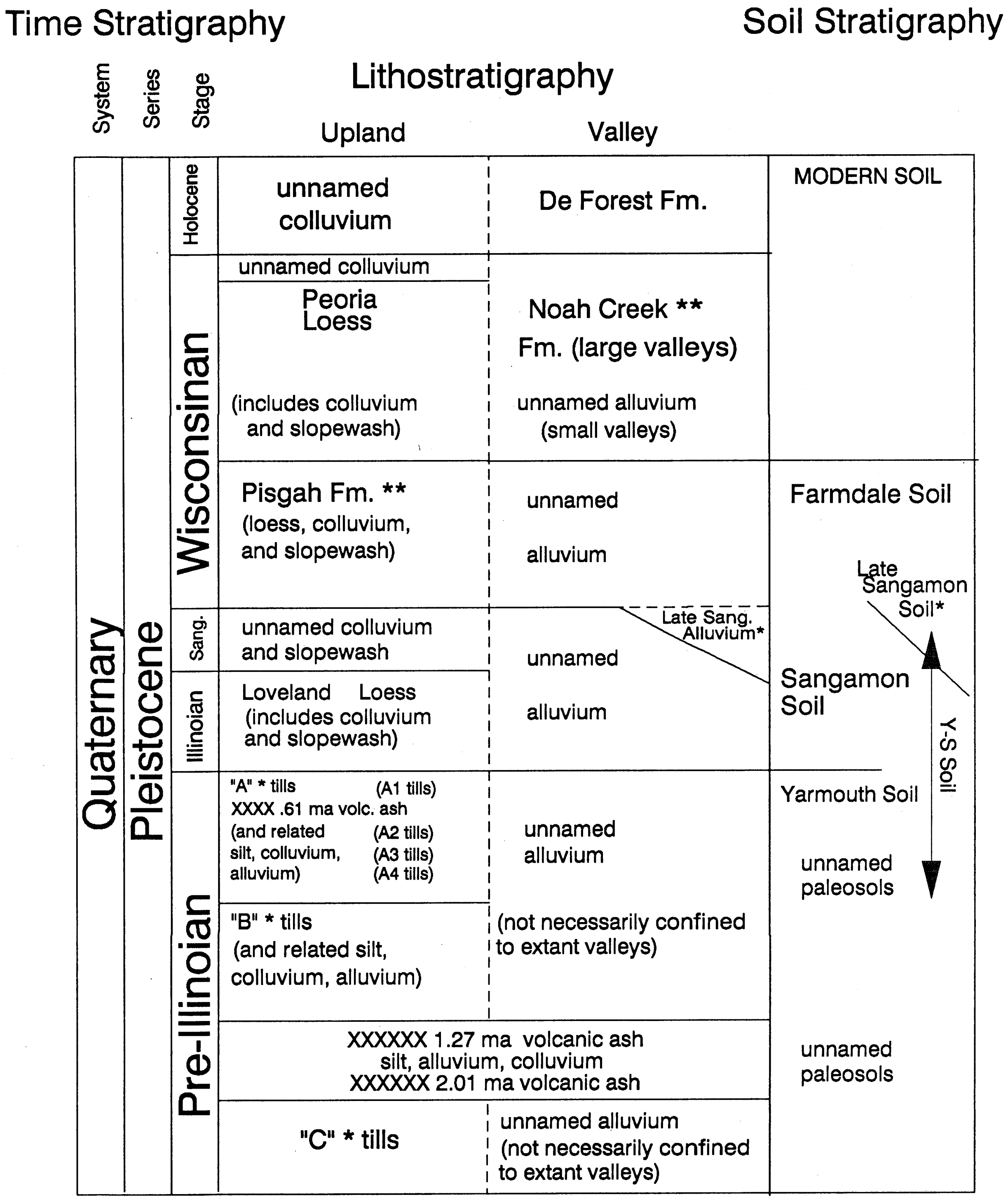
Investigations conducted in Harrison County by Daniels and co-workers established the stratigraphic framework for western Iowa's Holocene alluvial deposits (Daniels et al., 1963). These investigations were confined to a watershed in Harrison County in an area of moderately thick loess (60 to 80 feet). The alluvial fills in their study area were referred to as the DeForest Formation and sub-divided into five units. Subsequent investigations by Thompson and Bettis in eleven other western Iowa and two eastern Nebraska counties, including areas of thick as well as thin (3 m) loess, demonstrated that the general stratigraphic and lithologic relationships among units of the DeForest Fm. described by Daniels and others are present throughout the Middle Missouri drainage (Thompson and Bettis, 1981; Bettis and Thompson, 1982).

As originally defined by Daniels and others (1963) and Daniels and Jordan (1966), the DeForest Fm. encompassed five lithologically (and temporally) distinct alluvial fills separated by bounding unconformities (fluvial erosion surfaces and/or buried soils). The distinctive alluvial fills were designated members of the formation and from oldest to youngest included: Soetmelk, Watkins, Hatcher, Mullenix, and Turton. An additional unit, postsettlement alluvium, was recognized, but not given member status. Seven radiocarbon dates on organic materials recovered from the members of the formation provided a temporal framework for the alluvial fills:

Soetmelk----------- > 14,300 to 11,100 B.P.
Watkins------------ca. 11,000 to 2,020 B.P.
Hatcher----- ------2,020 to 1,800 B.P.
Mullenix-----------ca. 1,100 to > 250 B.P.
Turton-------------250 B.P. to 76 years ago
postsettlement-----Historic

Revision of the DeForest Fm.

The DeForest Fm. was originally defined for alluvial fills in the thick loess areas of western Iowa, but additional investigations of the Holocene alluvial fill sequence throughout Iowa and portions of adjacent states have necessitated revision of the formation in order to make it applicable in the various landscape regions of the Upper Midwest



Time Stratigraphy			Lithostratigraphy		Soil Stratigraphy
System	Series	Stage	Upland	Valley	
Quaternary	Pleistocene	Holocene	unnamed colluvium	De Forest Fm.	MODERN SOIL
		Wisconsinan	unnamed colluvium Peoria Loess (includes colluvium and slopewash)	Noah Creek ** Fm. (large valleys) unnamed alluvium (small valleys)	
			Pisgah Fm. ** (loess, colluvium, and slopewash)	unnamed alluvium	Farmdale Soil Late Sangamon Soil*
		Sang.	unnamed colluvium and slopewash	Late Sang. Alluvium* unnamed alluvium	Sangamon Soil
		Illinoian	Loveland Loess (includes colluvium and slopewash)		Y-S Soil
		Pre-Illinoian	"A" * tills (A1 tills) XXXX .61 ma volc. ash (and related silt, colluvium, alluvium) (A2 tills) (A3 tills) (A4 tills)	unnamed alluvium (not necessarily confined to extant valleys)	Yarmouth Soil unnamed paleosols
			"B" * tills (and related silt, colluvium, alluvium)		
			XXXXXX 1.27 ma volcanic ash silt, alluvium, colluvium XXXXXX 2.01 ma volcanic ash		unnamed paleosols
			"C" * tills	unnamed alluvium (not necessarily confined to extant valleys)	

* not formally defined

** proposed

Figure 2. Generalized Pleistocene stratigraphic framework for western Iowa.

(Bettis and Littke, 1987; Bettis and Mandel, n.d.). The nature of the materials in thick-loess areas such as western Iowa result in stream behavior that produces thick, often vertically stacked stratigraphic units. Such conditions tend to preserve a detailed record of cut-and-fill episodes in the stratigraphic record. The net result is that the alluvial stratigraphic record of small western Iowa valleys can be sub-divided further than that in areas where loess and Holocene alluvial fills are thinner and lateral channel migration tends to destroy older alluvial fills. The present litho-stratigraphic framework for Holocene alluvial deposits in Iowa differs from the DeForest Fm. as originally defined by Daniels et al. (1963) in three ways (Table 1). First, we expand the DeForest Fm. to include all Holocene alluvium in Iowa. Secondly, the Soetmelk Member is excluded from the formation to be included in an as yet unnamed lithostratigraphic unit encompassing Wisconsinan fluvial deposits; our studies indicate that the Soetmelk is related lithologically, biostratigraphically, and temporally to Wisconsinan loesses as well as coarse-grained alluvium in large valleys. Finally, we recognize two additional members (Corrington and Camp Creek), change the status of the Watkins and Hatcher members to beds in the newly defined Gunder Member, and likewise include the Mullenix and Turton as beds in the newly defined Roberts Creek Member. These changes allow a logical and simple lithostratigraphic classification applicable to all Holocene alluvial deposits in Iowa and adjacent areas. These stratigraphic units are shown schematically in Figure 3 and described below.

Table 1. DeForest Formation units as defined by Daniels et al. (1963) and their relationship to revised DeForest Fm. units presented in this volume.

Daniels et al. (1963)	Bettis (1990)
postsettlement alluvium	**Camp Creek Mbr.**
	Roberts Creek Mbr.
Turton Member	Turton Bed
Mullenix Member	Mullenix Bed
	Gunder Mbr.
Hatcher Member	Hatcher Bed
Watkins Member	Watkins Bed
Soetmelk Member	not included
not recognized	**Corrington Mbr.**

Gunder Member

The Gunder Mbr. consists of oxidized (as defined in Hallberg et al., 1978), dominantly silty and loamy alluvium, colluvium, and slopewash lacking a loess cover. Lower parts of the unit may be reduced (Hallberg et al., 1978) and/or coarser grained. This member includes the Watkins and Hatcher members of Daniels et al. (1963) which have now been redesignated as beds within the Gunder Mbr. The Watkins and Hatcher beds are differentiated only in the thick- and moderately thick-loess areas of western Iowa and adjacent states. Gunder Mbr. deposits unconformably overlie coarse-grained and often organic-rich older alluvium, loess, glacial till, or bedrock. Overlying younger members of the formation are separated from the Gunder Mbr. by a fluvial erosion surface or an unconformity marked by a buried soil. Buried soils (usually Entisols) have been documented within the Gunder Mbr., however, widely traceable, stable former landsurfaces have not been documented within the unit. Surface soils developed in the Gunder Mbr. in western Iowa are thick Mollisols (prairie soils) with brown or yellowish brown (10YR 4/3-5/3) cambic (Bw; soil structure, color change, but no secondary clay accumulation) or argillic (Bt; soil structure, color change, and secondary clay accumulation) subsurface horizons.

Watkins Bed

The Watkins Bed is the basal unit of the formation in western Iowa and consists of stratified, calcareous silt loam, loam, and sand. The unit is usually reduced and ranges in color from greenish gray (5GY 4/1) to olive brown (2.5Y 4/4), often with 7.5YR hue secondary iron oxide accumulations. The Watkins Bed is deeply buried, rarely crops out in stream banks and, as a result, has been examined primarily in deep borings. The unit ranges in thickness from 2 to 13 feet (0.6-4 m), and in 2nd-to 4th-order valleys, is separated from overlying deposits by a fluvial erosion surface. In larger valleys, as well as 1st-order valleys, a buried soil is preserved in the upper part of the Watkins Bed.

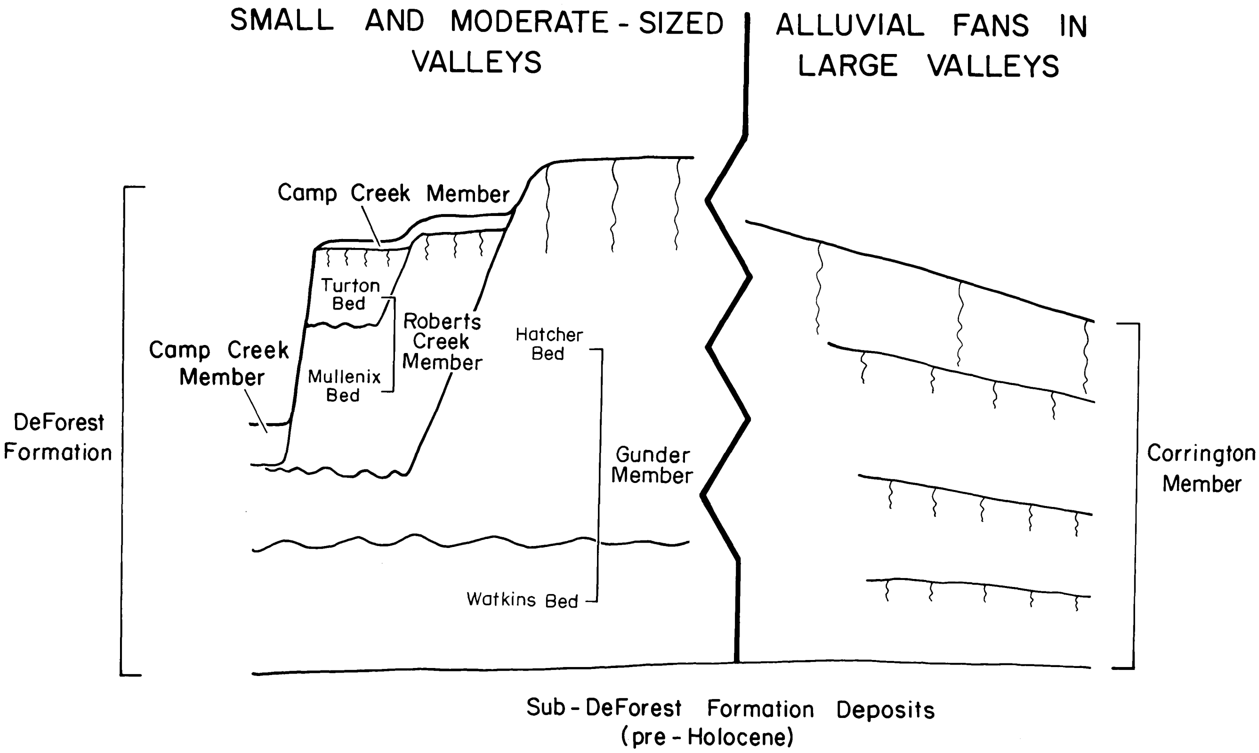


Figure 3. Generalized relationships among Holocene alluvial stratigraphic units in western Iowa.

Hatcher Bed

Deposits comprising the Hatcher Bed are usually massive, calcareous to noncalcareous, brown to yellowish brown (10YR 4/3-5/3) silt loam; beds of coarser alluvium are often present in the lower part of this unit, and in a few sections the lower part of the Hatcher Bed is reduced. Weathered exposures usually exhibit coarse columnar structural units three to six feet (1-3 m) high and one and a half feet (0.5 m) wide with coatings of secondary carbonate and silt along their surfaces. Carbonate concretions similar to those in the Peoria Loess are often found in the Hatcher Bed, but they are weathered, abraded, and oriented with their long axis horizontal to subhorizontal, indicating that they have been transported to their present location. Surface soils developed in the Hatcher Bed are Mollisols (Cumulic and Typic Hapludolls) with deep profiles. Weakly expressed buried soils are often found within the Hatcher Bed, but these are not traceable from one valley to another. Deposits comprising alluvial fans in small valleys (< 4th-order) in the thick and moderately thick loess regions of western Iowa are also included in the Hatcher Bed. Deposits in these small alluvial fans lack the well-expressed stratification and multiple buried soils characteristic of the Corrington Mbr. described below.

Corrington Member

The Corrington Mbr. is the most internally variable unit of the formation and consists of very dark brown to yellowish brown (10YR 2/2-5/4) oxidized loam to clay loam with interbedded lenses of sand and gravel. The unit is stratified and contains several buried soils. Surface soils developed into this unit in western Iowa are thick Mollisols (Cumulic Hapludolls) that have argillic (Bt) horizons. The Corrington Mbr. buries coarse-grained older alluvium, glacial till, loess, or bedrock, and can grade laterally into Gunder Mbr. deposits. Corrington Mbr. deposits make up alluvial fans located where small-and moderate-size valleys (2nd- and 3rd-order) enter large valleys.

Roberts Creek Member

The Roberts Creek Mbr. encompasses

dark-colored, clayey, silty, and loamy alluvium throughout Iowa. This unit includes the Mullenix and Turton members of Daniels et al. (1963), which have been redesignated as beds within the Roberts Creek Mbr. in the thick- and moderately thick-loess areas of western Iowa and adjacent states. Outside these areas of thicker loess the Mullenix and Turton beds are not distinguishable and the Roberts Creek Mbr. is not subdivided. Roberts Creek Mbr. deposits can overlie a wide variety of deposits including the Gunder and Corrington members, coarse-grained older alluvium, loess, and glacial till. Roberts Creek Mbr. deposits are found beneath the floodplain in small and large valleys and often overlap Gunder Mbr. deposits in second- and third-order valleys. The Roberts Creek Mbr. is separated from younger DeForest Fm. deposits (Camp Creek Mbr.) by either a fluvial erosion surface or an unconformity marked by a buried soil. Weakly expressed buried soils have been observed within the Roberts Creek Mbr., but these appear to not be traceable from one valley to another. Surface soils developed in the Roberts Creek Mbr. are thick, dark-colored Mollisols, Inceptisols (soils that lack the thick, dark-colored surface horizon of Mollisols and do not have significant secondary clay accumulation in their B horizons), and Entisols (soils that do not have the thick, dark-colored surface horizon of Mollisols and lack a B horizon). These soils are morphologically less well expressed and have darker colored B and C horizons than soils developed in the Gunder and Corrington members.

Mullenix Bed

This unit is differentiated only in the thick and moderately thick-loess region of western Iowa and adjacent states. It consists of very dark gray to dark grayish brown (10YR 3/1-4/2) stratified silt loam and clay loam which usually exhibits medium to coarse columnar structure. Thin, lenticular bodies of sand and gravel, marking paleochannels often occur in lower parts of the unit. Typically the Mullenix Bed is three to thirteen feet (1-4 m) thick. Usually the upper three to ten feet (1-3 m) of the unit is noncalcareous and the remainder is calcareous. Where it is the surficial unit, surface soils are Mollisols or Entisols (Cumulic Hapludolls and Typic Udifluvents). These soils have thick, dark-colored surface horizons (in the former case) and, in the latter case, lack a B horizon and are stratified below the A horizon.

Turton Bed

Like the Mullenix Bed, the Turton Bed is differentiated only in the thick- and moderately thick-loess areas of western Iowa and adjacent states. The unit consists of very dark gray to dark grayish brown (10YR 3/1-4/2) stratified silty clay loam to loam. The entire unit may be calcareous or the upper three to six feet (1-2 m) may be nonclacareous. The Turton Bed typically ranges from three to thirteen feet (1-4 m) in thickness and occurs as a fill inset into, and at times overlapping, the Mullenix Bed in the floodplain adjacent to modern entrenched channels. Surface soils developed in the Turton Bed are Mollisols and Entisols that are morphologically less well expressed than soils developed in the adjacent Mullenix Bed.

Camp Creek Member

The Camp Creek Mbr. encompasses deposits formerly referred to as "postsettlement alluvium" (Daniels et al., 1963; Daniels and Jordan, 1966; Bettis and Thompson, 1981; 1982). This unit usually consists of stratified, calcareous to noncalcareous, very dark gray to brown (10YR 3/1-5/3) silt loam to clay loam. It is inset into or unconformably overlies the Gunder, Corrington, and Roberts Creek members depending on the local geomorphic setting and history of land-use. Thickness of the Camp Creek Mbr. is quite variable, ranging from a few inches to over 16 feet (5 m). Surface soils developed in the Camp Creek Mbr. are Entisols (Typic Udifluvents). These soils consist of an organically enriched surface horizon (A horizon) grading to stratified, parent material. In areas where the unit is rapidly aggrading, surface soils are absent.

Distribution Within the Drainage Network

Investigations throughout western Iowa indicate that units comprising the DeForest Fm. have a predictable distribution pattern within the drainage network, in part related to their deposition in entrenched stream systems (Bettis and Thompson, 1982). In the following discussion position within the drainage network is described using the modified Horton channel-ordering system (Strahler, 1952), as applied to valleys (rather than channels) at a scale of 1:24,000 (7.5'). The following relationships pertain especially to western Iowa and adjacent areas of thick to moderately thick loess, but also apply in a slightly modified sense to valleys throughout the Upper Midwest (Bettis and Mandel, n.d.).

Stratigraphic and geographic relationships among DeForest Fm. alluvial fills vary depending on position within the drainage network. Detailed subsurface investigations in Smokey Hollow, a 0.75 mi^2 (1.9 km^2) drainage basin in southern Woodbury County demonstrate relationships typically found in 1st- through 3rd-order valleys in western Iowa. DeForest Fm. alluvial fills accumulated in entrenched streams and gullies in this valley. The density of borings in this investigation (over 50 borings along this reach) permitted the construction of isopachs of individual DeForest Fm. units (Figure 4). The isopachs show the extent of the entrenched drainage network preceding accumulation of the fills (providing that a subsequent episode of entrenchment was not more extensive; Figure 5). Where a buried soil is developed in the upper part of an alluvial fill entrenchment did not precede accumulation of the overlying alluvium at that location. These isopachs allow for a reconstruction of the valley's Holocene history, and show that the loci and extent of entrenchment and aggradation varied through time.

Gunder Member

The greatest volume of the valley fill is Gunder Mbr. alluvium (Watkins and Hatcher beds). Watkins Bed alluvium accumulated along the entire mainstem (3rd-order) of the valley and up 2nd-order tributaries along the western side of the valley (Figure 5a). A pre-Watkins headwall and plunge pool are evident where a 1st-order tributary joins the mainstem from the east about midway between the southern two 2nd-order tributaries. The Watkins Bed is best preserved in the upper portion of 1st- and 2nd-order tributaries where it was not affected by subsequent entrenchment. Farther down the drainage network post-Watkins entrenchment eroded the unit to varying degrees.

Hatcher Bed deposits are preserved throughout the drainage network (Figure 5b) and account for the greatest volume of the alluvial fill here and in most valleys. Plunge pools are evident in the lower reaches of tributaries on the west side of the valley as well as in the southern and central portions of the mainstem (Figure 5b). Along the mainstem Hatcher Bed alluvium forms a terrace standing three to ten feet (1-3 m) above younger alluvial fills in the floodplain. Areas where a soil is not shown in the upper part of the Hatcher Bed were eroded (entrenched) prior to accumulation of overlying units. Hatcher Bed deposits grade imperceptibly into Peoria Loess on the valley slopes, indicating that the valley slopes were the source for at least part of the unit.

Roberts Creek Member

Roberts Creek Mbr. deposits are more restricted in their distribution than Gunder Mbr. deposits as they were deposited in smaller entrenched channel systems inset into the Gunder Mbr. (Figures 5c and d). The Roberts Creek Mbr. is thickest beneath the central part of the floodplain, usually roughly paralleling the modern entrenched channel. The geometry and extent of the Roberts Creek Mbr. suggests that the unit usually fills a single entrenched channel system that is more or less mimicked by modern entrenched channels. Roberts Creek Mbr. deposits are usually exposed in the entrenched channel wall of western Iowa streams unless they have been completely removed by headward extension and channel widening.

Mullenix Bed deposits occupy the entire floodplain and extend into the upper parts of 2nd-order drainages that lack terrace-flooodplain relationships (Figure 5c). Three pre-Mullenix plunge pool areas can be seen along the mainstem of Smokey Hollow in Figure 5c. Buried soils in the upper part of the underlying Hatcher Bed indicate that pre-Mullenix entrenchment was in large part restricted to the mainstem and did not extend up most tributaries (Figure 5b). Accumulation of Roberts Creek Mbr. deposits did not occur on the east side of the valley. In that area surface soils are developed in the Hatcher Bed. An interesting, though not typical, feature of the pre-Mullenix entrenched channel system is that it was discontinuous along the mainstem (Figure 5c). This pattern is expressed in all subsequent entrenched channel systems in the valley.

Entrenchment preceding accumulation of the Turton Bed was restricted to a narrow belt in the floodplain that was essentially reoccupied by the modern entrenched stream in the valley. In many valleys the Turton Bed is absent, having been

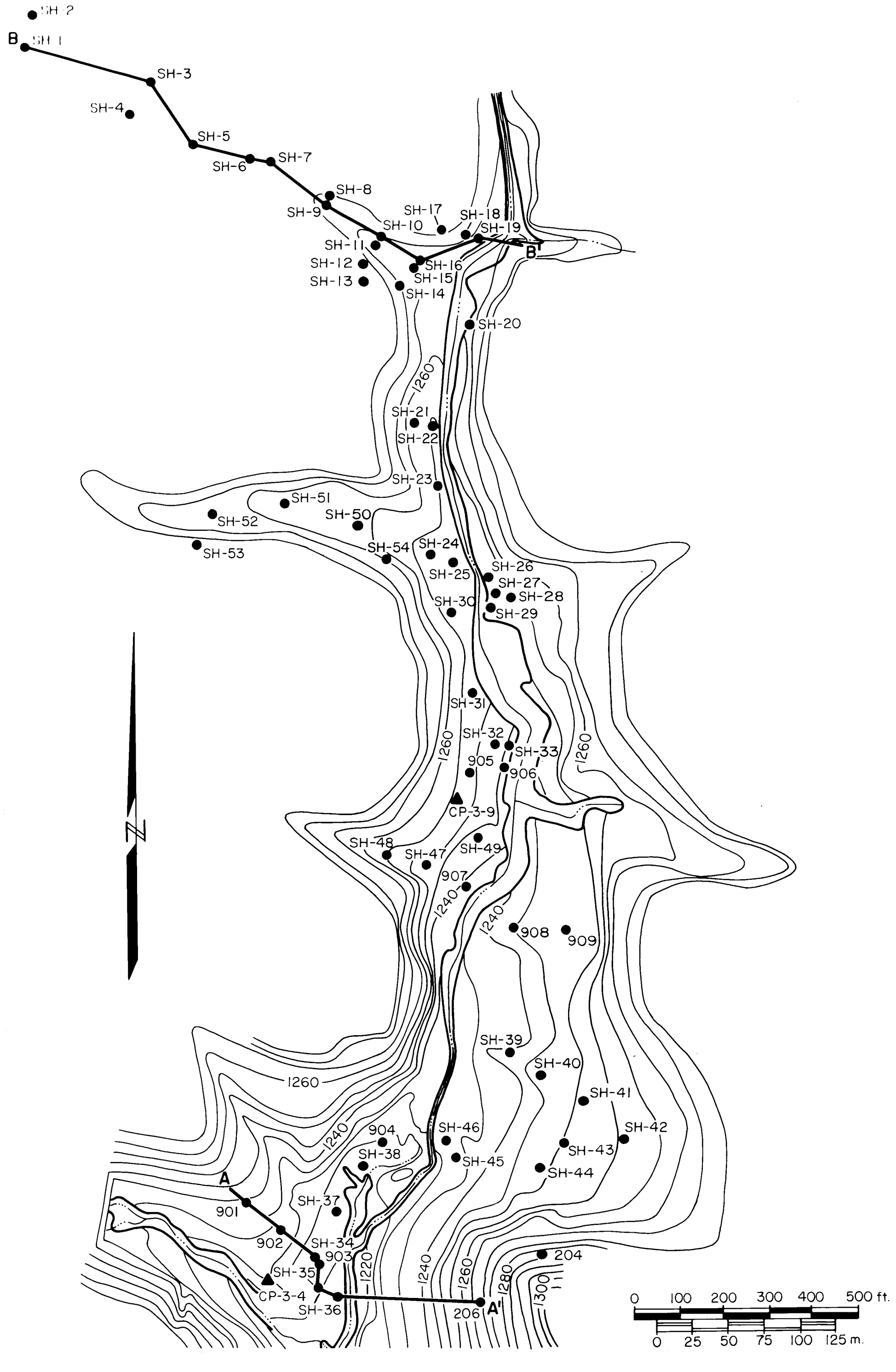


Figure 4. Topographic map of Smokey Hollow in southern Woodbury County showing location of borings used to construct isopachs presented in Figure 5. Contour interval is 5 feet (1.5 m).

Figure 5. Isopachs of DeForest Fm. units in Smokey Hollow. Note location of control points to relate the isopachs to the topographic map of the valley shown in Figure 4.

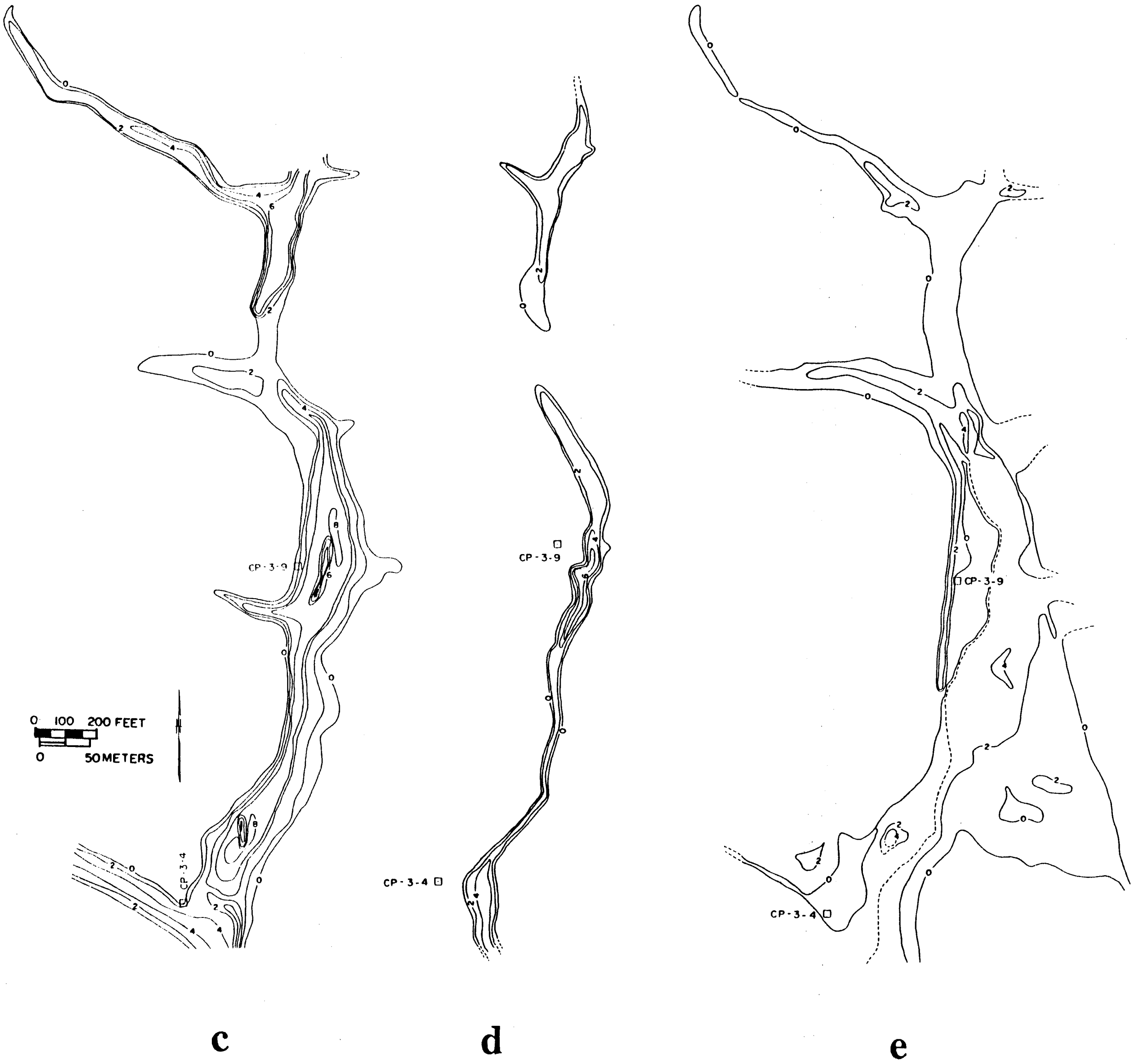


Figure 5. Continued.

removed during entrenchment and widening of the modern channel. The Turton Bed is restricted to the floodplain and does not usually occur in valleys smaller than 3rd-order. Roberts Creek Mbr. alluvium was derived in large part from erosion of older Holocene alluvium (the Gunder Mbr.).

Camp Creek Member

This unit is present in many parts of the valley floor: within and adjacent to the modern entrenched channel, across the floor of most sidevalleys, at the foot of steep slopes, and along most fence lines (Figure 5e). In some areas, especially in larger valleys, the Camp Creek Mbr. is quite thick in the floodplain area and often completely buries the surface of the Roberts Creek Mbr. Camp Creek Mbr. alluvium was derived from both erosion of older Holocene alluvium and older deposits (such as loess and glacial till) exposed on the valley wall slopes.

Chronologic Relationships

More than 130 radiocarbon dates from about 50 localities in western Iowa have been obtained on wood, charcoal, and other plant remains buried within the DeForest Fm. These dates and age-diagnostic archaeological associations, in combination with stratigraphic studies in various parts of drainage basins throughout the area, allow us to outline the Holocene evolution of western Iowa valleys in some detail. This outline shows that periods of entrenchment and subsequent alluviation were diachronous through the hierarchy of valleys in a given basin, but roughly synchronous in similar-order valleys of different basins. Figure 6 presents a chronogram showing spatial and temporal relationships of DeForest Fm. units in western Iowa.

First-order valleys were characterized by episodic aggradation and soil development, usually with no entrenchment during the Holocene. The rest of the drainage network, however, was much more dynamic during the Holocene and passed through several degradational and aggradational episodes.

Aggradation of the Watkins Bed of the Gunder Mbr. began as early as 11,500 B.P. in valleys larger than 4th-order (Daniels and Jordan, 1966), and extended into 2nd- and 3rd-order valleys by 10,500 B.P. Watkins Bed aggradation ended between about 10,800 and 10,200 B.P. in large valleys, when poorly drained floodplain soils began to develop, but continued until sometime after 8,000 B.P. in 2nd- and 3rd-order valleys higher in the drainage network.

Between about 7,000 and 4,000 B.P., 2nd- and 3rd-order valleys were characterized by net erosion and transport of sediment to downstream parts of the drainage system. A major fluvial erosion surface, termed the DeForest Gap, developed in the middle reaches of the drainage system during the middle Holocene (Figures 5, 6, and 7). Alluvium transported out of the middle reaches of the drainage network during the middle Holocene was deposited in larger valleys (Gunder Member) and alluvial fans (Corrington Member). Aggradation of alluvial fans was episodic with intervening periods of non-deposition and soil formation. This suggests that transport of deposits out of the contributory basins was also episodic and that temporary storage of alluvium in 2nd- and 3rd-order valleys did occur during the middle Holocene. Radiocarbon dates from within alluvial fans range from about 8,700 to 3,000 B.P. in western Iowa. This corresponds very well with the absence of deposits of this age in 2nd-and 3rd-order valleys that drain to the fans.

The Hatcher Bed of the Gunder Mbr. began accumulating in 4th-order and larger valleys around 10,000 B.P. In large valleys the Hatcher Bed interfingers with, and is at least in part the same age as the Corrington Mbr. Buried soils are common in the Hatcher Bed in large valleys indicating that aggradation was episodic. Some of these paleosols may be temporally related to paleosols in the Corrington Mbr. Aggradation of the Hatcher Bed continued until around 4,000 B.P. in 4th-order and larger valleys. Accumulation of the Hatcher Bed in valleys smaller than 4th-order did not begin until about 3,500 B.P. and continued until 2,000 B.P. Few buried soils have been recorded in the Hatcher Bed in these small valleys, suggesting that aggradation of the unit was not as episodic as it was in larger valleys. Upper parts of the Hatcher Bed aggraded much slower than lower parts and thick, sometimes bisequal surface soils developed.

Another episode of entrenchment occurred in 4th-order and larger valleys around 4,000 B.P. and isolated the former floodplain containing Gunder Mbr. deposits as a low terrace. This entrenchment propagated into upper parts of the drainage network, and affected 2nd- and 3rd-order valleys

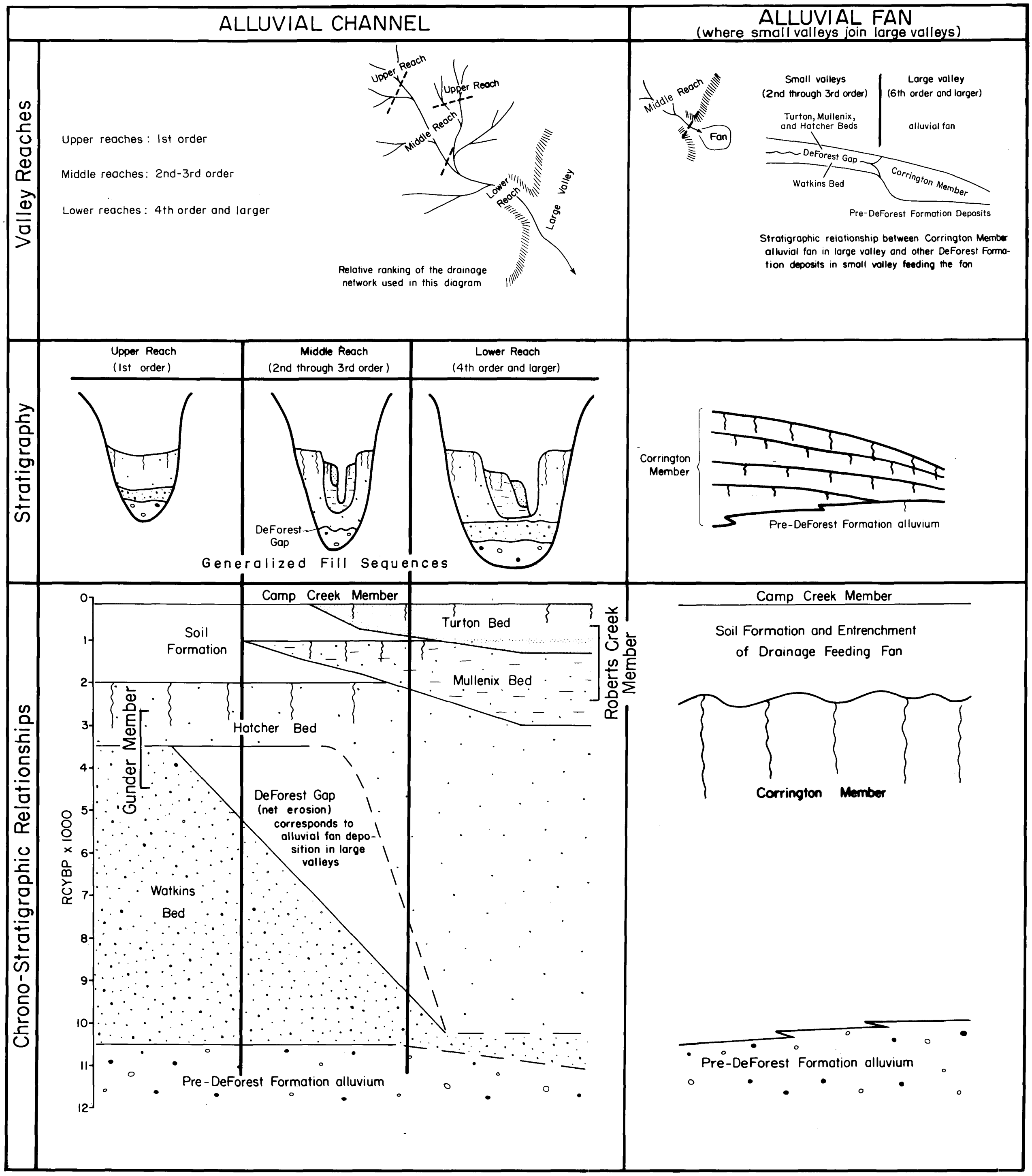


Figure 6. Chronogram of the DeForest Fm. in western Iowa. The chronogram shows stratigraphic and chronologic relationships among DeForest Fm. units proceeding from upper reaches of the drainage network (left side of diagram) to lower reaches (right side of diagram).

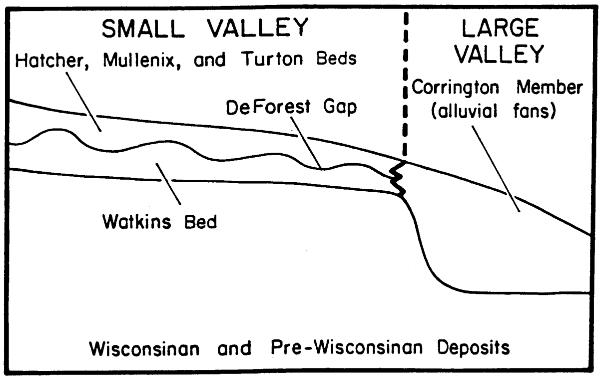


Figure 7. Cartoon showing the relationship among DeForest Fm. units in 3rd-order and smaller valleys with the Corrington Mbr. (alluvial fans) in large valleys. See text for a discussion of the temporal relationships.

between about 2,000 and 1,800 B.P. Following this entrenchment episode the Mullenix Bed of the Roberts Creek Mbr. began to accumulate in the recently formed entrenched channel belt. This aggradation began about 3,800 B.P. in large valleys and about 1,800 B.P. in 3rd-order valleys. Accumulation of the Mullenix Bed continued until about 1,400 B.P. in large valleys and 1,000 B.P. in 2nd- and 3rd-order valleys.

Another episode of entrenchment began in large valleys about 1,300 B.P. and reached 3rd-order valleys higher in the drainage network by about 800 B.P. The Turton Bed of the Roberts Creek Mbr. began accumulating in these entrenched channel areas soon thereafter. Aggradation continued until about 500 B.P. in large valleys and until about 150 B.P. in small valleys higher in the drainage network.

The Camp Creek Mbr. includes deposits that accumulated after about 500 B.P. in large valleys under the "primeval" conditions of the latest prehistoric and earliest Historic, as well as those that have accumulated throughout the drainage network during the Historic period under conditions of Euroamerican settlement and agriculture. Early Historic accounts and GLO surveys indicate that entrenched streams were not common in western Iowa before 1880 A.D. (Anderson, 1851; Piest et al., 1977). Most streams in large valleys occupied shallowly incised, meandering channel belts and smaller valleys tended to have poorly drained or marshy floodplains without well-defined channels. Between about 1880 and 1910 A.D. small-scale channelization of the larger valleys began, and was soon followed by entrenchment higher up in the drainage network. This entrenchment coincided with a dramatic increase in agricultural acreage, land clearing, and replacement of tall grass prairie with cropland. These changes increased slope erosion and sediment delivery to all elements of the drainage network and aggradation ensued. Continued aggradation in the larger valleys of western Iowa fostered severe flooding problems and losses to property and crops. This in turn led to extensive channelization projects in most larger valleys beginning shortly after 1910 and continuing into the 1940s. These projects were effective in reducing flooding in the large valleys, but the channelization also fostered entrenchment, channel widening and propagation of entrenched channels into upper parts of the drainage network.

The present extent of the entrenched drainage system in western Iowa is related to human modification of the lower parts of the drainage network, as well as hydrologic changes produced by a host of modern land-use changes. Other, equally extensive degradation/aggradation cycles occurred before humans modified the natural system to any great extent. On this field trip we will see that the stratigraphic record of Holocene degradation and aggradation episodes is traceable throughout the drainage network. The record consists of a repeatable sequence of lithologically distinct deposits that have specific geographic and chronologic relationships in the drainage network. These relationships reveal how sediment is transferred through this fluvial system on a Holocene time scale and shed light on factors that significantly influence the behavior of the system on this time scale.

DAY 1

DRIVE TO STOP 1.

The assembly area at the Best Western-Frontier Inn is situated on a broad, low Holocene terrace (probably middle Holocene) of the Missouri River. As we travel eastward toward the bluff line the surface elevation rises gradually. Lake Manawa is an abandoned Missouri River channel located south and west of I-29 (Figure 8). The Missouri River flowed through this area during the late Holocene. Note the delta along the north shore of the lake. This delta was built by Indian Creek before the creek was channelized and confined to a ditch on the west side of the lake.

The tributary valley located where I-29 and I-80 diverge is Mosquito Creek. Unlike most other valleys along this stretch of the bluff line, Mosquito Creek valley has no alluvial fan at its junction with the Missouri Valley. The absence of an alluvial fan at the junction of this valley with the Missouri River valley indicates that the Missouri River removed it, probably during the late Holocene when the river migrated into this area. At the stoplight at the intersection of IA-92 and IA-375 we turn right (southeast) and start to drive along the base of the bluff line.

At the intersection with US-275 there is a large borrow pit cut into the bluff. This is the location of the Lewis Central School site (Anderson et al., 1978). This site consists of an Archaic Period ossuary (cemetery) that was discovered approximately 10 feet (3 m) below the land surface during excavation of the borrow pit. The site contained remains of over 23 individuals and yielded a radiocarbon age on human bone of 2,815±80 B.P. (UCLA-2105). The site was reported to be within an alluvial terrace but in reality is within a colluvial slope deposit at the base of the bluff. In the last 3,000 years about 10 feet (3 m) of sediment accumulated in this landscape position.

Passing along the base of the bluff line we cross several small alluvial fans located where first-order valleys descend from the bluff line. On the west end of Pony Creek valley we turn left and pass up the valley to Stop 1 (Figure 8). Pony Creek valley has built a large, low-angle alluvial fan at its junction with the Missouri Valley. This suggests that the bluff line in the vicinity of Pony Creek is older than that to the north around Mosquito Creek.

STOP 1. TWIN PONIES: ENTRENCHED STREAM PROCESSES AND STRATIGRAPHY

At this stop we will introduce field-trip participants to entrenched stream processes, examine a reach of entrenched channel exhibiting various bank conditions, and discuss the Holocene stratigraphic units exposed along the entrenched channel. This is the smallest valley this trip will visit because outcrops in smaller valleys are too small for a group this large. We will look at three outcrops along a 0.5 mile stretch of entrenched stream. Bed and bank conditions, as well as the exposed sequence of alluvial fills along this reach are representative for this size valley in the Loess Hills region. Because stream processes vary in time and space, it is necessary to visit a reach of entrenched channel in order to get a feel for the range of channel conditions and bank stratigraphy characteristic of the area. A complete Holocene stratigraphic sequence is not present at any one outcrop, but examination of several outcrops along this reach will give participants a chance to see what the Holocene alluvial fill sequence looks like, and examine stratigraphic relationships among the units.

Twin Ponies watershed is a 25.2 mi^2 drainage basin that joins Mosquito Creek on the Missouri River floodplain (Figure 8). This basin is in the thick-loess region of western Iowa with more than 60 feet of Peoria Loess on broad divide areas. Stop 1 is in the junction area of two 3rd-order valleys (SW1/4 sec. 11 T74N R43W; Figure 9). The drainage area above the junction of these two valleys is 5.9 mi^2. Entrenched channels extend into the 2nd-order valleys of this basin, and a few entrenched laterals are present where 1st-order valleys descend to the main valley, or where flow concentrates along field margins paralleling the entrenched main channel. Flow in the two main channels is usually perennial, with the northern-most being greater at low stage. The southern-most entrenched channel was dry most of the summer and fall of 1989 after two consecutive years of drought.

Entrenched streams or gullies pass through several developmental stages that are characterized by different bank and bed stabilities and overall channel appearance (Heede, 1974; Bradford et al., 1978; Bettis and Thompson, 1982; Simon, n.d.).

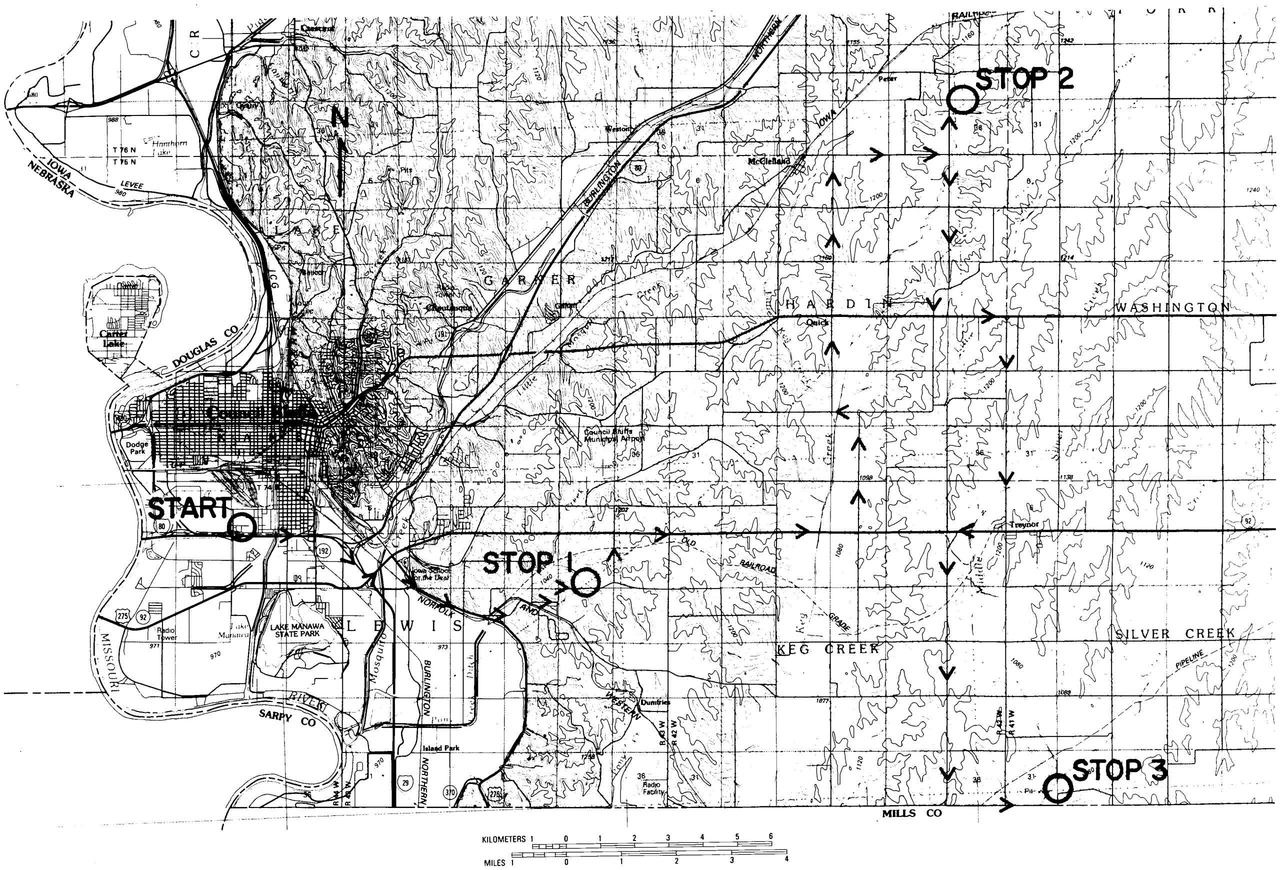


Figure 8. Route map for stops 1-3 of the fieldtrip. Base taken from USGS Pottawattamie County, Iowa 1:100,000 scale topographic map.

Several developmental stages are evident along the length of an entrenched channel at a point in time, and a channel cross-section passes through the sequence of stages with time. A six stage classification scheme for these stages developed in Tennessee (Simon, n.d.) also seems to be applicable in western Iowa:

I--stable vegetated banks lacking an entrenched channel. This is the initial condition of channels in western Iowa prior to an entrenchment cycle.

II--man-modified. Channelization and/or straightening that occurs primarily in the large and moderate-size valleys of western Iowa. This lowers local base level and increases stream power.

III--degradation. This can occur in man-altered reaches as the modified channels adjust to gradient and sediment-supply changes (Daniels and Jordan, 1966), or in upstream reaches as knickpoints move headward in response to lower base level downstream. Degradation by undercutting and pop-out failure further increases bank height (see Bradford et al., 1978 in the contributed papers). During this stage banks are steep and the width-to-depth ratio of the entrenched channel is small.

IV--threshold. Entrenchment slows relative to stage III but knickpoints may migrate up the entrenched channel. Banks are still unstable and significant widening begins to occur. Shallow planar (slab) failures are dominant, sometimes followed by deep seated rotational slumps in some areas (van der Poel et al., 1986). Most bank failure by mass wasting occurs in the spring following snowmelt and heavy rains. These conditions foster bank failure by adding weight (load) to the top of the bank, increasing shear stress, and by increasing pore pressure in the bank materials, thereby decreasing shear strength. As long as flow through the channel is able to transport debris mass wasting into the channel, this stage continues and further

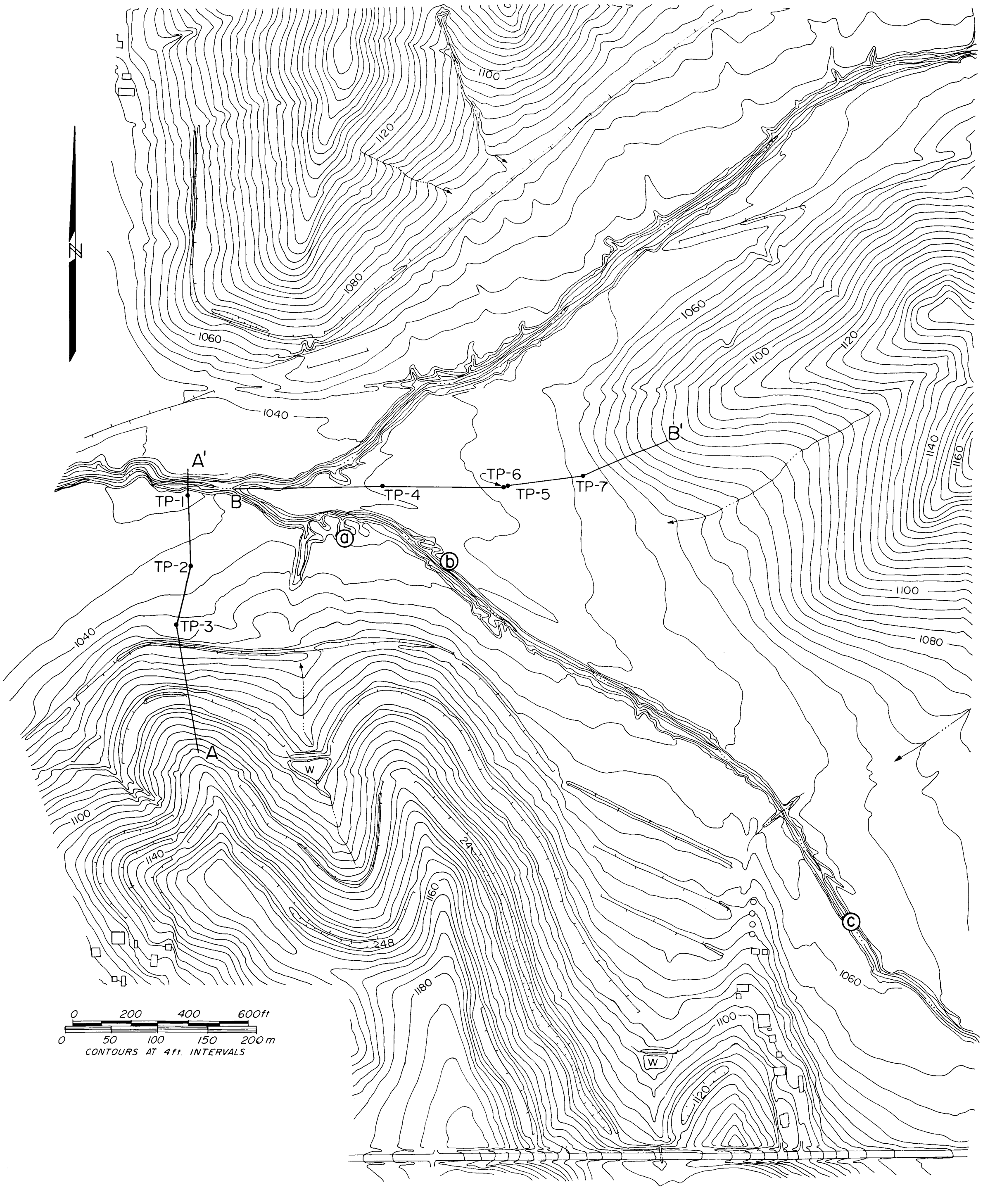


Figure 9. Topographic map of the Stop 1 area along Pony Creek in southwestern Pottawattamie County. Base from USDA-SCS transit survey; contour interval 4 ft. Locations of cross-sections discussed in the text are shown, and localities a-c are sites visited on the trip.

widening occurs.

V--aggradation. When more debris enters the channel than the stream can transport, aggradation begins. Channel reaches lower in the drainage network begin to aggrade first because gradients are lower. Rotational slumps at the end of stage IV significantly lower bank angles and aggradation lowers bank height. These two processes acting together result in bank stability.

VI--restabilization. Mass wasting decreases and vegetation becomes established on the banks, promoting further aggradation and moving the system back toward stage I. In western Iowa stages V and VI commonly take place concurrently.

Like any classification scheme of natural systems this is a generalization and the real world tends to show gradations between these generalized stages. At stop 1a we will see a 1st-order lateral headwall in stage III (the channel in Twin Ponies watershed has not been altered significantly by man) entering an entrenched 3rd-order main channel in stage IV/VI. The channel in the mainstem is not aggrading but the banks and channel margins are vegetated.

Stop 1a. Stratigraphy

At this stop we will see the Camp Creek, Roberts Creek, and Gunder members exposed in the headwall of a 1st-order tributary to the mainstem. Examine closely the color and stratification evident in the three units, and the nature of the surface soils developed on all three. Limited subsurface investigations have been conducted on the opposite side of the mainstem in this part of the valley. Figure 9 shows the location of borings and Figure 10 presents cross-sections constructed from the borings. Holocene alluvium (Gunder Mbr.) is separated from pre-Holocene deposits by a fluvial erosion surface. The Gunder Mbr. (Hatcher Bed) abuts the valley wall and occupies the greatest volume of the valley fill. The Roberts Creek Mbr. (Mullenix Bed) is present as a narrow remnant along the modern entrenched channel and is inset into the Gunder Mbr. on the peninsula between the two tributary channels. The Camp Creek Mbr. is relatively thin and buries both the Gunder and Roberts Creek members in this area. Descriptions of cores TP-1 and TP-4 are presented in Figure 11.

Stop 1b. Stratigraphy Exposed in the Banks of the Main Channel.

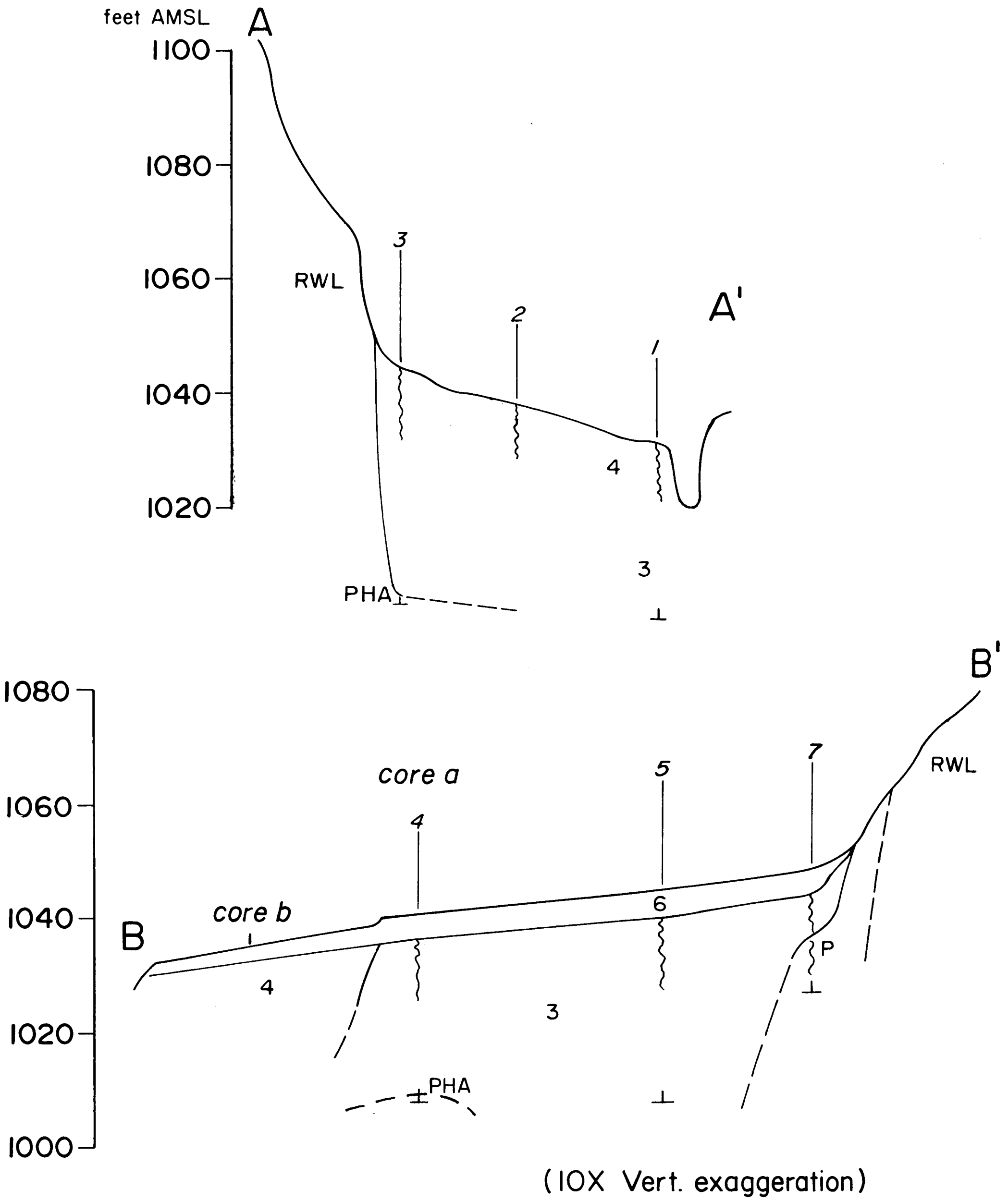
At this outcrop we will see the Roberts Creek Mbr. inset into the Gunder Mbr., with an indistinct boundary between the two. Close examination reveals rip-up clasts composed of Gunder Mbr. in the lower foot of the Roberts Creek Mbr. Notice the similarity in color and stratigraphic position of the alluvial fills in this outcrop with correlative units at the previous stop.

Although no datable material has been recovered from this valley dates from valleys of this size elsewhere in western Iowa suggest that the Roberts Creek Mbr. accumulated between about 1,800 and 1,000 B.P. while the Gunder Mbr. accumulated from 3,500 to 2,000 B.P. Therefore surface soils on the Gunder Mbr. have been developing for about 2,000 years, while those on the Roberts Creek Mbr. have been developing for about 1,000 years.

Note the lateral in stage III on the east side of the main channel and the slump at the base of the bank in the main channel (stage IV/VI).

Stop 1c. Channel facies of the Camp Creek Member Exposed in the Banks of the Main Channel.

A channel fill facies of the Camp Creek Mbr. is exposed in the eastern bank immediately upstream of the crossing here. Note the stratification and the poorly expressed surface soil in comparison to the thick, well expressed Mollisols where the Roberts Creek Mbr. (on the downstream side of the crossing) and Gunder Mbr. (on the west side of the entrenched channel upstream of the crossing) are the surficial deposit. Sawed bones (domestic animals), square nails, and broken china have been found in the channel sands in this exposure of the Camp Creek Mbr., demonstrating the Historic age of the unit.



KEY

6	Camp Creek Member	RWL	Reworked Loess
4	Roberts Creek Member Mullenix Bed	P	Pedisediment
3	Gunder Member Hatcher Bed	PHA	Pre-Holocene alluvium

Figure 10. Cross-sections A-A' and B-B' along Pony Creek showing Holocene alluvial stratigraphy. Cross-section locations are shown on Figure 9.

78TP-1

Location: NW 1/4 SW 1/4 sec. 11 T74N R43W Pottawattamie County, Iowa
Landscape position: floodplain
Parent material: alluvium
Date described: 11/11/80
Elevation: approximately 1032 feet

Depth inches (cm)	Soil Horizon	Description
		DeForest Fm.; Camp Creek Mbr.
0-21 (0-53)	Ap	dark grayish brown (10YR 4/2), silt loam, cloddy, friable, noneffervescent, abrupt boundary, few roots
		Roberts Creek Mbr.; Mullenix Bed
21-36 (57-91)	A1	black to very dark gray (10YR 2/1-3/1), silt loam, weak medium to fine granular, friable, noneffervescent, clear boundary, common roots
36-55 (91-140)	A2	black (10YR 2/1), silt loam, moderate fine subangular blocky, friable, noneffervescent, gradual boundary, few roots
55-75 (140-190)	Bw1	very dark grayish brown (10YR 3/2), light silty clay loam, moderate medium subangular blocky, friable, noneffervescent, clear boundary, few roots, common thin almost continuous very dark gray (10YR 3/1) coatings on ped surfaces
75-100 (190-254)	Bw2	dark brown (10YR 3/3), silty clay loam, moderate medium to coarse columnar, friable, noneffervescent, gradual boundary, common thin discontinuous very dark grayish brown (10YR 3/2) coatings on ped surfaces, thin continuous coatings in root channels
100-120 (254-305)	Bw3	dark brown (10YR 3/3), silty clay loam, weak medium subangular blocky, friable, noneffervescent, gradual boundary, very few thin discontinous very dark grayish brown (10YR 3/2) coatings on ped surfaces
120-121 (305-536)	C	dark grayish brown (10YR 4/2), with occasional thin brown (10YR 5/3) lenses, heavy silt loam, massive, friable, noneffervescent, abrupt boundary, common charcoal and burned earth at 193 in (490 cm) and from 197-198 in (500-503 cm), small mammal bones at 174 in (442 cm)
		Gunder Mbr.; Hatcher Bed
211-307 (536-780)	2C1	yellowish brown (10YR 5/4), silt loam, massive, very friable, noneffervescent, abrupt boundary, few medium brown (10YR 5/3) mottles
307-341 (780-866)	2Ab	dark brown (10YR 3/3), light silty clay loam, massive, slightly sticky slightly plastic, noneffervescent, gradual boundary, common fine gray (10YR 5/1) mottles; more porous than above
341-base (380) (866-965)	2Bwb	dark brown (10YR 3/3), light silty clay loam, weak medium subangular blocky, slightly sticky slightly plastic, noneffervescent, common medium brown (10YR 4/3) mottles, few thin discontinuous very dark grayish brown (10YR 3/2) coatings on ped surfaces, could not penetrate next unit (very heavy textured)

Figure 11. Descriptions of cores TP-1 and TP-4 collected from DeForest Fm. alluvium in Pony Creek valley at Stop 1. Locations of these cores are shown on Figure 9.

78TP-4
Location: NW 1/4 SW 1/4 sec. 11 T74N R43W Pottawattamie County, Iowa
Landscape position: low terrace
Parent material: alluvium
Date described: 11/12/80
Elevation: approximately 1040 feet

Depth inches (cm)	Soil Horizon	Description
		DeForest Fm.; Camp Creek Mbr.
0-10 (0-25)	Ap	very dark grayish brown (10YR 3/2), silt loam, massive, breaks along horizontal planes, friable, noneffervescent, abrupt boundary, few roots
10-54 (25-137)	C	dark grayish brown (10YR 4/2), silt loam, very weak medium subangular blocky to massive, very friable, noneffervescent, abrupt boundary, common roots
		Gunder Mbr.; Hatcher Bed
54-61 (137-155)	2Ab	very dark gray (10YR 3/1), silt loam, moderate medium subangular blocky, friable, noneffervescent, clear boundary common roots
61-81 (155-206)	2ABb	very dark grayish brown (10YR 3/2), silt loam, moderate medium subangular blocky, friable, noneffervescent, gradual boundary, few thin discontinuous very dark gray (10YR 3/1) coatings on ped surfaces
81-111 (206-282)	2Bw1b	very dark grayish brown (10YR 3/2), heavy silt loam, moderate medium to coarse subangular blocky, friable, noneffervescent, clear boundary, coatings on ped surfaces as above
111-129 (282-328)	2Bw2b	very dark grayish brown to dark grayish brown (10YR 3/2-4/2), silty clay loam, moderate coarse subangular blocky, friable, noneffervescent, gradual boundary, common thin discontinuous very dark grayish brown (10YR 3/2) coatings on ped surfaces
129-153 (328-389)	2Bw3b	dark brown (10YR 3/3), silty clay loam, weak medium to coarse subangular blocky, friable, noneffervescent, gradual boundary, common medium dark grayish brown (10YR 4/2) mottles, few thin discontinuous very dark grayish brown (10YR 3/2) coatings on ped surfaces
153-180 (389-457)	2BCb	brown (10YR 4/3-5/3), silt loam, weak medium subangular blocky to massive, very friable, noneffervescent, gradual boundary, mottles as above, very few fine oxides, very few thin discontinuous dark brown (10YR 3/3) coatings on ped surfaces
180-216 (457-549)	2C1	brown (10YR 4/3), silt loam, massive, with occasional very weak medium to fine subangular blocky zones, friable, noneffervescent, gradual boundary, few medium dark grayish brown (10YR 4/2) mottles
216-314 (549-798)	2C2	brown (10YR 5/3), silt loam, massive, friable, noneffervescent, clear boundary, few fine oxides
314-348 (798-844)	2C3	brown to yellowish brown (10YR 5/3-5/4), heavy silt loam, massive, slightly sticky slightly plastic, noneffervescent, abrupt boundary, few fine iron concretions, oxides as above
348-352 (844-894)	2C4	brown (10YR 5/3), clay loam, moderate medium angular blocky, sticky plastic, noneffervescent, abrupt boundary, common fine iron concretions, pressure faces on peds
252-378 (894-960)	2C5	brown (10YR 4/3), silt loam, massive, slightly sticky slightly plastic, noneffervescent, clear boundary, common fine oxides
		Pre-Holocene Alluvium
378-base (384) (960-975)	3Bb	brown (10YR 4/3), heavy silt loam, weak fine angular blocky, sticky plastic, noneffervescent, common fine iron concretions, oxides as above

Figure 11. Continued.

STOP 2. ENTRENCHED CHANNEL OF KEG CREEK

At this stop we will examine the alluvial stratigraphy exposed in the incised channel of Keg Creek and note that stratigraphic relationships similar to those observed along Twin Ponies Creek, as well as similar-appearing alluvial fills are present. We will also present radiocarbon dates from these larger valley deposits, and further discuss entrenched stream processes, particularly the effects of knickpoint migration in a previously entrenched channel.

Keg Creek flows through a moderate-sized valley (> 4th-order) with a drainage area of approximately 88 mi^2 (228 km^2) above Stop 2 (SE1/4 SW1/4 SW1/4 sec. 25 T76N R42W; Figures 8 and 12). Like all streams of this size in western Iowa, Keg Creek is perennial and occupies an entrenched channel. In this area Keg Creek has undergone limited straightening, primarily in proximity to bridge crossings. Knickpoint migration up channels in moderate-size valleys has resulted in deep entrenchment and bank instability problems throughout western Iowa, creating severe problems including channel widening at bridge and pipeline crossings [about 25 percent of the highway bridges in 13 western Iowa counties were endangered in 1980 (Hanson et al., 1986)], loss of agricultural land, and extreme sediment loading.

Stratigraphy

The same three units of the DeForest Fm. observed at Stop 1 are exposed in the east bank of Keg Creek at this stop (Figure 13). The sequence of stratigraphic units varies along the outcrop depending on the location and depth of pre-Camp Creek Mbr. Historic entrenchment. At this location the entrenched channel is about 20 feet (6.1 m) deep and contains a perennial stream. The channel bends through this reach with the outcrop we are interested in being on the inside bend. The following observations of the exposed units were made in August of 1989 and may vary somewhat from what is exposed at the time of the trip.

The Camp Creek Mbr. is the uppermost unit and occupies a channel inset into older Holocene alluvium along the middle and downstream portions of the exposure. This alluvium shows properties typical of the Camp Creek Mbr. including; well expressed stratification, oxidized colors, and very weak surface soil development. In the lowest part of the Camp Creek channel, at the bend in the modern incised channel, the alluvium is trough cross-bedded and consists of medium sand, pebbles, and a few rip-up clasts (Figure 13a). Broken glass was observed in this part of the section in 1989. About 30 feet downstream a metal fence post was observed lying nearly horizontal about one foot (0.3 m) above the base of the unit.

The Roberts Creek Mbr. consists of two alluvial fills, the Turton and Mullenix beds. Only the lower part of the Turton Bed is preserved at this site. On the upstream end of the bend in the exposure the Turton Bed consists of trough cross-bedded, dark grayish brown loam and sand containing abundant detrital organic material which was deposited at the base of a channel fill (Figure 13b). An organic mat collected from this zone yielded a radiocarbon age of 400±70 B.P. (Beta-32835). Farther downstream, the Turton Bed is planar-bedded grading to shallow trough cross-bedded, dark grayish brown to grayish brown fine sand, loam, and silt loam lacking organic remains (Figure 13a). The Turton Bed is separated from the overlying Camp Creek Mbr., and the underlying Mullenix Bed and Gunder Mbr. by angular unconformities (fluvial erosion surfaces).

The Mullenix Bed of the Roberts Creek Mbr. is present on the upstream end of the exposure (Figure 13b). In this part of the exposure the Mullenix Bed is the surficial unit (or it is buried by a thin increment of Camp Creek Mbr. alluvium) and a thick Mollisol is developed in its upper part. The Mullenix Bed is dark grayish brown silt loam to silty clay loam, and exhibits the coarse blocky and columnar structural units typical of the unit. Lower parts of the unit are stratified. Downstream of the bend the Mullenix Bed is absent because of subsequent pre-Turton entrenchment. The Mullenix Bed is buried by about one foot (30 cm) of Camp Creek Mbr. on the west side of the channel. You can observe the surface soil developed in the Mullenix Bed there.

The Gunder Mbr. is the lowest exposed alluvial fill in the section (Figure 13a and b). Upper parts of the unit have been eroded by episodes of entrenchment preceding aggradation of the overlying units in the section. Across most of the section the Gunder Mbr. is oxidized, brown to dark yellowish brown silt loam containing abundant krotovina filled with dark grayish brown silty clay loam. The fill of these krotovina erodes out to form potholes in the bed of the stream. The Gunder

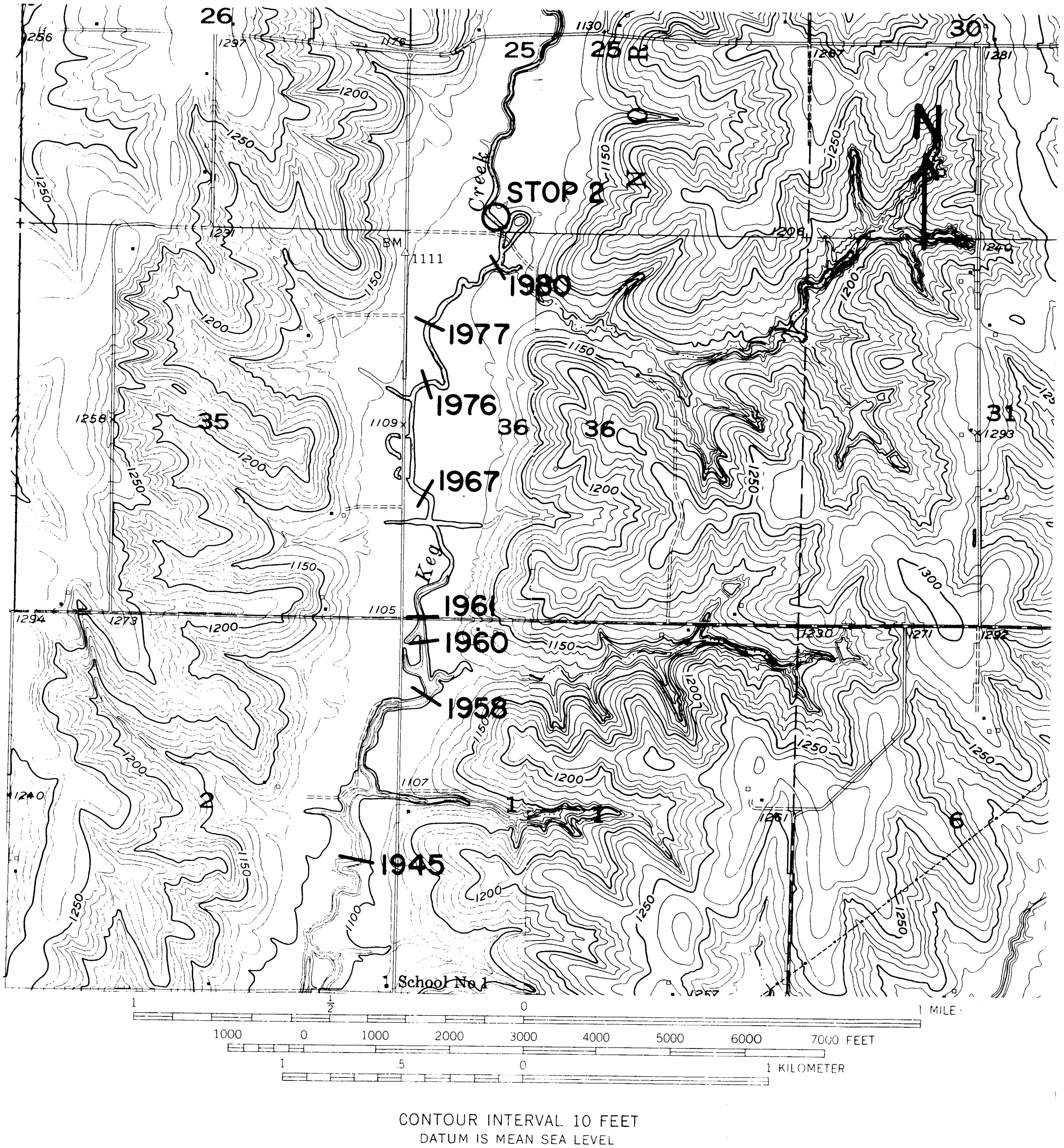


Figure 12. Topographic map of the Stop 2 area along Keg Creek in central Pottawattamie County. Lines with associated dates indicate the location of a knickpoint migrating up the channel. Base taken from USGS 7.5' McClelland and Taylor, Iowa quadrangles.

Mbr. becomes gleyed on the upstream end of the exposure where it is overlain by the Mullenix Bed of the Roberts Creek Mbr.

An approximately 3 foot (0.9 m) thick buried soil is present in the upper part of the Gunder Mbr. in the east bank (Figure 13a). This soil is laterally continuous, dark-colored, and moderately well horizonated. Texture within the solum is silty clay loam. Examination of this soil reveals some interesting complexities characteristic of soils developed in alluvium. There appears to be some faint color and textural banding most evident (though still subtle) in the lower part of the solum. Following the soil downstream, the origin of the banding becomes evident: the soil splits into at least three discernable soils. These soils are each developed in a fining upward sequence grading from silt loam to silty clay loam. The upper part of each sequence is darker colored and contains more organic carbon than the lower part. The composite soil in the upstream part of the section (where the three upward-fining sequences converge) probably owes much of its character, especially its dark color, organic matter content, and heavy texture, to depositional processes. Recognition of this fact and an appreciation of the lateral variability of this soil are important lessons for those of us who study alluvial stratigraphy using cores.

Charcoal collected from within this intra-Gunder Mbr. soil yielded a radiocarbon age of 10,840±370 B.P. (Beta-33178; Figure 13a). This is much older than dates from within the Gunder Mbr. in small valleys, but is in agreement with other dates from large valleys in western Iowa. The chronology of DeForest Fm. units in large verses small valleys will be discussed more fully at the next stop.

Knickpoint Migration

This reach of Keg Creek is also of interest because the migration of a knickpoint up the incised channel has been monitored intermittently since 1945 (R. F. Piest, USDA-ARS, personal communication, 1980). In 1945 a 2-foot-high overfall (knickpoint) was noted approximately 3/4 mile south (downstream) of McClelland Road (Figure 12). In 1958 the overfall was about 1/8 mile south of the road. At that time Pottawattamie County replaced the McClelland Road bridge and straightened the channel to the point of the overfall. Migration of the overfall continued and its location at selected points in time are shown on Figure 12. I observed the knickpoint in 1980 at which time it consisted of a series of four, two foot high overfalls spaced over a thirty foot reach of the channel. Today the former knickpoint area is marked by the steep channel reach at and upstream of the bend in the channel.

Knickpoint migration has been episodic along this reach related to high-flow events. On March 18 and 19, 1978 the knickpoint [at that time a five foot (1.5 m) overfall with attendant 10 ft (3 m) plunge pool] moved upstream 225 ft. (70 m) during a large snowmelt runoff event (van der Poel et al., 1986). This migration increased the bank height from 25 to 31 feet (7.6-9.5 m), not including the 10 ft (3 m) deep plunge pool that quickly filled with alluvium as the knickpoint migrated upstream. The increased bank height, combined with thawing of ground frost, infiltration of snowmelt, and light rain, resulted in massive bank failures and channel widening. Monitoring subsurface ground movements led van der Poel and co-workers (1986) to conclude that the banks widened by slab failure rather than rotational slump.

This reach of Keg Creek is in developmental stage IV. Banks are relatively unstable and poorly vegetated. Where the stream is impinging on the bank and near vertical channel walls are present, failure is very likely.

Channel widening following degradation, such as has occurred along this stretch of Keg Creek, necessitates extension or replacement of bridges crossing the channel because of pier and abutment undermining. Most bridges in western Iowa have been lengthened more than once, and many have been replaced in the last ten to 15 years. Grade-stabilization structures are considered to be the most effective remedial measure for stream degradation (Brice et al., 1978). Reinforced-concrete grade-stabilization structures costing between $300,000 and $1,300,000 have been very effective, but their cost is prohibitive in many situations. As part of an Iowa Department of Transportation-sponsored study at Iowa State University a low-cost ($120,000) gabion structure was built at the McClelland Road bridge across Keg Creek in 1982. The structure has performed well and a cost analysis shows that the cost of building the gabion structure was about 20 percent that of a comparable-size concrete structure. The paper by Hanson, et al. in the contributed papers describes the structure and its performance.

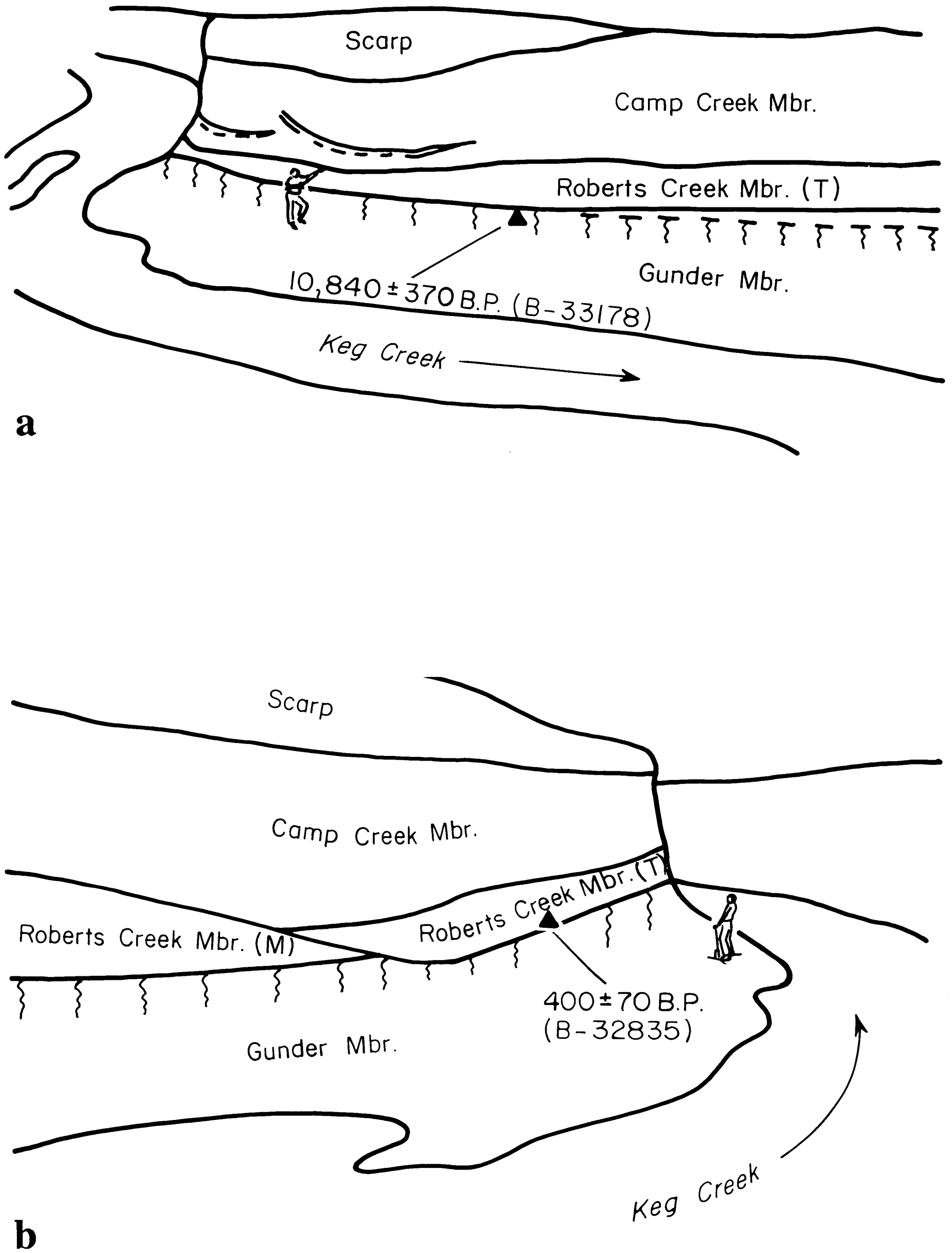


Figure 13. Sketches of outcrop along east bank of Keg Creek at Stop 2 where the Camp Creek, Roberts Creek, and Gunder members of the DeForest Fm. are exposed. Sketch "a" shows the portion of the section downstream of the channel bend, while sketch "b" shows that portion of the section upstream of the bend. Note person (6'3") for scale.

STOP 3. SILVER CREEK ENTRENCHED CHANNEL

At this stop we will view an exposure of the Gunder, Roberts Creek, and Camp Creek members and see that the lithology of these units, and stratigraphic relationships among units are very similar to those we examined at the last stop. Radiocarbon ages from organic remains in this outcrop also agree well with those obtained from similar stratigraphic positions at the previous stop. We will also discuss the results of subsurface investigations along Middle Silver Creek, upstream about 5 miles (8 km). These investigations provide additional radiocarbon ages on DeForest Fm. units in moderate size valleys, and demonstrate the relationships among the DeForest Fm. alluvial fills and the older Quaternary units of the valley wall and beneath the valley fill.

The Stop 3 exposure is located 0.25 mile (0.4 km) below the junction of Middle Silver Creek with Silver Creek, just north of the Mills/Pottawattamie county line (SE1/4 SE1/4 sec. 31 T74N R41W; Figure 8). Drainage area above this location is approximately 192 mi^2 (497 km^2) and the valley is larger than 5th-order. Peoria Loess attains a maximum thickness of about 33 ft (10 m) on uplands in this area (Allen, 1971). The channels of both Silver and Middle Silver creeks have been straightened, and their beds seem to be in a state of quasi-equilibrium with respect to depth. Both channels are in stage IV with some areas in stage VI. The entrenched channels in both valleys are beginning to develop low-amplitude meanders with consequent widening and bank instability on the outside bends.

3a. Silver Creek Stratigraphy and Chronology

At this stop the Gunder, Roberts Creek, and Camp Creek members of the DeForest Fm. are exposed in the western bank of the entrenched channel. Gunder Mbr. deposits are present from creek level to about midway up the section, and have been cut out during younger entrenchment on both the upstream and downstream ends of the exposure (Figure 14). The lower 3 to 4 feet (0.9-1.2 m) of the unit is reduced while the remainder of the Gunder Mbr. is mottled and oxidized. The Gunder Mbr. consists of weakly planar-bedded silt loam alluvium in this exposure. Low in the middle of the exposure, trough cross-bedded medium sand containing wood is present. This may be an area of local scour associated with a log jam, or the edge of a bar analogous to the one on the east side of the modern channel. A thin, weakly expressed paleosol occurs within the Gunder Mbr. one to two feet (30-60 cm) below the contact with the overlying Roberts Creek Mbr. (Figure 14).

A fluvial erosion surface separates the Gunder Mbr. from the overlying Roberts Creek Mbr. (Mullenix Bed). On the downstream end of the exposure, the Roberts Creek Mbr. fills a channel cutting out the underlying Gunder Mbr. (Figure 14). The coarsest deposits in the channel fill are medium to coarse sand, although armored mudballs the size of small cobbles were observed in trough cross-beds in the lower part of the channel fill. The base of the Roberts Creek channel fill was not exposed at low flow in 1989 suggesting that pre-Roberts Creek entrenchment was of the same degree as that of the modern channel. Elsewhere across the section the lower part of the Roberts Creek Mbr. appears to be a channel margin facies, with planar beds and shallow channels filled with planar beds, grading upward to massive (pedogenically altered) silt loam and silty clay loam alluvium. The stratified parts of the unit contain a few vertebrate fossils (including large mammal bones in fragmentary condition) and charcoal along some bedding planes.

A thick Mollisol with an A-Bw-C profile is developed in the upper part of the Roberts Creek Mbr. Notice that the soil passes across the Roberts Creek channel fill and in that area the solum is less well horizonated than upstream.

Camp Creek Mbr. alluvium mantles the Roberts Creek Mbr. across the exposure and is the surficial deposit (Figure 14). The lower few inches of the Camp Creek are stratified (planar bedded) and a thin Entisol with an A-C profile is developed in the upper part of the unit. The Camp Creek thickens over the Roberts Creek channel fill and stratification is more evident. Notice that the strata just above the soil developed in the Roberts Creek Mbr. contain more organic matter (are darker) than those higher up in the Camp Creek Mbr. Small burrows and root traces are more common in this part of the Camp Creek than higher in the section suggesting that aggradation occurred slowly initially then at a greater rate during the time that most of the Camp Creek Mbr. was deposited.

Another exposure of the Camp Creek Mbr. is present in the east bank below where we are

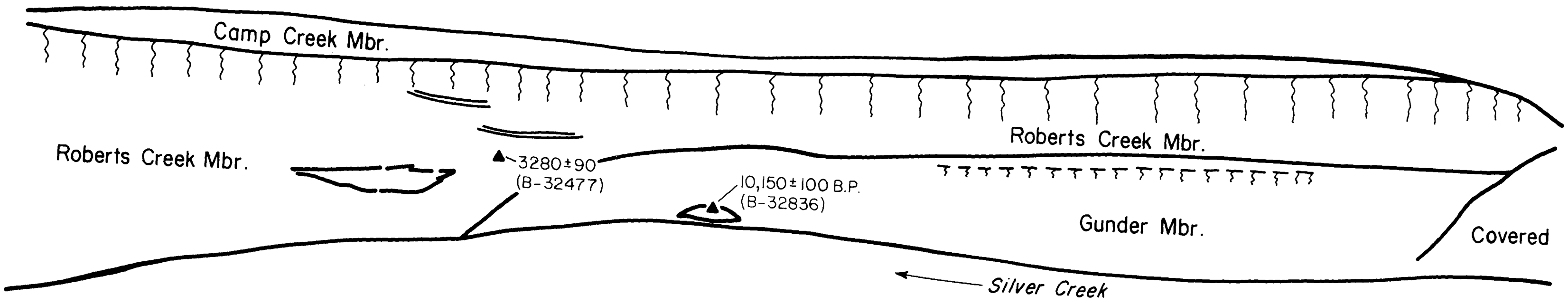


Figure 14. Sketch of outcrop along the west bank of Silver Creek at Stop 3. The Camp Creek, Roberts Creek, and Gunder members of the DeForest Fm. are exposed here. Section is approximately 15 ft. high.

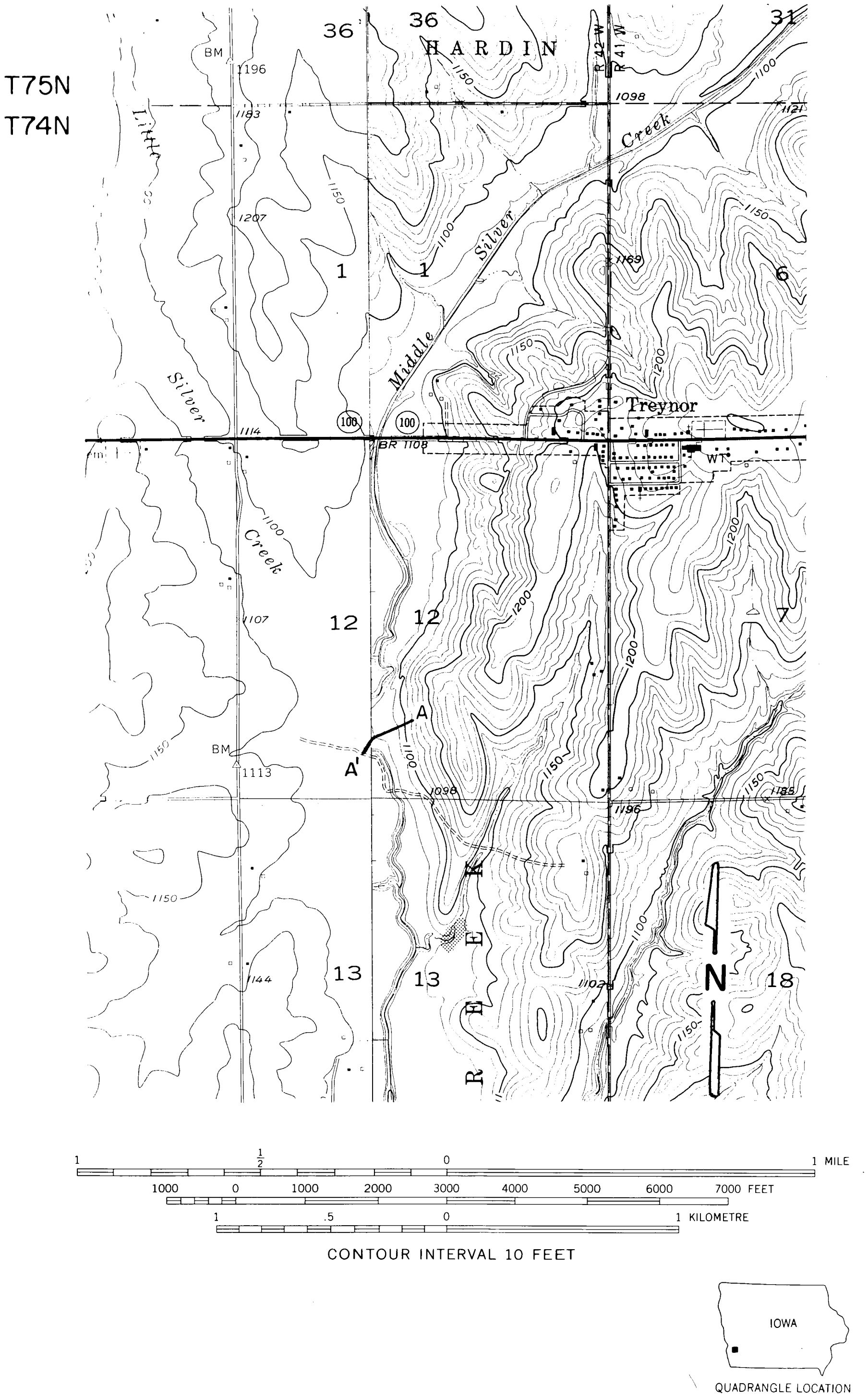


Figure 15. Topographic map of the Middle Silver Creek study area and the location of cross-section A-A'. Base taken from USGS 7.5' Treynor and Mineola, Iowa quadrangles.

standing. Deposits exposed here are the upper part of a channel-fill sequence that accumulated marginal to the main channel, possibly in a meander cutoff. Most of the deposits are planar bedded but one prominent bed consists of cross-bedded coarse silt. Notice that the planar beds consist of upward-fining couplets grading from silt loam at the base to dark-colored silty clay loam in the upper part. Each of these represents higher energy deposits (light-colored silt loam) overlain by lower energy deposits (dark-colored silty clay loam) accumulating during falling stage. Mud cracks are common in the upper part of these couplets. This sedimentation style is also characteristic of the Roberts Creek Mbr., and hints of this style are preserved in the Gunder Mbr. as well.

Two radiocarbon dates were obtained from the exposure on the west side of the creek. Wood from the sandy, trough-cross bedded, reduced part of the Gunder Mbr. in the central part of the section yielded an age of 10,150±100 B.P. (Beta-32836; Figure 14). This is about 700 years younger than the Gunder Mbr. date from Keg Creek. Charcoal disseminated along a bedding plane ten inches (25 cm) above the Gunder/Roberts Creek contact in the central part of the section (Figure 14) yielded an age of 3,280±90 B.P. (Beta-32477). This is considerably older than the date from the Roberts Creek Mbr. at Keg Creek, but the latter is from the Turton Bed, while the Silver Creek date is from the Mullenix Bed.

3b. Middle Silver Creek Stratigraphy and Chronology

Middle Silver Creek is a large tributary of Silver Creek that joins Silver Creek just upstream of Stop 3 (W1/2 NE1/4 and E1/2 NW1/4 sec. 13 T 74N R42W). Subsurface investigations were conducted along the east side of Middle Silver Creek valley about 4 miles (6.4 km) upstream of its junction with Silver Creek (Figure 15). At the study area, Middle Silver Creek is a 5th-order valley with a drainage area of 62 mi^2 (161 km^2).

Figure 16 shows a cross-section constructed from drill hole information and bank exposures. The alluvial fill is cut into pre-Illinoian till that has an "A-till" clay-mineral assemblage (see Stop 6 discussion). The Gunder Mbr. encompasses most of the valley fill along this side of Middle Silver Creek. A prominent, poorly drained, silty clay loam texture paleosol is present within the Gunder Mbr. Below this paleosol Gunder Mbr. deposits are stratified, reduced and calcareous, while above the soil the deposits are less stratified, mottled, oxidized, and weakly calcareous to neutral. Gunder Mbr. deposits are dominantly silt loam with thin silty clay loam lenses. The lower five feet of the unit contains beds of fine to coarse sand and a thin gravel lag rests on the eroded till surface.

The Gunder Mbr. grades laterally into resedimented Peoria Loess in the footslope and lower sideslope. Lenses of sand are present in the lower part of the unit in this position and a discontinuous stone line consisting of erratics and eroded carbonate concretions rests on the eroded till surface.

Surface soils developed in the Gunder Mbr. are Cumulic Hapludolls (Mollisols with A horizons overthickened by periodic accumulation of sediment on the soil surface) with thick sola and A-Bt-BC or A-Bw-BC profiles. Weakly expressed buried soils are present within the upper part of the Gunder Mbr. and some of these are within the modern solum.

The Roberts Creek Mbr. occupies a channel-margin remnant inset into the Gunder Mbr. (Figure 16), with a 2-foot-high scarp separating the surface of the two units. The Roberts Creek Mbr. consists of dark gray to very dark gray (10YR 4/1-3/1) massive, calcareous, light silty clay loam. The entire unit has been pedogenically altered and exhibits the coarse columnar structure characteristic of the Mullenix Bed. Surface soils developed in the Roberts Creek Mbr. are Cumulic Hapludolls and Haplaquolls (poorly drained Mollisols) that have A-Bw-BC profiles.

Camp Creek Mbr. deposits occupy a thin wedge of overbank sediment overlying the Roberts Creek Mbr. (Figure 16). The unit is massive, oxidized, noncalcareous, and other than burrows and root traces, lacks pedogenic alteration.

Four radiocarbon dates were obtained from the Middle Silver Creek study area, two in the area of the cross-section and two others downstream of the cross-section. Organics collected in core 5 from the A horizon of the poorly drained buried soil developed in the Gunder Mbr. yielded an age of 10,000±230 B.P. (Beta-5182) while charcoal collected from the bank of Middle Silver Creek below the paleosol yielded an age of 10,230±320 B.P. (Beta-5180). These ages are very similar to that of the Gunder Mbr. sequence observed in a

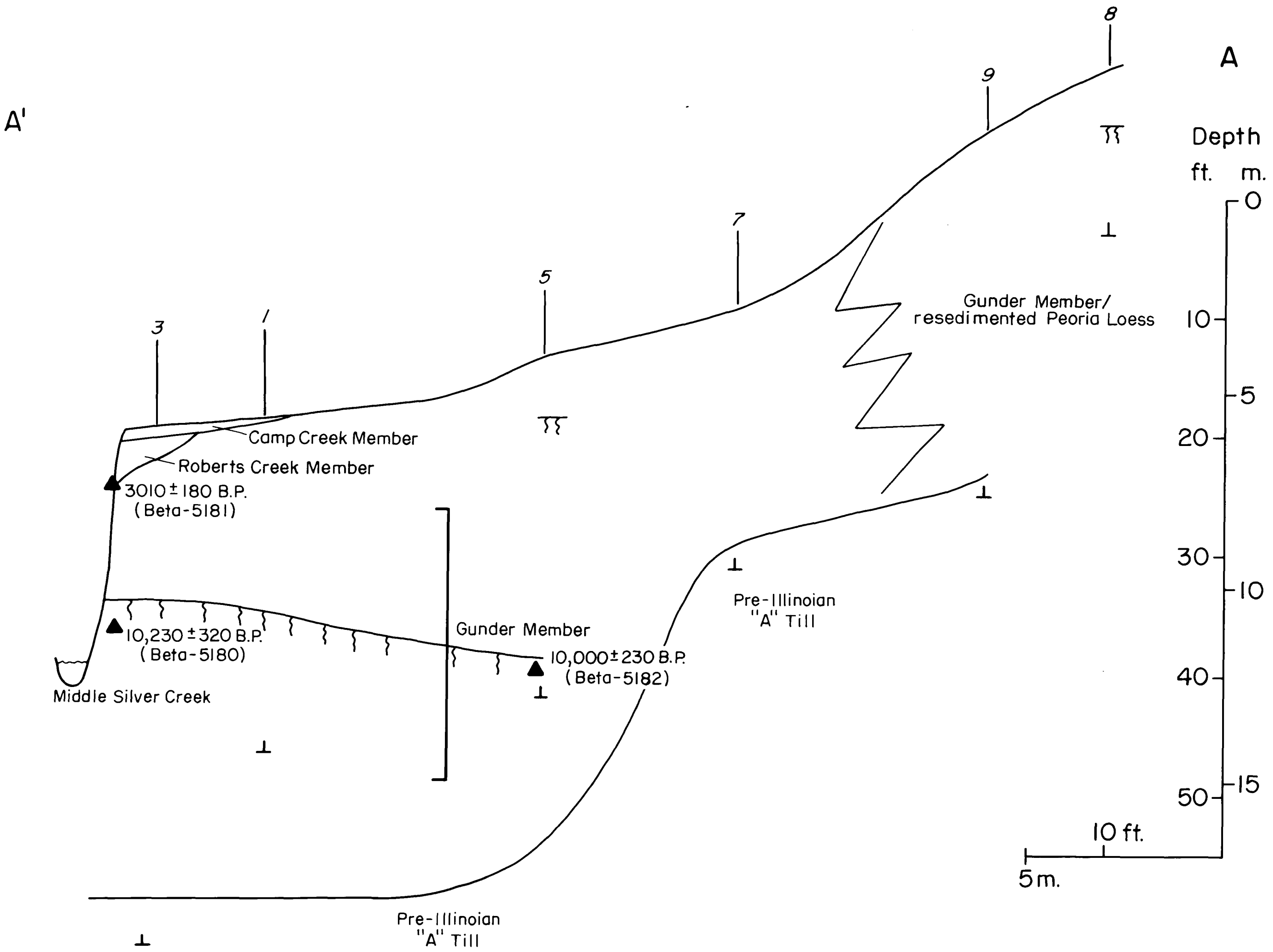


Figure 16. Cross-section A-A' at the Middle Silver Creek Study area showing Holocene alluvial stratigraphy along the east side of Middle Silver Creek valley. See Figure 15 for the cross-section location.

similar stratigraphic setting at Stop 3, and slightly younger than the age of the Gunder Mbr. sequence at Stop 2. Wood and plant remains collected from within a channel fill at the base of the Roberts Creek Mbr. (Mullenix Bed) about 40 feet (12.2 m) downstream of the cross-section was radiocarbon dated at 3,010±80 B.P. (Beta-5181). This age, too, is close to that obtained from a similar stratigraphic position at Stop 3. Finally, wood collected from the base of the Turton Bed of the Roberts Creek Mbr. about 1/3 mile (0.5 km) down stream of the cross-section yielded a radiocarbon age of 1,300±80 B.P. (Beta-5179). This date is about 900 years older than the date obtained from the base of the Turton Bed along Keg Creek at Stop 2, but still considerably younger than dates from the Mullenix Bed of the Roberts Creek Mbr. in these large valleys.

Lunch At Glenwood Lake Park

STOP 4. CHIEF WAUBONSIE SECTION

At this stop we will again examine the Gunder, Roberts Creek, and Camp Creek members, note the consistent lithologic properties observed at the previous stops, compare surface soils developed into the units, and discuss radiocarbon ages obtained from within the DeForest Fm. in Waubonsie Watershed. Peoria Loess is more than 65 feet (20 m) thick on narrow upland divides in this area. The landscape is extremely dissected with numerous deeply entrenched channels (gullies) extending far up into the drainage network. Waubonsie Creek is one of the highest sediment yielding streams in the United States. Maximum sediment concentrations of up to 27.6% by weight have been recorded from Waubonsie Creek floodwater (Bondurant, 1970).

The Chief Waubonsie section is located along the southeast bank of Waubonsie Creek in southern Mills County (N1/2 NE1/4 sec. 25 T71N R42W; Figures 17 and 18). A quartzite boulder marking the site of the tree that the body of Waubonsie, a Pottawattamie chief who died around 1848, was placed in is located in the woods on a sideslope just downstream of this exposure. At this location Waubonsie Creek has a drainage area of 15.5 mi^2 (40 km^2) and flows in a 4th-order valley. Archaeological and paleontological investigations in the early 1970s noted bedrock (Pennsylvanian) in the bed of the creek a few hundred feet downstream of this locality (Hotopp et al., 1975, site "at").

Figure 19 is a sketch of the Chief Waubonsie section showing the distribution of DeForest Fm. alluvial fills. The Gunder Mbr. (Hatcher Bed) underlies a 13 ft. (4 m) high terrace that merges with the base of the valley wall in a smooth, concave-upward profile. Large remnants of this terrace are present on the west side of the creek (the trailer is located on the margin of the terrace). The Gunder Mbr. consists of yellowish brown to light yellowish brown (10YR 5/4-6/4) massive, noncalcareous silt loam alluvium. Along the upstream part of the exposure, where the Gunder is the surficial unit, a buried A-Bw soil profile is present within the unit about seven feet (2.1 m) below the modern land surface. This paleosol appears to be developed in the upper part of an upward-fining sequence. A few, thin, discontinuous cutans are present in macropores in the Bw horizon and many krotovina are evident. The modern surface soil developed in the Gunder Mbr. is a Hapludoll (Mollisol without an argillic horizon) with a relatively thick Bw horizon. Thin continuous cutans line macropores in the Bw horizon and a few, thin, discontinuous cutans are present on ped faces in the B and BC horizons.

The Roberts Creek Mbr. (Mullenix Bed) is inset into the Gunder Mbr. and consists of pedogenically altered, grading downward to planar and trough-cross bedded, dark grayish brown to grayish brown (10YR 4/2-5/2) silty clay loam and silt loam alluvium. Lower parts of the unit contain carbonate gravels consisting of eroded concretions, shells, bones, a few armored mudballs, and rip-up clasts. Iron staining is very common in the lower half of the unit and extends downward into the underlying Gunder Mbr. Krotovina in the underlying Gunder Mbr. are filled with Roberts Creek Mbr. material, but rarely is the reverse true. The lateral contact between the Roberts Creek and Gunder members has been obliterated by pedogenesis near the land surface, but at depth the contact appears as a jumbled zone where clasts of Gunder Mbr. are included in Roberts Creek Mbr. alluvium. This is interpreted as the remains of a stream bank cut into the Gunder Mbr. that toppled into an aggrading Roberts Creek channel. The surface soil developed in the Roberts Creek Mbr. is a Cumulic Hapludoll with a dark-colored Bw horizon.

Charcoal collected from within the carbonate gravels at the base of the Roberts Creek Mbr. yielded a radiocarbon age of 4,070±250 B.P. (Beta-33176; Figure 19), while charcoal collected about 1m above the base of the Roberts Creek Mbr. yielded an age of 3,560±160 B.P. (Beta-33177). These ages are consistent with others from the Roberts Creek Mbr. in valleys larger than 3rd-order.

Another buried soil is evident in the Gunder Mbr. (Figure 19). This soil has a thick, dark-colored A-AB-Bw profile and is less well drained than the buried soil higher up in the Gunder Mbr.

A channel containing the Camp Creek Mbr. completely cuts out the Roberts Creek Mbr., and is set into the lower buried soil in the Gunder Mbr. on the southwest end of this section (Figure 19). The Camp Creek Mbr. consists of stratified (mostly planar-bedded) brown and light yellowish brown silt loam alluvium. The lateral contact with the Roberts Creek Mbr. is sharp but also exhibits a

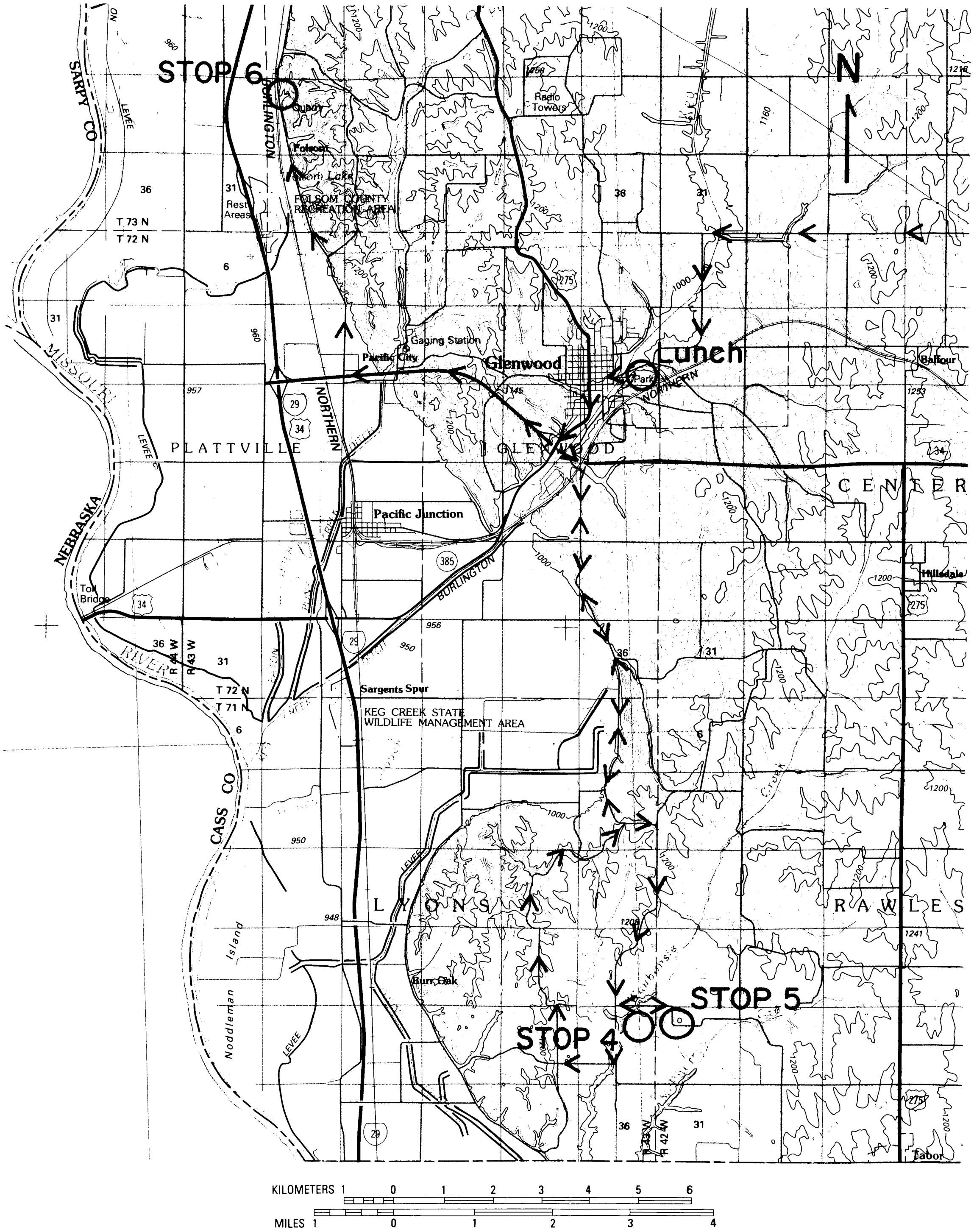


Figure 17. Map showing the fieldtrip route for the afternoon of Day 1. Base taken from USGS Mills County, Iowa 1:100,000 topographic map.

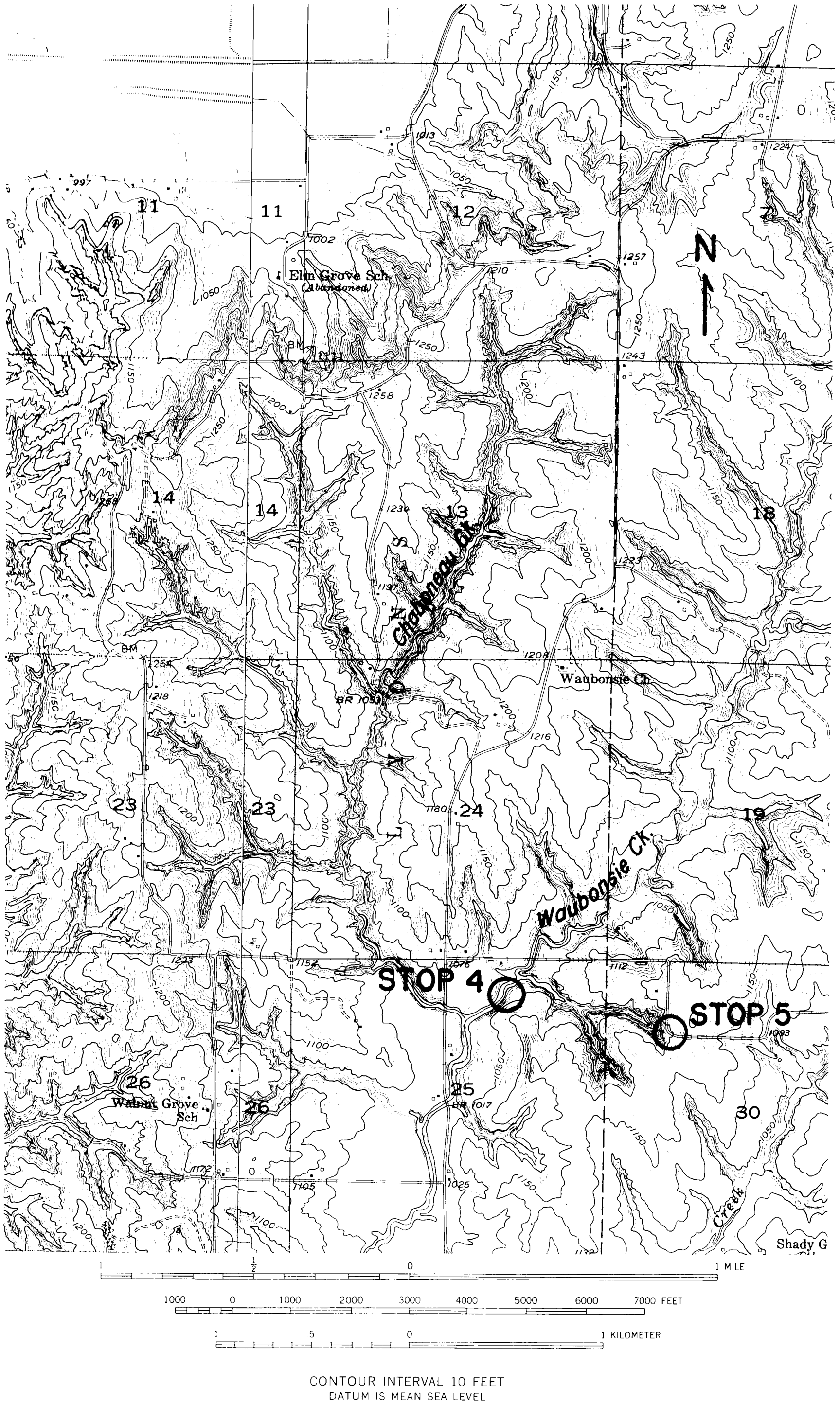


Figure 18. Topographic map showing the location of stops 4 and 5 in Waubonsie Watershed, southwestern Mills County, Iowa. Base taken from USGS 7.5' Tabor, Iowa and Rock Bluff, Iowa-Nebraska quadrangles.

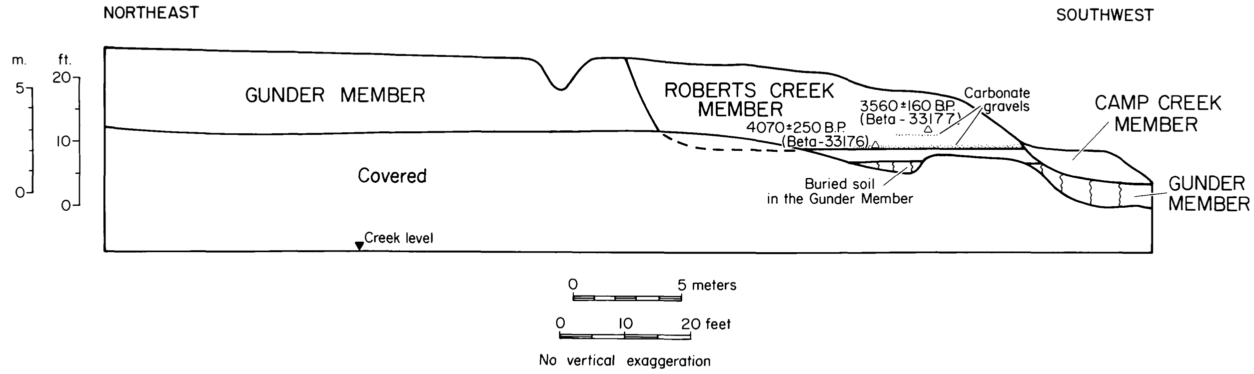


Figure 19. Sketch of the Chief Waubonsie section at Stop 4. Outcrop is along the southeast side of Waubonsie Creek in southwestern Mills County, Iowa.

jumbled appearance interpreted as bank debris. The surface soil developed in the Camp Creek Mbr. is a thin Entisol.

Upstream, just north of the tributary valley entering from the east and south of the bridge crossing Waubonsie Creek, another exposure showing Roberts Creek Mbr. (Mullenix Bed) overlying Gunder Mbr. (Hatcher Bed) is present. The contact between the two units is abrupt and marked in places by thin channel gravels of the Roberts Creek Mbr. Carbonized wood collected about two feet (61 cm) above the base of the Roberts Creek Mbr. in this exposure yielded a radiocarbon age of 2,560±70 B.P. (Beta-5357). Some planar bedding and evidence of channels is present in the Gunder Mbr. in this exposure. I have also observed zones of burned soil, ash piles, and flint chips suggesting the presence of an archaeological site in the Gunder Mbr. here.

Other radiocarbon-dated sections in the Waubonsie Watershed area provide us with a local radiocarbon chronology that can be compared with areas to the north where many more DeForest Fm. radiocarbon ages are available (Bettis and Thompson, 1982). About 2.5 miles (4 km) upstream from the Chief Waubonsie section is the locality containing the Garrett Farm and Pleasant Ridge local faunas (Fay, 1978; Hotopp et al., 1975 sites "br" and "bs" respectively; NW1/4, SW1/4, sec. 8, T71N, R42W). Both faunas were collected from Roberts Creek Mbr. deposits, the Garrett Farm from the Mullenix Bed and the Pleasant Ridge from the Turton Bed (L. P. Fay and R.S. Rhodes II personal communications, and my observations). Charcoal associated with the Garrett Farm local fauna was collected from a broad interval 20 to 6 feet (6-1.8 m) below the land surface and yielded a radiocarbon age of 3,400+280-290 B.P. (DIC-877; L.P. Fay personal communication). Across the creek at the Pleasant Ridge locality charcoal collected 11.5 feet (3.5 m) above the base of the Roberts Creek Mbr. (Turton Bed) yielded a radiocarbon age of 1,450±90 B.P. (DIC-1620; L.P. Fay personal communication). Both of these ages are associated with alluvium in a 4th-order valley, and are in agreement with ages from similar stratigraphic positions along Middle Silver and Silver creeks, as well as the Chief Waubonsie section.

Two radiocarbon ages from the Gunder Mbr. were obtained from an exposure along the west bank of McPherron Creek about 1 mile (1.6 km) southeast of the Chief Waubonsie section (SE1/4, SW1/4, sec. 30, T71N, R42W). This is a Reference Section for the Watkins Bed (Figure 1). At this location 28.5 feet (8.71 m) of Hatcher Bed unconformably overlies the Watkins Bed. Charcoal collected 4.3 feet (1.3 m) above the base of the Hatcher Bed yielded a radiocarbon age of 6870±210 B.P. (Beta-5354), while wood (*Ulmus rubra*-red elm) collected 7.8 feet (2.4 m) below the Hatcher/Watkins contact yielded an age of 8,180±110 B.P. (Beta-2425). These dates are associated with alluvium in a 4th-order valley. Recent slumping has buried the Watkins Bed in this exposure.

About 1.5 miles (2.4 km) north of the Chief Waubonsie section along Chaboneau Creek charcoal collected from the base of the Turton Bed of the Roberts Creek Mbr. yielded a radiocarbon

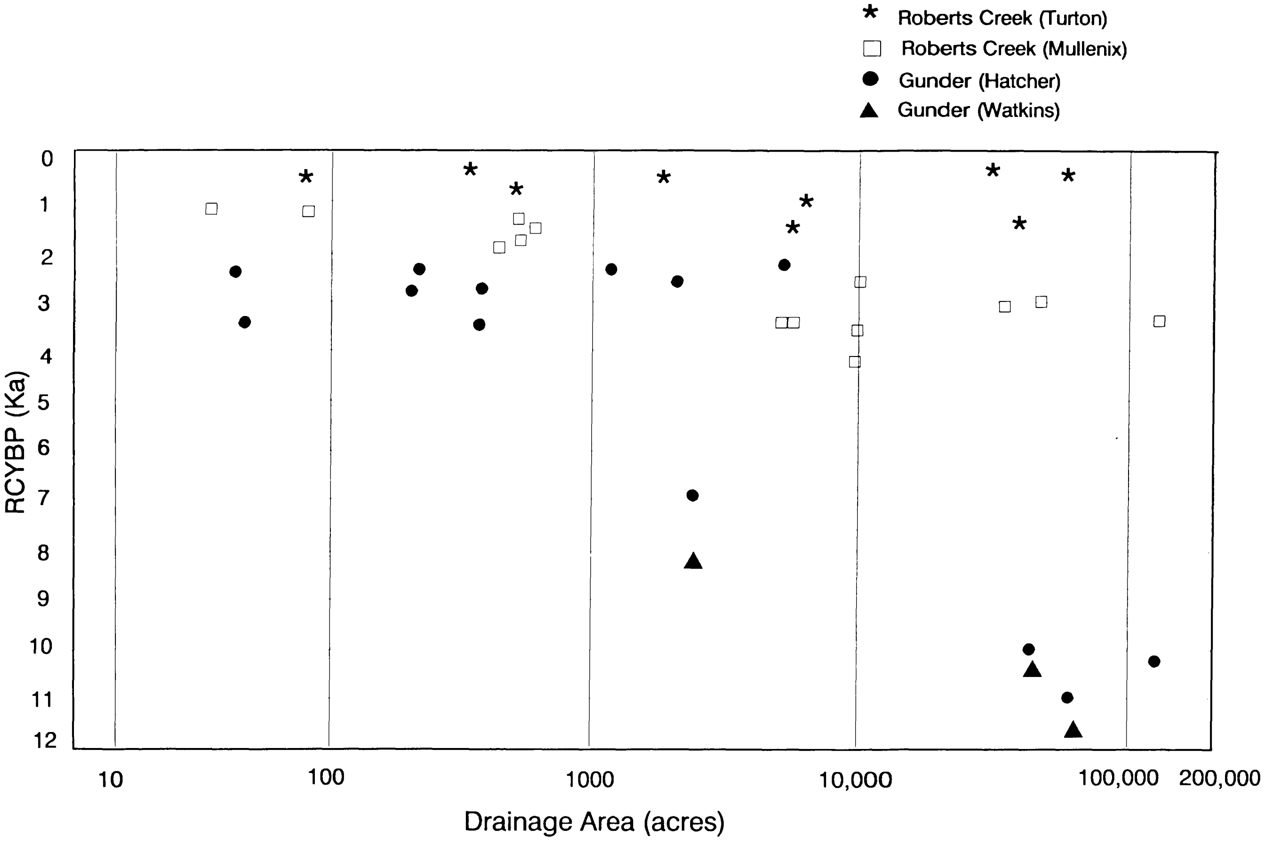


Figure 20. Plot of radiocarbon age versus drainage area for 22 localities in western Iowa. Note the trend for increasing age of a given lithounit with size of the drainage basin. Radiocarbon ages are uncorrected.

age of 705±85 B.P. (I-7381; Hotopp et al., 1975 site "o"). This date is associated with alluvium in a 3rd-order stream. Older Wisconsinan alluvium is also exposed in the entrenched channels in Waubonsie Watershed. This alluvium records multiple cut-and-fill episodes dating between 14,500 and 23,200 B.P. (Rhodes, 1984, and this volume).

One of the purposes of this fieldtrip is to discuss the long-term (Holocene) behavior of the entrenched fluvial system of western Iowa. A crucial aspect of our understanding of this behavior is provided by the good age control we have on aggradation episodes throughout western Iowa, especially in different parts of the drainage network throughout the area. As discussed in the introduction, the basal age of a given DeForest Fm. unit decreases in age progressing up the drainage network from large to smaller valleys. Figure 20 is a plot of radiocarbon age versus drainage basin area at the dated section for 22 localities in western Iowa. Ages from alluvial fans and multiple ages on the same bed are not included. Figure 21 shows a plot of ages from material at the base of the beds. As with most data sets of this sort, there is quite a bit of scatter, but a trend for a given unit to show an increase in basal age with increased size of the drainage area is apparent. This indicates that aggradation of a given DeForest Fm. lithounit began first in large valleys then propagated into smaller valleys higher in the drainage system. The overlap in ages from different stratigraphically adjacent units, moving from large to small valleys, tells us that entrenchment was also diachronous. It began in large valleys, and propagated into smaller valleys higher in the drainage network through time. For example, the Roberts Creek Mbr. was accumulating along the lower reaches of Waubonsie Creek, in a 5th-order valley (in the area of Stop 4), around 3,400 B.P. at the same time that

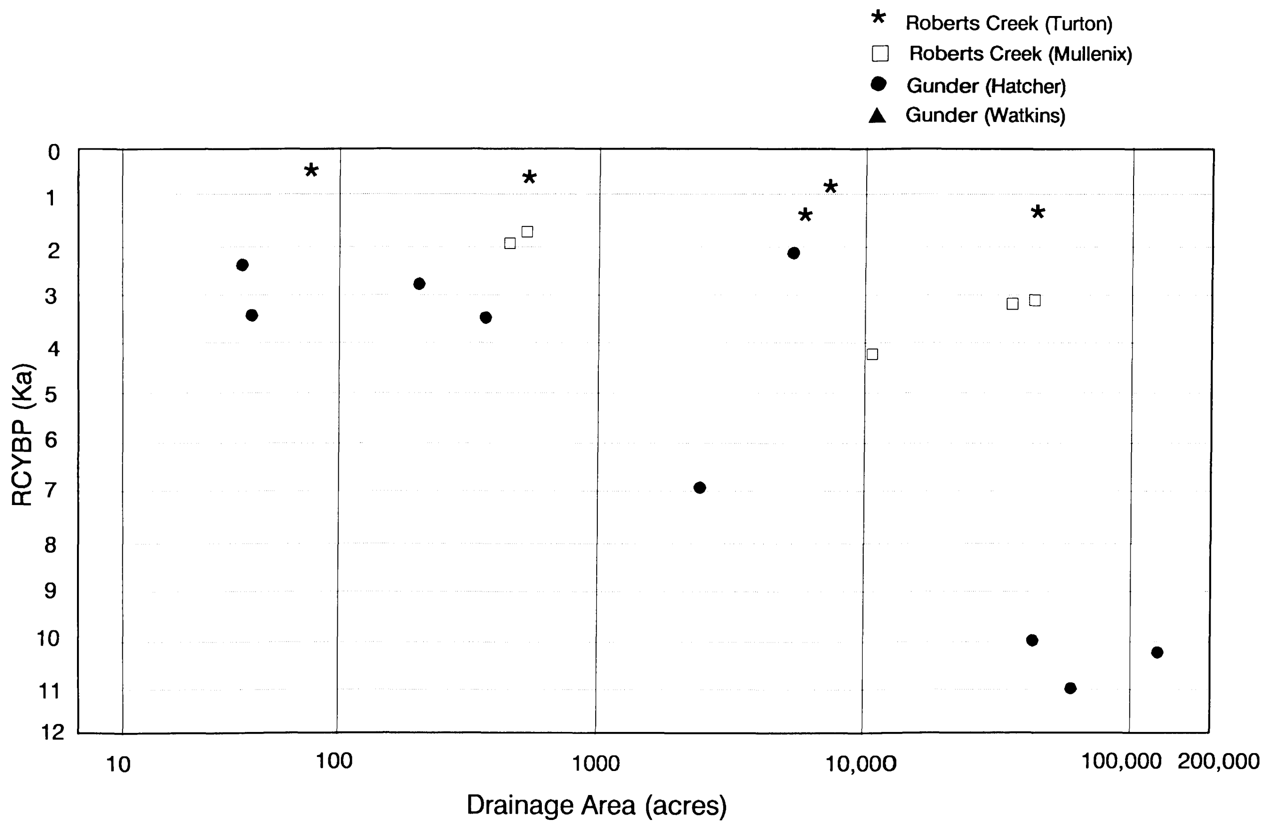


Figure 21. Plot of basal radiocarbon age versus drainage area for western Iowa localities. The trend for increasing age with size of the drainage basin is more apparent in this data set than in that presented in Figure 20. Radiocarbon ages are uncorrected.

the Hatcher Bed of the Gunder Mbr. was accumulating in the upper reaches of 3rd-order and smaller valleys, such as Smokey Hollow in southern Woodbury County. These relationships indicate that episodes of degradation followed by aggradation did not occur synchronously throughout the drainage network. Instead, these episodes began in large valleys low in the drainage network, then propagated up the drainage network through time. The time it took for the change in lower parts of the system to affect valleys higher in the network varied, but occurred on a scale of hundreds to thousands of years. These conclusions have important implications in regard to evaluation of the factors responsible for the degradation episodes that have occurred in western Iowa during the Holocene. Geomorphic change was diachronous through the drainage network and simple macroclimatic, or bioclimatic cause-and-effect models seem not to apply. The geomorphic changes that ultimately produced change in this fluvial system occurred low in the drainage network, and the causes of change must be sought there.

STOP 5. DEEP GULLY, VERTEBRATE PALEONTOLOGY, AND ARCHAEOLOGY

This stop is a late Wisconsinan and Holocene potpourri. We will briefly discuss a deep, active gully with a very small drainage area, then some aspects of the paleoecology of southwestern Iowa as deduced from the small mammal record (R. Sanders Rhodes II), and the archaeological record of western Iowa (Dave Benn), much of which is preserved in DeForest Fm. alluvium. Contributed papers by Rhodes and Benn are located in back of the field trip guide. We will wind up this stop with a summary and discussion of the Holocene alluvial history of western Iowa.

This stop is along a local gravel road where a deeply incised first-order drainage has extended to within a few hundred feet of the local divide (NW1/4 NW1/4 sec. 30 T71N R42W; Figure 18). The gully is approximately 60 feet (18.3m) deep, has vertical sides, and a slightly undercut headwall (don't get too close). Holocene alluvium (sideslope facies of the Gunder Mbr.) is exposed in the upper part of the gully wall, but most of the exposed deposits are older alluvium, colluvium, and loess. Note the extremely small drainage area above the gully, and that the gully has advanced through a forested area to its present position. Channeling of road drainage has exasperated the entrenchment problem here, especially the vertical drop at the end of the culvert. Gullies of this size are not uncommon in the Waubonsie Watershed area and to the south in Fremont County. When entrenchment of the drainage network to this magnitude occurs Holocene alluvium is completely removed and only the Camp Creek Mbr. is preserved in the stratigraphic record.

After this stop we will make a loop through a portion of Waubonsie Watershed that exhibits extensive entrenchment. In most of the drainageways in this area the Gunder Mbr. underlies the toeslope and footslope positions bordering the entrenched channels. The Roberts Creek Mbr., where preserved, is found as thin slices along the entrenched channel.

Discussion of Holocene Alluvial History of Western Iowa

As we've seen on this fieldtrip, several lithologically distinct alluvial fills comprise the DeForest Fm. in western Iowa. Stratigraphic and geomorphic relationships of the fills are predictable, and their distribution in drainage basins is mappable. Morphologic differences between members of the formation are a result of changes in sediment source and aggradation rates, as well as differential diagenesis-oxidation related phenomena primarily (Bettis, in press). The distribution pattern of the members both within a given valley reach, and in different order (size) valleys within the overall drainage network, are reflective of changes in the magnitude of entrenchment and aggradation episodes during the Holocene. The importance of these distribution patterns, and the chronologic relationships of the members of the formation is that they provide insights into the long-term behavior of western Iowa's fluvial system (Figure 6).

What caused the entrenchment episodes preceding aggradation of these units? This is the million dollar question and we haven't quite got the time machine in good enough working order to really say for certain, but what the heck, this is a FOP trip and its time for some wild and crazy speculation...

First and foremost in addressing this question we need to remember that entrenchment begins in the large valleys and propagates up the drainage network. Basal ages of alluvial fills from large valleys should therefor be considered as the minimum age of the entrenchment that got the ball rolling (or knickpoint moving).

The second aspect of fluvial system behavior to consider is that thresholds of stability in the system can be exceeded by progressive change in the system without an external forcing mechanism. This leads to what Schumm (1980) has called "complex response". Examples of complex response in drainage systems discussed by Schumm and his associates show that the intensity of the response (be it degradation or subsequent aggradation) usually decreases with time as the system approaches conditions of metastability (Womak and Schumm, 1977; Parker, 1977). The distribution of alluvial fills comprising the DeForest Fm. demonstrates that the intensity (both vertically and longitudinally along the valley profile) of entrenchment, and subsequent aggradation, decreased through the Holocene (see Figure 5). The alluvial fills comprising the DeForest Fm. then, may owe their origin, at least in part, to complex response of the fluvial system.

The logical question is complex response to what? My opinion is that the series of aggradational and degradational episodes resulting in the DeForest Fm. are a long-term response to the increase in local relief and sediment availability produced by Peoria Loess accumulation. The sequence of Holocene alluvial fills recognized in the thick-loess area of western Mississippi is lithologically and temporally very similar to the DeForest Fm. of western Iowa (Grissinger et al., 1982). These two areas are quite different climatically today, and probably have been throughout the Holocene. Both areas, however, witnessed increases in local relief and sediment availability as a result of Peoria Loess accumulation.

Superimposed on the large-scale response to Peoria Loess accumulation are responses to changes in Holocene climate. These smaller-order responses include the net transport of sediment out of second- and third-order valleys during the middle Holocene (probably a hydrologic response), and the accumulation of organic-rich late Holocene alluvium (Roberts Creek Mbr.) versus organic-poor early and middle Holocene alluvium (Gunder Mbr.) in large valleys (a water table, organic production, and possibly sedimentologic response). The magnitude of the post-Roberts Creek, pre-Camp Creek entrenchment upsets the pattern of decreased intensity through time. Human influences on the system superseded the climatic and inherent controls in this case.

Last, but not least, I would like to inject a cautionary note. There are many potentially important factors influencing the long-term behavior of the fluvial system that we haven't addressed. Next to nothing is known about the Missouri and its major tributaries. These are the local base level for the system we have been examining and discussing today. Other factors such as neotectonism may be operative (notice that for the most part the Missouri River and other large streams in the area tend to flow against their west and southwest valley walls). These are complex systems with the potential for lots of feedback (complex response) and multiple interactions (climate, vegetation, loess fall, etc.).

The bioclimatic system is also extremely complex and probably is not as well documented for the Holocene as one is led to believe. Large spatial gaps are present in the data sets used to reconstruct the biota (proxy climate), dating is not very detailed, and some significant ecotones have been missed (Chumbley, 1990; Chumbley et al., in press).

On this trip we've emphasized an aspect of long-term alluvial system behavior that has not been adequately addressed in models of Holocene stream behavior: the timing of aggradation and degradation events throughout the drainage network. We've demonstrated that the timing of these episodes varies in different parts of the drainage network, and that downvalley events control upvalley behavior. Local alluvial chronologies constructed from a restricted part of the drainage network (say 3rd- and 2nd-order valleys) then, do not necessarily provide a good assessment of the timing of the change that the drainage network is responding to. Only through studies of the range of valley sizes comprising a drainage network can we begin to focus in on the relationships among intrinsic and extrinsic factors affecting the Holocene behavior of the fluvial system.

DRIVE TO STOP 6

Several features of note are present on the way to Stop 6. Notice the presence of an alluvial fan/colluvial apron along the base of the valley wall where we enter the Missouri Valley after leaving Waubonsie Watershed. The presence of the fans and colluvial slopes suggest that the river has not been along the base of the bluff since the early Holocene or late Wisconsinan in this area.

Beginning just north of Omaha the Missouri River valley narrows as resistant Pennsylvanian rock is encountered. Several large re-entrants are present along the valley wall and we drive into one where we enter the valley north of Waubonsie Watershed. Bedrock is not exposed within the re-entrant areas, but is often exposed elsewhere along the valley wall. The re-entrants seem to have formed where lows in the bedrock surface occur, possibly where bedrock valleys intersect the Missouri Valley.

The base of the bluff line west and north of Glenwood stands in sharp contrast to that in the re-entrant south of Glenwood. The bluff descends sharply to the floodplain north of Glenwood and only small, steep alluvial fans are present. This morphology suggests that the Missouri River or one of its tributaries was flowing along the base of the bluff sometime during the late Holocene in this area. Historic records document a side channel of the Missouri River along the base of the bluff at Folsom (about 4 miles (6.4km) north of US-34) in 1890 (Hallberg et al., 1979: 20). Folsom Lake is an abandoned remnant of that side channel.

Just north of Boyer Hollow pre-Illinoian till appears high in the bluff line and carbonate-cemented, trough cross-bedded pre-Illinoian sand and gravel crop out in the middle to lower part of the slope. Just to the north Pennsylvanian limestone and shale (Virgilian; Shawnee Group) are exposed at the base of the bluff and form a more or less continuous outcrop north to Folsom Quarry (Stop 6).

STOP 6. PLIO-PLEISTOCENE ALLUVIAL DEPOSITS EXPOSED IN FOLSOM QUARRY

Stop description by B.J. Witzke, G.A. Ludvigson, E.A. Bettis.

At this stop we will examine alluvial deposits from the bottom of the Pleistocene (or top of the Pliocene) stratigraphic column. These deposits are buried by early Pleistocene "B-tills" and are related lithologically to western-source alluvial units in Nebraska. The distribution of these alluvial deposits in Iowa provides insights into the evolution of the regional southward draining fluvial system.

The Folsom Quarry and adjacent road-side outcrops in the east valley wall of the Missouri River Valley form the best-displayed sequence of sub-till "salt & pepper" sands and siltstones exposed in western Iowa (SE NW NW sec. 29, T73N, R43W; Figure 17). The basal "sand & pepper" sands overlie Pennsylvanian bedrock in the quarry (units 1, 2; Figure 22). These sands include common volcanic lithic fragments (dark "pepper" grains) which serve to characterize a suite of western-derived sediments distinct from carbonate-rich sands and gravels of glacigenic origin. This sand unit is dominantly fine-grained, although scattered pebbles along foreset laminae include quartz, quartzite, jaspery chert, granite/feldspar, with minor metamorphic and mafic igneous clasts. Foreset azimuths in the basal sand unit suggest a general southeasterly transport direction (see Witzke and Ludvigson, this guidebook). The basal sands are capped by an interval of siltstone (with characteristic "s & p" composition) containing carbonate-cemented ledges and carbonate nodules (including large septarian concretions; units 3-6, Figures 22 & 23). The upper silts (unit 6) display pedogenic fabrics.

A thick, moderately well expressed paleosol is developed in the upper, fine-grained (siltstone) portion (unit 6) of the "s & p" sequence (Figures 22 & 23). The contact between the paleosol and the overlying pre-Illinoian till (B-till) is wavy, and the upper preserved soil horizon appears to be compacted. Locally the paleosol is truncated, presumably as a result of subglacial erosion. The paleosol is fine-grained silt loam fining upward to silty clay loam, exhibits oxidized (10YR hue) colors, and consists of subsoil horizons with gradual boundaries (Figure 24). The paleosol matrix is leached, although the upper horizon shows strong

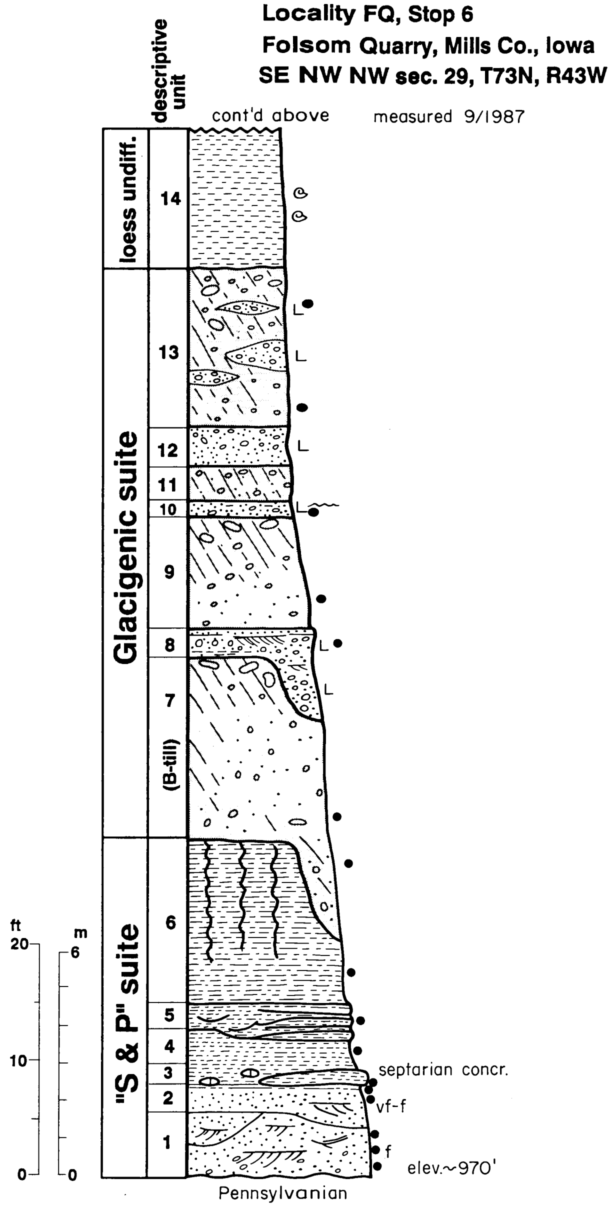


Figure 22. Graphic stratigraphic section for the Folsom Quarry, Mills Co., Iowa. Note: glacigenic sequence is truncated by loess-filled channel in west quarry, where loess overlies strata of the "s & p" suite ("salt and pepper"). Lithologic symbols follow Witzke and Ludvigson (this volume, Figure 5).

LOESS undifferentiated

Unit 14 (not measured) snails noted in lower 3 m; loess-filled channel cuts across entire glacigenic suite in west quarry area, where loess overlies silts of "s & p" suite.

GLACIGENIC SUITE

Unit 13 (4.2 m)

Till, oxidized to reduced, unleached, stratified with pods of glacigenic sand-gravel (with carbonate clasts), granitic boulders in top 2.7 m; local sand pod (to 3 m across) within lower 1.5 m of till, f-m sand, scattered pebbles, siltstone clasts to 40 cm; 1.9-2.7 m below top are local pods of sand-gravel (Cretaceous shark teeth noted).

Unit 12 (1.0 m)

Sand, f-m, at base; coarse sand and gravel at top; siltstone clasts up to 15 cm.

Unit 11 (95 cm)

Till, oxidized, unleached, horizontally stratified in lower 15 cm.

Unit 10 (40 cm)

Sand and gravel, gravel clasts to 10 cm; ripple cross-laminated sand in top 4 cm.

Unit 9 (3.0 m)

Till, unleached, consistently oxidized in top 1.0 m, remainder mostly unoxidized; boulders and large clasts in top 1.0 m.

Unit 8 (70 cm, locally to 4.0 m)

Sand and gravel, crossbedded with prominent gravel foresets; iron-oxide cementation in part; laminated to cross-laminated sand at top; siltstone at base to 25 cm; unconformably overlies lower till, locally channels through lower till unit (sand and gravel thickens to 4 m).

Unit 7 (4.9 m, thickness varies within quarry)

Till, unoxidized to oxidized, unleached; granite boulders (to 40 cm) in top 1 m; clay mineralogy suggests that this is a B-till; till unconformably overlies an irregular surface on underlying silts; lower till locally cut-out by channeling of overlying sand-gravel.

"SALT AND PEPPER" SUITE

Unit 6 (4.3 m)

Siltstone, light brown-gray, argillaceous; pedogenic fabrics throughout, blocky peds (2-10 cm) and slickensided ped faces increase in abundance upward, black Mn mottling and spots common, becomes more oxidized upward, small carbonate concretions (1-2 cm) and gypsum noted; unit locally truncated by till-filled channel, 5 cm thick till-filled dike cuts through siltstone adjacent to channel.

Unit 5 (95 cm)

Siltstone, light gray to buff, slightly argillaceous, micaceous, calcareous, forms calcite-cemented ledges and concretionary forms; interval displays complex sets of cross-cutting decimeter-scale channels and troughs, faint laminae noted, larger-scale tabular foresets noted laterally.

Unit 4 (80 cm)

Siltstone, buff to light brown gray, coarse silt approaches vf sand in part; slightly micaceous, finely laminated at mm-scale.

Unit 3 (0-40 cm)

Siltstone, buff, weakly calcareous to well-cemented, hard ledge former in part, slightly micaceous; fills swale in underlying unit, thickness complementary with below; large carbonate concretions to 25 cm, some with septaria.

Unit 2 (75-125 cm)

Sand dominated, "salt & pepper," vf-f grained, planar laminated; locally channeled up to 50 cm into underlying sand unit; top 9-30 cm is interlaminated siltstone, mudstone, and claystone.

Unit 1 (1.65 m)

Sand, "salt and pepper," uniformly fine-grained and well-sorted through most, some foresets with medium- to coarse-grained sand and pebbles (to 2 cm); interval displays crossbed sets 10-50 cm thick, up to 30° dip on foresets; cut-and-fill channels up to 1 m thick and 3 m wide; unit overlies weathered Pennsylvanian bedrock (calcareous shale with thin limestone layers).

Figure 23. Description of post-Pennsylvanian sequence in Folsom Quarry, Mills County, Iowa. Units are described in descending order and are keyed to Figure 22. Description by BJW, GAL, 9/1987.

Location: NW1/4, NW1/4, Sec. 29, T73N, R43W
Landscape position: road cut in bluffline; paleolandscape position inferred to be floodplain/low terrace
Parent material: alluvium
Described by: E.A. Bettis III; 8/18/89
Remarks: detailed description begins at top of preserved sub-till soil; overlying diamicton is mottled, jointed, reduced, and unleached (MJRU); clay mineral assemblage suggests that this is a "B" till; the diamicton contains abundant contorted bodies of sand and gravel, and the joints contain thick secondary carbonate and iron accumulations.

Depth (m)	Soil Horizon (weathering zone)	Description
0-0.2	AB?	dark yellowish brown (10YR4/4) light silty clay, moderate medium angular blocky structure, firm, strong effervescence grading downward to noneffffervescent, abundant slickensides on ped faces, common thin discontinuous very dark gray (7.5YR3/0) patches (Mn?) on slickensides, yellowish brown (10YR5/6) band of secondary iron accumulation runs through middle of horizon, common hard carbonate concretions up to 2.5 cm in diameter, clear smooth lower boundary
0.2-0.43	Bt?	dark yellowish brown (10YR4/4) silty clay loam, strong fine angular blocky, firm, noneffervescent, common slickensides on ped faces, few thin discontinuous dark grayish brown (10YR4/2) coatings on ped surfaces usually associated with slickensides, few coarse dark grayish brown (10YR4/2) blobs (krotovina?), few hard carbonate concretions up to 1.75 cm in diameter, common gypsum crystals up to 0.5 cm long, gradual smooth boundary
0.43-0.66	Bw1	dark yellowish brown (10YR4/4) silty clay loam, strong fine angular blocky, firm, noneffervescent, common slickensides on ped faces, few thin discontinuous dark grayish brown (10YR4/2) patches on ped faces, few hard carbonate concretions up to 4 cm in diameter, abundant gypsum crystals up to 4 cm long, gradual smooth boundary
0.66-1.09	Bw2	brown, yellowish brown, and dark yellowish brown, (10YR5/3, 5/4, 4/4, & 7.5YR4/4) silty clay loam, strong fine angular blocky, firm, noneffervescent, common slickensides on ped faces, thin discontinuous dark grayish brown (10YR4/2) patches on slickensides, occasional coarse very dark grayish brown zones (krotovina?), abundant gypsum crystals up to 4 cm long, gradual smooth boundary
1.09-1.60	BC	yellowish brown (10YR5/4) silty clay loam, strong medium to fine angular blocky, firm, noneffervescent, few medium to coarse dark yellowish brown (10YR4/4) zones, few medium hard noneffervescent nodules (siderite or barite ?), few modern root channels lined with thin discontinuous very dark gray (10YR3/1) cutans, thin discontinuous coatings of gypsum along few subvertical joints, gradual smooth lower boundary
1.60-2.36	C1	yellowish brown (10YR5/4) silt loam, strong fine angular blocky to platy "structure", firm, noneffervescent, few dark yellowish brown (10YR4/4) streaks, few medium hard noneffervescent nodules (siderite or barite?), gypsum accumulation along joint faces as above, diffuse patches of gypsum associated with 10YR4/4 streaks, gradual smooth boundary
2.36-2.82	C2	yellowish brown (10YR5/4) silt loam, moderate medium to strong fine angular blocky "structure", friable to firm, noneffervescent, few thin discontinuous brown (10YR4/3) cutans, few fine to medium hard noneffervescent nodules (siderite or barite?), lower 10 cm contains common filaments and few blades of gypsum, clear smooth boundary
2.82-3.10	C3	brown (10YR5/3) silty clay loam, strong medium to coarse grading downward to fine to medium angular blocky "structure", firm, noneffervescent, few to common coarse krotovina filled with fine to medium sand, clear irregular boundary
3.10-3.24	Ck	zone of large, elliptical carbonate nodules flattened parallel to bedding in the enclosing pale olive (5Y6/4) laminated silty clay loam, bedding is very deformed by nodule growth, strong medium angular blocky "structure", firm, noneffervescent, common fine patches of iron and manganese oxides on faces of "peds", clear irregular boundary, (Unit 3 in Figures 22 and 23)

Figure 24. Description of the soil developed in the siltstone (Unit 6) of the "salt and pepper suite".

effervescence toward the contact with the overlying calcareous till. Soil structure is dominantly angular blocky with thin discontinuous cutans evident in the horizon designated "Bt?". Many of the ped faces are slickensided, and thin secondary manganese oxide patches are present on the slickensided ped faces throughout most of the solum. Large (tens of centimeters) elliptical septarian carbonate concretions are present in a band beneath the solum while small subspherical carbonate nodules are present in the upper 66 cm of the paleosol. Analysis of the microfabric and isotopic composition of these nodules suggests that the large and small nodules have different growth histories (see Ludvigson et al., this volume). Other small noncalcareous (siderite or barite?) nodules are present in the lower part of the soil profile.

On the basis of the observed morphology, this paleosol appears to have developed on a poorly-drained floodplain, probably with intermittent flooding and slow aggradation. The relatively thick soil profile with gradual horizon boundaries, coupled with evidence for only minor clay translocation suggests the floodplain setting. Carbon and oxygen isotopic ratios from the large septarian concretions record evidence of warmer paleoclimates than those preserved in authigenic carbonates from younger Quaternary deposits examined in western Iowa (Ludvigson et al., this guidebook). The gleyed colors below the solum suggest reducing conditions. The 10YR colors of the solum may have developed during the later stages of this soil's development, after entrenchment changed this landscape position into a well-drained position. The profile seems to have a fairly complex history that may be further unraveled by micromorphologic studies.

Above this paleosol, the overlying glacigenic sequence includes two or more till units (units 7, 9, 11, 13) with inter-and intra-till sand and gravel intervals (units 8, 10, 12, 13). The composition of the glacigenic sands can be readily contrasted with underlying "salt & pepper" sands, and field trip participants are encouraged to examine both types of sand. Clay mineralogy of the basal till (43:29:28; EX:Ill:K+C) suggests assignment to the B-till sequence of Boellstorff (1978). Overlying tills belong to the A-till sequence of Boellstorff (1978). The till sequence is capped by a thick interval of loess (unit 14); a loess-filled channel truncates the entire glacigenic sequence to overlie "s & p" sediments in the western quarry area.

The lower interval of "s & p" sediments seen at Stop 6 has been variously interpreted. Udden (1903) assigned the interval at this locality to the "ante-glacial silts," and acknowledged the possibility that it may be of preglacial age. Kay and Apfel (1929, p. 121) interpreted the sequence in this area to show probable "Nebraskan" till above pre-glacial sands and clays ("s & p" unit), "probably of Tertiary age." Lugn (1935, p. 66-67) suggested that this sand-silt unit in the area occupied a post-"Nebraskan" position ("Aftonian"), but was uncertain of this assignment. Miller (1964) assigned the basal sand-silt unit in Mills County to the "Fullerton Formation." He reported "Nebraskan" till below supposed "Fullerton" 2.7 km north of the quarry. A more detailed discussion of the development of the stratigraphic terminology of this interval is presented in the contributed paper by Witzke and Ludvigson.

The basal "s & p" sequence seen at Stop 6 represents a western-sourced fluvial unit deposited prior to B-till deposition (Witzke and Ludvigson, this guidebook). The occurrence of "s & p" sediments at this locality is clear evidence that a southward diversion of western-derived fluvial systems was not developed, that is, the Missouri River drainage was not present at the time of deposition. The modern Missouri River Valley cuts across the glacigenic sequence displayed at Stop 6, suggesting that the valley entrenchment post-dates deposition of the tills.

DAY 2

ROAD LOG - Council Bluffs to Loveland

0.0	(0)	Begin at the Best Western Frontier Inn parking lot, Council Bluffs (route and stop locations on inside of back cover). This area is located on an early to middle Holocene terrace of the Missouri River. Borings for I-80 indicate that the alluvial fill is about 85 feet (26m) thick in this area and consists predominantly of medium to coarse sand. Other borings from around this area indicate that the alluvial fill ranges from about 85 to 100 feet in thickness and usually contains a thin basal gravel (Miller 1964; IDNR-GSB file data). Approaching the bluff line the stratigraphy becomes much more complex as wedges of tributary alluvium and slope deposits interfinger with the main valley deposits. The bedrock surface is deeper on the east side of the present valley and the modern channel sits on a bench above the deeper part of the valley floor. The Calhoun Terrace in Omaha sits on a yet higher bedrock bench where the bedrock surface is above the base of the modern Missouri River channel. Leave parking lot. Turn right onto 27th Avenue and proceed to stop sign.
0.2	(0.2)	Stop sign. Turn left onto 24th St.
0.5	(0.3)	Turn right onto I-80 west ramp and enter interstate.
0.9	(0.4)	Bear right onto I-29 north. Drive along Holocene floodplain of the Missouri River.
5.5	(4.6)	Note pit in the bluff line on the right. This is a fill dirt pit that has exposed multiple weakly expressed buried soils within the Peoria Loess. The Peoria lies directly on calcareous pebbly sands in this pit.
6.3	(0.8)	Iowa Lake on the right near base of bluff. This was the active Missouri River channel in 1890 (Hallberg et al., 1979).
7.7	(1.4)	Notice the houses on the edge of the bluff line to the right. Nice view that gets better every day. Several small landslides are evident along this steep bluff. Also notice the truncated spurs along this section of the bluff line. Most of the bluff line area is Holocene in age. The Missouri River has been on both sides of its valley during the last 8,000 to 10,000 years, and at a much younger date in many areas.
9.6	(1.9)	Crescent Quarry in the bluff line on the right. Pennsylvanian limestone is quarried here for aggregate. A relatively thick sequence of pre-Illinoina till(s) is present above the rock. The till sequence is unconformably overlain by Wisconsianan loesses. The contact between the till and loess is abrupt and high relief. To my knowledge Loveland Loess has not been observed in the quarry. Handy and Davidson (1956) noted the presence of Pearlette Ash (Lava Creek B?) enclosed in "Sappa" silt in the pit in the early 1950s, but it has not been observed recently.
11.4	(1.8)	Pidgeon Creek valley to right.
12.7	(1.3)	Scenic loess bluffs on right.
13.1	(0.4)	Ascend 5 foot (1.5m) scarp onto early to middle Holocene terrace.
15.0	(1.9)	Honey Creek exit (exit 66). Cross Honey Creek Ditch. All streams entering the Missouri Valley in Iowa are confined to leveed ditches. The levees and associated straightened and

channelized reaches extend many miles up the valleys, and the streams no longer flood their lower reaches and adjacent portions of the Missouri River valley. Constant dredging keeps the ditches operative at a large cost to the drainage districts that maintain the system.

18.5	(3.5)	Well developed colluvial slopes along the base of the eastern bluff line (on right). The base of the slope grades onto the Missouri River flood plain in a smooth concave upward profile. The colluvial slope consists of an apron of interfingering alluvial fan and slope deposits shed off the adjacent bluff area. Where the apron is well developed, and steep as well as low-angle fans are present, the deposits comprising the colluvial apron are early through middle late Holocene in age (ca. 8,500-2,500 B.P.).
19.7	(1.2)	Cross I-680 east exit.
20.3	(0.6)	Turn right onto Loveland exit (exit 72; IA-362) and proceed to stop sign.
20.6	(0.3)	At stop sign turn left onto county road G-14 and proceed east through the tunnel under the railroad tracks, then across another set of tracks to a stop sign. Loveland Paratype section directly ahead (Figure 25).
20.8	(0.2)	At stop sign turn right on G-14 and proceed south. Enter town of Loveland, cross bridge.
21.0	(0.2)	Turn left at the Dew Drop Inn. Proceed east into suburban Loveland.
21.1	(0.1)	T-intersection, bear right then turn left into drive of the Primitive Baptist Church. This is the oldest Baptist congregation in Iowa west of the Des Moines River. Services were first held here in 1856. Park and walk to section. Our group may be too large to fit into the parking area so many of us may have to park along the street.

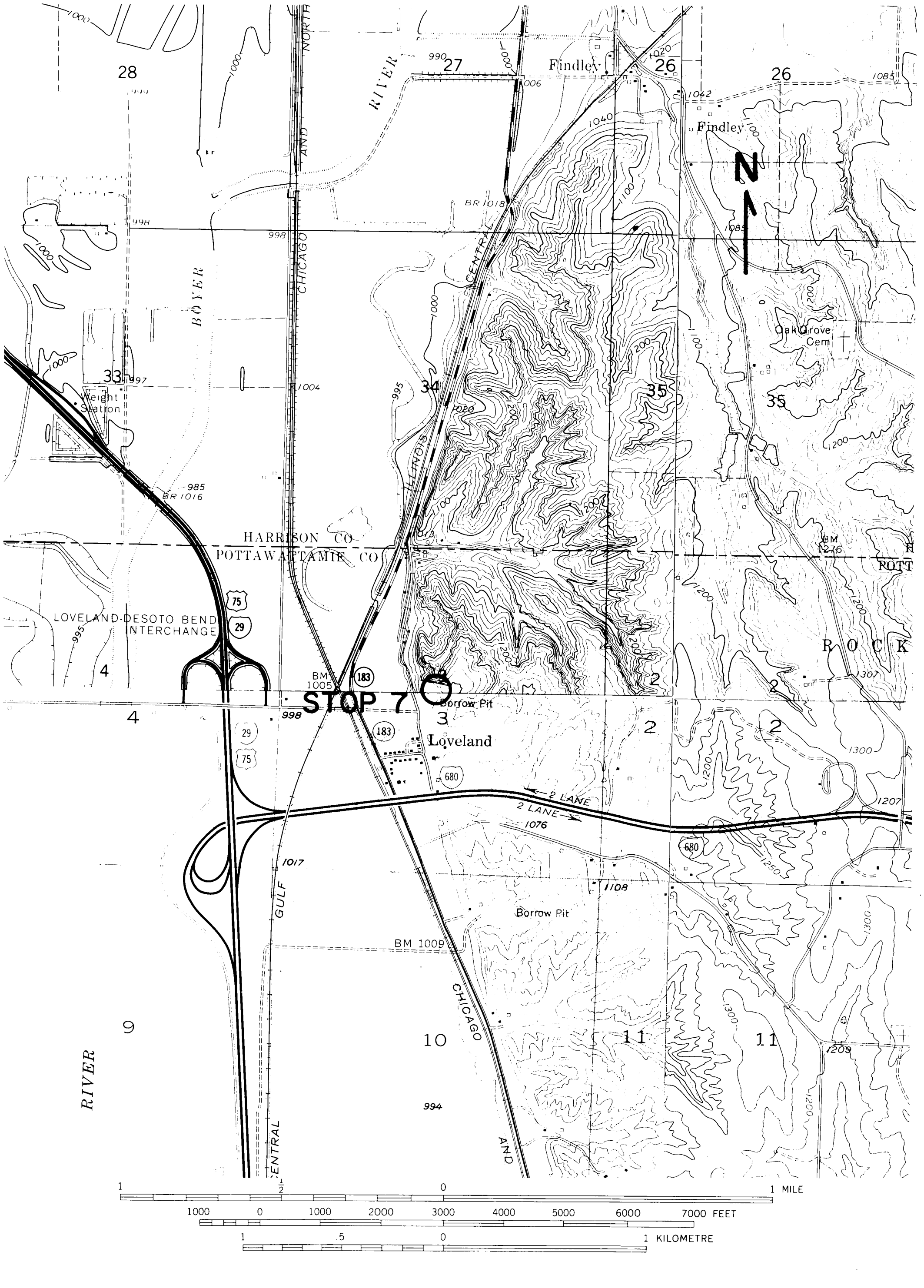


Figure 25. Topographic map showing the location of Stop 7 at the Loveland Paratype in northwestern Pottawattamie County, Iowa. Base taken from USGS 7.5' Loveland, Missouri Valley, Beebeetown, and Honey Creek, Iowa quadrangles.

STOP 7. LOVELAND PARATYPE SECTION

Discussion leaders: E.A. Bettis, T.J. Kemmis, S.L. Forman, E.A. Oches, M.L. Thompson, G.A. Ludvigson, and L.A. Gonzalez

The Loveland Paratype Section is our first (welcome?) relief from the alluvial stratigraphy of Western Iowa. A thick stratigraphic section is exposed and we will, of course, concentrate on the Loveland Loess and the Sangamon Soil developed in it. However, we will also discuss the stratigraphy and chronology of the overlying loesses of the Pisgah Formation and Peoria Loess, and, for you till commandos, whack on one of the underlying pre-Illinoian diamicton units.

LOVELAND LOESS

The Loveland Loess (or Loveland Silt) is the most widespread pre-Wisconsinan loess in the Midcontinent. It has been described throughout the Upper Midwest in the Missouri, Mississippi, and Ohio River basins (Willman and Frye, 1970; Reed and Dreeszen, 1965; Ruhe and Olson, 1978; Ruhe, 1969), and identified at several localities adjacent to the Mississippi Valley in Arkansas, and Mississippi (e.g., McCraw and Autin, 1989, and references therein). Unlike Wisconsinan loesses of the Midcontinent, the Loveland Loess has not been extensively studied, either for mineralogical composition, geometry (and thinning relationships), or chronology (other than the infamous "count down" method). Regional stratigraphic relationships suggest that the Loveland Loess is Illinoian in age and that the Sangamon Soil developed in the upper part of the unit is buried by Wisconsinan deposits. At complete sections in the Upper Midwest, the Loveland Loess is buried by the Roxana Silt in Illinois, Wisconsin, eastern Minnesota, Missouri, and Arkansas, or its correlatives in other states (the Pisgah Formation in Iowa and the Gilman Canyon Formation in Nebraska). Recently Miller and others (1985) suggested greater complexity to the loess record in the Mississippi drainage. They propose that an early Wisconsinan loess (Sicily Island Loess) occupies a stratigraphic position between the Loveland Loess and Roxana Silt along the Mississippi Valley south of Thebes Gap, and that the Roxana Silt pinches out somewhere north of Vicksburg, Mississippi (see Figure 4 in McCraw and Autin, 1989). The potential complexity of this loess record, coupled with recently determined "young" thermoluminescence (TL) age estimates of 80-90 ka for the Loveland Loess in Iowa and eastern Nebraska (Canfield, 1985; Norton and Bradford, 1985), bring into question whether or not the Loveland Loess is actually Illinoian.

History of the "Loveland" in Iowa

The definition of the Loveland as well as the types of deposits included in it have changed over the past 90 years. The first descriptions of the unit were made back in the time when the debate still raged between an eolian or aqueous origin for loess. The name "Loveland" was proposed by Shimek (1909, p. 405) for reddish to yellowish silt and clay that overlay "Aftonian beds" at Logan in western Harrison County, and "Kansan" till at the Type Section in the bluff above Loveland in Pottawattamie County. Shimek noted that the Loveland was buried by calcareous loess now known to be Wisconsinan and included associated sand and gravel deposits in the Loveland. He believed that the unit was for the most part glaciofluvial in origin (quite ironic since Shimek was the major proponent of an eolian origin for the overlying Wisconsinan loess). Kay and Graham (1943) discussed the development of the term "Loveland" and applied it to Shimek's silt, which they referred to as the "loess phase", as well as underlying sand, gravel, and stratified silt and clay, all of which they grouped into the Loveland Fm. Further, Kay and Graham (1943) included the volcanic ash and its enclosing beds at the County Line ash site in Harrison County, which we will see at the next stop, in the Loveland Fm. Mickelson (1949) restudied the Loveland Fm. of western Iowa and concluded that the sand and gravels were below and could be stratigraphically separated from the Loveland Loess. He suggested the term "Loveland" be restricted to the loess, and that the deposits enclosing the volcanic ash at the County Line site be part of the Sappa of Reed (1948). Condra and others (1950) recognized three phases of the Loveland Fm., a valley phase consisting of stratified silts and clays with laminae of sand, an upland phase consisting of massive loess, and a colluvial or slope phase separating the other two phases. In 1965 Reed and Dreeszen differentiated a lower sand and gravel (Crete) member, and an upper silt member (Loveland loess) of the Loveland Fm. in Nebraska. In 1957 the Type Section of the Loveland FM. was destroyed during excavation of a borrow pit for road construction. Daniels and Handy (1959) described a new Type Section (the present Paratype) on the north end of the borrow pit where the following section was exposed (present stratigraphic units and soil nomenclature indicated in parentheses):

0-78 ft.--------oxidized and unleached Wisconsin (Peoria) loess
78-83 ft.-------oxidized and leached Wisconsin (Peoria) loess
83-91 ft.-------oxidized and unleached Wisconsin (Peoria) loess
91-102 ft.------oxidized and leached Wisconsin (Peoria) loess
102-102.25 ft.--A1b soil horizon in Farmdale increment (Pisgah Fm.)
102.25-104 ft.--C1b soil horizon in Farmdale increment (Pisgah Fm.)
104-114 ft.-----oxidized and unleached Farmdale increment (Pisgah Fm.)
114-118 ft.-----Sangamon Soil (inceptisol) developed in Loveland Loess
118-123 ft.-----oxidized and leached Loveland Loess
123-130 ft.-----oxidized and unleached Loveland Loess
130-134 ft.-----oxidized and unleached Kansan (Pre-Illinoian) till

The present section is a little north of the area described by Daniels and Handy. It differs in that the Loveland Loess is thicker (24 ft. here vs. 16 ft.), and the Sangamon Soil is also a little thicker, but is still weakly expressed morphologically. The contacts between units seen in this section are similar to those described by Daniels and Handy (1959).

Chronology of the loesses at the Loveland Paratype

The first aspect of the Paratype Section we will discuss is the chronology of the loesses. Refer to the paper by Steve Forman for a summary of the available radiocarbon and thermoluminescence (TL) ages from this section. He will begin this part of the discussion. The crux of the issue is this: the Loveland Loess is beyond the range of radiocarbon dating and is not directly associated with other datable materials such as bone or volcanic ash. Loess is an ideal material for TL dating. Until 1989 no one had attempted to apply TL dating techniques to the Loveland Loess at the Paratype. Canfield obtained a TL age estimate of 82.7 ka (regeneration method) from the Loveland Loess near Plattsmouth Nebraska, about 40 miles (64 km) south of here (Canfield, 1985), while Norton and Bradford (1985), also using the regeneration method obtained a similar TL age estimate (89.2 ka) from Loveland Loess near Treynor, Iowa. Both of these age estimates suggested that the Loveland was younger in age than Illinoian, or that TL dating was providing only minimum age estimates. TL age estimates from the Paratype were determined using several methods, and the results suggest that the Loveland Loess was deposited around 140±20 ka. Forman attributes the disparity between these age estimates and those obtained by both Canfield (1985) and Norton and Bradford (1985) to different TL dating methods. TL age estimates obtained at the Paratype from the overlying Pisgah Fm. loess and the Peoria Loess agree well with radiocarbon ages determined on disseminated organic matter and an AMS-determined radiocarbon age on gastropod shell. These ages indicate that the Pisgah Fm. loess was deposited between about 35 and 25 ka, while the Peoria Loess began to accumulate shortly after 25 ka. Amino-acid ratios determined on gastropod shells from the Pisgah Fm. and Peoria Loess in this section support the TL age estimates and radiocarbon ages, and suggest a relatively short period of time with little or no warming between the end of Pisgah Fm. loess deposition and the onset of Peoria Loess accumulation (see contributed paper by Oches et al.).

The Sangamon Soil and Weathering Profile in the Loveland Loess

Its hard (no pun intended) to get a good look at the morphology of the Sangamon Soil here because of the brick-like nature of the desiccated soil. You can see, however, that the Sangamon Soil shows weak soil structure, diffuse soil horizon boundaries, little or no evidence for clay translocation, and reddening within the solum (Figure 26). The upper few inches of the profile are calcareous because of post-burial recharge from overlying calcareous loesses, but the Loveland Loess exhibits a relatively thick leached zone associated with the weathering profile of the Sangamon Soil. These characteristics are typical for the Sangamon Soil in bluffline exposures. These characteristics contrast with those described from a site about 16 miles (25 km) east of the bluffline (see contributed paper by Thompson and Soukup). Michael Thompson will discuss the morphology and micromorphology of the Sangamon Soil at this eastern site, and show that the Sangamon Soil varies regionally.

Carbonate nodules are present in the lower part of the weathering profile of the Sangamon Soil. Greg Ludvigson and Louis Gonzalez will discuss the carbon and oxygen isotope records preserved in these nodules and discuss some of the factors influencing isotopic composition of pedogenic carbonates, the relationships among matrix- and nodule-isotopic signals, and some of the complexities involved in attempting to derive paleoclimatic information from isotope data.

Pisgah Formation

Differences and disagreements in stratigraphic nomenclature have tended to overshadow the similarity of the loess sequence across the Upper Midwest. In order to facilitate correlation we propose to formally name the Wisconsinan loesses of Iowa. We propose the name Pisgah Formation for the unit referred to as basal Wisconsin sediment (or basal Wisconsin loess) in Iowa. This unit occupies the stratigraphic position of the Roxana Silt of Illinois and the Gilman Canyon Fm. of Nebraska. This unit includes loess, colluvium, slope deposits, and mixing zone materials. It overlies the Sangamon Soil developed in Loveland Loess at the Loveland Paratype, and has the Farmdale Soil developed in its upper part. The Pisgah Fm. is buried by Peoria Loess. Where it is loess, the Pisgah Fm. differs mineralogically from the Roxana Silt and does not contain the buried soils characteristic of the Gilman Canyon Fm. We propose to call the soil developed in the upper part of the Pisgah Fm. the Farmdale Soil (formerly referred to as the basal Wisconsin soil or the basal loess paleosol in Iowa) because it is in the same stratigraphic position as the Farmdale Soil of Illinois.

There are a few features of the Pisgah Fm. loess to observe at this stop. The Farmdale Soil developed in the upper part of the Pisgah Fm. can be examined on the face above the first step. Several discontinuous dark brown burned zones are evident at and around the Pisgah Fm./Peoria Loess contact. These zones contain charcoal flecks, thin orange (burned) zones at their base, and a few pockets of ash. Similar burned zones have been observed at this stratigraphic position in other exposures in western Iowa and eastern Nebraska.

Peoria Loess

We propose that the loess referred to as Wisconsinan loess in Iowa be called Peoria Loess after the unit in Illinois. This loess occupies the same stratigraphic position as the Peoria Loess, it imperceptibly grades into the Peoria Loess of Illinois, and it has a similar mineralogy.

The Peoria Loess section here is quite thick and has two leached zones in its lower part. In some areas it exhibits primary eolian bedding. A good example of the eolian bedding can be observed on the western side of the face above the second step. Here the loess exhibits different bedding structures, including planar stratification, cross-bedding, and ripples (amplitude 3-4 mm) that are inversely graded. The presence of this primary bedding indicates that loess deposition in this interval was very rapid, vegetation was locally absent, and soil mixing processes were overwhelmed by deposition. Note that the bedding disappears laterally as well as vertically in the section.

Pre-Illinoian Glacial Sequence

Last, but not least, is the pre-Illinoian diamicton sequence at the base of the section, and in another section west of the loess exposure. The pre-Illinoian glacial sequence at the site has not been studied in detail, but preliminary observations suggest that it consists of a thick sequence of resedimented diamictons and associated meltwater deposits. This interpretation is based on deposit types (discontinuous diamicton and stratified sand and gravel beds), deposit geometry (discontinuous, dipping beds), contacts between beds (which show the absence of pervasive shear, but evidence for soft-sediment deformation), and the presence of deformation structures suggesting collapse related to ice melt rather than active-ice shearing processes. The diamicton is noticeable more affected by secondary weathering than Wisconsinan glacial deposits, and exhibits numerous secondary features such as oxidation, extensive jointing, and accumulation of secondary iron and carbonate along joint faces and some bedding planes. The clay mineralogy of this diamicton (average 60:26:14, EX:ILL:K+C) suggests that this is one of the "A" tills of Boellstorff (1978; data on file at IDNR-GSB), part of the youngest sequence of pre-Illinoian glacial deposits in this part of the Midwest.

Location: NW 1/4, SE 1/4, Sec. 3, T77N, R44W
Described by: E.A. Bettis III and T.J. Kemmis; 6/28/89
Remarks: section described from top of Sangamon Soil down. Section extremely dry. Described at section cleaned by backhoe 6/89.

Depth (cm)	Soil Horizon (weathering zone)	Description
0-23	Ab	very pale brown (10YR7/4)-dry, brown to yellowish brown (10YR5/3-5/4)-moist silt loam, weak fine subangular blocky to granular, very hard, moderate effervescence, clear smooth boundary, common to abundant fine to medium soft secondary carbonate accumulations, some are vertical and occur along joints while others are spherical, few fine charcoal flecks, common secondary (recent) fractures giving the horizon a blocky appearance
23-46	Bw1b	light yellowish brown (10YR6/4)-dry, brown to yellowish brown (10YR5/3-5/4) silt loam, weak fine to medium subangular blocky, very hard, noneffervescent matrix, gradual smooth boundary, common to abundant fine to medium soft spherical secondary carbonate accumulations, very few fine charcoal flecks, recent fractures give blocky appearance to horizon with larger blocks than above
46-71	Bw2b	very pale brown (10YR7/3-7/4)-dry, brown (10YR5/3) silt loam, moderate medium subangular blocky breaking to weak coarse columnar, very hard, noneffervescent, gradual smooth boundary, laterally discontinuous zones of few fine soft spherical secondary carbonate accumulations, few charcoal flecks, common fine secondary manganese accumulations, fractures to coarse columns
71-117	Bw3b	very pale brown to light yellowish brown (10YR7/4-6/4)-dry, yellowish brown (10YR5/4) silt loam, weak to moderate medium subangular blocky weathering out to medium to coarse angular blocky, very hard, noneffervescent, gradual smooth boundary, abundant thin discontinuous very pale brown (10YR7/3)-moist silans, common fine secondary manganese accumulations, common fine soft secondary iron accumulations, common large krotovina appear to be filled with A horizon material, fractures to coarse columns
117-142	Bw4b	very pale brown (10YR7/4)-dry, yellowish brown to light yellowish brown (10YR5/4-6/4) silt loam, weak medium subangular blocky weathering out to coarse angular blocks as above, very hard, noneffervescent, gradual smooth boundary, abundant fine secondary manganese accumulations, few fine soft secondary iron accumulations, abundant thin discontinuous very pale brown (10YR7/3)-moist silans, fractures to coarse columns
142-188	BCb	very pale brown (10YR7/4)-dry, dark yellowish brown to light brown (10YR4/6-7.5YR6/4) silt loam, weak medium to fine subangular blocky, friable, noneffervescent, gradual irregular (because of krotovina) boundary, abundant fine brown (7.5YR5/2)-moist mottles, abundant fine secondary manganese accumulations, abundant coarse (9cm diameter) krotovina filled with material from both over and underlying horizons, common subvertical fractures along which very thin discontinuous cutans are present
188-132	C1 (OL)	light yellowish brown to very pale brown (10YR6/4-7/4)-dry, brown (10YR5/3) silt loam, massive, hard to friable, noneffervescent, abrupt smooth boundary, abundant fine secondary manganese accumulations, few to common large krotovina filled with material from overlying horizon and containing very abundant fine secondary manganese accumulations and abundant fine to medium brown (7.5YR5/2)-moist mottles, fractures with very thin discontinuous cutans as above but decreasing with depth, fractures to coarse columns

Figure 26. Detailed description of the Sangamon Soil, Loveland Loess and underlying pre-Illinoian diamicton at the Loveland Partaype in Pottawattamie County, Iowa.

132-396	C2 (OL-OL2)	as above but laterally some areas have weak to very weak effervescence, gradual lateral boundary with noneffervescent areas, abrupt to clear smooth lower boundary
396-549	C3 (OL-OL2)	light yellowish brown to very pale brown (10YR6/4-7/4)-dry, brown (10YR5/3) silt loam, massive, hard, noneffervescent matrix, common to abundant fine to medium soft secondary carbonate accumulations in some parts of this zone absent in others, abundant fine manganese accumulations, fractures into very coarse columns with the fractures becoming farther spaced with depth (10's of cm at the base of this zone)
549-640	C4 (OU2)	very pale brown (10YR7/3-8/3)-dry, light yellowish brown to very pale brown (10YR6/4-7/4) silt loam, massive, very hard, violent effervescence, clear smooth boundary, common hard spherical to tubular secondary carbonate accumulations, abundant fine secondary manganese accumulations in pores (root channels), thin continuous secondary carbonate coatings in pores overlying the manganese accumulations
640-737	C5 (OU2)	light gray to very pale brown (10YR7/2-7/3)-dry, brown to pale brown (10YR5/3-6/3) silt loam, massive, very hard, violent effervescence, gradual smooth boundary, few fine hard secondary carbonate nodules, few fine hard secondary iron accumulations, abundant hard medium and soft fine secondary manganese accumulations in pores and in matrix, abundant continuous secondary carbonate coatings and filaments in pores, very few fine pebbles mostly in lower half of zone
737-787	2C1 (JOU2)	very pale brown (10YR7/4)-dry, pale brown to light yellowish brown (10YR6/3-6/4) silt loam matrix-dominated diamicton, massive, very hard, violent effervescence, clear smooth boundary, jointed at 2-3m interval, contains a high percentage of metamorphic clasts with lesser amounts of carbonate lithologies, pebbles occur individually in the matrix, few thin discontinuous secondary carbonate coatings on pebbles, common soft secondary carbonate accumulations in matrix, common thin discontinuous manganese accumulations in pores and tubular root channels
787-838	2C2 (OU2)	very pale brown (10YR7/4)-dry, pale brown to light yellowish brown (10YR6/3-6/4) silt loam matrix-dominated diamicton, massive, very hard, violent effervescence, abrupt smooth boundary, pebbles as above, abundant soft 1-3cm diameter secondary carbonate accumulations, common soft to hard subspherical 3-5cm diameter secondary carbonate accumulations, manganese accumulations as above
838-945	2C3 (OU2)	very pale brown (10YR7/4)-dry, pale brown to light yellowish brown matrix dominated diamicton with irregular pods and lenses of Gc(m)-Dc(m), at top of unit pods appear to be horizontal and undeformed, within the unit they are irregularly shaped with some lenses deformed to subvertical orientations, these irregularly-shaped pods and lenses appear not to have been glaciotectonically deformed by shear, pods within the diamicton tend to have gradational contacts with the silt loam matrix, massive, very hard, gradual smooth boundary, few coarse hard secondary carbonate accumulations (up to 12cm long) in upper 25cm of horizon, thin discontinuous coatings of secondary carbonate on some clasts, few fine secondary manganese accumulations along tubular pores in silt loam diamicton
945-base (975)	2C4 (OU2)	olive yellow (2.5Y6/6)-moist sandy loam matrix to clast supported diamicton with common coarse pebbles and fine cobbles, massive, firm, violent effervescence, clasts are dominantly igneous and metamorphic lithologies, abundant medium hard secondary carbonate accumulations

Figure 26. Continued.

ROAD LOG - Loveland to County Line Ash Site

21.3 (0.2) At Dew Drop Inn turn right onto G-14/ IA-183 and proceed north. Cross bridge and proceed north on IA-183.

22.0 (0.7) Note exposure in bluff line. Peoria Loess overlying Pisgah Fm. burying the Sangamon Soil in Loveland Loess is exposed. The units and associated soils appear very similar to those at the Loveland section. Also notice that the base of the bluff is truncated along this area. The profile is concave upward then drops sharply to the road. Alluvial fans and colluvial aprons are poorly developed to absent. The Missouri or Boyer River has apparently been along this portion of the bluff during the late Holocene.

23.0 (1.0) Cross under railroad bridge and enter junction of Boyer River valley with the Missouri River valley.

23.2 (0.2) Notice alluvial fan emanating from a 3rd-order tributary on the south side of the Boyer Valley. Several houses marking the old town of Findley are located on the fan. Deposits comprising this fan are the Corrington Member of the DeForest Fm. Cross drainage ditch.

23.9 (0.7) Cross Boyer Ditch. The Boyer River has been straightened upstream to the town of Dennison in Crawford County. The Boyer River heads marginal to the Des Moines Lobe and carried outwash from both the Des Moines Lobe and "Tazewell" ice sheets. Des Moines Lobe outwash is below the modern floodplain in the lower 2/3 of the valley.

Calcareous loess-mantled alluvium comprising the "Tazewell" terrace is above the level of the modern floodplain through much of the Boyer valley, but below floodplain level down valley of the town of Logan (Daniels and Jordan, 1966). The alluvium comprising the "Tazewell" terrace is in part outwash, but also contains appreciable amounts of alluvium derived from cutting of Wisconsinan "Iowan" erosion surfaces. The "Tazewell" terrace is mantled with a full increment of Peoria Loess that lies directly on calcareous alluvium. Below Logan and in the lower reaches of other tributaries the elevation of the terrace above the modern floodplain consists entirely of Peoria Loess. Topographically higher and older "Late Sangamon" terraces are also present in the larger tributaries to the Missouri Valley (Daniels and Jordan, 1966). A paleosol is developed in the upper part of the loess-mantled alluvium in these terraces. The alluvium in these terraces is mantled by both Pisgah Fm., with the Farmdale Soil developed in its upper part, and Peoria Loess. Shimek's Peckenpaugh sections (SW1/4 sec. 19 T79N R43W Harrison County) were exposures of a "Late Sangamon" terrace sequence at Logan. Shimek's original classification designated the paleosol developed in the alluvium as the Loveland (Fm.) and the underlying sand and gravel Aftonian (Shimek, 1910 p. 336). Daniels reclassified the section in 1966.

24.9 (1.0) Enter town of Missouri Valley.

25.3 (0.4) Junction of IA-183 with US-30. Turn left onto US-30 and proceed west.

25.4 (0.1) Stop light on US-30.

25.6 (0.2) Turn right onto IA-183 (Lewis and Clark Trail) and proceed north.

25.8 (0.2) Turn left at T-intersection and follow IA-183 around turn to right then proceed north along the base of the bluff. Directly north of the T intersection is the Third Ward Schoolhouse section of Shimek (1910). The section consists of Peoria Loess, Pisgah Fm. with Farmdale

		Soil developed in upper part, overlying the Sangamon Soil developed in Loveland Loess.
26.2	(0.4)	Small borrow pit on right exposes Peoria Loess over Farmdale Soil developed in Pisgah Fm. over Sangamon Soil in Loveland Loess over an erosion surface on jointed, oxidized unleached pre-Illinoian till (A1 till). The jointing in the till is quite spectacular and highlighted by thick accumulations of secondary carbonate along the joints.
27.0	(.8)	The base of the bluff line along this part of the valley is characterized by a general absence of colluvial slopes and small, steep alluvial fans emanating from tributaries. This is a youthful valley margin and the Missouri or one of its tributaries was against this part of the valley wall during the late Holocene. Notice the borrow pit dug into the base of the bluff at the seed dealership. The sequence exposed here is Peoria Loess over the Farmdale Soil developed in Pisgah Fm. overlying the Sangamon Soil developed in Loveland Loess.
30.0	(3.0)	Cross Willow River ditch and bear left on IA-183. This is the Willow River valley studied by Daniels and Jordan (1966). The DeForest Fm. was defined in this basin. The original type sections for the formation have been innundated and/or destroyed by channel widening. The town of Calhoun is situated on a loess-mantled terrace on the north side of the mouth of the Willow River valley. This terrace was mapped as a "Tazewell" terrace by Daniels and consists of Peoria Loess overlying calcareous pebbly sand. The surface of the alluvium under the mantle of Peoria Loess is below the level of the modern floodplain. The Willow River heads on the Southern Iowa Drift plain and did not carry Wisconsinan outwash. The alluvium was apparently derived from erosion of the surrounding watershed during development of Wisconsinan "Iowan" erosion surfaces. Calhoun was the first village platted in Harrison County (1853).
31.6	(1.6)	Note colluvial apron and alluvial fan complex at the mouth of Sawmill Hollow.
34.5	(2.9)	Exposure in bluff: Peoria Loess overlies Farmdale Soil developed in Pisgah Fm. overlying Sangamon Soil developed in Loveland Loess.
35.7	(1.2)	Junction of IA-127. Proceed north along IA-183. Logan to the east.
36.6	(0.9)	Cross bridge over Steer Creek. Note truncated spur ahead and large, low-angle alluvial fan at the mouth of Steer Creek. Gully growth was studied in Steer Creek watershed by Beer (1962; Beer and Johnson, 1963) using an historical approach where variables deemed important in gully growth were evaluated from the past growth of gullies. He concluded that for the period between 1938 and 1958 a logarithmic model incorporating runoff, deviation of precipitation from normal, gully length, distance from the head of the gully to watershed divide, and land treatment factors best represented the observed gully development.
37.0	(0.4)	Follow IA-183 (turn right). Note eroded bluff with catsteps (or should they be cowsteps?) on right. Deposits exposed here are: Peoria Loess over Pisgah Fm. overlying the Sangamon Soil developed in Loveland Loess that in turn buries a paleosol developed in pre-Illinoian till.
39.6	(2.6)	Enter Soldier River valley. This valley heads on the Southern Iowa Drift Plain just outside of the margin of the Wisconsinan "Tazewell" ice advance. Wisconsinan outwash was not carried down this valley.
40.3	(0.7)	Rise onto dissected loess-mantled terrace. The surface of the loess-mantle is 80-90 feet (24-27m) above the adjacent floodplain. Age of the alluvium beneath the loess and the nature of the stratigraphy of these terraces is unknown.

42.4	(2.1)	Drop off terrace and enter cutoff valley meander. Note isolated terrace remnant on left. The cutoff valley segment is Holocene in age (no Peoria Loess). The colluvial apron along the base of the valley slope descends gradually toward the center of the cutoff suggesting that the cutoff may be early to middle Holocene in age.
43.8	(1.4)	Rise onto dissected, loess-mantled terrace.
44.4	(0.6)	Drop off terrace into Soldier River floodplain.
44.7	(0.3)	Large old gravel pit on right exposes sub-till, fossiliferous sand and gravel. This is the Peyton pit, where "Aftonan" fauna was collected by a number of geologists including Calvin and Shimek. The section in the pit consists of pre-Illinoian till [Kansan of Calvin (1909) and Shimek (1910)] overlying sand and gravel (Aftonian of above). The pit owner reported to Shimek that "dark blue clay" (considered by Shimek to be "Nebraskan" drift) lay beneath the sand and gravel. Photos of the section in Calvin (1909) and in the Calvin slide collection at the University of Iowa Geology Department show that the sands are trough cross-bedded and that the section is dominantly sand with pebbles confined to a few shallow trough fills. The contact of the upper till with the underlying sand and gravel is sharp with no evidence of a paleosol at the contact.
45.1	(0.3)	Rise onto dissected loess-mantled terrace then descend to Soldier River floodplain.
45.3	(0.2)	Enter town of Pisgah.
45.8	(0.5)	Turn left onto county road F-20 just north of the McCord FS gas station. Proceed west.
46.1	(0.3)	Cross Soldier River bridge. Loess-mantled terraces to left and right. Test wells drilled in this area indicate that depth to rock (Dakota Sandstone or Pennsylvanian) is about 70 to 75 feet (21-23m) on the floodplain in this part of the valley (Hunt and Runkle, 1985). Proceed to the west on county road F-20. Notice that the main stem of the valley we are going up is entrenched, but that the laterals are not. Also notice that as we approach the Missouri River bluff line the topography gets very steep. Valleys draining to the Soldier extend essentially to the bluff line in this area and many examples of stream (valley) capture are present.
49.8	(3.7)	View of Missouri River valley from Murray Hill (Figure 27). At this location the top of the bluff is about 250 feet (76m) above the floodplain of the Missouri Valley. The Missouri Valley is approximately 12.5 miles (20km) wide here. Descend Murray Hill. Exposures along Murray Hill have attracted Pleistocene geologists for a long time. "Aftonian" fauna has been collected from sand and gravel exposed here (Calvin, 1909; Shimek, 1910; Hay, 1914). Several radiocarbon dates from the Farmdale Soil developed in the upper part of the Pisgah Fm. have been collected here (G.R. Hallberg and G.A. Miller, personal communication). These dates average about 23,500 B.P. and are in agreement with those from the same stratigraphic position at the Loveland Paratype Section (Forman, this volume). The Pisgah Fm. overlies the Sangamon Soil developed in Loveland Loess at Murray Hill. Large septarian carbonate nodules are present in the lower part of the Sangamon Soil here. These are the QNS-2 nodules discussed by Ludvigson et al. in this volume. A complex sequence of pre-Illinoian tills and interbedded sand and gravel lay beneath the Loveland Loess along Murray Hill.
50.3	(0.5)	At base of hill turn right onto county road C-14 (Larpenteur Memorial Road). Proceed

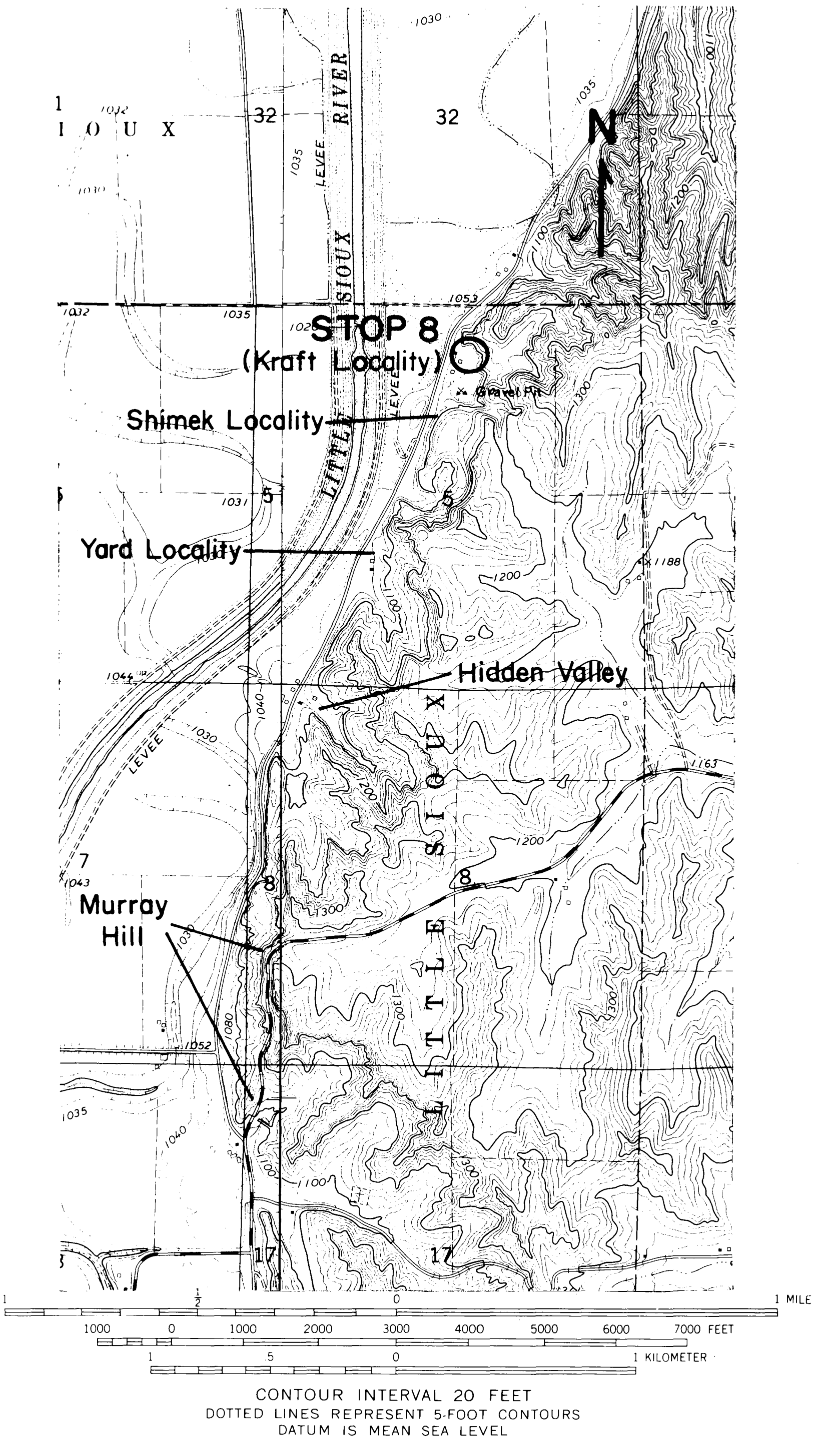


Figure 27. Topographic map showing the location of Murray Hill, Hidden Valley and the various localities of the County Line ash site in northwestern Harrison County, Iowa. Base taken from USGS 7.5' Pisqah, Iowa, and Little Sioux, Iowa-Nebraska quadrangles.

north on gravel road along the base of the bluff. Note shallow exposures in colluvial slope along road. On the left (to the west) is an abandoned channel of the Little Sioux River. Prior to channelization and levee construction most of the Missouri's tributaries on the Iowa side flowed through Yazoo channel systems along the base of the bluff before entering the Missouri channel.

51.4 (1.1) Note pre-Illinoian till high in the bluff.

51.5 (0.1) Cross creek, house on right, barn and bins on left. The Hidden Valley site (13HR28), a stratified Woodland burial locale, is located in this small valley (Tiffany et al., 1988). The skeletal remains of seven individuals dating from about 1,200 to 1,700 B.P. were recovered from DeForest Fm. alluvium in the valley.

51.9 (0.4) Near base of the bluff north of the trailer is an exposure of the Lava Creek B ash. This is the Yard Locality of the County Line Exposures.

52.0 (0.1) Exposure of Lava Creek B ash in road cut to right. This is the Shimek Locality of the County Line Exposures. We will discuss this locality at Stop 8.

52.4 (0.4) Brick house at base of bluff. STOP 8. Kraft Locality of the County Line exposures. Park along the road. We will walk up the driveway into the pit where the Lava Creek B ash and associated deposits are exposed.

STOP 8. EXPOSURE OF THE LAVA CREEK B VOLCANIC ASH AT THE COUNTY LINE ASH SITE (KRAFT LOCALITY)

Leaders: E.A. Bettis, T.J. Kemmis, B.B. Miller

Volcanic ashes are present in the pre-Illinoian sequence of western Iowa. The County Line ash site was described by Shimek (1910 p. 388, his County-Line exposure) from a road cut along the Little Sioux River at or near what is now referred to as the Shimek Locality (see contributed paper by Paulson and Miller). At this locality Shimek described the following section:

5. Loess to the top of the cut
4. more than 15 feet of Loveland, reddish joint clay with lines of very large calcareous nodules
3. Kansan, bluish, very calcareous till
2. Aftonian:
    - 15 feet of fine whitish silt
    - 5 feet of shell-bearing fine silt mixed with sand
    - 7 feet of very ferruginous coarse gravel
    - 6 to 12 feet of cross-bedded sand
1. 10 feet of Nebraskan drift

Shimek did not recognize volcanic ash in the section, but it probably occurred within the 15 feet of Aftonian fine whitish silt (upper part of unit 2). Shimek was also the only person to interpret the presence of a till (Kansan; unit 3) above the sand and gravels in the section.

At the County Line site, Kay and Graham (1943) included all the deposits above Shimek's Nebraskan till in the Loveland Formation. By this time several gravel pits were operating in the area. Several exposures of the Loveland Formation deposits, silts and bedded sands, were available for study. Kay and Graham recognized a three-foot thick bed of volcanic ash beneath a concretion-bearing zone of the Loveland, loess phase. They also described a three-foot thick loess phase beneath the ash that graded into underlying Loveland sand and gravel (Kay and Graham, 1943, p. 87).

In his work on the Loveland Formation, Mickelson (1949) studied the County Line exposures and concluded that the ash and underlying deposits were stratigraphically distinct from the overlying loess phase of the Loveland, and recommended that they be excluded from the formation and included in the Sappa of Reed (1948).

Chronologic Position of the County Line Ash

Frye and others (1948) determined the chemical composition of the ash and correlated it with the Pearlette of Kansas (early Yarmouthan age). On the basis of bulk geochemistry, Swineford (1949) suggested that the source area of the ash was the Valle Grande crater in New Mexico.

Izett and others (1971) determined that the Pearlette was comprised of three different but closely related ash varieties, which they referred to as types B, S, and O. They suggested that the source areas for these ashes was the Yellowstone caldera complex, and correlated the ashes with formally named ash-flow tuffs mapped by the U.S. Geological Survey in the Yellowstone National Park area. The ash at the County Line site was a type-O Pearlette, and became Lava Creek B ash in the new correlation scheme (Izett and Wilcox, 1982). K-Ar ages of sanidine in the Lava Creek B tuffs of the type area indicate that the associated ash was deposited about 620 ka.

The name "Hartford" ash was proposed for the ash at the County Line site by Boellstorff (1973). He studied the geochemistry and performed fission-track dating on shards from ash localities in the central Plains and concluded that there were three different-age ashes having very similar, type-O Pearlette geochemistry. The ash at the County Line site yielded fission-track ages of about 710 ka and was correlated with an ash bed at Hartford, South Dakota with a similar age and geochemistry.

So folks, there is still uncertainty in the age and correlation of the ashes. Pick your favorite geochronologist and associated age for the ash at this site. Let's just say the ash is older than 500 ka and younger than 800 ka and leave it at that.

Stratigraphic Position of the Ash

We will examine the stratigraphic position of the ash at the Kraft locality located north of the Shimek locality. A sketch of the exposure is presented in Figure 28. Here the ash appears to be part of a conformable alluvial sequence (as conformable as such sequences are), but the depositional environment is problematic. The ash is about 15 inches thick, has an abrupt lower boundary with stratified silty clay and fine sand laminae (unit A2 in

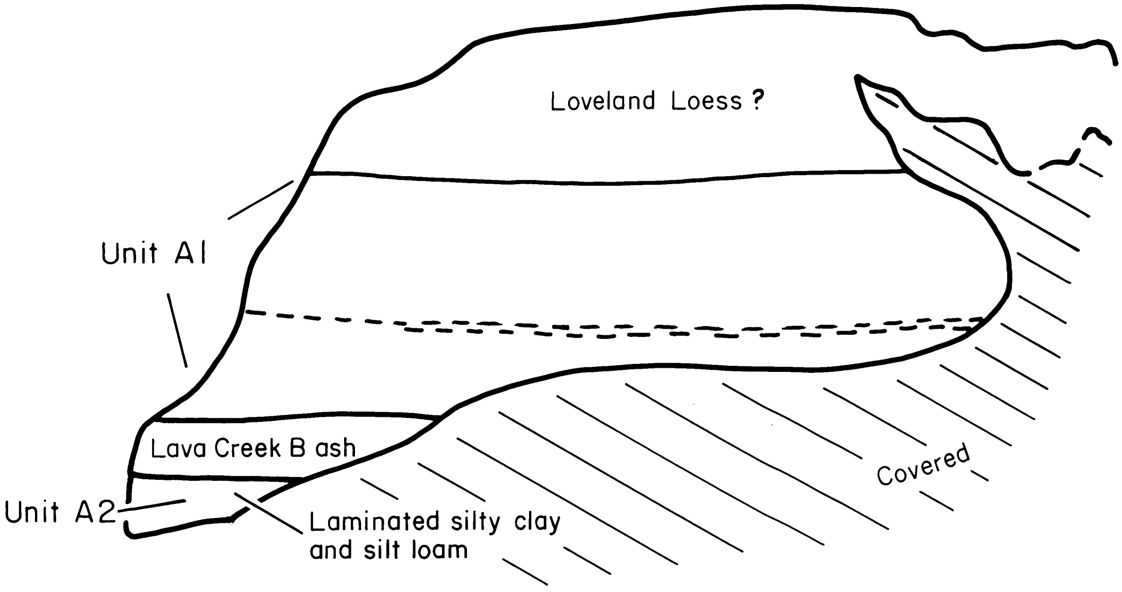


Figure 28. Sketch of the Kraft locality of the County Line ash site. Units are described in text. Dashed line through Unit A1 indicates position of nearly continuous zone of coarse beds. Sketched section faces south.

Figure 28). The upper contact of the ash is gradational, and thin strata of ashy silt loam are stratified with silt loam alluvium. This grades upward to a sequence about 46 feet (14 m) thick of bedded silt loam containing thin lenses of sand and fine gravel (unit A1 in Figure 28). This unit contains several normally graded (fining-upward) units. The coarse beds contain clasts up to 4 inches (10 cm) in diameter, but are dominantly coarse sand. The coarse beds are typically two feet (60 cm) wide and spaced every three to five feet (1-1.5 m). In cross-section these beds fill pools and riffles, while in transverse section they are planar bedded. Overlying fine-grained beds are thinly bedded to laminated and planar bedded. There is no evidence for deep channelization in the section. Also there is little evidence for subaerial exposure throughout this interval; only one bed exhibiting small, subvertical burrows was observed about two-thirds of the way up in the interval. Unit A1 grades upward into massive loess that has been called Loveland Loess by most workers at the site. Complicating the interpretation of this section, and most other pre-Illinoian sequences, is the extensive secondary alteration of the deposits, including deep oxidation, post-depositional jointing, and secondary precipitation of calcite into conspicuous septarian nodules up to 8 inches (20 cm) in diameter that occur along bedding planes in unit A1. The graded beds in unit A1 suggest a local, high-energy source (flood pulses). The absence of pedogenic features within the sequence suggest uninterrupted deposition. Such as depositional setting could be a rapidly aggrading alluvial fan or, more likely in this case, a distal outwash setting. Pebble fabrics measured in several of the coarse beds indicate transport directions to the southwest. These fabrics indicate that the source was not the Missouri River, but an unknown drainage source to the northeast.

The paleoenvironmental record from three fossil mammal faunas and associated gastropod assemblages recovered from above and below the ash at this locality and the Shimek and Yard localities immediately to the south (see contributed paper by Paulson and Miller) suggests a somewhat different depositional setting. Barry Miller will discuss these faunas and what they tell us about the environment during accumulation of this sequence. The faunal evidence (from somewhat different site stratigraphies) suggest periodic deposition on a floodplain (more likely to result in pedogenic events during accumulation of the sequence) and a significant warming trend spanning deposition. As yet, work remains to resolve the paleoenvironments at this site.

A test hole drilled at the Shimek Locality (graphic log presented in Paulson and Miller, this volume) shows that the ash is underlain by about 30 feet (9 m) of sand and gravel that overlie pre-Illinoian till ("A3" till of Boellstorff) burying 55 more feet (16.7 m) of sand and gravel that overlies Cretaceous bedrock. Well logs and conversations with Mr. Kraft, who has lived here during most of the time the gravel pits have operated, indicate that the sand and gravels beneath the ash and above the till extend into the bluff to the east, further supporting the inference that the sand-and-gravel sequence is part of a fluvial system whose head is to the northeast.

Discussion

The two stops visited today show that an extensive and complex stratigraphic record is present in western Iowa. Major unconformities are not always marked by abrupt and clearly defined contacts. Secondary alteration is often significant and complicates interpretation of the record. In the past it seems that this complexity has gone largely unapppreciated in favor of naming and correlating a plethora of units in widely separated sections that rarely expose but a few units. We know that correlation on the basis of gross appearance, the nature of secondary alterations (including soil morphology) and assumed stratigraphic and temporal relationships of "marker" beds has resulted in a stratigraphic maze for this area (see Witzke and Ludvigson, this volume). A start toward a realistic stratigraphic framework founded on demonstrated relationships has been made by Boellstorff (1978) and Hallberg (1986). What they have presented is a skeleton that needs much fleshing out.

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DEPOSITIONAL STRATIGRAPHY, SITE CONTEXT AND PREHISTORIC CULTURAL OVERVIEW

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This presentation will review archaeological manifestations and research problems in the prehistory of Native American cultures of western Iowa. We will be concerned with the evidence for prehistoric human activities as it occurs in archaeological sites. Sites have primary context in the natural landscape, so this will be our starting point; i.e., the conditions of site preservation which currently influence our perspective of the prehistoric cultural record.

Consideration of the natural context of archaeological sites begins with a dichotomy of the landscape into uplands and valleys. Since the termination of major loess deposition in western Iowa (ca. 12,500 B.P.) and the retreat of glacial ice from north-central Iowa, upland landforms have received modest increments of eolian sediment and have been subjected to surface erosion. Erosion accelerated due to farming activities in the Historic period. Eroded sediments are stored and transported through the drainage network in valleys. In terms of archaeological site formation, upland and valley environments are differentially affected by physical processes that affect the record of the past. In the uplands, weathering of sediments (soil formation), pedoturbation and erosion are the principal physical processes that affect sites. In valleys, sites are affected by aggradation and degradation of sedimentary deposits, and to a significant extent by soil formation.

More analytical time and publication space has been expended on depositional contexts (valleys) than erosional contexts (uplands) because the former preserve a clearer and more detailed archaeological record. This is because valley alluvium contains a thicker vertical dimension; upland stratigraphy is compressed, while valley stratigraphy can be greatly expanded. Coincidently, valley environments tended to attract prehistoric human beings more often as they exploited resources of forest and riparian habitats. In western Iowa the stratigraphic context of archaeological remains has been investigated most intensively through the study of the DeForest Formation.

Discussion of prehistoric societies is organized into culture periods derived from assemblages of diagnostic artifacts and associated radiocarbon dates (see Benn, 1986). The culture periods parallel the study units in the state planning document for the preservation of cultural resources (E. Henning, 1985).

PRE-CLOVIS (pre-12,000 B.P.).

There are no known sites for this period in any part of Iowa. Pre-Clovis sites are rare in the western hemisphere, and demonstrations of their authenticity often are plagued by uncertain contexts and dating. If such sites exist in Iowa--Pre-Clovis human populations may have been too sparse to have spread to the upper Midwest--they would lie beneath or beyond the edge of the Des Moines Lobe ice sheet. Pre-Clovis remains should consist of evidence for human activity in association with Pleistocene fauna and flora in a stratigraphic context of glacial-age sediments. Evidence of human activity may consist of flake or chopper tool industries rather than lanceolate points (of the subsequent period), and bone or wooden tools in associations with butchered animals.

No other culture period better demonstrates the need for a geoarchaeological perspective than Pre-Clovis. The western Iowa landscape before 12,000 B.P. was radically different physiographically and biotically from today's. Pre-Clovis sites should be sought best on landscape elements of appropriate age with the best chance for preservation of human evidence: e.g., within or beneath loess deposits or on Pleistocene landforms buried beneath Holocene-age colluvium.

PALEO-INDIAN
(12,000-8,000 B.P.)

The archaeological potential of late Wisconsinan and early Holocene deposits is unknown. Loess exposures have not yielded recognized evidence of human presence. Outwash deposits in the major valleys of western Iowa consist of high energy sediments that are not conducive to the preservation of human evidence. Investigations in small and moderate-size valleys that did not carry outwash indicate deposits of this age are deeply buried and, in many cases, severely eroded. The overall perception is that a substantial part of the late Wisconsinan and early Holocene landscape has been modified or destroyed and therefore is no longer available for study.

Less than a dozen Paleo-Indian sites are recorded in the Western Iowa Basin. Some of these sites are represented by isolated finds of lanceolate points on uplands and benches or late Wisconsinan terraces, and a larger number of lanceolate point finds have been made by collectors but not reported as sites. Paleo-Indian points are found on the surface as far north as Lake East Okoboji on the Des Moines Lobe (Tiffany, ed., 1982). A few Paleo-Indian kill sites excavated from alluvial fans give the best cultural information (e.g., Cherokee Sewer site in Anderson and Semken, eds., 1980). The predominant remains in kill sites are butchered bison with smaller animals and a few seeds also being present. A fall-winter hunting pattern for bison is indicated. Tools from the Cherokee Sewer site include unfluted lanceolate points of late Paleo-Indian derivation (horizon III; ca. 8,500 B.P.) followed by small side notched points, endscrapers, flake tools and a variety of worked bone (e.g., choppers, awls, "flute") in later (Archaic) levels.

EARLY-MIDDLE ARCHAIC
(8,500-4,000 B.P.).

This period covers the entire Atlantic climatic episode, or Altithermal, the warmest and driest part of the Holocene period. During this time, prairie vegetation occupied most of the landscape, and the incidence of fires probably increased.

Small valleys (orders 2,3) in areas of thick loess contain a stratigraphic hiatus spanning the mid-Holocene. This is the DeForest Gap (8,000-3,500 B.P.; Bettis and Thompson, 1981; see Figure 1c,d). There are no preserved deposits that represent this period in this part of the drainage network. No studies have been done to show how far north into the northwest Plains this stratigraphic gap occurs in small valleys, but some manifestation of it is anticipated (because fans are present--see below). The DeForest Gap presents an interesting analytical problem for archaeologists. The gap is not merely evidence for erosion; it is also evidence of a <u>missing</u> part of the record. The "missing" record is the prehistoric settlement system in small valleys, which we presume once existed because archaeological evidence shows later people inhabited small valleys.

Sediments transported from small valleys during the development of the DeForest Gap were deposited in larger valleys (4+ orders) in the form of alluvial/colluvial fans and alluvium on valley floors. Fan deposits encompass the Corrington Member of the DeForest Formation (Figure 1b,c). Large fans can be more than 33 ft. (10m) thick and many acres in extent. Arrays of radiocarbon dates from Corrington fans in the Little Sioux River valley (Hoyer, 1980) show that fans accreted rapidly between 8,500-4,000 B.P. and ceased aggrading by 2,500 B.P. Fan sediments are elevated and well drained, offering prime valley locations for human occupation as well as a context for excellent preservation of archaeological evidence.

In large valleys the Gunder Member began accumulating on the valley floor ca. 10,5000 B.P. and continued to aggrade until ca. 4,000 B.P. Today, these deposits comprise a low terrace with buried Archaic sites and surficial Woodland sites (see below). At the M.A.D. site (13CF102) on the Boyer River the Gunder Member was at least 12 ft. (3.6m) thick with a well developed soil profile extending from its surface (Benn et al., 1981).

Early and Middle Archaic sites are almost as uncommon as Paleo-Indian sites for the same reasons: low populations and subsequent changes in the landscape. There are less than a dozen Archaic sites of the two periods in upland, bench and Wisconsinan terrace settings. These consist of isolated human burials (e.g., Turin, Fisher et al., 1985) and lithic scatters. A slightly larger number of Archaic sites have been discovered fortuitously in deeply buried contexts of alluvial fans and mid-Holocene terraces (e.g., Cherokee Sewer site

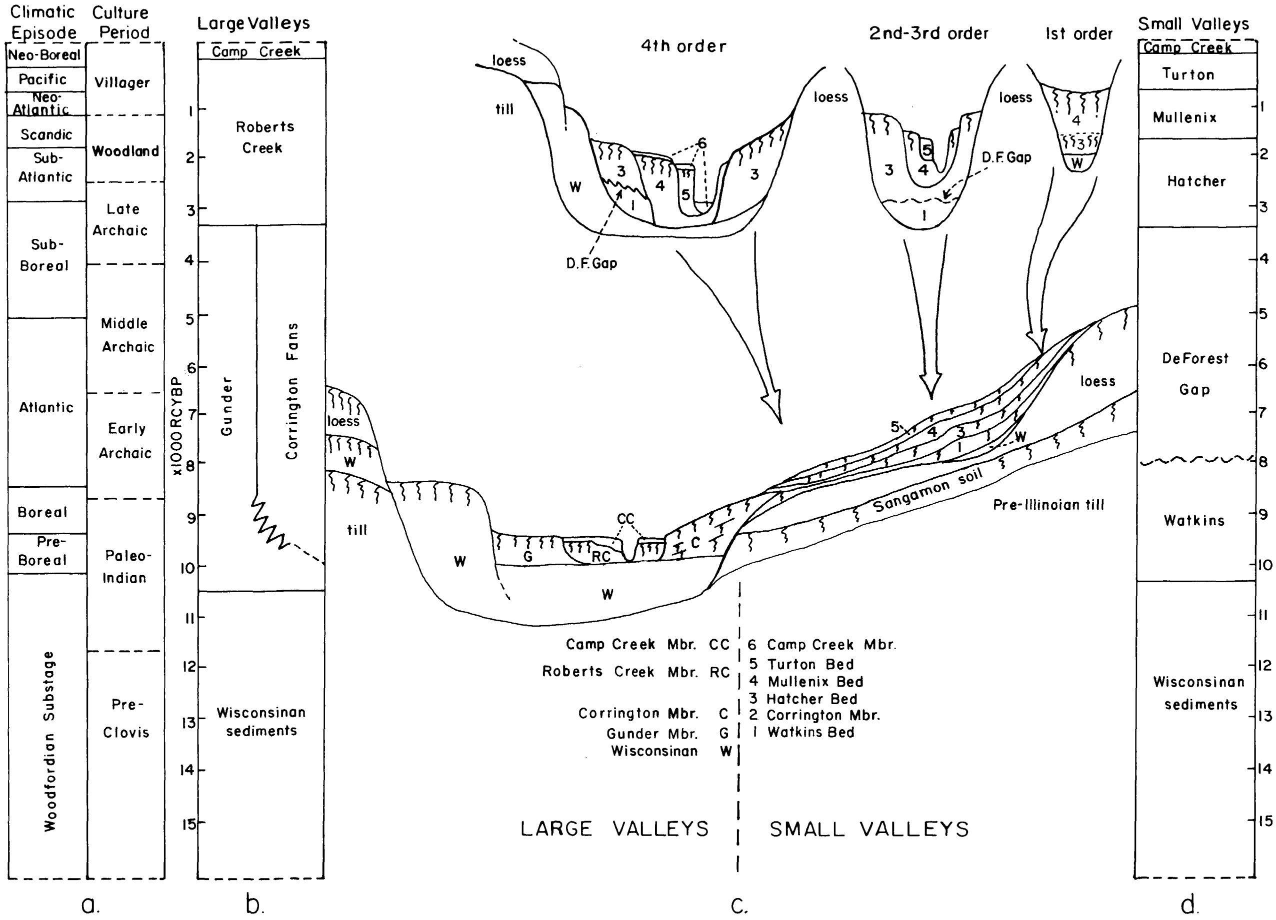

Figure 1. Western Iowa Basin stratigraphic, climatic, and cultural relationships.

in Anderson and Semken, eds., 1980; the Hill site in Frankforter, 1958). Well preserved sites have yielded mostly bison remains with elk, deer, rabbit, coyote, wolf, birds, turtles and a few fish and mussels represented. As with the previous period, there are too few sites and too little variation in the site data to develop reliable generalizations about Archaic subsistence and settlement patterns.

Others (Ludwickson, et al., 1981:112) have reasoned that the effects of the Altithermal climatic episode might have forced Archaic peoples to forage for diverse resources in the river valleys. The shift to broad spectrum subsistence by Archaic people established this pattern as a basis for later Woodland economies. The argument that climate affected a change in Archaic subsistence could be countered with the proposition that relatively mesic prairie in Iowa (compared to the plains) would have attracted large bison herds, thereby encouraging adherence to the old bison hunting tradition. Resolutions to these and other questions must be sought in the buried contexts of the DeForest Formation in western Iowa. In this alluvium are Archaic sites with good preservation of floral and faunal remains. There is a reasonably large body of evidence from sites of Woodland hunters and gatherers for making comparisons with Archaic sites to determine if there were differences in subsistence patterns.

PRAIRIE/PLAINS LATE ARCHAIC (4,000-2,500 B.P.)

The archaeological potential of the DeForest Formation has proven to be high (Figure 1 b,c,d). Late Archaic period sites are common in the Hatcher Bed of the Gunder Member, and sites of the same age are deeply buried in terraces underlain by the Roberts Creek Member at the M.A.D. sites. Woodland materials are found throughout the Mullenix Bed of the Roberts Creek Member in small valleys and in the upper half of the Roberts Creek Member in large valleys. Typical locations for sites in these fills are on small, inset terraces within gullies in small valleys and on river banks in large valleys. Many of these sites have excellent preservation, including organic remains.

Because of the association between materials of specific cultural ages and particular beds within the DeForest Formation, it is possible to utilize geological context to predict relative ages of cultural deposits, even if those deposits lack diagnostic artifacts. For instance, cultural remains buried in the Hatcher Bed belong within the Archaic period; likewise, materials in the Mullenix Bed are Woodland age (e.g., Sterns Creek culture). Similarly, in large valleys, Archaic remains tend to be buried in the Roberts Creek Member, while Woodland artifacts usually occur near the surface of this member. Knowledge of these relationships enables archaeologists to provide relative dates for sites with minimal remains (e.g., fire-cracked rock scatters) and to develop preliminary ages for isolated artifacts found in situ during reconnaissance surveys.

Glimpses of Late Archaic culture come from a few buried sites in the Loess Hills and from projectile point complexes found on the shores of lakes on the Des Moines Lobe. At the Lewis Central School ossuary site (Anderson et al., 1978) which will be passed on the drive to Stop 1, about two dozen flesh and bundle burials were excavated from 3m deep in a colluvial slope. One burial was associated with a kit of utilitarian tools, including a point, scraper, knife, awl, antler beamer, flakes and worked mussel shell. The authors note that a burial program incorporating the curation of skeletal remains (in bundles) and the grouping of burials implies the development of integrative mechanisms within communities and the potential recognition of territorial boundary rights between communities. Behaviors pertaining to social integration and territoriality may be linked to the development of complex (i.e., inequality) societies. Other buried habitation sites indicate Late Archaic settlements can be found in a variety of contexts. For instance, a probable house floor is exposed in the alluvium in a 2nd-order valley at the Benson site (Thompson and Benn, 1983), and Late Archaic components were present in alluvial terraces and in a fan at the M.A.D. sites in the Boyer River valley (Benn et al., 1981). Finally, several types of Late Archaic points occur frequently in the surface collections from lakeshore sites on the Des Moines Lobe, indicating the existence of a large, permanent population in this region (Lensink, 1984).

Sites of the Prairie/Plains Late Archaic period are grossly underrepresented in western Iowa compared to surrounding regions. Research farther east of the Prairie Peninsula has demonstrated that human populations increased significantly by the Late Archaic period. This was the time when a pattern of efficient and selective hunting and gathering became established and formed the basis for subsequent culture changes in the Woodland and post-Woodland periods. The State of Iowa is in the pivotal position where it will be determined how far west and at what rate this type of culture change occurred on the prairies.

The general perception of the Late Archaic period in other Iowa river basins is that sites are numerous and that settlements are aligned with river valleys. There is no reason to reject these patterns for the Prairie/Plains Late Archaic of western Iowa. Finding Late Archaic sites will require systematic searches for diagnostic artifacts in existing collections, surveys of bluffs along major river valleys and systematic probes for buried sites in alluvium of appropriate ages.

PLAINS AND NORTH CENTRAL WOODLAND (2,500-700 B.P.).

Woodland sites are the most numerous of the dated manifestations in the Western Iowa Basin. Detailed knowledge of cultural phases and their geographic distributions are not yet developed, but the cultural and ceramic sequences for the Prairie/Plains and the Prairie Lakes subareas already are complicated, and becoming more so with each new investigation (Johnson, 1973; Tiffany, 1978; Benn, ed., 1981; 1983; Tiffany, ed., 1982; Haas, 1983). A significant limitation to the reconstruction of Woodland settlement patterns is that seasonal habitation sites are deeply buried in alluvial fills in small valleys (e.g., Rainbow site; Benn, ed., 1981). Inability to effectively locate these sites with surface-oriented archaeological surveys prohibits the development of site density models.

The Mid-America Woodland tradition covers the Prairie/Plains subarea of western Iowa and eastern Nebraska. The cultural sequence in Western Iowa is: Crawford phase of the Valley/Orleans I variant (Early Woodland period ca. 2,500-2,050 B.P.); unnamed phase of the Valley/Orleans I variant (Middle Woodland period ca. 2,050-1,650 B.P.); Floyd phase of the Boyer variant (early Late Woodland period ca. 1,650-1,250 B.P.); Sterns Creek and unnamed phases of the Loseke Creek variant (late Late Woodland ca. 1,250-750 B.P.). An unnamed Woodland tradition in the Prairie Lakes subarea (i.e., North Central unit in the Des Moines Lobe) has no named phases, only a ceramic sequence: Fox Lake series (ca. +2,150-1,450 B.P.); Arthur Cord Roughened (ca. +1,550-1,350 B.P.); Lake Benton series (ca. 1,450-1,150 B.P.); and Loseke ware (ca. 1,250-750 B.P.). Four key traits of all these Woodland manifestations are:

1. Intensification and elaboration of ceremonial-ritual behavior, symbolic artifacts and cooperative construction efforts seemingly associated with birth (rebirth) and death.

2. Improved technologies, such as the bow and arrow, ceramics and horticulture, which facilitated more intensive exploitation and utilization of resources.

3. More cooperative production by complex human aggregates doing more labor-intensive subsistence activities which yielded an overall increase in production.

4. A population increase that approached the perceived limits of the Woodland settlement-subsistence system.

Woodland traditions on the western prairies show trajectories in cultural processes similar to contemporary societies in the Mississippi River basin in the Midwest. The Early Woodland period is distinguished by the manufacture of small numbers of pottery vessels. Ceramics were introduced to western prairie peoples apparently from the east, but the new technology did not immediately affect the basic Archaic hunting and gathering subsistence pattern. This subsistence pattern was a diffuse one; a pattern of procuring riverine, forest and prairie resources at seasonal campsites. Evidence for intensification (i.e., social inequality) of socio-economic systems begins to appear during the Middle Woodland period. Pottery vessels are made larger and more numerous, and complex ceramic decorative styles are shared within regions. Methods of human burial are elaborated with additions of interaction sphere paraphernalia (e.g., obsidian bifaces, platform pipes, marine shell, copper, etc.), utilitarian tools and animal carcasses within the tomb and overlying earthen mounds.

The level of intensification in western Middle Woodland cultures does not approach the complexity of the Hopewellian cult in midwestern cultures. But, the processes of intensification culminate in a mixed horticultural-foraging economy during the Late Woodland period on the western prairies. Evidence for these processes materializes as changes in technology and burial practices. The bow and arrow becomes widely used as an effective weapon for warfare and for the individual hunter. Ceramic vessels evolved into voluminous, thin-walled and efficient cooking containers. Large numbers of storage pits are now employed to store foodstuffs, among which are the cultivars, squash and maize. With the advent of the Loseke Creek variant the basic technologies and subsistence of later Plains Village cultures are in use. Some Woodland groups continued in the direction of centripetal development to become villagers: e.g., Mill Creek, Central Plains. Others appear to have lived in less circumscribed organizations: e.g., Loseke variant, Great Oasis.

GREAT OASIS
(1,150-850 B.P.).

This is a widespread manifestation in the Middle Missouri region, Western Iowa Basin and the Des Moines Lobe (Henning, 1971; Ludwickson, et al., 1981:133). Great Oasis ceramics are globular vessels with distinctive incised rim decorations and carefully shaped rim forms (Henning and Henning, 1978). Other traits--e.g., prolific bone tool technology, numerous end (hide) scrapers, triangular points, maize, etc.--and ceramics point to close relationships between Great Oasis and Mill Creek cultures of northwestern Iowa. Great Oasis settlement patterns differ from Mill Creek in that the latter include a few large villages and many small camps or house clusters (Williams, 1975). Great Oasis is considered to have been antecedent to villager cultures classified as the Initial variant of the Middle Missouri tradition (Henning, 1971:130; Henning and Henning, 1978:15; Tiffany, 1983:96-7; Benn in Tiffany, ed., 1982:181-2), although the classification of Great Oasis as part of the Woodland (Tiffany, 1983:96-7) or Initial Middle Missouri tradition (Henning and Henning, 1978:14) is being debated.

Great Oasis is central to an understanding of prehistory in the Western Iowa Basin because it was one of the cultures involved in the dramatic economic changes during the Late Woodland period. The ties between Great Oasis, Loseke Creek and Mill Creek manifestations at opposite ends of the cultural spectrum seem to reveal the processes of human interaction and economic transformation. Some of the presumed ties are the following. There are strong relationships in vessel and rim form, decorative motifs and mixing of attributes between Great Oasis and Loseke wares (Benn and Rogers, 1985:52). The geographic distributions and temporal range of Loseke and Great Oasis complexes correspond in many areas, and the locations and types of sites of both complexes appear to be the same in the Des Moines Lobe region. Additionally, Woodland and Great Oasis social organization is predicted to have been tightly-knit bands of exogamous, patrilineal clans (i.e., descent traced through the male line; Henning, 1982:284), in contrast to the matrilineal (female) descent and matrilocal (wife's) residence of Mill Creek peoples (Ibid.; Anderson, 1981:117). Great Oasis and Mill Creek peoples shared the technologies cited above and were co-residents at some villages in northwest Iowa (Henning, 1982:282). They also shared participation in a Mississippian interaction sphere from the southeasterly direction. Great Oasis became involved first with the trade in fresh and salt water shell, and Mill Creek people followed by obtaining these materials and ceramics, copper, ornaments and decorative motifs from the Cahokia site at East St. Louis, Illinois.

The Great Oasis and Loseke complexes are unusual in another way; their distributions span a major ecotone by occurring in the western Prairies/Plains and on the Des Moines Lobe. This is a characteristic shared with only one other culture, Oneota. It would be useful to know if the Great Oasis and Loseke socio-economic organizations were pliable enough to adapt to different circumstances and if mobility was one of their patterns; or whether the cultures were composed of different ethnic groups with the same technology. The Loseke variant is dispersed over too large an area to represent a single interacting culture. Henning (1980:9) has queried whether Great Oasis grew maize or traded for it (with Mill Creek) or did both--a question that parallels their known function as traders of exotic shells. These are a few of the issues that extend inquiries beyond the content of cultures to the processes of their formation and change.

MILL CREEK-OVER
(1,100-600 B.P.).

This distinctive cultural group inhabited the major creek and river valleys of northwestern Iowa. Mill Creek culture belongs to the Middle Missouri tradition (Orr, 1963; Ives, 1962; Vis and Henning, 1969; Anderson, 1969, 1972, 1981, 1985; Henning ed., 1968; Tiffany, 1982). Mill Creek villages consist of groupings of square or rectangular earth lodges and cover about 1-4 acres, often with a fortification. The sites are usually conspicuous accumulations of midden on river terraces or blufftops. The middens are extraordinarily prolific. They contain numerous superimposed hearths, pits and other constructional features, quantities of animal bones and plant remains, and a wide range of specialized ceramic, bone, shell and stone tools and ornaments. Mill Creek ceramics are made in olla, bowl and bottle forms, and rim treatment (i.e., decoration, form) is the distinguishing typological feature on the ollas. The villages were occupied year-round and probably were moved at intervals of a decade or two as local resources became over-exploited. Temporary procurement sites and seasonal camps also may be part of the Mill Creek pattern. The Mill Creek populace conducted a regular trade with peoples at Cahokia.

Mill Creek sites have been intensively researched to the point where some authors have ventured to supply explanations for the development of the culture before A.D. 1250 (the Neo-Atlantic episode) and the abandonment of the area by A.D. 1450 (the Pacific episode). The most famous of the explanations (Baerreis and Bryson, 1965; Henning ed., 1968; Dallman, 1983) states that Mill Creek horticulturalists enjoyed a successful productive system during the relatively wet Neo-Atlantic episode but were stressed to the point of moving away during the drier Pacific episode. The deterministic bent of this climatic hypothesis has been tempered in recent years by suggestions that social factors may have accompanied changes in climate; thus, changes in Mill Creek culture are viewed as a system responding to a variety of stimuli (Anderson, 1984). The factor of climate directly affecting change in Mill Creek has even been rejected by Henning (1982:281) in favor of the argument that competition for the bison herds (with the Oneota) eventually caused the Mill Creek people to move west.

Duane Anderson (1984) calls for research into the processes of Mill Creek culture formation and dissolution by undertaking new investigations into the subsistence base and settlement systems. Investigation of the settlement pattern is particularly important, since the site records of Mill Creek components are a mass of presumptions built up through three generations of researchers with no comprehensive, modern survey of Mill Creek sites. Anderson also encourages the application of systems theory to elucidate the problem of processual changes.

CENTRAL PLAINS
(1,050-650 B.P.).

Earth lodges of the Central Plains tradition are concentrated in the dissected loess hills around Glenwood, Iowa, where a trip stop will be made for lunch (The Mills County Historical Museum will be open during the stop). Earthlodges are found as far north as Sioux City and south of the Iowa border. The Iowa complex may be a separate classification within the Nebraska phase, which extends throughout eastern Nebraska (Anderson, 1961; Orr, 1963; Gradwohl, 1969; Zimmerman, 1971, 1976, 1977; Hotopp, 1978, 1979; Ludwickson, et al., 1981:154). The Glenwood manifestation, like other parts of the Nebraska phase, consists of earthlodges widely spaced on ridges, or in small groups on terraces and fans. Occasionally, lodges occur in large groups (villages?). Lodges vary in floor size, a possible reflection of different houses for summer and winter use or other functions (e.g., charnal houses, ceremonial lodges). Central Plains settlements are positioned to exploit the gallery forests in valleys, and subsistence remains demonstrate heavy exploitation of woodland animals and horticultural products. Glenwood ceramics are grouped in two wares reflecting their Plains origin (i.e., grit temper) and distant Mississippian influences (i.e., shell temper), and ceramic types are defined by rim form and decoration.

Attempts to find a temporal sequence in Glenwood ceramics and settlement patterns have not met with success (Hotopp, 1978:123). The evidence shows that immigrant Central Plains people occupied peacefully and then abandoned the western edge of Iowa after a dozen or more generations. Perhaps no more than 200 persons comprised this group (Zimmerman et al., 1978:13). The citations above give much attention to the internal dynamics of the Nebraska phase in Iowa, but little interest has been shown in the broader cultural context of the origins and inter-cultural contacts of Central Plains people.

Regarding Woodland antecedents, new radiocarbon dates and ceramic analysis of the Sterns Creek materials place this phase in the Glenwood locality immediately before and perhaps during the time of the Central Plains occupations (Haas, 1983). Furthermore, Sterns Creek ceramics share many common attributes of grit tempered paste and body form and treatment with Central Plains ceramics. The co-existence of Central Plains and Late Woodland groups in the Loess Hills seems to be a viable option, which might be investigated by excavating Woodland and Glenwood sites in small valleys like Sterns Creek. In terms of geographic distributions, there is an apparent void in the interior of southwest Iowa at the time of the Glenwood-Central Plains occupation. Is this void a figment of survey biases? (The writer once viewed lodge depressions on the hillslope above the M.A.D. sites at Denison, Iowa, well north of the Glenwood locality.)

CORECTIONVILLE-BLUE EARTH
AND ORR ONEOTA
(850-150 B.P.).

Oneota is a complex of distinctive technologies and ceramic types that spread over a vast area of the Midwest and eastern Plains. The State of Iowa is the geographic focus of the Oneota tradition (Henning, 1961, 1970; Harvey, 1979; Henning and Schermer, 1985). The Correctionville-Blue Earth phase is distributed in the Des Moines Lobe, along the Little Sioux River and in extreme southwest

Iowa. Orr phase sites occur in northwest Iowa and possibly in the extreme southwestern part of the state. Orr is identified with the Ioway Indian tribe, and tribes like the Oto, Omaha and Missouri also represent some portion of the Oneota population.

The most visible Oneota sites are large villages, sometimes covering hundreds of acres, located on the terraces and floodplains of broad river valleys. Large sites probably are accretionary, i.e., they represent reoccupations of the same locations. Houses, huge cache pits and dense middens of animal bones, floral remains, pottery and tools typically comprise Oneota village sites. The largest site, Blood Run on the Big Sioux River, had hundreds of earthen (burial) mounds, large earthworks and stone alignments as well (Ibid.). Many small Oneota sites also exist as inconspicuous components on sites of earlier ages (e.g., Arthur site in Tiffany, ed., 1982; M.A.D. sites in Benn et al., 1981). The Oneota economy featured a mixed pattern of hunting bison and elk, foraging for smaller animals and plants in valley bottom environments, and cultivating maize, beans, squash and sunflowers.

The Oneota intrusion into the Western Iowa Basin probably was initiated by an immigration of Chiwere-speaking people. However, the rapid Oneota expansion also must have involved passive and coercive absorption of disparate ethnic groups into the Oneota lifestyle and ideology. Attempts have been made to link westward expansion of the Oneota to the favorable environment of the Neo-Atlantic episode (Harvey, 1979), but this causation has been rejected (Overstreet, 1981). The Oneota system probably was attracted to northwest Iowa by at least two resources: the great bison herds and the catlinite quarries of southern Minnesota and the Big Sioux watershed. Trade in catlinite appears to have contributed to the development of the Blood Run site. The encroaching Oneota pressured local populations like the Mill Creek and Great Oasis people (Henning, 1982:281; Anderson, 1984), who did not trade with the Oneota, probably fortified against them and eventually left the region.

The Oneota phenomenon, more than any other, confronts archaeologists with the necessity to explain all culture change in terms other than purely material and environmental. Duane Anderson (1984) makes the same argument for Mill Creek culture. In the case of the Oneota, this hunting-horticultural tribe imposed on another, well established hunting-horticultural society: Mill Creek. Explaining this event as one tribe being "better adapted" than another to changing climate or any other material aspect is simplistic and theoretically faulty. Ethnographic work in tribal societies around the world demonstrates that how political, social and ideological structures function within the economy has a great deal to do with the trajectory of the culture (e.g., expansion, contraction, stability, upheaval, etc.). Furthermore, as this argument applies to late prehistoric societies like the Oneota, it must also be applied to earlier Archaic and Woodland manifestations.

CONCLUSIONS

By now it should be evident how geological processes have extensively influenced our perception of the prehistoric archaeological record in western Iowa. Lacking adequate samples of sites, for instance, the cultural records of the Pre-Clovis, Paleo-Indian and Archaic periods are virtually unknown. Likewise, the category of Woodland-age sites contains numerous examples with known contexts on terraces and within the Mullenix Bed, yet exceedingly few of these sites have yielded detailed cultural information owing to their deep burial and expense of intensive excavations. We may even be lulled into believing that settlement patterns of late prehistoric Great Oasis, Mill Creek/Over, Glenwood and Oneota cultures are thoroughly recorded, when in fact the sites of temporary, seasonal occupations lie undisclosed beneath sediments of the Turton Bed and Camp Creek Member. All of this amounts to speculation if archaeologists fail to recognize and implement the primary tenet of their methodology: that natural processes forming the landscape determine the conditions of the archaeological record.

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LATE QUATERNARY FOSSIL MAMMALS IN MILLS AND FREMONT COUNTIES, IOWA

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INTRODUCTION

History of Investigations

The Loess Hills of Mills and Fremont counties, Iowa, have yielded isolated fossils of the extinct Pleistocene mammalian megafauna to both amateur and professional collectors for over one hundred years (Todd, 1880, 1889; Calvin, 1909, 1911; Hay, 1914; Delavan, 1926). Indeed, for the Loess Hills region as a whole, the first scientific reports of the presence of Pleistocene fossils, an extinct bonnet-horned muskox, *Symbos cavifrons,* (Leidy, 1870) closely followed the settlement of this area by European farmers in the late 1840s to 1860s (Bonney, 1986). Many early reports assigned these isolated finds to the so-called "Aftonian" fauna, an association that is best regarded as dubious in the light of more recent research (see Rhodes and Semken, 1986). Even today, isolated specimens of these spectacular fossils commonly are found in creek beds, excavations, and with the gravel from pumped sand pits.

Systematic investigations were initiated in Mills and Fremont counties in the 1970s during archeological and paleontological, survey and salvage excavations of the Office of the Iowa State Archaeologist; this research was supported by various agencies of the National Park Service (Bardwell, 1981; Hotopp et al., 1975; Rhodes and Semken, 1976) and this effort has continued to present. Most of these studies, together with rich archeological faunas found elsewhere in Iowa's Loess Hills region, have been summarized in Rhodes and Semken (1986), which is reprinted in this guidebook, and the present paper will only address the localities from Mills and Fremont counties (including the newly completed analysis of the Chaboneau local fauna of Behrends, 1989). Semken and Falk (1987) have summarized the Late Pleistocene and Holocene mammalian remains from a larger region (the Dakotas, Nebraska, and all Iowa) and have included many of the same sites in their analysis.

Pre-Wisconsinan Record

Although presently not documented by adequately described fossil sites, it is likely that pre-Wisconsinan Pleistocene (or even late Tertiary) vertebrate assemblages will eventually be found in Mills and Fremont counties. Not only have isolated elements of Miocene/Pliocene mammalian taxa been found elsewhere in western Iowa and northern Missouri (Shimek, 1910; Calvin, 1911; Rhodes and Semken, 1986), but Witzke and Ludvigson (1988, this volume) also have identified fluvial sediments in Mills and Fremont counties with a western-derived volcaniclastic lithic assemblage that are probably correlative to Tertiary units of the Ogallala Group of Nebraska. Both facts suggest that fossils of this age will eventually be found in this area.

Fluvial sediments of undoubted pre-Wisconsinan Pleistocene age also occur in Mills and Fremont counties. These are found both beneath and interbedded with the pre-Illinoian glacial tills. Early workers such as Shimek (1909) regarded these sediments to be "Aftonian" in age and they are known to have a distinctive lithic assemblage (Witzke and Ludvigson, 1988, this volume). Unfortunately, exposures usually are poor and these deposits have been little studied in the recent past. An intensive search of these sediments might also turn up mammalian assemblages of this age, but none are presently known. Rhodes and Semken (1986) have evaluated the classical, more prolific, so-called "Aftonian" sites to the north in Harrison and Monona counties and concluded that many perplexing biostratigraphic problems remain unanswered. The interested reader is referred to Rhodes and Semken (1986) for that analysis since these questions are beyond the scope of this paper.

Analytical Procedures

This paper focuses on the analysis of the ten Wisconsinan and Holocene sites (twelve fossiliferous horizons) in Mills and Fremont counties from which relatively large samples of the climatically-sensitive micromammals have been recovered (Fig. 1, Table 1). Although two distinctly different types of sites have been used (noncultural fluvial accumulations and cultural fill from archeological sites) all sites have had significant volumes of fossiliferous matrix water-screened on 1/16" (about 1.6 mm) mesh wire screen (standard fly-wire window screen). The taphonomic pathways by which the fossil remains reach their final resting place are quite different between these two types of sites and the effects on the analysis of the "cultural filter" is poorly understood (Semken, 1983; Semken and Falk, 1987; Bardwell, 1981; Behrends, 1989).

Other analytical uncertainties also hinder the analysis. See Rhodes and Semken (1986:98-104; here reprinted, also see errata in Appendix 1) and Semken and Falk (1987:178-181) for a more detailed discussion of the below concerns. The absolute dates of these sites are based on radiocarbon analysis of various substances that have differing sensitivity to error. This becomes especially critical for the very young Holocene sites where the errors could be a significant fraction of the sites' ages. Radiocarbon dates in this paper have not been corrected for "secular variation" in radiocarbon. Unfortunately, besides the near total disruption that intensive agricultural use brings, little is known of the exact nature of the changes to the biota of the Loess Hills that were caused by the settlement of the area in the late 1800s by European farmers (Bowles, 1981; Mutel, 1989). This makes it difficult to reconstruct both the character of the undisturbed presettlement biota and that of vanished climatic regimes.

One analytical tool is to look at the overlapping patterns of the modern distributions of the taxa recovered as fossils ("analysis of sympatries"). Here the analysis is constrained by the accuracy with which the modern distributions are known. The areas of sympatry are not reproduced here for the sites discussed; see the figures in Rhodes and Semken (1986) for versions redrafted to a common set of range maps (Hall, 1981). Another tool is to calculate the relative frequencies of taxa or individuals present when grouped by their modern "center of distribution" (see Table 2). These percentages (Fig. 3) have been recalculated for both the per taxon and per MNI (minimum number of individuals; see Table 3) basis to the centers of distribution used in Jones and Birney (1988). Since Rhodes and Semken (1986) use Hoffmann and Jones (1970) as the source for their center of distribution data, and since Jones and Birney (1988) have both subdivided the "deciduous forest" category of Hoffmann and Jones into "New England" and "eastern widespread" and also reassigned southern bog lemming (*Synaptomys cooperi*) from the "boreomontane" to "New England" category, there are somewhat different interpretations presented below for this data, especially for the Holocene faunas to which southern bog lemming contributes significant proportions. Furthermore, unlike Rhodes and Semken (1986), indeterminate and commensal/domestic taxa have been included in the basic sum. Although both the entire fauna and a subset (Insectivora, Lagomorpha, and Rodentia - "ILR" taxa) are presented in Figure 3, this discussion generally is restricted to the more climatically sensitive ILR taxa (see Rhodes and Semken, 1986). The modern habits and habitats of the recovered taxa also are useful in analysis of the

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Figure 1. Locality map of parts of Mills and Fremont counties, Iowa. All perennial streams (west of Silver Creek and the West Nishnabotna River and east of Missouri Valley bluffs) and Missouri Valley bluff line (hachures) from the USGS 1:100,000 county topographic maps. Numbered sites correspond to fieldtrip stops. Lettered localities are discussed in the text and are:

A - Thurman lf
B - "Giangreco lf"
C - Chaboneau lf and "Wilson lb"
D - Waubonsie and Craigmile lfs
E - Pleasant Ridge lf
F - Garrett Farm lf

Glenwood earthlodge faunules:
  G - 13ML155
  H - 13ML130
  I - 13ML126
  J - 13ML124

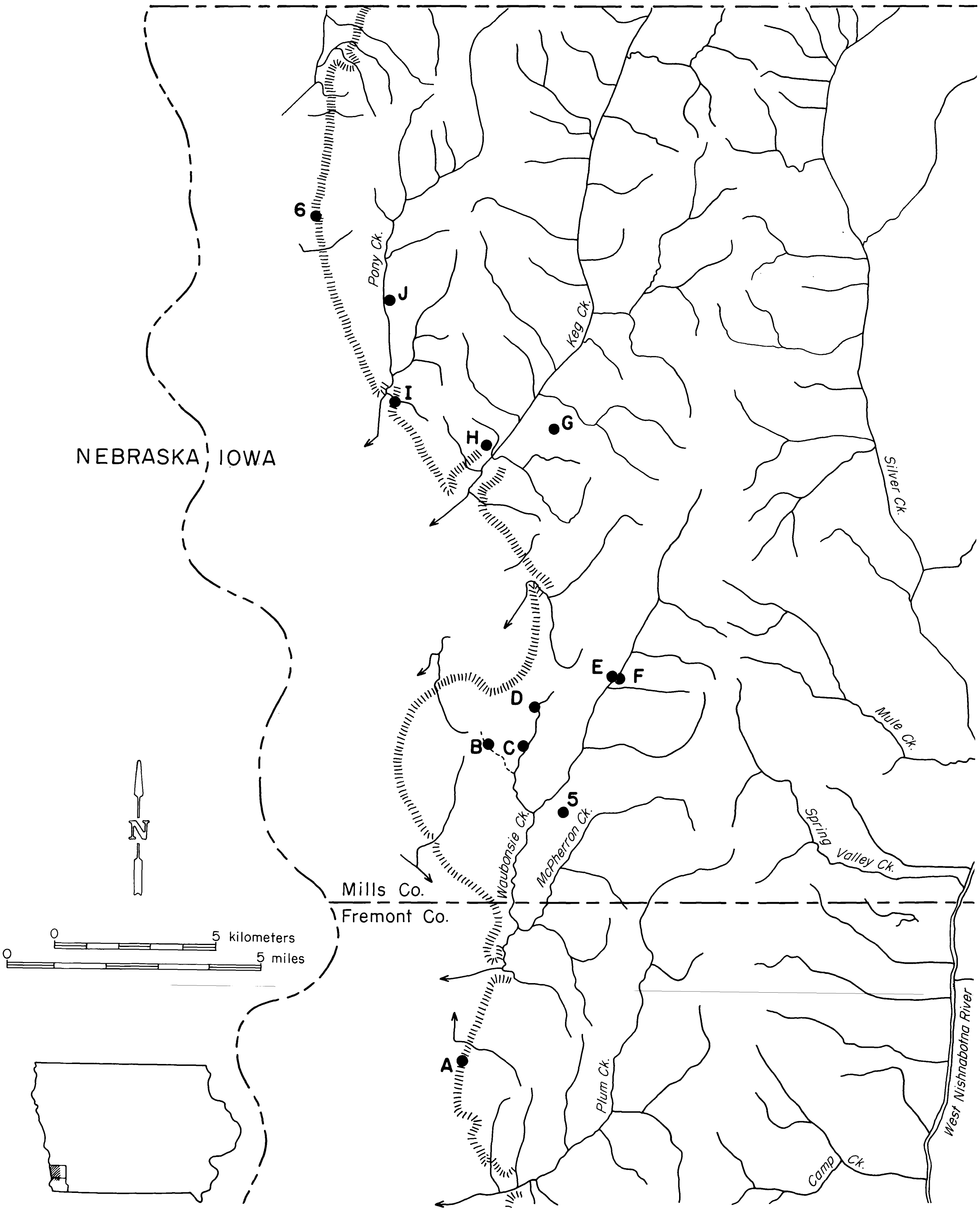

6
Pony Ck.
J
Keg Ck.
I
G
H
NEBRASKA
IOWA
Silver Ck.
E
F
D
Mule Ck.
B
C
5
Spring
Valley Ck.
Waubonsie Ck.
McPherron Ck.
N
Mills Co.
Fremont Co.
0
5 kilometers
0
5 miles
A
Plum Ck.
West Nishnabotna River
Camp Ck.

Table 1. Selected paleontological and archeological sites from Mills and Fremont counties, Iowa.

Site and local fauna name	Location	Age in uncorrected radiocarbon years before present (1950)	Material dated
Chaboneau local fauna Fig. 1, C	SE, SW, 13, 71N, 43W Mills Co.	705 ± 85 BP (I-7381)	Wood charcoal
Glenwood earthlodge faunas:			
13ML155 Fig. 1, G	SE, NE, 13, 72N, 43W Mills Co.	About 698 BP [690 ± 50 BP (Wis. 877); 705 ± 50 BP (Wis. 878)]	Wood charcoal
13ML124 Fig. 1, J	SW, SE, 33, 73N, 43W Mills Co.	735 ± 95 BP (GX 2005)	Wood charcoal
13ML130 Fig. 1, H	SW, SE, 14, 72N, 43W Mills Co.	About 807 BP [712 ± 90 BP (I 6295); 765 ± 110 BP (I 6297); 945 ± 100 BP (I 6296)]	Wood charcoal
13ML126 Fig. 1, I	SW, SE, 9, 72N, 43W Mills Co.	About 852 BP [730 ± 55 BP (Wis. 632); 840 ± 60 BP (Wis. 712); 985 ± 45 BP (Wis. 633)]	Wood charcoal
Thurman local fauna Fig. 1, A	NW, NW, 23, 70N, 43W Fremont Co.	970 ± 150 BP (I-6392)	Charcoal fragments
Pleasant Ridge local fauna Fig. 1, E	NW, SW, 8, 71N, 42W Mills Co.	1,450 ± 90 BP (DIC-1620)	Charcoal fragments
Garrett Farm local fauna Fig. 1, F	NW, SW, 8, 71N, 42W Mills Co.	About 3,600 BP [3,400 + 280, - 290 BP (DIC-877); 3,590 ± 75 BP (DIC-2520); 3,600 ± 305 BP (DIC-2521)]	Charcoal fragments
"Giangreco local fauna" Fig. 1, B	SW, SE, 14, 71N, 43W Mills Co.	Estimated to be about 11,000 BP	As yet undated
Waubonsie local fauna Fig. 1, D	NW, NE, 13, 71N, 43W Mills Co.	About 14,800 BP [14,430 ± 1030 (I-7496); 14,830 + 1060, - 1220 (DIC-1688, pre-treated to remove humic acids)]	Charcoal fragments
"Wilson local biota" Fig. 1, C	SE, SW, 13, 71N, 43W Mills Co.	About 18,000 BP [17,950 ± 310 (I-7383); 18,100 ± 310 (I-7382)]	Individual wood fragments
Craigmile local fauna Fig. 1, D	NW, NE, 13, 71N, 43W Mills Co.	23,240 ± 535 BP (DIC-1369)	Unfractionated bone collagen

Table 1. Continued.

Sediments washed; geomorphic and depositional setting	Other comments	References
Channel-lag gravel and interbedded silts; within alluvial fill with well-developed associated stream terrace above.	At site "o" of Hotopp et al., 1975.	Behrends, 1989; Hotopp, et al., 1975; Rhodes & Semken, 1976.
Cache pit & feature matrix; at surface on hilltop.	---	Bardwell, 1981; Hotopp, 1978; William Green, pers. comm., 1990.
"Cultural fill" only; at surface on stream terrace.	One charcoal date rejected (1,520 ± 100 BP, GX 2006)	Bardwell, 1981; Fulmer, 1974; Hotopp, 1978.
Cache pit & feature matrix; at surface on stream terrace.	---	Bardwell, 1981; Johnson, 1972; Hotopp, 1978.
All site matrix; at surface on hilltop.	---	Bardwell, 1981; Johnson, 1972; Hotopp, 1978.
Silts associated with a sand-filled channel on pre-Illinoian till; small channel at Missouri River bluff edge.	Covered by slumped Peoria loess and originally misidentified as a Wisconsinan-age deposit.	Jenkins, 1972; Rhodes & Semken, 1986.
Two vertically discrete channel-lag gravels; within alluvial fill with well-developed associated (?) stream terrace above.	Interbedded silts not tested. At site "bs" of Hotopp et al., 1975.	Fay, 1978, 1980; Rhodes & Semken, 1986.
Channel-lag gravel and closely overlying silts; within alluvial fill with narrow stream terrace remnant above.	At site "br" of Hotopp et al., 1975.	Fay, 1978, 1980; Rhodes & Semken, 1986.
Channel-lag gravel and closely overlying silts; deeply buried.	At site "au" of Hotopp et al., 1975. Under study.	Rhodes & Semken, 1976.
Channel-lag gravel; deeply buried beneath seemingly unrelated stream terrace.	At site "k" of Hotopp et al., 1975.	Rhodes, 1984.
Bedded sandy silt alluvium; deeply buried beneath much younger stream terrace.	At site "o" of Hotopp et al., 1975. Under study. Correlative unit also present in site "k" (Fig. 1, D) between the Craigmile and Waubonsie local faunas.	Hotopp et al., 1975; Rhodes & Semken, 1976; Rhodes, 1984:8-9.
Originally channel-lag gravel, but all calcareous clasts leached away; deeply buried beneath seemingly unrelated terrace.	At site "k" of Hotopp et al., 1975.	Rhodes, 1984.

Table 2. Mammals found as fossils in ten selected localities or living today in Mills and Fremont counties, Iowa.

Scientific name	Common name	Center of distribution (Jones & Birney, 1988)	Comments
MARSUPIALIA			
Didelphis virginiana Kerr	Virginia opossum	Neotropical	Fossils not reported, but many small archeological faunas not evaluated.
INSECTIVORA			
Sorex			
Sorex sp(p). small (cinereus or hoyi)	---	Boreomontane	---
Sorex sp(p). large (arcticus or palustris)	---	Boreomontane	---
S. arcticus Kerr	Arctic shrew	Boreomontane	Extirpated.
S. cinereus Kerr (including S. haydeni Baird)	Masked shrew	Boreomontane	
S. (Microsorex) hoyi Baird	Pygmy shrew	Boreomontane	Extirpated.
S. palustris Richardson	Water shrew	Boreomontane	Extirpated.
Blarina			
B. brevicauda (Say) ssp. undet.	Northern short-tailed shrew	New England	
B. b. brevicauda (Say)	---	---	
B. b. talpoides (Gapper) (= "B. b. kirtlandi")	---	---	Subspecies may be extirpated.
B. hylophaga Elliot (= "B. carolinensis")	Elliot's short-tailed shrew	Plains/Grassland	
Cryptotis parva (Say)	Least shrew	Eastern widespread	
Scalopus aquaticus (Linnaeus)	Eastern mole	Eastern widespread	
CHIROPTERA			
Chiroptera undetermined	---	Indeterminate	---
Myotis			
M. lucifugus (Le Conte)	Little brown myotis	Widespread	Fossils not reported.
M. septentrionalis (Trouessart)	Northern myotis	New England	Fossils not reported.
M. sodalis Miller & GM Allen	Social myotis	Eastern widespread	Fossils not reported.
Lasionycteris noctivagans (Le Conte)	Silver-haired bat	Widespread	Fossils not reported.
Pipistrellus subflavus (F. Cuvier)	Eastern pipistrelle	Eastern Widespread	Fossils not reported.

Table 2. Continued.

Scientific name	Common name	Center of distribution	Comments
CHIROPTERA continued			
Eptesicus fuscus (Palisot de Beauvois)	Big brown bat	Widespread	
Lasiurus			
L. borealis (Müller)	Red bat	Widespread	Fossils not reported.
L. cinereus (Palisot de Beauvois)	Hoary bat	Widespread	Fossils not reported.
Nycticeius humeralis (Rafinesque)	Evening bat	Eastern widespread	Fossils not reported.
EDENTATA			
Dasypus bellus (Simpson)	Beautiful armadillo	Indeterminate	EXTINCT.
LAGOMORPHA			
Leporidae undetermined	---	Indeterminate	---
Sylvilagus sp(p). undetermined	---	Indeterminate	---
S. floridanus (JA Allen)	Eastern cottontail	Eastern widespread	
Lepus townsendii Bachman	White-tailed jackrabbit	Plains/Grassland	Fossils not reported.
RODENTIA			
Tamias			
T. (Eutamias) minimus Bachman	Least chipmunk	Boreomontane	Extirpated.
T. striatus (Linnaeus)	Eastern chipmunk	Eastern widespread	
Marmota monax Linnaeus	Woodchuck	Eastern widespread	
Spermophilus			
S. franklinii (Sabine)	Franklin's ground squirrel	Plains/Grassland	
S. richardsonii (Sabine)	Richardson's ground squirrel	Plains/Grassland	Extirpated.
S. tridecemlineatus (Mitchell)	Thirteen-lined ground squirrel	Plains/Grassland	
Cynomys ludovicianus (Ord)	Black-tailed prairie dog	Plains/Grassland	Not assigned to a center of distribution by Jones & Birney (1988); Hoffman & Jones (1970) assign to "steppe" which is here considered equivalent to Jones & Birney's plains/grassland category.
Sciurus sp(p). undetermined	---	Eastern widespread	---
S. carolinensis Gmelin	Grey squirrel	Eastern widespread	Fossils not reported.
S. niger Linnaeus	Fox squirrel	Eastern widespread	

Table 2. Continued.

Scientific name	Common name	Center of distribution	Comments
RODENTIA continued			
Tamiasciurus hudsonicus (Erxleben)	Red squirrel	Boreomontane	Extirpated.
Glaucomys volans (Linnaeus)	Southern flying squirrel	Eastern widespread	Fossils not reported.
Thomomys talpoides (Richardson)	Northern pocket gopher	Boreomontane	Extirpated.
Geomys bursarius (Shaw)	Plains pocket gopher	Plains/Grassland	
Perognathus			
P. flavescens Merriam	Plains pocket mouse	Plains/Grassland	
Castor canadensis Kuhl	Beaver	Widespread	
Oryzomys palustris (Harlan)	Marsh rice rat	Commensal/Domestic	Extirpated. Assigned to Neotropical center of distribution by Jones & Birney (1988); here considered commensal/domestic because of its exclusive association with Glenwood focus archeological sites in Mills and Fremont counties.
Reithrodontomys sp(p). undet.	---	Plains/Grassland	See R. megalotis below.
R. megalotis (Baird)	Western harvest mouse	Plains/Grassland	Assigned to southwestern center of distribution by Jones & Birney (1988); here, plains/grassland, the alternative that they believe less preferable (p. 61), is used.
Peromyscus sp(p). undetermined	---	Indeterminate	---
P. leucopus (Rafinesque)	White-footed mouse	Eastern widespread	
P. maniculatus (Wagner)	Deer mouse	Widespread	
Onychomys sp(p). undetermined	---	Indeterminate	---
O. leucogaster (Weid-Neuweid)	Northern grasshopper mouse	Plains/Grassland	Extirpated.
[Sigmodon hispidus Say & Ord	Hispid cotton rat	---	Although Bowles (1975) and Hall (1981) show this taxon as Occurring in southwestern Iowa and northern Missouri, it's occurrence is rejected following Lampe & Bowles (1985) and Schwartz & Schwartz (1981).]
Neotoma sp(p). undetermined	---	Indeterminate	---
N. floridana (Ord)	Eastern woodrat	Eastern widespread	Extirpated.
Clethrionomys gapperi (Vigors)	Southern red-backed vole	Boreomontane	Extirpated.
Phenacomys intermedius Merriam	Heather vole	Boreomontane	Extirpated.

Table 2. Continued.

Scientific name	Common name	Center of distribution	Comments
RODENTIA continued			
Microtus sp(p). undetermined	---	Indeterminate	---
M. (Pedomys) ochrogaster (Wagner)	Prairie vole	Plains/Grassland	
M. pennsylvanicus (Ord)	Meadow vole	Boreomontane	
M. (Pitymys) pinetorum (Le Conte)	Woodland vole	Eastern widespread	
M. xanthognathus (Leach)	Yellow-cheeked vole	Boreomontane	Extirpated. Not assigned to a center of distribution by Jones & Birney (1988); here considered boreomontane.
Ondatra zibethicus (Linnaeus)	Muskrat	Widespread	
Synaptomys			
S. borealis (Richardson)	Northern bog lemming	Boreomontane	Extirpated.
S. cooperi Baird	Southern bog lemming	New England	
Mus musculus Linnaeus	House mouse	Commensal/Domestic	Fossils not reported. Introduced by European settlers.
Rattus norvegicus (Berkenhout)	Norway rat	Commensal/Domestic	Fossils not reported. Introduced by European settlers.
Zapus sp(p). undetermined	---	Indeterminate	---
Z. hudsonius (Zimmermann)	Meadow jumping mouse	Boreomontane	
Erethizon dorsatum (Linnaeus)	Porcupine	Widespread	Fossils not reported, but many small archeological faunas not evaluated. Although Mills and Fremont counties lack historic records of its presence, it is likely that this taxon was present in presettlement southwestern Iowa and was extirpated by European settlers.
CARNIVORA			
Carnivora undetermined	---	Indeterminate	---
Canis sp(p). undetermined	---	Indeterminate	---
C. familiaris Linnaeus	Domestic dog	Commensal/Domestic	Present in presettlement Indian cultures.
C. latrans Say	Coyote	Widespread	Fossils not reported, but many small archeological faunas not evaluated.
C. lupus Linnaeus	Grey wolf	Widespread	Fossils not reported, but many small archeological faunas not evaluated. Extirpated by European settlers.
Vulpes			
[V. velox (Say)	Swift fox	---	Although Hall (1981) shows this taxon as occurring in presettlement southwestern Iowa, it is here rejected following Bowles (1975) and Lampe & Bowles (1985).]
V. vulpes (Linnaeus)	Red fox	Widespread	Fossils not reported, but many small archeological faunas not evaluated.

Table 2. Continued.

Scientific name	Common name	Center of distribution	Comments
CARNIVORA continued			
Urocyon cinereoargenteus (Schreber)	Grey fox	Widespread	Fossils not reported, but many small archeological faunas not evaluated.
Ursus americanus Pallas	Black bear	Widespread	Fossils not reported, but many small archeological faunas not evaluated. Extirpated by European settlers.
Procyon lotor (Linnaeus)	Raccoon	Widespread	
Mustelidae undetermined	---	Indeterminate	---
Mustela sp(p). undetermined	---	Indeterminate	---
M. frenata Lichtenstein	Long-tailed weasel	Widespread	Fossils not reported.
M. nivalis Linnaeus	Least weasel	Boreomontane	Fossils not reported.
M. vison Schreber	Mink	Widespread	
Taxidea taxus (Schreber)	Badger	Widespread	Fossils not reported, but many small archeological faunas not evaluated.
Spilogale putorius (Linnaeus)	Eastern spotted skunk	Plains/Grassland	Fossils not reported, but many small archeological faunas not evaluated.
Mephitis sp(p). undetermined	---	Indeterminate	---
M. mephitis (Schreber)	Striped skunk	Widespread	Fossils not reported, but many small archeological faunas not evaluated.
Lutra canadensis (Schreber)	River otter	Widespread	Fossils not reported.
Felis			
F. catus Linnaeus	Domestic cat	Commensal/Domestic	Fossils not reported. Introduced by European settlers.
F. concolor Linnaeus	Mountain lion	Widespread	Fossils not reported, but many small archeological faunas not evaluated. Extirpated by European settlers.
F. rufus (Schreber)	Bobcat	Widespread	
PROBOSCIDEA			
Mammut sp(p). undetermined	Mastodon	Indeterminate	EXTINCT.
[Mammuthus sp(p). undetermined	Mammoth	---	EXTINCT. Found in late Holocene Thurman lf, rejected here as intrusive by redeposition from older sediments.]
PERISSODACTYLA			
Equus sp(p). undetermined	---	Indeterminate	Native North American species EXTINCT.
E. caballus Linnaeus	Domestic horse	Commensal/Domestic	Fossils not reported. Introduced by European settlers.
E. asinus Linnaeus	Domestic donkey	Commensal/Domestic	Fossils not reported. Introduced by European settlers.

Table 2. Continued.

Scientific name	Common name	Center of distribution	Comments
ARTIODACTYLA			
Artiodactyla undetermined	---	Indeterminate	---
Sus domesticus Erxleben	Domestic pig	Commensal/Domestic	Fossils not reported. Introduced by European settlers.
Cervus elaphus Linnaeus	Wapiti	Widespread	Extirpated by European settlers.
Odocoileus sp(p). undetermined	---	Widespread	The two species of Odocoileus are difficult to diagnose from the most commonly found fossils and most identifications from western Iowa to species are suspect.
O. hemionus (Rafinesque)	Mule deer	Widespread	
O. virginianus (Zimmermann)	White-tailed deer	Widespread	
Sangamona fugitiva Hay	Stilt-legged deer	Indeterminate	EXTINCT. Churcher (1984) believes that this cervid taxon is invalid.
Bison sp(p). undetermined	---	Indeterminate	
B. bison (Linnaeus)	Bison	Widespread	Extirpated by European settlers.
Bos taurus Linnaeus	European cattle	Commensal/Domestic	Fossils not reported. Introduced by European settlers.
Capra hircus Linnaeus	Domestic goat	Commensal/Domestic	Fossils not reported. Introduced by European settlers.
Ovis aries Linnaeus	Domestic sheep	Commensal/Domestic	Fossils not reported. Introduced by European settlers.

Notes:

Other extinct taxa of the North American Late Pleistocene megafauna (see Kurtén & Anderson, 1980) have been found as isolated individuals or in pumped sand and gravel pits on the Missouri River floodplain in Mills and Fremont counties and in faunas elsewhere in western Iowa. They can be expected to be found here and include: Megalonyx jeffersonii (Desmarest), Jefferson's ground sloth; Glossotherium harlani (Owen), Harlan's ground sloth; Castoroides ohioensis Foster, giant beaver; Mammuthus spp., mammoths; Platygonus sp., extinct peccary; Camelops spp., New World camels; Cervalces scotti (Lydekker), stag-moose; Euceratherium collinium Furlong & Sinclair, shrub-ox; Symbos cavifrons (Leidy), bonnet-horned muskox; and possibly others (Anderson & Williams, 1974; Calvin, 1909, 1911; Delavan, 1926; Dulian, 1975; Hay, 1914; Kurtén & Anderson, 1980; Todd, 1880).

Fossils also have been found nearby of the elsewhere extant, but here climatically extirpated taxa Perognathus hispidus Baird, hispid pocket mouse; Vulpes velox (Say), swift fox; Martes americana (Turton), pine martin; Rangifer tarandus (Linnaeus), caribou; Antilocapra americana (Ord), pronghorn; and Ovibos moschatus (Zimmermann), muskox (unpublished specimens in Paleontological Repository, Department of Geology, the University of Iowa; Dallman, 1983; Dulian, 1975; Falk, 1981; Semken, 1980, 1982).

Table 3. Extant mammals and minimum number of individuals of fossil mammals in ten selected localities in Mills and Fremont counties, Iowa.

Taxon	Cntr Dstb	Craig	Waubo	GarFm	PlRdg	Thurm	ML126	ML130	GlEly	ML124	ML155	GlLte	Chabo	Today
MARSUPIALIA														
Didelphis virginiana	N	-	-	-	-	-	-	-	-	-	-	-	-	X
INSECTIVORA														
Sorex														
Sorex spp. small	B	-	[1]	-	-	-	-	-	-	-	-	-	-	na
Sorex spp. large	B	[6]	-	-	-	-	-	-	-	-	-	-	-	na
S. arcticus	B	3	2	-	-	-	-	-	-	-	-	-	-	-
S. cinereus	B	8	4	-	1	-	-	-	-	-	-	-	2	X
S. (Microsorex) hoyi	B	1	-	-	-	-	-	-	-	-	-	-	-	-
S. palustris	B	1	-	-	-	-	-	-	-	-	-	-	-	-
Blarina														
B. brevicauda sum of the 2 subspecies	NE	3	7	2	5	3	-	2	2	2	-	2	5	X
B. b. brevicauda	?	(3)	-	-	(5)	(1)	-	(1)	(1)	(2)	-	(2)	(3)	(X)
B. b. talpoides	?	-	(7)	(2)	-	(2)	-	(1?)	(1)	-	-	-	(2)	(?)
B. hylophaga	P/G	-	-	1	-	-	-	-	-	-	-	-	-	X
Cryptotis parva	EW	-	-	1	3	-	-	-	-	-	1	1	3	X
Scalopus aquaticus	EW	1	3	1	2	1	1	1	2	-	1	1	5	X
CHIROPTERA														
Chiroptera undet.	I	-	-	-	1	-	-	{-}	{-}	-	{1}	{1}	1	na
Myotis														
M. lucifugus	W	-	-	-	-	-	-	{-}	{-}	-	{-}	{-}	-	X
M. septentrionalis	NE	-	-	-	-	-	-	{-}	{-}	-	{-}	{-}	-	X
M. sodalis	EW	-	-	-	-	-	-	{-}	{-}	-	{-}	{-}	-	X
Lasionycteris														
L. noctivagans	W	-	-	-	-	-	-	{-}	{-}	-	{-}	{-}	-	X
Pipistrellus														
P. subflavus	EW	-	-	-	-	-	-	{-}	{-}	-	{-}	{-}	-	X
Eptesicus fuscus	W	-	-	1	-	-	-	{-}	{-}	-	{-}	{-}	-	X
Lasiurus														
L. borealis	W	-	-	-	-	-	-	{-}	{-}	-	{-}	{-}	-	X
L. cinereus	W	-	-	-	-	-	-	{-}	{-}	-	{-}	{-}	-	X

Table 3. Continued.

Taxon	Cntr Dstb	Craig	Waubo	GarFm	PlRdg	Thurm	ML126	ML130	GlEly	ML124	ML155	GlLte	Chabo	Today
CHIROPTERA continued														
Nycticeius humeralis	EW	-	-	-	-	-	-	{-}	{-}	-	{-}	{-}	-	X
EDENTATA														
Dasypus bellus	I	1	-	-	-	-	-	-	-	-	-	-	-	-
LAGOMORPHA														
Leporidae undet.	I	2	1	2	2	-	-	-	-	-	-	-	2	na
Sylvilagus spp.	I	-	-	-	-	1	-	-	-	-	-	-	-	na
S. floridanus	EW	-	-	-	-	-	3	5	8	2	6	8	-	X
Lepus townsendii	P/G	-	-	-	-	-	-	-	-	-	-	-	-	X
RODENTIA														
Tamias														
T. (*Eu.*) *minimus*	B	1	-	-	-	-	-	-	-	-	-	-	-	-
T. striatus	EW	2	3	-	-	1	-	-	-	1	1	2	1	X
Marmota monax	EW	-	-	-	-	-	-	-	-	-	-	-	-	X
Spermophilus														
S. franklinii	P/G	5	1	-	2	-	1	3	4	1	2	3	-	X
S. richardsonii	P/G	-	-	-	-	-	-	-	-	-	-	-	1	-
S. tridecemlineatus	P/G	8	1	1	3	-	1	-	1	1	1	2	1	X
Cynomys ludovicianus	P/G	1	-	-	-	-	-	-	-	-	-	-	1	-
Sciurus spp.	EW	-	-	-	-	1	-	-	-	-	-	-	3	na
S. carolinensis	EW	-	-	-	-	-	-	-	-	-	-	-	-	X
S. niger	EW	-	-	-	-	-	-	-	-	2	2	4	-	X
Tamiasciurus														
T. hudsonicus	B	-	2	-	-	-	-	-	-	-	-	-	2	-
Glaucomys volans	EW	-	-	-	-	-	-	-	-	-	-	-	-	X
Thomomys talpoides	B	7	5	-	-	-	-	-	-	-	-	-	-	-
Geomys bursarius	P/G	7	1	8	4	4	2	4	6	5	2	7	10	X
Perognathus														
P. flavescens	P/G	-	-	2	2	-	1	-	1	1	1	2	2	X

Table 3. Continued.

Taxon	Cntr Dstb	Craig	Waubo	GarFm	PlRdg	Thurm	ML126	ML130	GlEly	ML124	ML155	GlLte	Chabo	Today
RODENTIA continued														
Castor canadensis	W	-	-	-	-	-	-	1	1	1	1	2	-	X
Oryzomys palustris	C/D	-	-	-	-	-	21	21	42	5	27	32	-	-
Reithrodontomys spp.	P/G	-	-	-	-	-	-	-	-	-	-	-	1	na
R. megalotis	P/G	-	-	-	-	-	-	-	-	-	-	-	-	X
Peromyscus spp.	I	1	8	-	-	7	[2]	-	[2]	[4]	[2]	[6]	-	na
P. leucopus	EW	-	-	5	10	-	2	1	3	3	5	8	23	X
P. maniculatus	W	-	-	1	2	-	6	5	11	1	4	5	-	X
Onychomys spp.	I	-	1	-	-	-	-	-	-	-	-	-	-	na
O. leucogaster	P/G	-	-	2	2	-	2	-	2	-	1	1	1	-
Neotoma spp.	I	-	1	1	-	1	-	-	-	-	-	-	-	na
N. floridana	EW	-	-	-	1	-	-	-	-	-	-	-	-	-
Clethrionomys														
C. gapperi	B	9	8	1	-	-	-	-	-	1	-	1	6	-
Phenacomys														
P. intermedius	B	1	5	-	-	-	-	-	-	-	-	-	3	-
Microtus spp.	I	-	-	-	-	-	-	-	-	-	[5]	[5]	-	na
M. (Pe.) ochrogaster	P/G	9	2	16	12	6	2	-	2	2	3	5	23	X
M. pennsylvanicus	B	84	31	3	5	3	-	-	-	-	1	1	26	X
M. (Pi.) pinetorum	EW	1	10	-	1	-	-	-	-	1	-	1	9	X
M. xanthognathus	B	-	8	-	-	-	-	-	-	-	-	-	-	-
Ondatra zibethicus	W	1	-	-	1	-	2	1	3	1	1	2	-	X
Synaptomys														
S. borealis	B	1	-	-	-	-	-	-	-	-	-	-	-	-
S. cooperi	NE	1	7	10	3	2	1	2	3	1	-	1	8	X
Mus musculus	C/D	-	-	-	-	-	-	-	-	-	-	-	-	Xei
Rattus norvegicus	C/D	-	-	-	-	-	-	-	-	-	-	-	-	Xei
Zapus spp.	I	2	-	-	-	-	-	-	-	-	-	-	-	na
Z. hudsonius	B	-	5	1	1	-	-	-	-	-	-	-	-	X
Erethizon dorsatum	W	-	-	-	-	-	-	-	-	-	-	-	-	Xex

Table 3. Continued.

Taxon	Cntr Dstb	Craig	Waubo	GarFm	PlRdg	Thurm	ML126	ML130	GlEly	ML124	ML155	GlLte	Chabo	Today
CARNIVORA														
Carnivora undet.	I	-	-	-	-	-	-	nr	nr	-	nr	nr	1	na
Canis spp.	I	-	-	-	-	-	1	nr	nr	1	nr	nr	-	na
C. familiaris	C/D	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
C. latrans	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
C. lupus	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xex
Vulpes														
V. vulpes	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
Urocyon														
U. cinereoargenteus	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
Ursus americanus	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xex
Procyon lotor	W	-	-	-	1	-	-	nr	nr	-	nr	nr	-	X
Mustelidae undet.	I	-	-	1	-	-	-	nr	nr	-	nr	nr	-	na
Mustela spp.	I	1	-	-	-	-	-	nr	nr	-	nr	nr	-	na
M. frenata	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
M. nivalis	B	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
M. vison	W	-	-	-	1	-	-	nr	nr	-	nr	nr	-	X
Taxidea taxus	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
Spilogale putorius	P/G	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
Mephitis spp.	I	1	-	-	-	-	-	nr	nr	-	nr	nr	-	na
M. mephitis	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
Lutra canadensis	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
Felis														
F. catus	C/D	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xei
F. concolor	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xex
F. rufus	W	-	-	-	-	-	1	nr	nr	-	nr	nr	-	X
PROBOSCIDEA														
Mammut spp.	I	1	-	-	-	-	-	nr	nr	-	nr	nr	-	-

Table 3. Continued.

Taxon	Cntr Dstb	Craig	Waubo	GarFm	PlRdg	Thurm	ML126	ML130	GlEly	ML124	ML155	GlLte	Chabo	Today
PERISSODACTYLA														
Equus spp.	I	1	-	-	-	-	-	nr	nr	-	nr	nr	-	na
E. caballus	C/D	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xei
E. asinus	C/D	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xei
ARTIODACTYLA														
Artiodactyla undet.	I	-	1	-	1	-	-	nr	nr	-	nr	nr	-	na
Sus domesticus	C/D	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xei
Cervus elaphus	W	-	-	1	-	-	1	nr	nr	-	nr	nr	-	Xex
Odocoileus spp.	W	-	-	-	-	1	2	nr	nr	2	nr	nr	-	na
O. hemionus	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
O. virginianus	W	-	-	-	-	-	-	nr	nr	-	nr	nr	-	X
Sangamona fugitiva	I	1	-	-	-	-	-	nr	nr	-	nr	nr	-	-
Bison spp.	I	1	-	-	-	-	-	nr	nr	-	nr	nr	-	na
B. bison	W	-	-	1	1	2	2	nr	nr	1	nr	nr	1	Xex
Bos taurus	C/D	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xei
Capra hircus	C/D	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xei
Ovis aries	C/D	-	-	-	-	-	-	nr	nr	-	nr	nr	-	Xei
All taxa ----------	MNI	173	118	62	67	33	54	--	--	39	--	--	141	--
	Taxa	31	23	21	24	13	18	--	--	20	--	--	25	57 * 60 △
ILR taxa ----------	MNI	166	117	58	62	30	47	46	93	35	67	102	138	--
	Taxa	24	22	17	19	11	13	11	15	17	17	21	22	27 * 28 △

* presettlement
△ postsettlement

Table 3. Continued.

Notes:

a) "ILR" indicates that the taxa belonging to the orders Insectivora, Lagomorpha, and Rodentia.

b) Centers of distribution column (Cntr Dstb) is after Jones & Birney (1988) and the symbols mean: B = boreomontane, C/D = commensal/domestic, EW = eastern widespread, I = indeterminate (including extinct), N = neotropical, NE = New England, P/G = plains/grassland, and W = widespread.

c) The code to faunas is: Craig = Craigmile lf (Rhodes, 1984); Waubo = Waubonsie lf (Rhodes, 1984); GarFm = Garrett Farm lf (Fay, 1978, 1980); PlRdg = Pleasant Ridge lf (Fay 1978, 1980); Thurm = Thurman lf (Jenkins, 1972); ML126 = Glenwood earthlodge 13ML126 faunule (Bardwell, 1981; Johnson, 1972); ML130 = Glenwood earthlodge 13ML130 faunule (Bardwell, 1981; Johnson, 1972); GlEly = Glenwood early, the combined faunules from 13ML126 and 13ML130; ML124 = Glenwood earthlodge 13ML124 faunule (Bardwell, 1981; Fulmer, 1974); ML155 = Glenwood earthlodge 13ML155 faunule (Bardwell, 1981); GlLte = Glenwood late (middle & late of Bardwell, 1981), combined faunules from 13ML124 & 13ML155; Chabo = Chaboneau lf (Behrends, 1989); and Today = the present day mammals of the area inferred from distribution maps in Hall (1981), Bowles (1975), Lampe & Bowles (1985), and Jones & Birney (1988).

d) Numbers in the columns indicate the minimum number of individuals of each taxon identified in each site. Numbers in curly brackets "{#}" are excluded from this compilation because sites 13ML130 and 13ML155 are incompletely reported; numbers in parentheses "(#)" are subspecies of Blarina brevicauda which are included in the sum for that species and thus are excluded from the counts; numbers in square brackets "[#]" are excluded from the counts of taxa, but are included in the MNI counts. A dash "-" indicates that the taxon is not reported from a site and an "nr" indicates that these mammals are not reported in the cited papers.

e) In the "Today" column: na = not applicable because represented at species level, X = taxon present in both pre- and postsettlement times, Xex = present in presettlement time but extirpated by European settlers, Xei = introduced by European settlers.

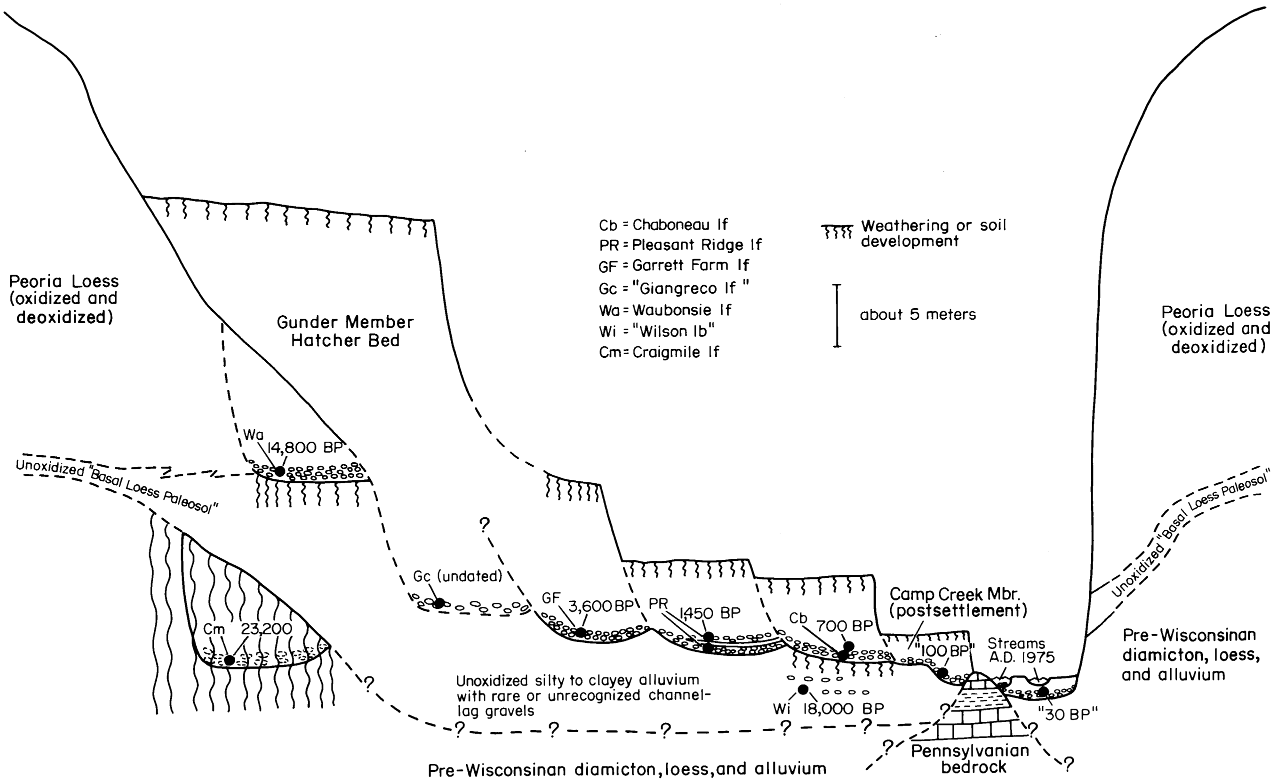


Figure 2. Diagrammatic composite section of alluvial fills in the Waubonsie watershed of Mills and Fremont counties, Iowa. The stratigraphic positions of radiocarbon dates and units tested for vertebrates are shown by the labeled dots. Since there is frequently only one and never more than three fill units exposed in any one cutbank, this diagram is highly speculative. The basal fill ages, relative depths of entrenchment, and thicknesses of the alluvial fills substantially varies with the position of any locality in the drainage network. All fill units are confined to deep, narrow valleys and their volumes are much less than this schematic diagram implies. Rotational slumps (not illustrated) often obscure the stratigraphic relationships within many of the cutbanks.

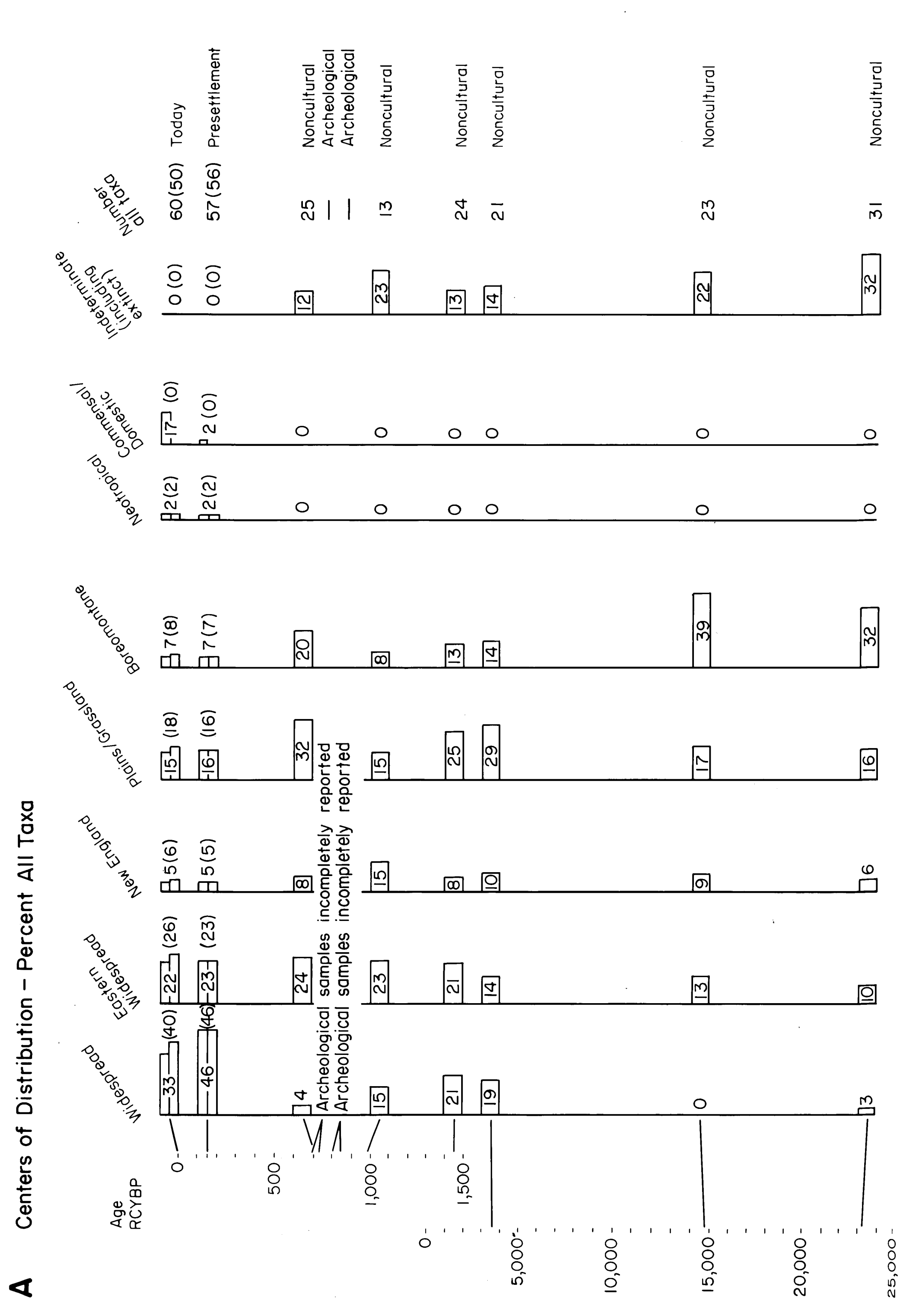
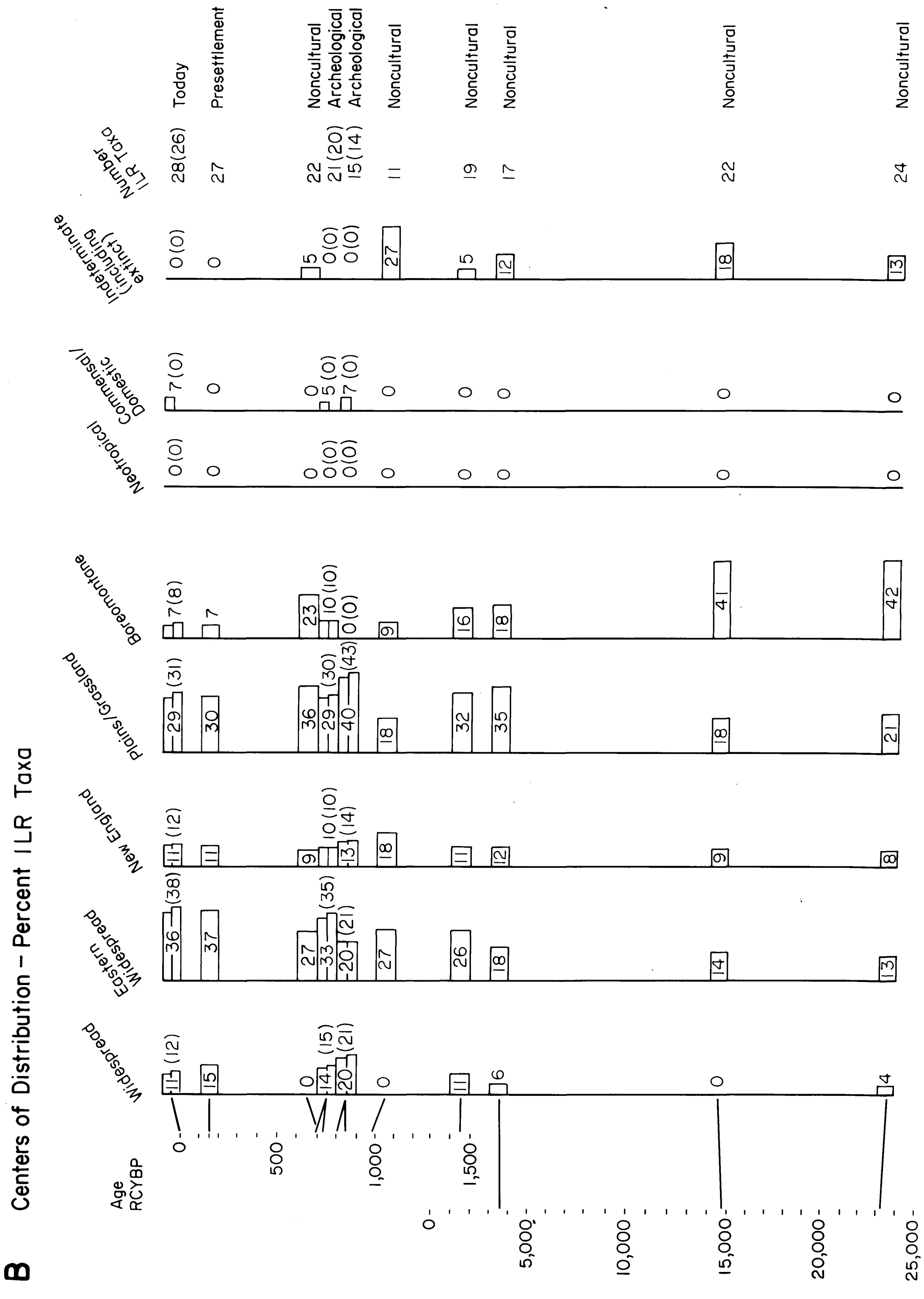


Figure 3. Frequency distributions by zoogeographic centers of distribution for both the fossil mammals found in Wisconsinan and Holocene sites and the modern mammal fauna of Mills and Fremont counties, Iowa. Note change in scale of radiocarbon years (left column) at 1,500 BP. The numbers on or by the bars are the percentage values graphed; where a bar is split horizontally, the lower half and the number in parentheses have been recalculated to exclude any commensal/domestic taxa or individuals. The right column is sample size. Compiled from data in Tables 1 and 2 in which any complications and all sources are cited.



B Centers of Distribution – Percent ILR Taxa

Figure 3. Continued.

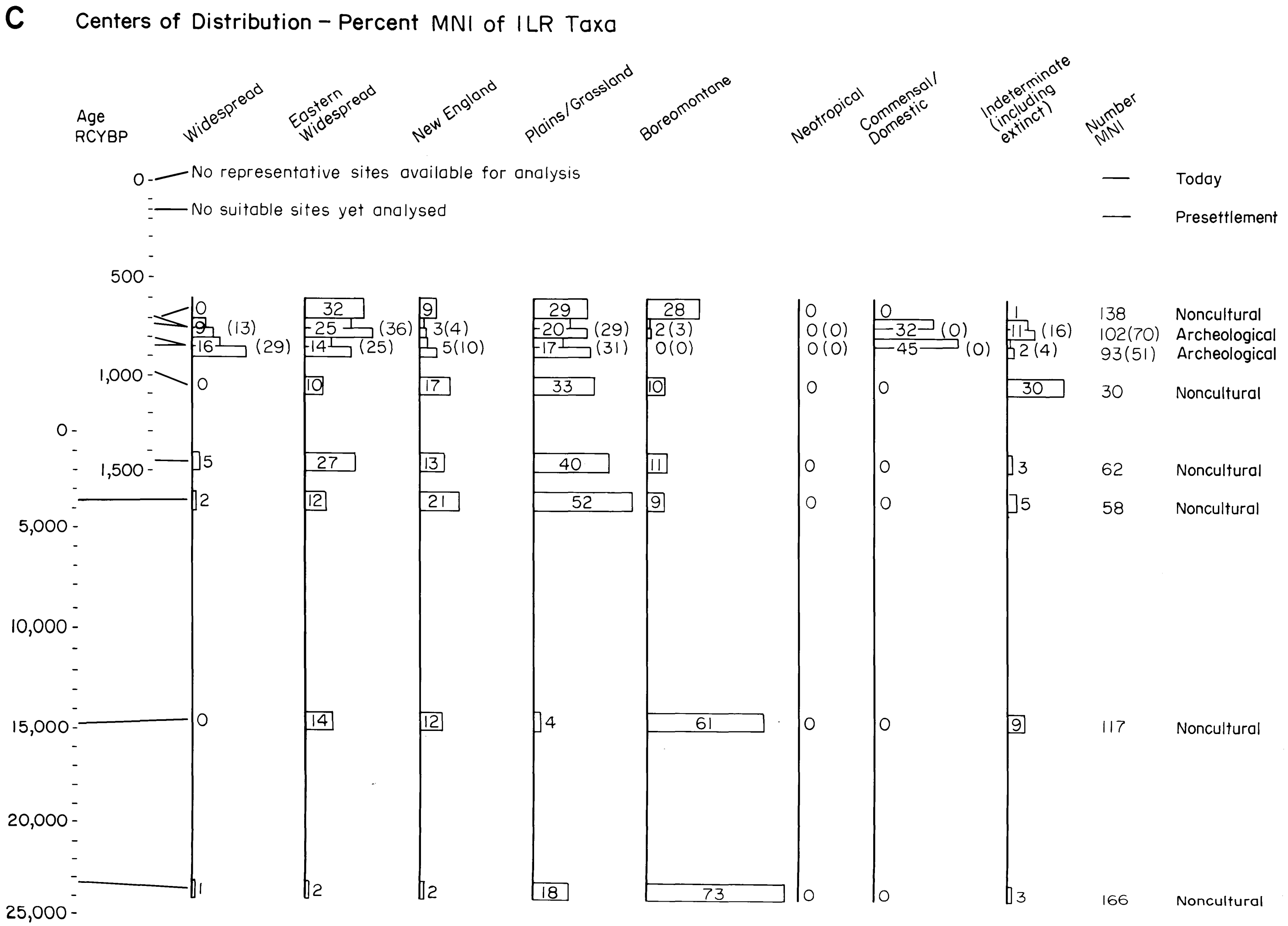

C Centers of Distribution – Percent MNI of ILR Taxa

Figure 3. Continued.

paleoenvironment, but no attempt is here made to systematize this procedure and it will only be used qualitatively.

For those taxa they treat, this paper uses the nomenclature of Jones and Birney (1988); Hall (1981) is used for the other wild mammals' names and Clutton-Brock (1981) for the domestic taxa.

WISCONSINAN AND HOLOCENE BIOTAS

In 1972 and 1973 about one third (32 kilometers of outcrop along gully bottoms) of the Waubonsie watershed was surveyed for paleontological and archeological sites (Hotopp et al., 1975). Seventy-five localities were examined and 51 of them found to contain vertebrate remains. At five of these sites, seven fossiliferous horizons were intensively investigated in 1974 (Rhodes and Semken, 1976). Although all yielded adequate samples of small mammals, none were as rich in fossil material as the more prolific cave accumulations tend to be. These seven horizons (two of which are yet incompletely analyzed), plus the Thurman lf (local fauna) and the mammalian remains recovered at four Glenwood Focus earthlodges form the basis for this report.

Seven of the eight discussed noncultural faunas thus have been recovered from alluvial sediments of ancestors of Waubonsie Creek or its tributaries at sites where the modern creeks have eroded large cutbanks (Hotopp et al., 1975). Unfortunately, the lithostratigraphy at these sites was not related, at the time of their excavation, to the now well-documented chronology of Holocene alluvial fills in the small valleys of western Iowa (Daniels et al., 1963; Bettis and Thompson, 1982). The assignments of these sites in Rhodes and Semken (1986) to members of the DeForest Formation was based solely on radiocarbon dates, ignored the relative position in the drainage order of the sites, and, since these alluvial fills now are known to be substantially time transgressive along valley system profiles, thus are suspect (Bettis, this volume). Although no one cutbank contains more than three fill units, a highly speculative, composite "cartoon" is presented in Figure 2 that shows the geometric relationships of all major known fill units from which fossils have been recovered in the Waubonsie watershed.

In five of the seven faunas, the bulk of the fossils were recovered from channel-lag gravels that were composed of carbonate clasts, loess nodules, and calcareous tufa. The sediments containing the Craigmile lf were completely leached of carbonate, but it undoubtedly also was a carbonate-clast channel-lag when originally deposited. The sediments of the "Wilson lb" (local biota) obviously were alluvially bedded, but lacked any well-defined channel lag. The Thurman lf, the only noncultural site outside the Waubonsie watershed, seems to be an alluvial fill of a tiny valley draining directly onto the Missouri River floodplain from the bluffs that was subsequently buried by slumping of Pleistocene sediments from above (Jenkins, 1972).

In the tallest cutbanks of the Waubonsie watershed sections, healed rotational slumps were observable, but not obvious. Because of the similarity in the appearance of many strata, slump blocks often were hard to detect and the stratigraphic sequence difficult to reconstruct with any assurance. Although deep burial and bank instability prevented excavation to any great distance into the cutbanks, sampling for vertebrates was confined to the smallest vertical areas and stratigraphically thinnest possible sampling units consistent with maximum fossil recovery.

None of the four Glenwood archeological sites (dating very late in the Holocene) used here were buried and it is thus not possible to relate them directly to the alluvial fill sequence. Unfortunately, no Paleoindian, Archaic, or Woodland archeological sites with adequate mammalian faunas are yet reported from this area. Faunas from such earlier Holocene sites would be of great interest and undoubtedly eventually will be found buried within the same alluvial fills where channel-lag gravels have yielded good noncultural faunas.

The Wisconsinan

All Wisconsinan faunas from midcontinental North America are strongly disharmonious in their faunal composition; that is, the taxa found together as fossils, even when not extinct, are no longer found living together anywhere in the world today. This is well accepted as indicating that the glacial climates had their own distinctive character and were inexact analogs of any modern one (Graham and Mead, 1987). The Wisconsinan biota thus was assembled from the individualistic migrations of organisms in response to the changing climate and not a simple southward displacement of today's biomes. The two fully analyzed Wisconsinan faunas from the Waubonsie watershed (the 23,200 BP Craigmile lf and the 14,800 BP Waubonsie lf) are strongly disharmonious and fully consistent with this hypothesis (see Rhodes and Semken, 1986; Rhodes, 1984).

The Craigmile lf (Fig. 1, D) is the only site at which the radiocarbon age has been determined on bone (Rhodes, 1984). Although this bone "collagen" date is more accurate than a whole bone date, the collagen was not fractionated into separately analyzed samples so this date must be regarded as a minimum (Taylor, 1980). The Craigmile is dominated by boreomontane taxa, both on a per taxon and a per MNI basis (Fig. 3). Most individuals are meadow and grassland inhabitants (Rhodes, 1984). Except the extinct beautiful armadillo (*Dasypus bellus*) whose occurrence here is puzzling, all the recovered mammals have modern ranges that either include Mills County today or are found to the northeast, north, or northwest (Rhodes, 1984; Rhodes and Semken, 1986). This suggests that the environment of 23,000 years ago was a boreal grassland unlike any found today with little woodland vegetation and presents scant support for the concept of Wisconsinan climatic equability (Rhodes, 1984) so evident farther to the south on the Plains (Graham and Mead, 1987) and in the southeastern United States (Semken, 1988). Recent work at the St. Charles paleobotanical site about 170 km to the east-northeast in Warren County, Iowa, documents a very open vegetation at about 34,000 RCYBP (Baker et al., n. d.) and is the first corroborating evidence from this region supporting a prairie or pine savannah biota in the time period preceding the classical Wisconsinan. See the reprinted copy of Rhodes and Semken (1986) here included for a more detailed discussion of the Craigmile 1f.

Full glacial conditions (circa 21,000 - 16,500 BP) in southwestern Iowa are represented by the as yet incompletely studied "Wilson lb" (Fig. 1, C). Since no channel-lag gravels of this age were located, the mammalian samples are small in the absence of a natural concentrating mechanism, but, preliminary analysis suggests that the faunal diversity may be reduced from that of both earlier and later deposits. Good preservation of plant material in this biota eventually may allow a better understanding of this time; macrofossils of spruce (mostly needles) are the most obvious fossil material (Hotopp, et al., 1975). A biota (including mammals) almost that of true arctic tundra has been documented about 350 km to the east at the 17,000 to 18,000 RCYBP Conklin Quarry site in Johnson County, Iowa (Baker et al., 1986). Farther to the east in Illinois, Johnson (1990) has identified extensive full glacial development of permafrost-related phenomena. Undoubted, but undated, physical indications of permafrost (involutions, etc.) have been found nearer to Mills County in stratigraphic intervals correlative with the full glacial period, at the above mentioned St. Charles site (Baker et al., n. d.) and in northeastern Adair County, Iowa (Ruhe, 1967). Though it seems unlikely that true tundra extended so far to the southwest as Mills and Fremont counties, the full glacial biota must have been one well adapted to extreme cold and the vegetation probably was open and dominated by stunted spruce groves.

By 14,800 BP, the Waubonsie lf (Fig. 1, D) shows that climatic amelioration already was occurring with a distinct, though small, increase in the numbers of eastern widespread and New England ILR taxa at the expense of the boreomontane and plains/grassland species (Fig. 3, C). Indeed, increased presence of forest-dependent, boreomontane ecotypes such as red squirrel (*Tamiasciurus hudsonicus*) support this hypothesis (Rhodes, 1984). Nevertheless, grassland and meadow ecotypes continued to dominate the environment demonstrating the generally open nature of the vegetation and implying that there was a well-developed mosaic of grassland, shrub, and forest vegetation (see Rhodes and Semken, 1986, for a more detailed discussion). It again is not necessary to invoke the concept of climatic equability to explain the disharmonious nature of the Waubonsie lf; indeed, Dulian (1975) shows at the nearby Bryton lb, Audubon County, Iowa, dating from 12,400 RCYBP, that when the modern climatic parameters that restrict each taxon are compared, there is no inherent incompatibility among the currently allopatric members of his less diverse fauna.

Although differing in degree, both Wisconsinan faunas indicate that the summer, winter, and average annual temperatures were all 4° - 5° C colder than present (Rhodes, 1984). Absolute precipitation appears to have been less than present, but more effective. North-facing slope exposures probably were even colder and drier, and supported the most boreal of the members of the biota (Rhodes, 1984). Although largely an open boreal grassland, groves of conifers were present, and both they and deciduous forest trees, invading from the southeast, undoubtedly became more common toward the end of the Wisconsinan.

The Holocene

The climatic changes during the Wisconsinan/Holocene transition had a profound effect on the mammalian fauna of the Loess Hills. Even though suitable alluvial sediments probably are present in Mills and Fremont counties, the currently reported faunal history has a 11,000 year gap between 14,800 and 3,600 BP. The "Giangreco lf" (Fig. 1, B) may fall into this gap at about 11,000 BP (based on its seemingly greater than expected faunal diversity), but it is as yet undated and the faunal analysis is far from complete. Even if all western Iowa is considered (see Rhodes and Semken, 1986), with the late Wisconsinan Brayton lb of Dulian (1975) and the middle Holocene Cherokee Sewer site of Semken (1980), there is still a 4,000 year gap at the time of maximum biotic instability around 10,000 BP. Nonetheless, to quote Rhodes and Semken (1986:109):

> "... it can be inferred from localities in the surrounding regions that as the climate became warmer, boreal small mammals gradually retreated northward and austral taxa reoccupied their former ranges (Lundelius et al., 1983; Hudak, 1984[; Graham and Mead, 1987]). The most spectacular biotic effect at the end of the Wisconsinan was the sudden collapse of the megafaunal community and the extinction of most of its members. This remarkable extinction event defines the end of the Rancholabrean land mammal age and corresponds with the generally accepted end of the Wisconsinan glacial stage.
>
> The Wisconsinan sites in western Iowa provide evidence supporting the concept of rich, boreal grasslands which were grazed by the megamammal fauna (Guthrie, 1968; 1984). By 8,400 YBP, when analyzed sites again are available, this glacial-age biome had disappeared from the state. As Guthrie (1968; 1984) suggested, and as examination of Table 1 [Rhodes and Semken, 1986:97] reveals, this environmental change would most heavily effect the large grazers. Their prime habitat, the boreal grasslands, had been eliminated by climatic change at the end of the Wisconsinan.
>
> Although the mammalian fauna changed most rapidly around 10,000 years ago, the small mammals were constantly undergoing range adjustments both before and after the glacial/interglacial transition. Although of smaller magnitude, this process continued throughout the Holocene (Semken, 1983; 1984). These range adjustments undoubtedly were responses to the smaller-scale climatic fluctuations within both the glacial and interglacial climatic regimes."

The 3,600 BP Garrett Farm lf (Fig. 1, F) is slightly disharmonious and clearly demonstrates the difference between glacial and interglacial faunas (Fay, 1978, 1980). The percentage representation of boreomontane and plains/grassland (both for taxa and MNIs) has almost exactly reversed from that in the Wisconsinan faunas with plains/grassland (equals the "steppe" category of Hoffmann and Jones, 1970) now dominating (Fig. 3). The deciduous forest taxa (and MNI) also are now present in greater proportions and represented by the New England and eastern widespread ILR taxa. Both the analysis of sympatry and proportional representation data suggest that the climate was slightly drier and warmer than that of today (see Rhodes and Semken, 1986). Nevertheless, heavily-forested, relatively mesic habitats must have persisted, perhaps on northeastern slope-exposures in the deeply-dissected gully systems, since they are documented by the presence of southern red-backed vole (*Clethrionomys gapperi*) in this fauna. This forest-dwelling vole (Jackson, 1961) persisted as late as the 705 BP Chaboneau lf (Behrends, 1989), but seemingly was climatically extirpated from Mills and Fremont counties sometime before European settlement.

The 1,450 BP Pleasant Ridge lf (Fig. 1, E) is harmonious (all recovered taxa are found coexisting in one area today) and has an area of sympatry in nearly the same location of that of the Garrett Farm (Fay, 1978, 1980; Rhodes and Semken, 1986). It also represents a climate drier and warmer than that of today (Rhodes and Semken, 1986). Although both eastern widespread and New England taxa have increased their representation (on an MNI basis) at the expense of plains/grassland taxa, this change (seemingly a slight increase of moisture or decrease of temperature) may be misleading because the rather small numbers of individuals recovered in each fauna could spuriously magnify the importance of any one identification.

The 970 BP Thurman lf (Fig. 1, A) also is harmonious (Jenkins, 1972; Rhodes and Semken, 1986). The remains of mammoth (*Mammuthus* sp.) are rejected as having been redeposited in this fauna from older Pleistocene sediments lying topographically above it in the rugged bluff edge. Unfortunately, the small sample size at this site (only 11 ILR taxa represented by 30 MNI were recovered) makes interpretation problematic, but seems to indicate a climate similar to the two older Holocene local faunas.

The newly reported, 705 BP Chaboneau lf (Fig. 1, C), with five of 27 mammalian taxa disjunct from its area of maximal sympatry (a small area in southeastern Nebraska), again is disharmonious and distinctly more so than any other late Holocene local fauna (Behrends, 1989). Although all five "missing" taxa co-occur to the northwest along the front ranges of the Rocky Mountains (in areas where altitudinal zonation allows inhabitants of the boreomontane conifer forest to live in proximity to inhabitants of the high plains), it is unlikely (in disagreement with Behrends, 1989) that these "resolved" sympatries reflect the local occurrence in Mills and Fremont counties of integrated short-grass, high plains biota.

Explanation for these occurrences rather should be sought on a species by species basis in the unique topography and bioenvironmental diversity it causes in the Loess Hills (Mutel, 1989). Richardson's ground squirrel (*Spermophilus richardsonii*) presently is found in the far northwestern corner of Iowa and is thought to be reinvading the state (Lampe et al., 1981). Both it and the nearby (found less than 100 km directly to the west in Nebraska; Hall, 1981) black-tailed prairie dog (*Cynomys ludovicianus*) would have been likely inhabitants of the impoverished, compared to that of the Plains proper, prairie patches of midheight grass so characteristic of the most xeric uplands and slopes in the Loess Hills today (Mutel, 1989). The well-documented and long-continued persistence of southern red-backed vole has been addressed above; both it and the red squirrel (*Tamiasciurus hudsonicus*) could represent patches of mesic deciduous forest since both are known to occur there to the northeast of Mills County in north central Iowa (Bowles, 1975).

Most anomalous is the presence of heather vole (*Phenacomys intermedius*) in the Chaboneau lf because it today approaches Iowa no closer than northeasternmost Minnesota (Hazard, 1982). This taxon presently is found in open, dry coniferous forest (pine and spruce) with water nearby, in shrubby vegetation at forest borders, or in moist, mossy meadows; it seems constrained by its food source -- the bark, buds, and fruits of a wide variety of shrubs (Banfield, 1974). Since its fossils have been found, quite reasonably, in the Wisconsinan local faunas (including the sediments containing the "Wilson lb" into which the Chaboneau lf alluvial fill is incised), its presence might be explained as simple redeposition from Wisconsinan-age sediments. The poor state of preservation of the fossils in the underlying sediments, and the lack in the Chaboneau lf of the fossils of other more physically robust and strictly Wisconsinan-age taxa makes this hypothesis unlikely (Behrends, 1989). The most parsimonious explanation is that, even in the undoubted absence of appropriate coniferous vegetation, heather vole lingered as a relictual population only in the deepest and coolest loess ravines in Mills County (Behrends, 1989), perhaps living in association with the many cold seeps and small springs that rise in these narrow canyons.

Although the maximal area of sympatry of the Chaboneau lf indicates a climate scarcely different from that of today, it could have been slightly drier than the present (Behrends, 1989) because the presence of Richardson's ground squirrel, black-tailed prairie dog, and northern grasshopper mouse (*Onychomys leucogaster*) all support the hypothesis of less moisture. Paradoxically, southern red-backed vole, red squirrel, and heather vole seem to indicate increased moisture or cooler temperatures that would make the precipitation that did fall more effective. The small northeastward shift of the sympatry from the position of the three earlier Holocene local faunas may be insignificant, but, when taken with the increased percent MNI representation (compared to the earlier Holocene faunas) of boreomontane at the expense of plains/grassland taxa would support the hypothesis that the macroclimate was cooler and drier than previously.

When Bardwell's (1981) four Glenwood focus archeological faunas (from sites outside the Waubonsie watershed but nearby and from about the same age as the Chaboneau lf to about 150 years older) are combined, they yield a sympatry intermediate in location, between that of the Chaboneau and that of the three earlier Holocene local faunas (see Rhodes and Semken, 1986). Southern red-backed vole and marsh rice rat

(*Oryzomys palustris*) are both disjunct from the sympatry; the marsh rice rat now only occurs substantially to the south, but is here considered a cultural commensal (see below) and excluded from this analysis (Bardwell, 1981; Behrends, 1989). For the discussion of the percentage representations in these archeological faunas see below.

The "cultural filter" and small mammal faunas

A unique opportunity is presented in Mills County for the comparison of faunas at nearby noncultural and archeological sites (Graham and Semken, 1987; Behrends, 1989). The Chaboneau lf (at 705 BP) is scarcely 12 km south of the nearest of the Glenwood earthlodges of the same age (Behrends, 1989) and provides a foundation upon which the investigation of the differing taphonomic pathways between these two types of sites can be based. Although not as strongly skewed as many archeological faunas, the individual Glenwood earthlodge faunas (see Table 3) all are somewhat "unbalanced"; characterized by large MNIs of one taxon and a somewhat lower species diversity than would be expected in a noncultural fauna (Semken and Falk, 1987:179-180; Rhodes and Semken, 1986:116-117). It seems likely that several factors contribute to this phenomenon. While the accumulation of mammal remains can be easily explained in most noncultural sites (predator dens or roosts in caves; natural pit-trapping in sinkholes; concentration by stream action in fluvial settings; and so on), there is a lack of obvious mechanisms by which small mammal remains could be concentrated (and they indeed do seem concentrated in cultural fill when compared to surrounding "sterile" matrix) in many archeological sites. Did the small mammals form part of the human subsistence base, were they foraging on the stores or garbage at the site, did Indian dogs bring their remains back, were their remains disgorged by predators roosting or denning in disintegrating structures after site abandonment (Bardwell, 1981; Semken, 1983; Behrends, 1989)? Indeed, the relative importance of each of these postulated mechanisms probably depends on the exact type of archeological site and the depositional environment of its containing sediments.

Furthermore, in the comparison of the Chaboneau lf with the Glenwood focus sites, it seems likely that the archeological sites reflect the small mammals from areally much smaller catchments. The fluvial environment of the Chaboneau would have received bones from not only resident small mammals dying in and near its channel, but also would have received bone-rich input in the form of scats of carnivorous animals and regurgitated boluses of predatory birds, both of which could hunt their prey over substantial ranges. The above postulated mechanisms by which small mammal bones came to be found in the Glenwood sites would tend to bias these samples toward the mammals living in close by areas. In late Holocene archeological sites like the Glenwood focus, the possibility of substantial human alteration of the natural environment also must be considered. The Glenwood peoples were semi-sedentary horticulturists (Anderson, 1975) who constructed timber-supported earthlodges as dwellings; they thus would not only have altered the environment about their habitations by trampling and firewood gathering, but also by the felling of trees for structural use and the planting of garden plots. Such activities could have had a great impact on the small mammal fauna in the likely small catchment area from which it comes.

For the purposes of this analysis, the faunas from the two earliest and two latest earthlodges have been combined even though the individual sites lie as much as 6 km apart. Since each set of sites has one each from contrasting topographic settings, it is hoped that the effects of the above postulated smaller catchment areas will be somewhat ameliorated. Earthlodge 13ML155 (Fig. 1, G) is located on a hilltop and dates about 698 BP, the counts of its fauna have been combined with those of 13ML124 (Fig. 1, J), which is on a stream terrace and dates 735 BP; 13ML130 (Fig. 1, H) is on a stream terrace and dates about 807 BP, its fauna has been combined with that of 13ML126 (Fig. 1, I), which is on a hilltop and dates about 852 BP (Hotopp, 1978; Bardwell, 1981). Unfortunately, the radiocarbon dates for these earthlodges were obtained on charcoal from structural timbers (Hotopp, 1978), so the exact chronology is difficult to resolve; with the sensitivity of currently available AMS dating techniques on carbonized material of more ephemeral nature it may be possible to place more precisely these lodge occupations (William Green, personal communication, 1990). Nonetheless, Bardwell (1981) has examined these faunas separately and detected distinct temporal (with the dates on structural timbers) and topographic differences in them; see the reprinted

Rhodes and Semken (1986) for a summary of her analysis.

The most obvious difference between the Chaboneau and two combined Glenwood faunas is the overwhelming presence of marsh rice rat in the archeological sites and its total absence in the noncultural accumulation (Bardwell, 1981; Behrends, 1989). The marsh rice rat is found today living over 500 km to the southeast of Mills County (Bee et al., 1981; Hall, 1981; if a doubtful record of a single specimen in Kansas is not rejected, and Hall, 1981, accepts it as valid, it might be found as close as 250 km to the southwest). Although more noncultural sites of similar age need to be examined near these Glenwood earthlodges to confirm this absence, Behrends (1989) reasonably concludes that the marsh rice rat is a cultural commensal living in intimate association with the Glenwood peoples and its presence has little significance for the reconstruction of the paleoenvironment or paleoclimate.

Since the areas of sympatry of the Chaboneau and combined (all four) Glenwood faunas are similar, Behrends (1989) concludes that, in the presence of the adequate faunal diversity that the varied topographic settings of the four archeological sites provide, the general interpretation of these archeological sites is as accurate as that of the noncultural accumulation. However, even when marsh rice rat is excluded, there are real and distinct differences in faunal compositions between the Glenwood sites and the Chaboneau. Behrends (1989) notes that the most striking difference is the near reversal of the relative abundances of cricetines (native mice) and microtines (voles). In the most general terms, cricetines have brachydont molars that indicate a browsing habit while microtines have extremely hypsodont molars that are characteristic of grazing habits. The Chaboneau has 18% MNI ILR cricetines and 54% microtines (calculated from table 2); the early and late combined Glenwood sites have 35% and 29% cricetines and only 16% and 23% microtines respectively. This reversal could indicate that there was a decreased importance of thickly-grown grass in the smaller catchment areas around the Glenwood lodges, perhaps because of trampling or cultivation by their inhabitants.

When the percentage representation by centers of distribution is recalculated to exclude marsh rice rat (lower half bars in Fig. 3), the Glenwood faunas still are quite different from the Chaboneau. Although the reduced samples are smaller than desirable, the boreomontane elements, primarily microtines and representing a quarter of the Chaboneau, are nearly absent in both the early and late combined Glenwood faunas; they are replaced by a combination of eastern widespread and widespread taxa (absent in the Chaboneau). Since taxa with wide natural distributions generally tend to be less susceptible to human disturbance of the environment, a straight forward interpretation would be that the eastern widespread and widespread taxa are more strongly represented because they were able to exploit the areas of disturbed vegetation near the lodges of the Glenwood horticulturists. Unfortunately, 11% of the early and 16% of the late Glenwood combined ILR representation (excluding marsh rice rat) is due to the eastern widespread taxon, eastern cottontail (*Sylvilagus floridanus*); this large fur-bearer could have been purposefully collected by the Glenwood peoples as a part of their subsistence base.

Furthermore, the taxa absent in the Glenwood sites (Behrends, 1989) are those most likely to have been surviving in the most atypical vegetational relicts, the very dry prairies and cool, forested patches. These elements of the biotic mosaic would have been the most easily disturbed or may even have not occurred near enough to the Glenwood sites (relief is about 15 meters less in their vicinity than near the Chaboneau) to be adequately sampled. Two of the taxa present only in the Glenwood sites are both large fur-bearers and inhabitants of riverine habitats; these could be explained either by Indian subsistence activities or the proximity of larger streams (than at the Chaboneau) to the Glenwood sites (Behrends, 1989).

The above is highly speculative, but it at least serves to document real differences in the small mammal faunal composition of archeological and noncultural sites of the same age in the same geographic area. Not only do more Holocene noncultural sites need to be studied near archeologically-rich locals, but, well-designed studies must be undertaken with the zooarcheological remains themselves to determine exactly how they have come to be in the archeological site. Only then will we be able to confidently interpret the meaning of zooarcheological remains such as those in the

Glenwood earthlodges.

CONCLUSIONS

Although large chronologic gaps remain, a start has been made on acquiring a framework of small mammal sites for the reconstruction of Wisconsinan and Holocene paleoenvironments and paleoclimates of southwestern Iowa. Completion of the analysis of the "Giangreco lf," should it prove to be of the proper age when dated, may fill the important void at the transition between the Wisconsinan and the Holocene. Further fieldwork, in conjunction with simultaneous study of the lithostratigraphy of the Holocene alluvial fills, would undoubtedly recover faunas from the earlier parts of the Holocene that are now missing. Indeed, some named alluvial beds may be represented by multiple fill episodes (Bettis, this volume) and may yield further material of different ages than now known. Although much less fossil rich than the channel-lag gravels, the silts that overlie them in the fill sequences also are known to bear bone (Hotopp et al., 1975; Fay, 1978) and, if there is significant time depth in these associated silts, they could, with perhaps an unreasonably large effort, yield faunas of intermediate ages. The preservation of bone at shallow depths in archeological sites suggests that it also might be worthwhile to wash for microvertebrates in stratigraphic columns through the pedologic horizons of the surficial soils and in buried paleosols of the alluvial fills. Such paleosols are known to yield good samples of fossil rodents as close by as central Nebraska (eg Neuner and Schultz, 1979).

The provisional outline of the climatic and environmental history of southwestern Iowa is not repeated here, so the interested reader should see the reprinted copy of Rhodes and Semken (1986:123-124) that is included in this field guide. As more sites are located and reported from the geographically small area that is Mills and Fremont counties, it shall be possible to use increasingly sophisticated analytical techniques for these reconstructions, but they probably will never approach the precision of the continuous records from the paleobotanical sites recovered in areas that, unlike the Loess Hills, have suitable lakes available for analysis.

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APPENDIX A

Errata for Rhodes and Semken (1986). Quaternary biostratigraphy and paleoecology of fossil mammals from the Loess Hills region of western Iowa. Proc. Iowa Acad. Sci. 93:94-129.

Page	Column	Paragraph	Line	replace	with
98	1	4	22	"secton"	"section"
118	2	2	21	"trade time"	"trade item"
119	1	4	6	"presettlement"	"present"
122	1	2	7	"inhabitatnt"	"inhabitant"
123	1	4	9	"contains"	"contain"
124	1	1	5	"Although,"	"Although"
129	1	-	10	"(Zimmerman)"	"(Zimmermann)"
129	1	-	15	"(Zimmerman)"	"(Zimmermann)"

Midwest Friends of the Pleistocene 37th Field Conference, May 12-13,1990

PETROGRAPHIC AND STRATIGRAPHIC COMPARISONS OF SUB-TILL AND INTER-TILL ALLUVIAL UNITS IN WESTERN IOWA; IMPLICATIONS FOR DEVELOPMENT OF THE MISSOURI RIVER DRAINAGE

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INTRODUCTION

Studies of Neogene stratigraphy in western Iowa and eastern Nebraska by Boellstorff (1978a,b), Hallberg (1987), and others resulted in recognition of a complex pre-Illinoian glacial and inter-glacial sequence. Recent international definition places the Pliocene-Pleistocene boundary at about 1.6 to 1.7 Ma [million years ago] (Aguirre and Pasini, 1985), although this boundary does not correspond to any biostratigraphic or paleomagnetic event and may need re-evaluation (Jenkins, 1987). The identification of glacial tills below a 2.0 Ma volcanic ash in Iowa (Boellstorff, 1978c; Hallberg, 1987) indicates that the oldest tills (C-tills) and associated strata in western Iowa can be assigned to the Pliocene, if the cited Plio-Pleistocene boundary is acceptable. Paleomagnetic and volcanic ash chronology in western Iowa and eastern Nebraska has constrained a sequence of seven (or more) pre-Illinoian glacial tills each separated by paleosols and/or eolian and fluvial deposits (Boellstorff, 1978c; Izett, 1981; Hallberg, 1987). The glacial sequence encompasses portions of the late Pliocene (C-tills; approx. 2.1-2.5 Ma) and early to middle Pleistocene (A1, A2, A3, A4, B tills; approx. 0.5-0.9 Ma). Inter- and sub-till alluvial units have been given a variety of names, although stratigraphic definitions and correlation of units in the Iowa-Nebraska region have been fraught with difficulties and are in need of re-study. This study was initiated in an effort to identify the oldest sub-till Cenozoic strata in the state of Iowa, but, of necessity, it was expanded to include comparative stratigraphic and petrographic studies of both sub-till and inter-till alluvial units.

The age of the oldest sub-till Cenozoic sediments in western Iowa is not presently known, although a number of pre-Pleistocene alluvial units are recognized immediately west of Iowa in parts of eastern Nebraska, especially Cedar and Knox counties (Fig. 1). There is a general absence of biostratigraphic data to constrain the temporal sequence of sub-till alluvial stratigraphic units in western Iowa. Therefore, we attempted a petrographic comparison of alluvial units in western Iowa with various known Cenozoic intervals in eastern Nebraska in hopes that compositional contrasts may prove to have some stratigraphic utility or paleoenvironmental significance. Our investigation sampled both sub-till and inter-till sand, gravel, and mudstone units from surface exposures and subsurface materials in western Iowa. We then compared these to selected samples from Miocene, Pliocene, and Quaternary fluvial units in nearby Nebraska, including the far eastern outcrops of the Ogallala Group beginning only 30 km west of the Iowa border (see sub-till Ogallala edge, Fig. 2).

"SALT AND PEPPER" SANDS AND RELATED SEDIMENTS

Distribution and General Stratigraphy

Existing well records show widespread distribution of sub-till fluvial units in western Iowa, primarily in broad upland divide areas (Fig. 3). These deposits include the "salt and pepper" sands, so-called by local drillers because of scattered dark grains ("pepper") with more abundant light-colored grains ("salt"). Miller (1964, p. 16) also described strata in western Iowa as "salt-and-pepper gray quartz sand." These sands, confined beneath glacial tills, locally yield potable groundwater in western Iowa. Our attention was initially drawn to exposures near Folsom Lake, Mills County (see Field Trip Stop 6; Loc. FQ on Fig. 2), where "salt and pepper" ("s & p") sands are well exposed

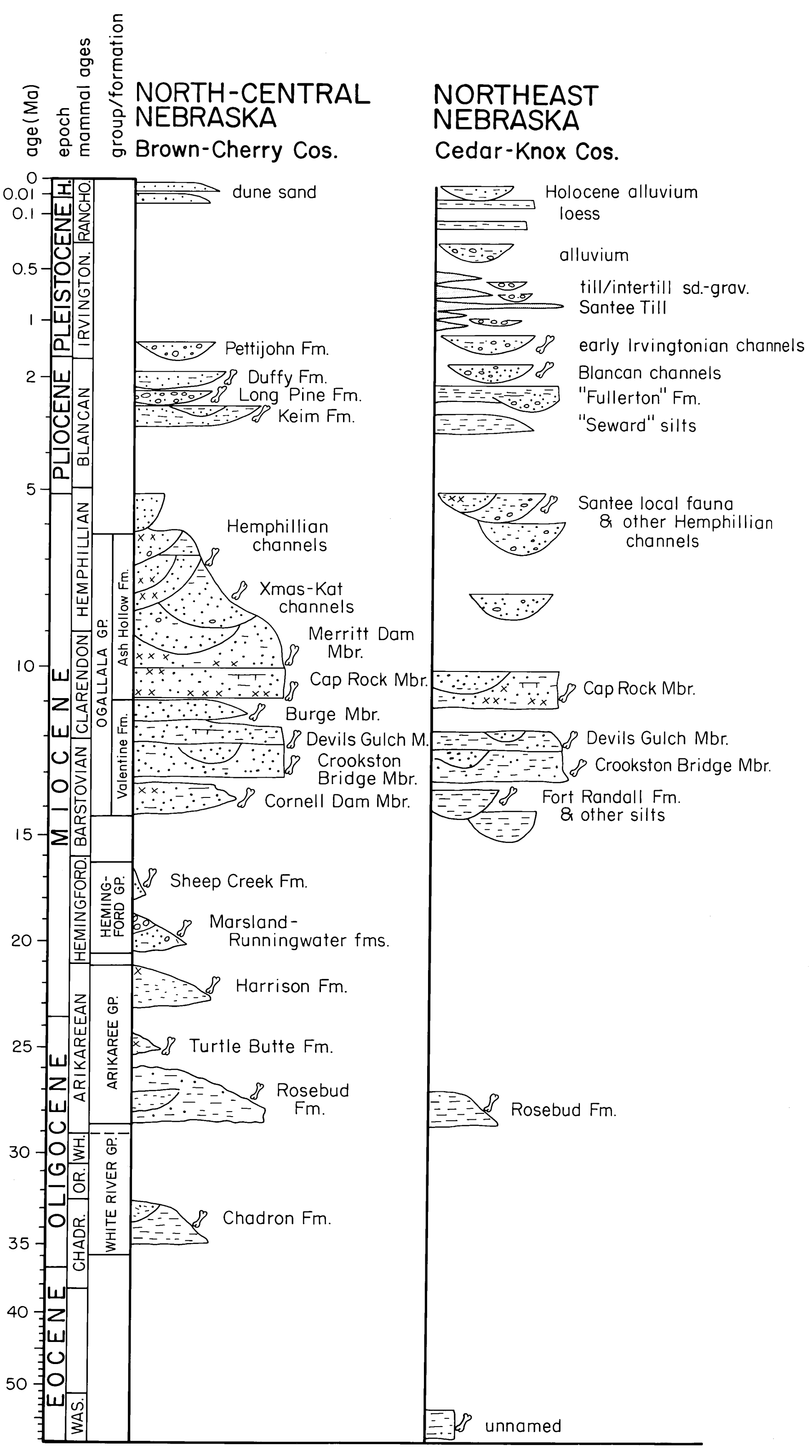


Figure 1. Generalized composite Cenozoic stratigraphy and chronologic sequence for northeast and north-central Nebraska. Symbols as in Fig. 5. Adapted from Skinner and Hibbard (1972), Skinner and Johnson (1984), Voorhies (1969, 1977), Reed and Dreeszen (1965).

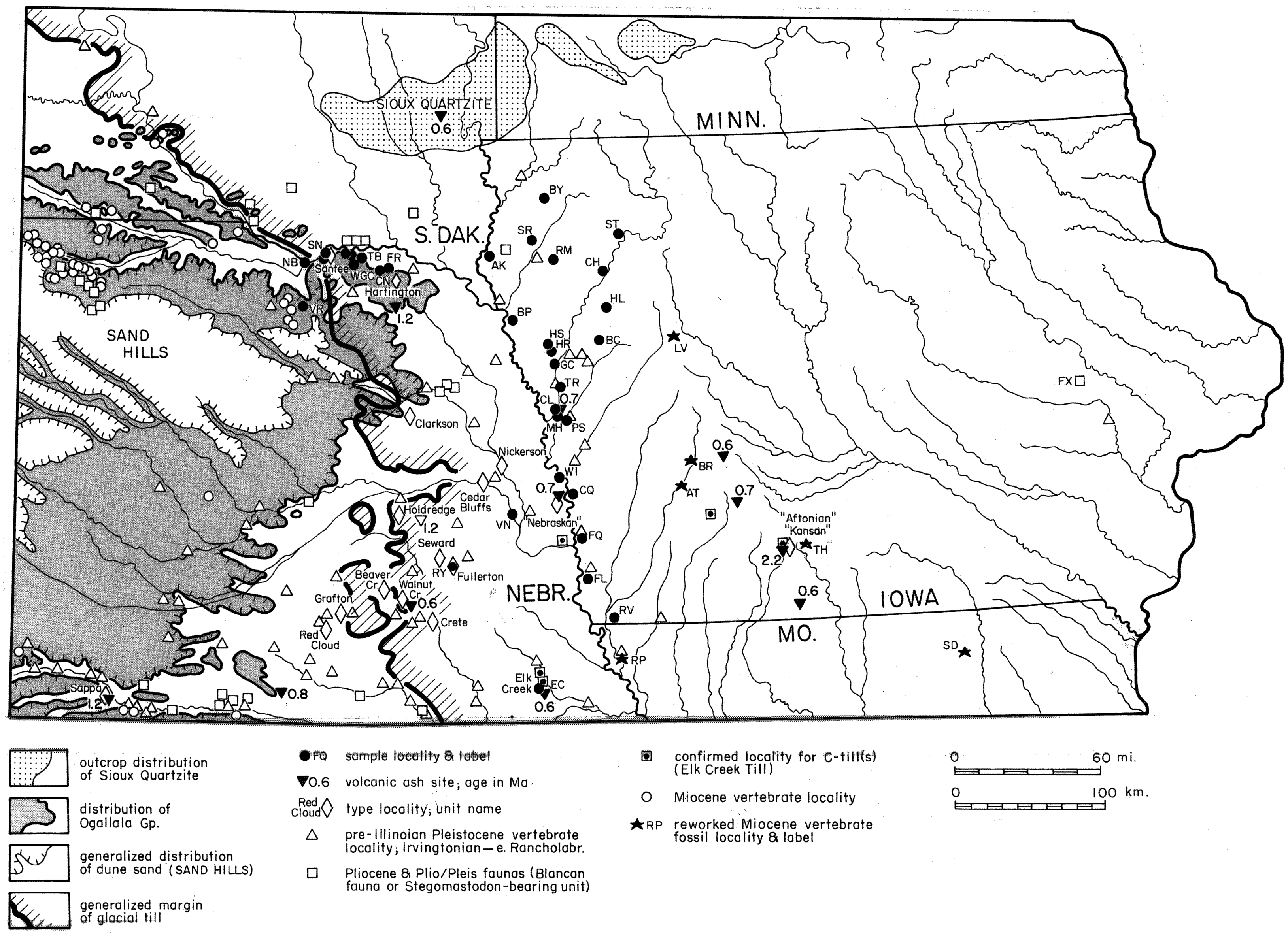


Figure 2. General location map for Iowa, eastern Nebraska, and adjacent area. Known distribution of Ogallala Group and glacial till margin shown; type localities, ash sites, and sampling locations indicated.

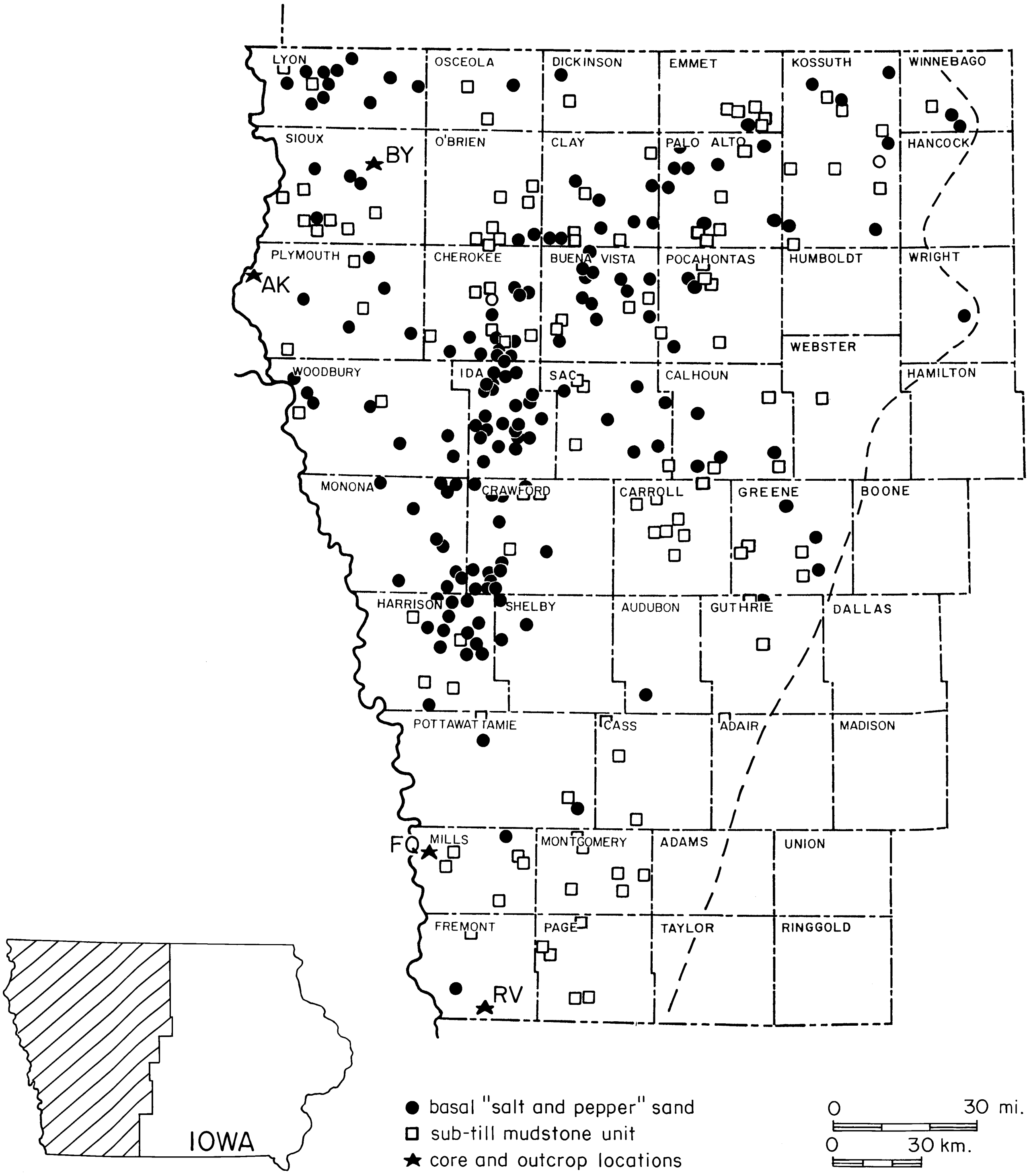


Figure 3. Known distribution of sub-till mudstones and "salt & pepper" sands in western Iowa. Data largely from well records stored at the Iowa DNR, Geological Survey Bureau, Iowa City.

beneath pre-Illinoian tills. Sand units within the Ogallala Group of Nebraska have also been termed "salt and pepper" sands by drillers in that area (D. Evans, 1988, pers. comm). "Salt and pepper" sand units in Iowa are commonly associated with intervals of siltstone and mudrock, possibly finer-grained overbank and floodbasin facies deposited adjacent to sand-channel facies in the fluvial systems. These sediments contrast with detrital carbonate-rich sands and gravels which occur either in an inter-till position or locally above Cretaceous bedrock (Fig. 4). The carbonate-rich sands and gravels (discussed in later section) have not been seen in stratigraphic position below "salt and pepper" sand units in western Iowa, suggesting an older relative age for the "salt and pepper" sand units.

"Salt and pepper" sands and their associated mudrocks occur in Iowa primarily in a sub-till stratigraphic position, but locally occur above a basal till (Fig. 4; also Miller, 1964). It is not known with certainty if "s & p" sand deposition in Iowa occurred during one or more episodes, and if more than one "salt and pepper" unit is represented in the stratigraphic sequence. However, the local occurrence of "salt and pepper" sands above till suggests that at least some "s & p" sand sedimentation succeeded the early stages of glaciation in western Iowa. "Salt and pepper" sand units are locally overlain by a sequence of as many as six discrete till units (with intervening paleosols or sands and gravels), suggesting an age no younger than the B-tills (early Pleistocene). Preliminary analyses of the till sequence in western Iowa and eastern Nebraska (data from Hallberg, 1988, pers. comm.; Bettis, 1990, pers. comm) suggest that the B-tills have a clay mineralogy distinct from all other tills in the area (lowest expandables, 43-53%; highest K-C, 23-28%). "Salt and pepper" sand units are known to occur in Iowa below probable B-till units at the Folsom Quarry, Mills County (Field Trip Stop 6), and the Riverton core, Fremont County (Fig. 5). Although additional study is needed, the observed stratigraphic relations suggest that the "salt and pepper" sand units in western Iowa are older than the B-tills but locally occur above a basal till, probably one of the C-tills (Elk Creek Till). Fluvial units in eastern Nebraska and western Iowa that occur between the B- and C-tills, which include "s & p" sand lithologies, are known to contain at least two volcanic ashes (1.27 and 2.0 Ma)(Boellstorff, 1978a; Hallberg, 1987). However, it cannot be demonstrated that all "salt and pepper" sand units in western Iowa were deposited during the interval separating deposition of the B- and C-tills. As discussed later, there is limited biostratigraphic and stratigraphic evidence to suggest that some pre-glacial sedimentation of "s & p" sand and associated mudrocks may have occurred in western Iowa. The informal term "salt and pepper sand" is used, therefore, as a descriptive lithologic label and does not identify a specific stratigraphic interval.

General Lithologies and Sedimentary Features

The "salt and pepper" sands and their associated sediments form a distinctive lithologic suite that can be contrasted with other fluvial and glacial sediments seen in the Missouri River Valley in Iowa and Nebraska. To facilitate discussion, the suite of sediments that includes the "salt and pepper" sands and stratigraphically-associated siltstone, mudstone, and claystone lithologies will be termed the "s & p suite." Intervals assigned to this suite reach maximum thicknesses to about 60 m (200 ft) in western Iowa. In many stratigraphic sequences the "s & p suite" is dominated by siltstone, mudstone, and claystone lithologies (e.g., Figs. 4, 5, and Folsom Quarry, Mills Co., Field Stop 6). Clay composition within mudrocks of the "s & p" suite is characterized by high percentages of expandables (3 samples range 72-73%), and volcanic ashes or ash-rich mudrocks (well preserved angular glass shards) are locally present. Siltstones and mudstones in the "s & p" suite are micaceous to varying degrees and display fine laminations in some intervals (e.g. Boyden core, Fig. 5); calcareous cements and carbonate concretions (some with septaria) occur locally (see Ludvigson et al., this volume). Mudrocks locally display pedogenic alteration, as seen in the top 4 m of the "s & p" suite at the Folsom Quarry, Mills County.

Sands of the "s & p" suite form a distinctive facies that is generally dominated by very fine- to fine-grained lithologies with minor fine- to coarse-grained or pebbly sand. The mineralogy and provenance of these sands is discussed in a subsequent section, but the general absence or scarcity of carbonate grains and the consistent presence of dark volcanic lithic grains (volcanic glass with plagioclase microlites) are noteworthy. Coarse sand and pebbles are rare to absent in many sequences of the "s & p" suite, but locally occur

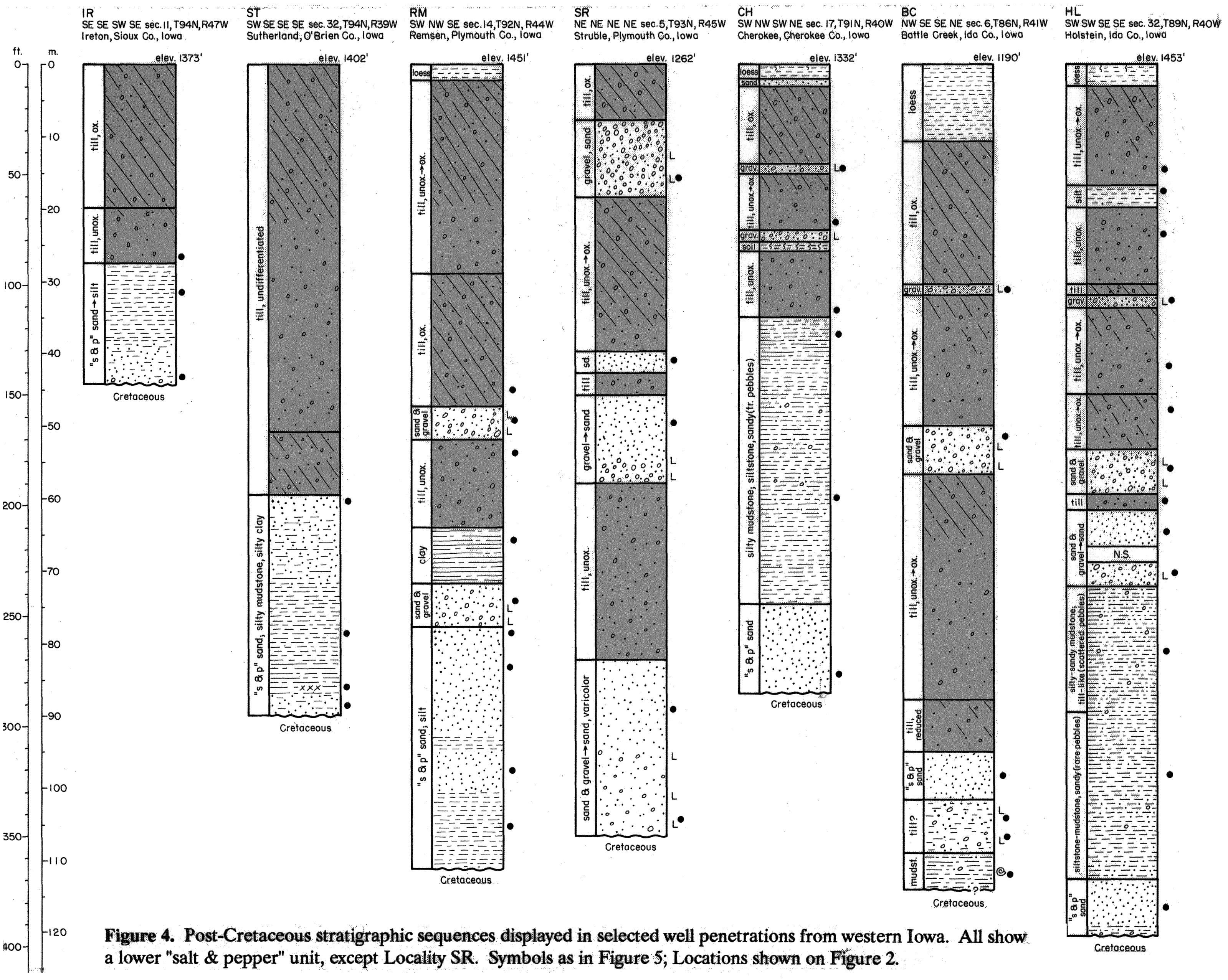


Figure 4. Post-Cretaceous stratigraphic sequences displayed in selected well penetrations from western Iowa. All show a lower "salt & pepper" unit, except Locality SR. Symbols as in Figure 5; Locations shown on Figure 2.

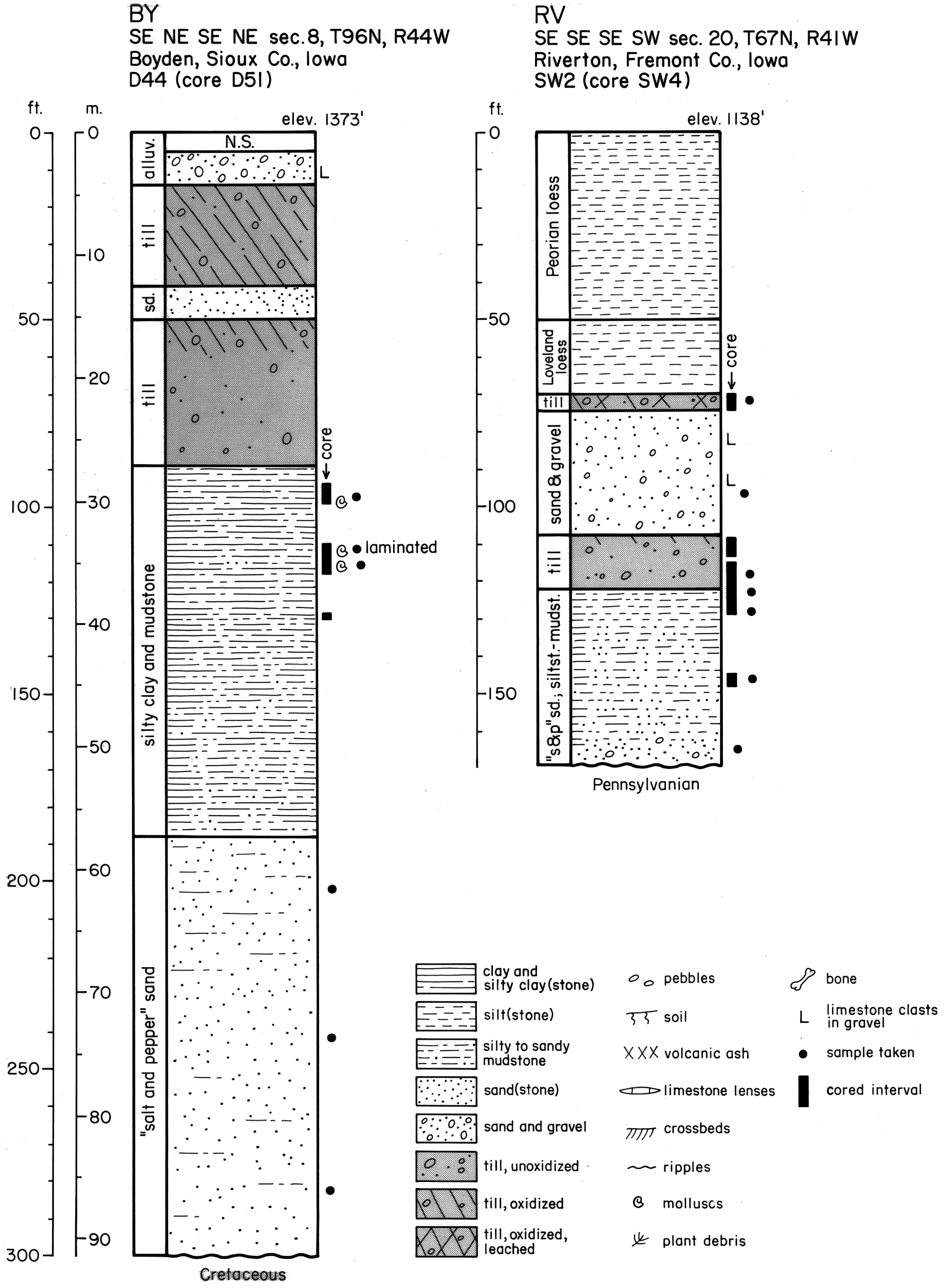


Figure 5. Stratigraphic sequences from western Iowa showing sub-till "salt & pepper" sand-mudstone units. Note inter-till alluvial units. Locations for two well sections shown on Figs. 2 and 3.

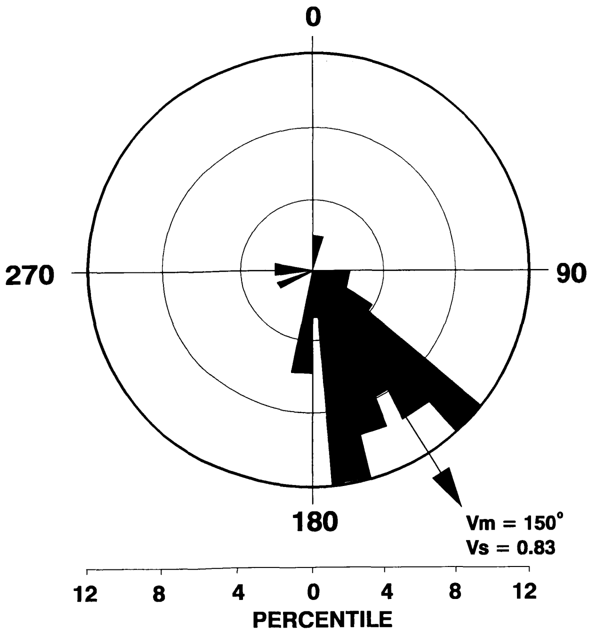


Figure 6. Paleocurrent measurements from basal "salt & pepper" sand unit at Folsom Quarry, Mills County, Iowa (Loc. FQ on Figs. 2 and 3; Field Trip Stop 6). Shown are azimuths of crossbed foreset laminae (n = 50).

along foresets (as at Folsom Quarry). Pebble collections from Folsom Quarry are dominated by quartz (including vein quartz, quartzite, jaspery chert) and granitic rock; minor metamorphic (schist) and mafic igneous rocks (basalt) and sedimentary intraclasts and lithoclasts are present. Sand units exposed at the Folsom Quarry display prominent tabular crossbeds (sets are 10-50 cm thick, foresets dip up to 30°) that are cut and filled by numerous trough crossbeds and small channel fills (up to 1 m deep and 3 m wide). Foreset directions at this locality display a vector mean of 150° (i.e. southeast)(Fig. 6).

Identifiable fossils have not been recovered at the primary exposure of the "s & p" suite at the Folsom Quarry, although the presence of indeterminate bone scrap suggests that additional collecting efforts may be fruitful. Calcareous claystones above "s & p" sands in the Boyden core (Fig. 5) contain shallow-water gastropods (*Helisoma anterosa, Gyraulus* aff. *parvus, Lymnea reflexa*; T. Frest, pers. comm., 1980), ostracods (*Candona* sp.), and indeterminate bone fragments.

GLACIGENIC SANDS AND GRAVELS

A distinctive suite of sand and gravel lithologies in western Iowa is generally associated with the pre-Illinoian till sequence. Sand and gravel units commonly occur in an inter-till stratigraphic position (Fig. 4), although isolated pods of identical lithologies are also seen in intra-till positions within stratified till sequences (e.g. Folsom Quarry). Similar units are locally present in sub-till or supra-till (sub-loess) positions. The sand and gravel units that are associated with glacial till sequences in western Iowa are here termed the "glacigenic suite." These units range approximately 1-15 m (3-50 ft) in thickness. This suite is interpreted to have been glacial-derived, either from 1) fluvial resedimentation and reworking of weathered till units during interglacial or nonglacial times, or 2) from glacial outwash or supra- or sub-glacial aqueous transport. Unlike the "s & p" suite which is dominated by mudrocks and fine sands, the glacigenic suite is dominated by fine to coarse sand, pebbly sand, and gravel. However, some intervals of siltstone and claystone occur in inter-till positions (Fig. 4) and are included within the glacigenic suite for general discussion. Characteristic sand and gravel lithologies of the glacigenic suite occur at the County-line ash site (see Field Trip Stop) in close association with intervals of mudstone and volcanic ash, indicating episodic airborne volcanic input to the sedimentary systems. Aquatic molluscs and mammal fossils are known from some glacigenic sands and gravels in western Iowa (e.g., Calvin, 1909; Shimek, 1910; Paulson and Miller, this volume).

Distinctive lithologies characterize the sands and gravels of the glacigenic suite, especially the consistent occurrence of carbonate clasts in the gravel fraction. Carbonate clasts have not been seen in the gravel fraction of the "s & p" suite. Sands associated with this suite do not resemble those seen in the "s & p" suite and differ in the scarcity or absence of dark volcanic lithic grains and the general abundance of carbonate grains. Nevertheless, some fine sand and silt units in the glacigenic suite locally lack carbonate grains, possibly due to leaching and/or mechanical diminution of carbonate content with decreasing grain size. A variety of carbonate lithologies have been identified during point-counting of the glacigenic sands that include: 1) skeletal lime wackestones and crinoidal wackestones-packstones (common Paleozoic lithologies), 2) unfossiliferous lime mudstones, 3) unfossiliferous dolomite and dolomitized crinoidal wackestones (common Paleozoic lithologies), 4) radiaxial calcite spar and spherulitic calcite, 5) calcite-cemented sands, and 6) spar-filled forams and inoceramid packstones (typical Cretaceous lithologies).

GRANITIC GRAVELS

A distinctive suite of coarse granitic sand and gravel locally occurs in northwest Iowa which closely resembles western-derived "granitic" sand and gravel units in Nebraska (Stanley and Wayne, 1972) and eastern South Dakota (Flint, 1955). Although granitic clasts also occur in the "s & p" and glacigenic suites, the granitic sand and gravel suite differs from the glacigenic suite in the absence of carbonate grains and the general scarcity of metamorphic and mafic igneous clasts. The granitic sand and gravel suite is separated from the "s & p" suite by its coarser grain size and apparent absence of dark volcanic grains. Gravel clasts and pebbles of the granitic suite are dominated by coarse-grained granites with derivative quartz and pink K-feldspar grains; secondary components include chert (especially jaspery chert) and white to brown quartzite. Sands of this suite are composed almost exclusively of quartz (minor chert) and K-feldspar.

The granitic suite in Iowa is best represented near Akron (Loc. AK, Fig. 2), where granitic sands and gravels occur above mudrocks of the "s & p" suite or Cretaceous shales and below glacigenic alluvium or till (Fig 7). Granitic sand and gravel in this area has yielded teeth and bones of *Stegomastodon mirificus* (Calvin, 1909). Granitic sand and gravel units in Iowa occur in a sub-till stratigraphic position, and have not been identified in southern Iowa.

BIOSTRATIGRAPHY AND GENERAL CHRONOLOGY

The chronology of the Neogene stratigraphic sequence in western Iowa is difficult to constrain by available data, although several datable volcanic ashes and limited mammalian vertebrate fossils offer some control. Neogene vertebrate faunas and ash chronology in Nebraska are better defined, especially the Miocene Ogallala sequence (Fig. 1)(ash chronology after Boellstorff, 1978c; Izett, 1981). Ogallala faunas are well known in northeast Nebraska (e.g., Voorhies and Thomasson, 1979; Voorhies, 1969), where the Ogallala sequence occurs beneath various sand and gravel units (granitic and glacigenic suites) and the Santee and Hartington tills (A3). Late Hemphillian and Blancan faunas are also recognized in northeast Nebraska (Voorhies, 1977) and southeast South Dakota (Martin and Harksen, 1975) a short distance west of the Iowa border. Diverse Miocene through early Pleistocene vertebrate assemblages are also described from west of the till edge in north-central Nebraska (e.g. Skinner and Johnson, 1984; Skinner and Hibbard, 1972).

Vertebrate faunal data is sparse in the pre-loess sequence in western Iowa, and many existing collections are from an uncertain or debatable stratigraphic context. Quaternary faunas from glacigenic sand units in western Iowa have been described as the "Aftonian mammal fauna" (Calvin, 1909), originially thought to occupy a position between the "Kansan" and "pre-Kansan" tills. With the recognition that seven or more pre-Illinoian till units are present in western Iowa, it is now apparent that the term "Aftonian" has been broadly used to include faunas recovered from any or all inter-till units (and possibly post-till units as well)(see Rhodes and Semken, 1986). "Aftonian" collections characteristically include *Mammuthus* spp., *Camelops sp*., and *Equus* spp., along with other non-diagnostic elements. The occurrence of *Bison* has not been verified in any Iowa "Aftonian" collection, which is consistent with an Irvingtonian (i.e. pre-*Bison*) age assignment. However, the presence of *Megalonyx jeffersoni* (species identification of skull with unusual zygomatic morphology after McDonald and Anderson, 1983) in the classic "Aftonian" fauna at Turin, Monona County (Loc. TR, Fig. 2) suggested a Rancholabrean (ibid.) or transitional Irvingtonian-Rancholabrean (Rhodes and Semken, 1986) assignment for the sand unit at Turin. If these assignments are correct and if the Turin local fauna occupies an inter-till position (as illustrated by Shimek, 1910), then the base of the Rancholabrean is recognized within the pre-Illinoian glacial sequence of western Iowa (i.e., the Rancholabrean is not exclusively Wisconsinan through Illinoian as some have suggested). In sum,

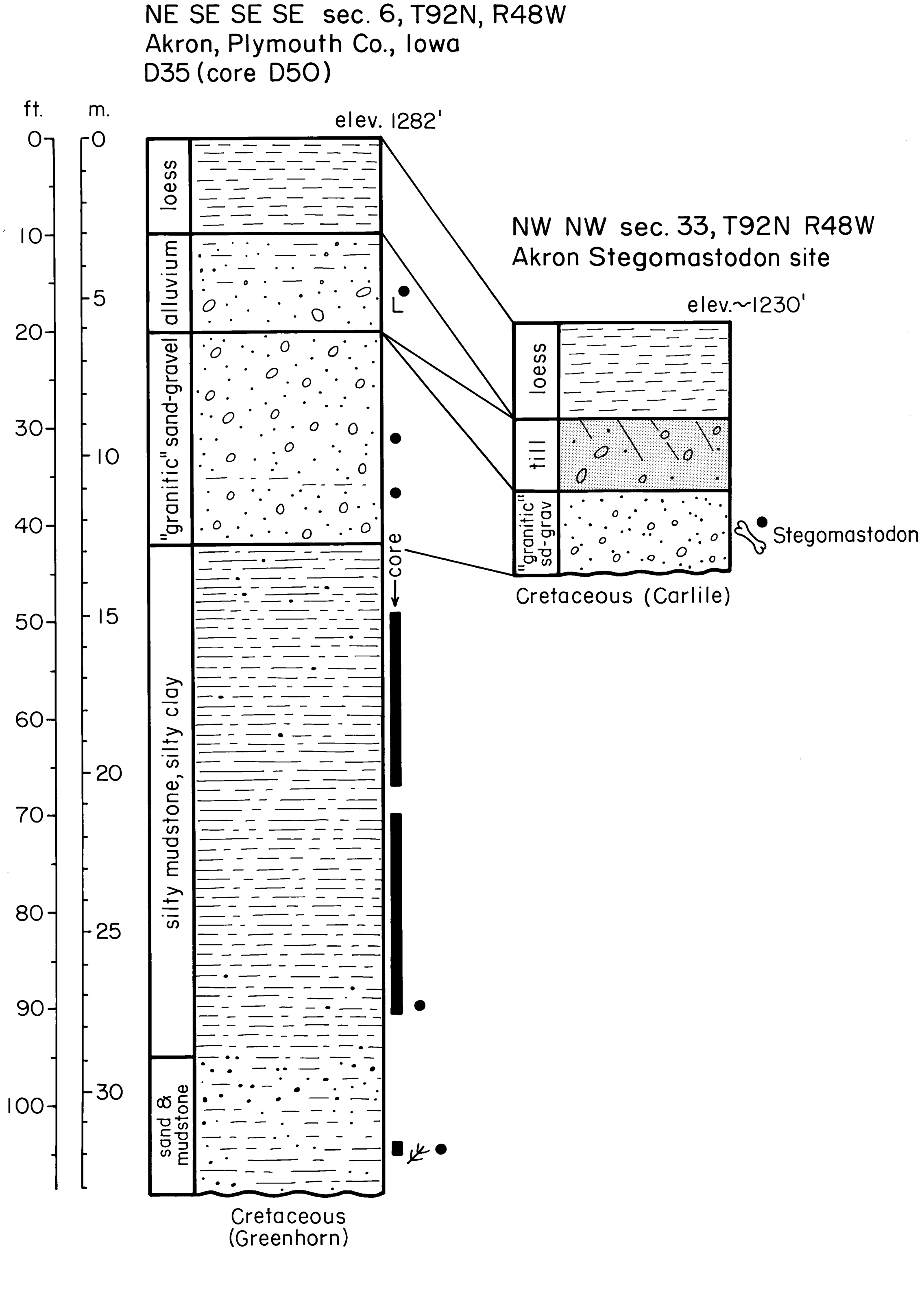


Figure 7. Post-Cretaceous stratigraphic sequences from near Akron, northwest Iowa (Loc. AK, Figs. 2 and 3). Sequence from Akron *Stegomastodon* site adapted from Shimek (1910) (adhering lithologic sample removed from bone). Symbols as in Figure 5.

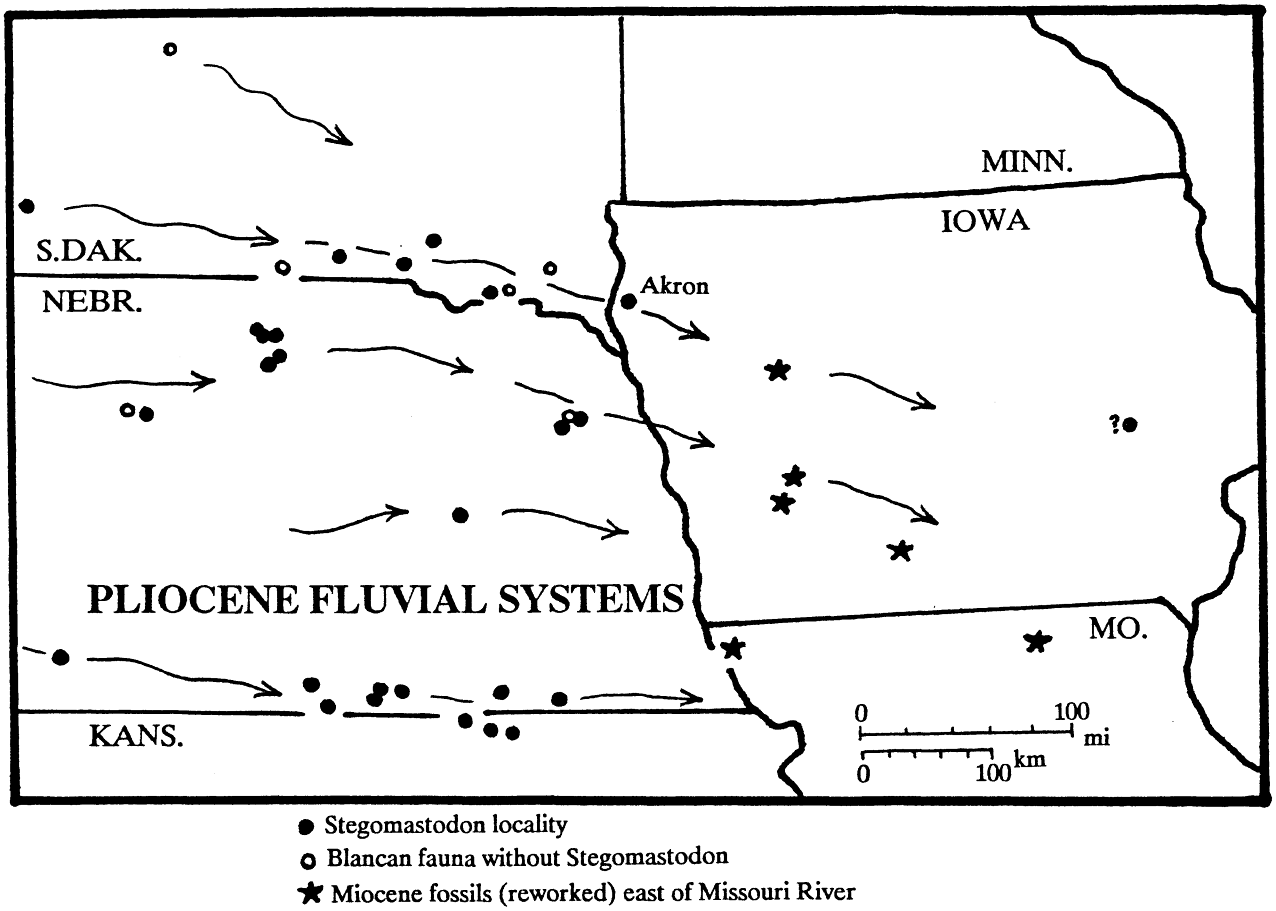


Figure 8. Location of *Stegomastodon* sites or other Blancan-Sappan faunas in Nebraska and adjacent areas. Occurrence of reworked Miocene fossils in Iowa-Missouri also noted. Arrows schematically illustrate general eastward drainage of fluvial systems during the Miocene-Pliocene. *Stegomastodon* localities largely derived from Schultz (1934), Pinsof (1985), and Eshelman (1975).

mammal faunas and volcanic ashes (610 and 738 ka) in inter-till positions in eastern Nebraska and western Iowa suggest an Irvingtonian and possibly early Rancholabrean age for the sequence of A and B tills and intervening fluvial units.

The occurrence of *Stegomastodon mirificus* in granite gravels of northwestern Iowa (Hay, 1914) provides some general chronologic constraints for the stratigraphic sequence near Akron (Fig. 7). *Stegomastodon* is most characteristic of Blancan units across the Great Plains, although one species (*S. barbouri*) is known to co-occur with *Mammuthus* in some early Irvingtonian (Sappan) faunas (Martin and Schultz, 1982; Madden, 1986). Sappan faunas are constrained at two midwestern localities below a 1.2 Ma ash (Martin and Schultz, 1982), indicating that the youngest occurrences of *Stegomastodon* in the region are apparently older than the B-tills. *Stegomastodon* has been recovered from various Blancan and Sappan units west of the Iowa line (Figs. 2,8), co-occurring at some localities with other Blancan-Sappan elements such as *Procastoroides sweeti* and *Titanotylopus*. The presence of *S. mirificus* at Akron suggests a Blancan assignment, although it is not known if the species ranges into the Sappan. Regardless, mudstones of the "s & p" suite occur in stratigraphic position below the *Stegomastodon* gravels, suggesting a Blancan (Pliocene) or older age for the Akron mudstone interval. Similar stratigraphic occurrences of Blancan sands and gravels above "s & p" mudstones are noted in southeastern South Dakota (Martin and Harksen, 1975) and northeast Nebraska (Blancan or Sappan gravels above mudstones of the Ogallala Gp.).

An anomalous fauna of Pliocene(?) and

Miocene mammal fossils has been recovered from Quaternary glacigenic sand and gravel units and modern alluvium at several localities in western Iowa and northern Missouri (locations shown on Figs. 2 and 8; collections reposited at University of Iowa, Dept. of Geology). These occurrences include: 1) supposed "Aftonian" gravels near Thayer, Union Co., Iowa, and Rockport, Atchison Co., Missouri (Calvin, 1909, 1911); 2) possible Wisconsinan gravels from near Atlantic, Cass Co., and Lake View, Sac Co., Iowa; and 3) reworked alluvium along stream courses near Brayton, Audubon Co., Iowa, and Sidney, northwest Adair Co., Missouri. Fossils include rhinoceros teeth from Lake View and Brayton (aff. *Teleoceras*). Virtually all rhinoceros species became extinct in North America near the end of the Hemphillian (latest Miocene), although an indeterminate "Hemphillo-Blancan" (earliest Pliocene?) rhino fossil is known from one locality (Savage and Russell, 1983). Rhino fossils are well known from Ogallala strata in northeast Nebraska (e.g., Voorhies and Thomasson, 1979), but are unknown from post-Ogallala units in the upper Midwest. Fossils from small three-toed horses include: 1) indeterminate lower molars and upper cheek teeth (some aff. *Pseudhipparion*) from Atlantic and Thayer, and 2) limb bones from Thayer (proximal metapodials, astragalus, phalanx) and Sidney (distal metapodials). The best preserved small horse tooth is from Rockport, which is an upper molar assigned to the Clarendonian (Miocene) *Pseudhipparion gratum*, a form well known from the Ash Hollow Formation in the Ogallala Group of Nebraska (original species identification after Calvin, 1911; Hay, 1914; interpretation as a pre-Blancan taxon further confirmed by Hibbard, 1948, and Voorhies, pers. comm., in Rhodes and Semken, 1986, p. 96, and this study). Small three-toed horses did not survive the Pliocene (Blancan), and only one genus survived the Miocene in North America (Savage and Russell, 1983). A distal metapodial of an indeterminate ruminant from Brayton (possibly an antilocaprid smaller than modern *Antilocapra*) may also belong with this collection of pre-Pleistocene mammals. The presence of three-toed horses and rhinos in the Iowa and Missouri collections indicates derivation of this fauna from deposits of Tertiary age, most likely Miocene Ogallala equivalents.

Were these reworked Miocene fossils from Missouri and Iowa derived locally through erosion of distal sub-till Ogallala outliers present east of the Missouri River, or alternatively, were they derived from Ogallala strata in Nebraska and transported eastward into Iowa and Missouri by Quaternary rivers or glacial lobes? The general derivation of glacigenic sand from northern and northeastward sources and the development of a general southwestward Quaternary drainage in western Iowa would tend to preclude the latter alternative. Reworked Ogallala fossils have also been recovered from Plio-Pleistocene granitic and glacigenic sand and gravel units in southeast South Dakota and northeast Nebraska (e.g. Flint, 1955), and a local origin for these occurrences is also likely.

COMPARATIVE PETROGRAPHY AND INTERPRETATION OF PROVENANCES

Introduction

Various inter-till and sub-till alluvial units were sampled from exposures and well penetrations in western Iowa (Figs. 2,4). Samples from various units in eastern Nebraska and the Missouri River Valley were taken for comparative purposes (Fig. 2); these include 1) Ogallala and Hemphillian units from northeast Nebraska, 2) granite gravels above Ogallala strata in northeast Nebraska, 3) glacigenic sands and gravels from northeast and southeast Nebraska, 4) type section of the Fullerton Formation (as defined by Reed and Dreeszen, 1965), 5) modern Missouri River alluvium at Niobrara, Nebraska (Loc. NB), and Wilson Island State Park, Iowa (Loc. WI), and 6) modern Platte River alluvium at Venice, Nebraska (Loc. VN), and various localities in central Nebraska. Sand, siltstone, and mudrocks were vacuum impregnated with epoxide resin and standard thin sections were prepared. Thin sections were point-counted and data tabulated using the Gazzi-Dickinson method (Ingersoll et al, 1984). This method was used in order to minimize apparent differences in detrital modes that are artifacts of grain-size differences, thus facilitating comparisons between compositions of different suites of sediments. The composition of gravel and pebble clasts was tabulated by standard counts of 200 individual sieved grains >2 mm.

Compositional Characteristics

Sand and mudrocks of the "s & p" suite are characterized by the presence of volcanic rock fragments (up to 7%, avg. 2.6%) and by the absence or general scarcity of Paleozoic carbonate grains (Witzke and Ludvigson, 1988). Quartz is the primary component (range 50.6-78.9%, avg. 66.2%), dominantly monocrystalline quartz with secondary polycrystalline forms (chert). Plagioclase is consistently present (range 1-6.3%, avg. 4.0 %), and K-feldspar content is variable (1-13.3%, avg. 8.4%). Metamorphic lithic grains consistently occur, but are variable (range 0.3-8%, avg. 2.5%). Gravel clasts from sand units within the suite are dominated by quartz, chert, and granite, and Paleozoic carbonate clasts have not been recovered (see earlier discussion).

Glacigenic sands and gravels display compositions that are notably different from those of the "s & p" suite. Sands lack or contain only trace amounts of volcanic lithic grains (0-0.6%), but carbonate rock fragments are typically present (up to 35%). However, some fine glacigenic sands and silts locally lack carbonate grains, possibly due to post-depositional leaching. Associated gravels consistently contain carbonate clasts (larger clasts are not as easily leached). Glacigenic sands display an overall lower plagioclase content (range 0-1.6%, avg. 1.0%) than seen in the "s & p" suite, although K-feldspar content is comparable (range 5-15%, avg. 10.9%). Glacigenic gravel data was derived from Carman (1931) and this study. Pebble counts from glacigenic gravels in western Iowa are generally indistinguishable from pebble counts derived from glacial tills in the region (Boellstorff, 1973), verifying a glacigenic source for the gravels. However, pebble count data from gravel units of the glacigenic suite differ significantly from that seen in the "s & p" suite. Glacigenic gravels in western Iowa consistently contain carbonate lithoclasts, especially Paleozoic-type dolostone and limestone; carbonate clast content ranges from 13-80%, whereas pebble counts from the "s & p" suite at Folsom Quarry have failed to disclose any carbonate gravel (see Fig. 9). The ratio of siliceous resistate (quartz, chert, quartzite) to unstable grains (igneous and metamorphic rock fragments, feldspar) is notably less in the glacigenic gravels than seen in the "s & p" suite (Fig. 9).

The granitic sand and gravel suite is compositionally characterized by an abundance of only a few grain types, dominantly quartz (including chert) and K-feldspar in the sand fraction, and quartz, K-feldspar, and coarsely-crystalline granite clasts (composed dominantly of quartz and pink feldspars) in the gravel fraction. Traces of mafic and intermediate igneous and metamorphic lithoclasts are noted in granite gravels in northeast Nebraska. Granite and chert clasts and feldspar grains seen in the granitic suite closely resemble many pebbles in the "s & p" suite. However, most granite clasts in the glacigenic suite (especially biotite granites and granitic gneisses) are of differing composition than lithoclasts of the granitic suite, and must have been derived from different souce areas. The granitic sand and gravel suite includes generally coarser grained lithologies than seen in the "s & p" suite, and volcanic lithic grains have not been seen in the granitic sands and gravels at Akron, Iowa.

Comparisons Between Eastern Nebraska and Western Iowa

A number of sedimentary units in eastern Nebraska compare favorably with the "s & p" suite of western Iowa. The consistent presence of volcanic lithic grains, relatively high plagioclase content (>2%), and the general absence or scarcity of carbonate rock fragments indicates close similarities between the the "s & p" suite in western Iowa and mudrocks and sands of the Ogallala Group (Valentine and Ash Hollow Fms.), Hemphillian channels (Santee local fauna; Voorhies, 1977), Fullerton Formation, and modern Platte and Missouri River alluvium in eastern Nebraska . These various units in Nebraska can logically be included as part of the "s & p" suite. Likewise, granitic sands and gravels at Akron, Iowa, are compositionally indistinguishable from western-derived Blancan and Irvingtonian granite-gravel channels in eastern Nebraska and closely resemble the coarse sand and gravel fraction of modern Platte River alluvium sampled in central Nebraska.

QFL modal analysis of sands is inadequate by itself to distinguish the glacigenic suite from the "s & p" suite, although the scarcity of aphanitic lithic grains separates the granitic sand and gravel suite on the QFL diagram (Fig. 10). Additional triangular plots, including the standard QpLvLsm and QmPK diagrams of Dickinson and Suczek (1979), were constructed which serve to contrast

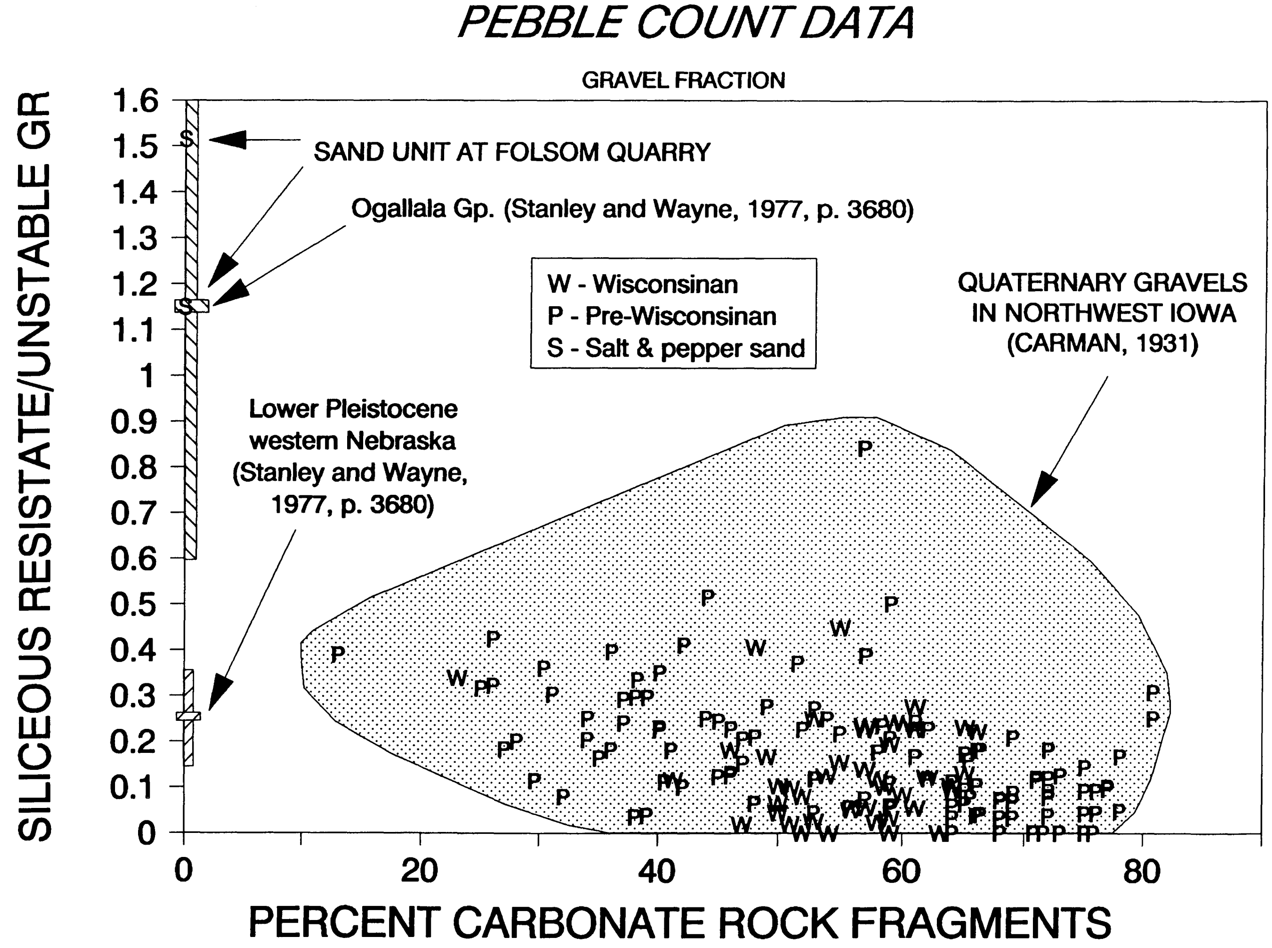


Figure 9. Pebble count data for Pleistocene glacigenic gravels contrasted with pebbles from basal "salt & pepper" sand at Locality FQ (Field Trip Stop 6). Data expressed on plot of carbonate rock percent vs ratio of siliceous resistate (quartz, chert, quartzite) over unstable grains (igneous and metamorphic lithoclasts, feldspar). Pebble count data after Carman (1931) and this study.

differing compositional parameters (Fig. 10). A plot of lithic grains clearly separates the glacigenic suite (high Lc, low Lv) from other sedimentary associations (Fig. 10, LcLvLsm plot). The high content of K-feldspar in the granite gravels serves to separate that suite on the QmPK plot (Fig. 10). The overlapping fields seen on the various plots (Fig. 10) also suggest a relatively high degree of compositional similarity between the various lithologies.

Provenance

Detrital sediments of the glacigenic suite in western Iowa are interpreted to have been sourced from Precambrian crystalline terranes in Minnesota and Ontario, as well as intervening regions of Sioux Quartzite and Paleozoic and Cretaceous bedrock. The presence of Cretaceous fossils in some western Iowa glacigenic gravels (including shark teeth in upper stratified gravel pod at Folsom Quarry), the presence of Cretaceous carbonates (forams and inoceramids), and the apparent contribution of Cretaceous marine shale to the clay composition of the pre-Illinoian tills, all suggest derivation from nearby Cretaceous strata in Minnesota and northern Iowa (and probably including the eastern fringe of the Dakotas).

Abundant limestone and dolostone detritus in the glacigenic suite were most likely sourced from Paleozoic carbonate bedrock units in northern Iowa and southern Minnesota and transported into western Iowa by southwestward expansion of successive pre-Illinoian glacial lobes (Minnesota

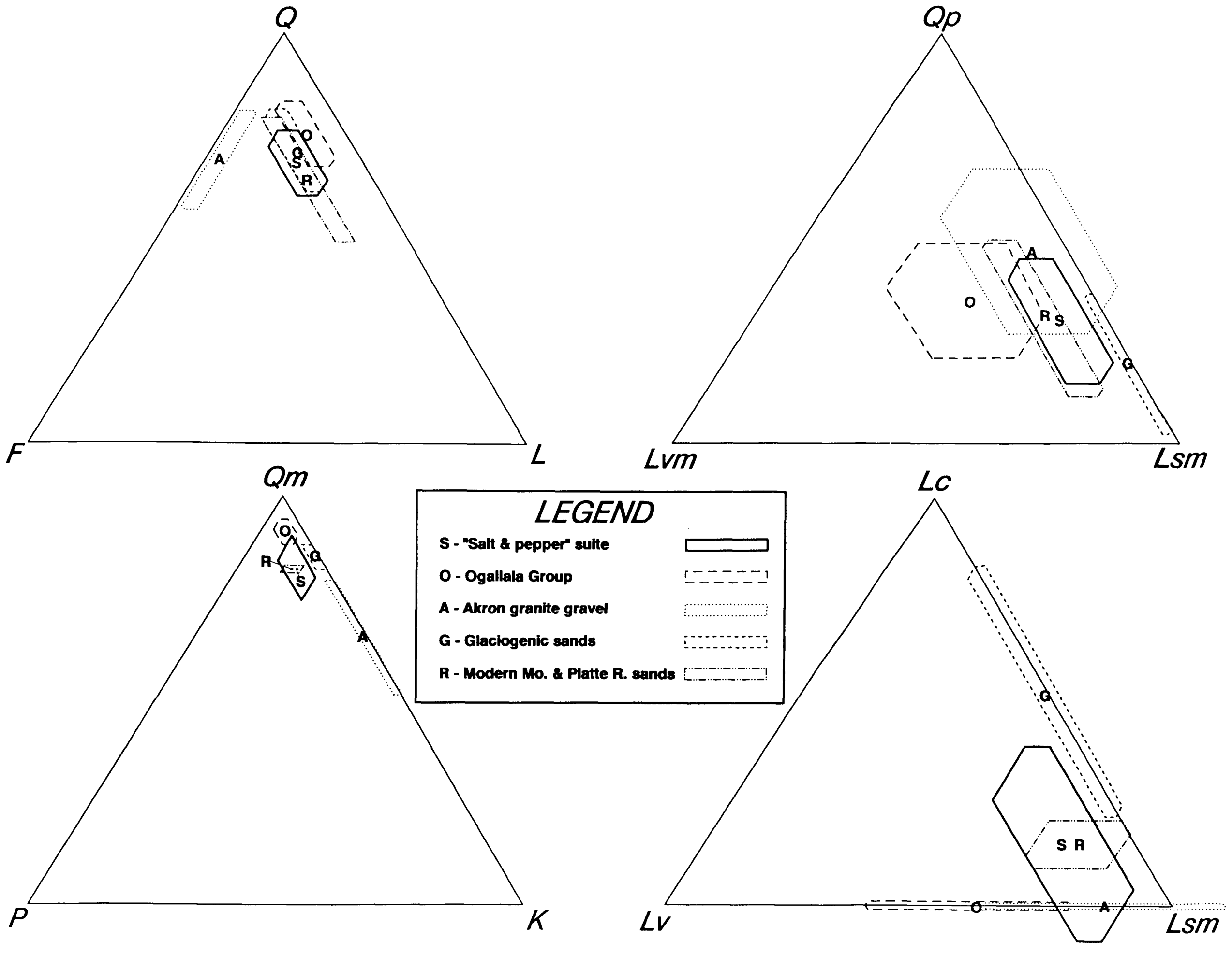


Figure 10. Triangular QFL, QpLvmLsm, QmPK, and LcLvLsm diagrams comparing the populations of detrital framework grains in sands from late Cenozoic units from western Iowa and eastern Nebraska. Mean values for each unit are plotted with letter symbols, and the hexagonal fields enclose one standard deviation from the mean for each grain parameter. Hexagons plotting outside the triangular diagram indicate skewed populations with most of the data plotting along the enclosed axis. Grain parameters are: Q, total quartzose grains; F, feldspars; L, total lithic fragments; Qp, polycrystalline quartz; Qm, monocrystalline quartz; Lc, carbonate rock fragments; Lv, volcanic rock fragments; Lvm, volcanic and metavolcanic rock fragments; Lsm, combined sedimentary and metasedimentary rock fragments; P, plagioclase; K, K-feldspar.

Lobe of Aber, 1982) and their associated outwash. Glacial lobes (Dakota Lobe of Aber, 1982) that expanded southward or southeastward across the Dakotas into eastern Nebraska would probably carry a smaller component of Paleozoic carbonate clasts because of the absence of Paleozoic bedrock outcrop between Manitoba and southeast Nebraska. All examined till units in western Iowa contain a significant component of Paleozoic-type carbonates (Boellstorff, 1973), suggesting that glacial transportation of sediments into western Iowa was dominantly from Minnesota Lobe advance. Nevertheless, some apparent glacial-derived sands and gravels examined in eastern Nebraska (Cedar and Johnson Cos.) contain only sparse carbonate clasts, but do contain Paleozoic chert clasts with Devonian fossils possibly derived from Manitoba bedrock and transported by advance of Dakota Lobes. Although beyond the scope of this paper and deserving additional study, there may be two compositionally distinctive suites of glacigenic sands and gravels in eastern Nebraska: 1) A suite indistinguishable from that seen in western Iowa and containing abundant Paleozoic carbonate clasts (gravels >10% carbonate) and probably transported from Minnesota Lobe advances; and 2) A suite with sparse to absent Paleozoic carbonate clasts, but containing some Paleozoic and Precambrian lithologies from probable Canadian sources and transported by Dakota Lobe advances. The oldest Phanerozoic tills in central North America, the C-tills (including the Elk Creek Till) of southeastern Nebraska and southwestern Iowa, are characterized by the highest abundances of Paleozoic carbonate clasts (up to 78%) in the till sequence (Boellstorff, 1973; Hallberg, 1988, pers. comm.).

There is general agreement that the Plio-Pleistocene granitic gravels of Nebraska, South Dakota, and Kansas were derived from Laramide uplifts to the west (e.g. Flint, 1955; Stanley and Wayne, 1972). The close compositional similarity of modern Platte River gravels with the granitic suite further underscores this interpretation. Stanley and Wayne (1972, p. 3678) indicated that in Nebraska the "granitic gravels . . . are composed principally of Sherman Granite detritus derived from the front ranges of the Rocky Mountains in Wyoming and Colorado." The occurrence of typical granite gravels in northwestern Iowa is certainly an indication that western-derived fluvial systems flowed into western Iowa unimpeded by an intervening north-south drainage network (i.e. the modern Big Sioux and Missouri Rivers). East of the till border in eastern Nebraska, some granitic gravels incorporate clasts of probable Sioux Quartzite with other Minnesota Precambrian lithologies and locally-derived upper Paleozoic and Cretaceous clasts (Stanley and Wayne, 1972). This suggests that glacigenic input (via glacial outwash or the erosion of older till units) to the western-derived fluvial systems locally mixed lithologies of the glacigenic and granitic suites. Alternatively, southward-draining tributaries from adjacent upland regions in southwest Minnesota (especially the Sioux Quartzite Ridge and adjacent granites of the Minnesota River Valley) may have contributed northern Precambrian detritus to the western-derived trunk streams during pre-glacial or inter-glacial times as well.

The "s & p" suite in western Iowa is also interpreted to have been western-derived, sourced from the Rocky Mountain region. Although both the "s & p" and granitic suites are both interpreted to have been sourced from the same general areas, compositional contrasts between these two suites are most likely the result of differences in overall grain size in contrasting flow regimes. In addition, some of the compositional variation in western-sourced fluvial sediments must also relate to the tectonic and erosional history of Laramide uplifts and/or volcanic centers in the source areas. As seen in modern Platte River alluvium, the coarse sand and gravel fraction is similar to the granitic suite whereas the occurrence of dark volcanic lithic grains in the fine sand and silt fraction suggests assignment to the "s & p" suite. The close similarities of the "s & p" suite of western Iowa with sediments of the Ogallala Group and other western-derived units in Nebraska strongly supports a western source for the Iowa occurrences. In addition, the general dissimilarity of this suite with the glacigenic suite further indicates different source areas. Sparse occurrences of probable Sioux Quartzite clasts and possible northern-derived igneous and metamorphic clasts in the "s & p" sand at the Folsom Quarry suggest possible input of glacigenic detritus to the western-derived streams that apparently flowed across western Iowa prior to deposition of the B-tills. If this latter suggestion is true, the "s & p" unit at Folsom Quarry would be no older than the oldest glaciation in the area (C-tills). Miller (1964) reported the "s & p" unit above "Nebraskan" tills 2.7 km (1.7 mi) north of the quarry, and, therefore, weathering of local tills are a possible source for the minor influx of glacigenic clasts to the western-sourced alluvium.

STRATIGRAPHIC IMPLICATIONS

Previous Stratigraphic Nomenclature

Stratigraphic nomenclature applied to the post-Cretaceous sequence in western Iowa has a long and tortuous history involving miscorrelation, poorly-defined lithostratigraphic units, and an early paradigm that only two till units were present in the area ("Kansan" and "Nebraskan"). During the first three decades of the 1900s a general concept of the pre-loess sequence had emerged, in ascending order: 1) a basal "ante-glacial" silt and sand unit of possible Tertiary age (e.g., Udden, 1903, who included "s & p" unit at Folsom Quarry), 2) Nebraskan till, 3) gumbotill and Aftonian gravels, 4) Kansan till, and 5) Yarmouth gumbotill and valley gravels (e.g. Carman, 1917). Kay and Apfel (1929) also interpreted a pre-glacial, probably Tertiary, interval of sands and clays in the Council Bluffs area. Subsequent studies attempted to apply eastern Nebraska stratigraphic nomenclature (after Lugn, 1935; Condra et al., 1950) to the western Iowa sequence, and Miller (1964) proposed a pre-loess sequence as follows: 1) David City (?) Fm., 2) Nebraskan till, 3) Fullerton Fm., 4) Kansan till, 5) Grand Island Fm., 6) Sappa Fm. (with Pearlette Ash), and 7) Crete Fm. The interval termed Grand Island in Iowa by Miller (1964) is a glacigenic sand and gravel that is lithologically dissimilar to the western-derived granite gravels represented in the type Grand Island. Lugn (1935) identified two till units in Nebraska, whereas Condra et al. (1950) recognized four till units in eastern Nebraska: Nebraskan, Kansan, Illinoian, and Iowan (early Wisconsinan).

New stratigraphic interpretations led Reed and Dreeszen (1965) to propose a revised and complex stratigraphy for the glaciated areas of eastern Nebraska, in ascending chronologic order: 1) David City and basal Seward sands and gravels; 2) Elk Creek Till (Nebraskan) and correlative Seward Formation silts; 3) Iowa Point Till (Nebraskan) and correlative Fullerton Formation silts and Holdredge basal sands and gravels; 4) Afton Soil; 5) Nickerson Till and pro-glacial Atchison Formation sands (early Kansan); 6) Fontanelle Soil; 7) Cedar Bluffs Till and correlative sands of the Walnut Creek Formation (medial Kansan); 8) basal Grand Island sand and gravel, Sappa Formation silts, Pearlette Ash (late Kansan); 9) Yarmouth Soil; 10) Clarkson Till and correlative fluvial and eolian sediments of the Grafton Formation (early Illinoian); 11) Santee Till and supposedly equivalent fluvial and eolian sediments of the Beaver Creek Formation (medial Illinoian); 12) Crete sand and gravel; 13) Loveland Loess (late Illinoian); 14) Sangamon Soil; 15) Hartington Till (medial Wisconsinan); and 16) various mid and late Wisconsinan eolian, fluvial, and soil units. This complex stratigraphy recognized seven rather than four glaciations in the area. The Reed and Dreeszen (1965) stratigraphic nomenclature was never adopted for general use in western Iowa.

Boellstorff (1973, 1978a,b) studied the till sequence using classic exposures and subsurface cores in eastern Nebraska and western Iowa, and recognized several significant problems with the Reed and Dreeszen (1965) stratigraphy: 1) The till sequence had been incorrectly ordered (the youngest till [A1] is the type Clarkson not Hartington Till). 2) All tills are pre-Illinoian (he interpreted no Illinoian or Wisconsinan tills). 3) He suggested that the Santee, Hartington, and Nickerson tills represent the same group of tills (A3), creating problems with previous glacial and periglacial correlations and the definitions of several inter-till alluvial and pedogenic units. 4) Till units were recognized beneath the Nebraskan Till of Shimek (see Hallberg, 1987), indicating conceptual problems with previous ideas about till chronology and the so-called Nebraskan glacial stage. 5) The recognition of two so-called "Pearlette" ashes in the region (see also Izett, 1981) created problems with the correct placement of the Sappa Formation in the sequence. The Sappa Formation was generally identified by its co-occurrence with the "Pearlette Ash"; the type Sappa sequence contained a 1.27 Ma ash, whereas many units termed "Sappa" in Iowa and Nebraska contained a 0.61 Ma ash. The important studies of Boellstorff (1973, 1978a,b,c), therefore, left the stratigraphic nomenclature of the inter-glacial and pre-glacial sequence of western Iowa and eastern Nebraska in a general state of nomenclatorial confusion. Many units lacked formal stratigraphic nomenclature (including the B-tills and upper "Sappa" unit), and serious questions remained about the actual chronology of the alluvial stratigraphic sequence. This situation has not changed significantly in the past decade.

Potential Stratigraphic Relationships Between Iowa-Nebraska

Gross lithologic and stratigraphic comparisons of the three compositional suites in western Iowa with various alluvial units of Nebraska enable some tentative ideas to be drawn about general stratigraphic relationships and chronology. The "s & p" suite of western Iowa apparently pre-dates the B-till sequence (see earlier discussion), suggesting comparisons with "s & p" sand and mudrock sequences in eastern Nebraska including intervals interpreted as type Sappa equivalents, Fullerton Formation, Seward Formation, and Ogallala Group. Some "s & p" units in western Iowa occur above a basal till suggesting probable correlation with units commonly termed Sappa and/or Fullerton. A pre-Sappa correlation is indicated for that part of the sequence in Iowa containing a 2.0 Ma ash; this interval is generally termed Fullerton

Formation in Nebraska, although the actual stratigraphic relationships of either the type Fullerton section of Lugn (1935) or "substitute type" Fullerton section of Reed and Dreeszen (1965) are not presently known.

Silts and mudrocks of the Seward Formation in eastern Nebraska were not examined for this study, and it is not known if the interval belongs to the "s & p" suite. The Seward, which apparently occupies a position below the oldest (C) tills, was originally interpreted as a distal facies of Ogallala strata (Condra et al., 1950). However, Reed and Dreeszen (1965) and other workers have subsequently interpreted the Seward as a periglacial equivalent of the Elk Creek Till. Further compositional and stratigraphic studies are needed to contrast the Seward with "s & p" units in Iowa. Close compositional similarities of the Ogallala Group of northeast Nebraska and the "s & p" suite of western Iowa have already been discussed. The general sub-till stratigraphic placement of most "s & p" units in western Iowa does not preclude the possibility that some of the Iowa units may be Ogallala equivalents. As discussed, the recovery of reworked Ogallala fossils in Iowa is most parsimonious with the idea that Ogallala outliers east of the Missouri River provided a local source for the fossils. To summarize, available data for the "s & p" suite in Iowa suggests that some intervals correlate with strata termed Fullerton Formation in Nebraska. However, it is not inconceivable that some "s & p" units in Iowa equate with Ogallala and/or Seward strata in eastern Nebraska.

The presence of granite gravels with *Stegomastodon* in northwest Iowa invites comparison with granite gravel units in Nebraska and southeastern South Dakota containing *Stegomastodon* or other Blancan-Sappan fauna. This includes gravel units variably termed Red Cloud, Holdredge, "probably Grand Island" (Schultz, 1934, p.373), Broadwater-Lisco (Schultz and Stout, 1948), Long Pine (Skinner et al., 1972), and Belleville (Eshelman, 1975) in Nebraska, and Herrick, Grand Island, and Bon Homme (Christensen, 1974) in South Dakota. Eshelman (1975, p.5,7) pointed out "the cluttered and confused status . . ." of alluvial stratigraphy across the central Plains and suggested that it is ". . . conceivable that the Red Cloud, Holdredge, Fullerton, and Belleville formations are at least in part equivalent in age." The presence of *Stegomastodon*-bearing granite gravels in northwest Iowa above mudrocks of the "s & p" suite suggests two or three possible stratigraphic analogs in eastern Nebraska: 1) Red Cloud gravel on Fullerton Formation, 2) Red Cloud or Holdredge gravels on Ogallala Group, and 3) possibly Holdredge on Seward Formation if Seward is "s & p" suite. Granite gravels overlie Ogallala strata at many localities in northeast Nebraska only 70-90 km west of Akron, although Reed and Dreeszen (1965, p.30,64) have also interpreted Holdredge gravels above Seward mudrocks in that area. Blancan sand and gravel is also known to overlie an "undated silt" unit and underlie till in southeastern South Dakota (Martin and Harksen, 1975), a stratigraphic sequence perhaps analogous to that seen at Akron, Iowa.

In summary, potential stratigraphic correlations of "s & p" and granite gravel units in western Iowa with sequences to the west has proven difficult. However, Blancan-Sappan granite gravels are present in northwest Iowa that probably correlate with the Holdredge, Red Cloud, and/or Bon Homme gravels of Nebraska and South Dakota. "S & p" units in Iowa correlate, at least in part, with the "Fullerton" Formation of Nebraska. However, if more than one "s & p" unit occurs in Iowa, additional correlations with strata of the Ogallala Group, Seward Formation, and/or type Sappa Formation in Nebraska are also conceivable.

HISTORICAL IMPLICATIONS OF THE WESTERN IOWA SEQUENCE

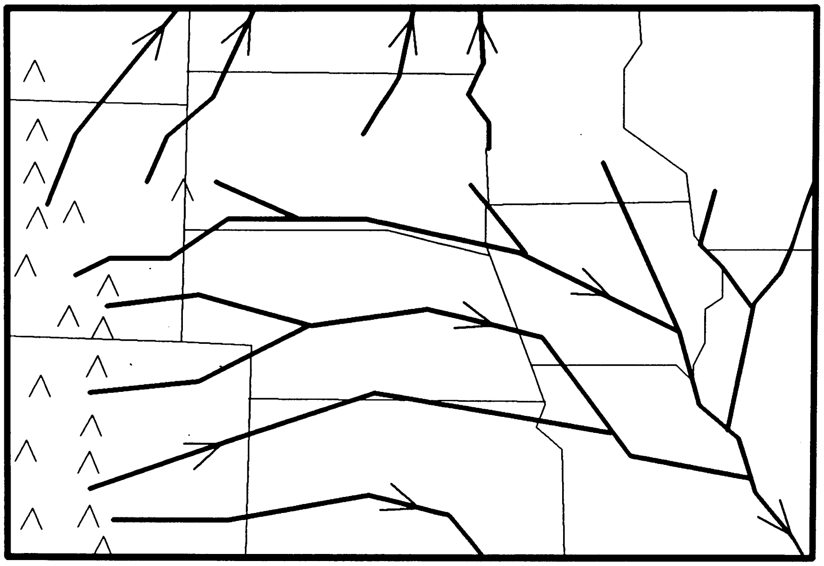
The Missouri River presently diverts southward all western-derived fluvial systems headwatered in the Rocky Mountains-Black Hills areas which flow eastward across South Dakota and Nebraska (e.g. Belle Fourche, Cheyenne, Niobrara, Platte Rivers). This modern drainage network does not permit deposition of western-derived sediments anywhere in Iowa outside of the entrenched Missouri River Valley. The widespread occurrence of western-derived fluvial sediments in western Iowa, particularly sands and mudrocks of the "s & p" suite (Fig. 3), provides clear and convincing evidence for a drainage network considerably different than seen in the area today. It can be concluded that there was no southward draining proto-Missouri River in the area when deposition of "s & p" and granitic suite sediments was occurring in western Iowa.

The occurrence of "s & p" sediments beneath the B-tills and above probable C-tills indicates that a west-to-east drainage trended across at least part of western Iowa immediately preceding B-till deposition. Nevertheless, it can be assumed that a temporary southward diversion must have occurred earlier in western Iowa and eastern Nebraska in response to the southward expansion of glacial lobes responsible for deposition of the C-tills in the region. The general absence of "s & p" sediments in the post-B-till sequence outside the Missouri River Valley in western Iowa, and the significant change to northeastern-derived glacigenic fluvial sediments in the post-B-till sequence, indicate that a southward-draining proto-Missouri system was established in the region during or following B-till deposition. This is not to say that the modern Missouri River drainage pattern was established at that time, merely that a southward diversion of western-derived sediments had occurred. The location of the main trunk stream ("proto-Missouri" River) for such a drainage network probably shifted in response to the advance and retreat of continental glacial lobes across the region. The southward expansion of ice sheets would cut off older west-to-east drainages, forcing a southward diversion in ice-marginal, interlobate, and other outwash settings. A schematic representation of regional drainage patterns during the Miocene, Plio-Pleistocene (pre-B-till) is illustrated in Figure 11; the eastward drainages were diverted by glacial advances during the Quaternary (post-B-till), schematically shown in Figure 11.

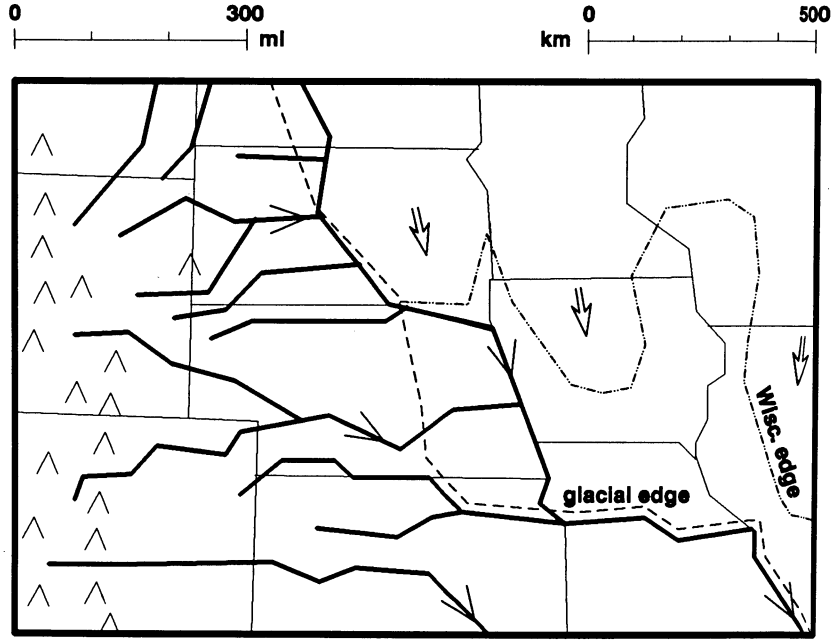
Condra et al. (1950, p. 4) recognized buried channels and a pre-glacial drainage system in the area: "There are places in South Dakota, Nebraska, Iowa and Missouri where pre-glacial drainage courses extended eastward and southeastward across the location of the present Missouri River Valley." They (ibid.) proposed that major changes in drainage patterns occurred during the "Nebraskan" to "late or post-Kansan" interval. Flint (1955, p. 147) described the southward drainage diversion in South Dakota: "The radical diversion of the drainage of the eastern part of the State [S.Dak.] from an east-flowing system to a generally south-flowing system was an event of such wide importance that it constitutes a time marker from which both earlier and later events are dated." Flint (ibid.) suggested this diversion separated ". . . Sangamon and Wisconsin history from pre-Illinoian history."

The modern Missouri River Valley entrenchment apparently cuts across the pre-Illinoian till sequence (as exposed in its valley walls). Most wells drilled in the valley floor in Iowa do not penetrate any till but show silt, sand and gravel alluvium above Pennsylvanian or Cretaceous bedrock. This alluvium resembles modern Missouri alluvium in part, and contains a mixture of both glacigenic and "s & p" suite sediments, with additional Cretaceous lithoclasts probably derived from farther up the Missouri Valley (including Campanian lignite, R. Ravn, 1988, pers. comm.). The general absence of till within the Missouri Valley suggests a post-till bedrock entrenchment. However, the description of till from two well penetrations below the floor of the Missouri Valley in Monona County (including the Whiting town well) may provide evidence that the incised Missouri Valley actually was occupied by glacial ice, that is, the valley, or portions of it, might have a pre-Illinoian origin. Alternatively, these isolated till occurrences may indicate that the river valley was incised into the till sequence preserving scattered till remnants below alluvium within the valley; this interpretation is compatible with an Illinoian origin for the development of the modern Missouri Valley. Deep incision (120-200 m) of the Missouri River Valley in the Lewis and Clarke Lake area (separating Yankton Ridge, S.Dak. and Devils Nest area, Nebr.) cuts across the A-till sequence (and possibly even younger tills) and into underlying Cretaceous and Tertiary units, indicating a probable Illinoian origin for that part of the valley (e.g. Flint, 1955).

Thick sequences of Loveland Loess (Illinoian) in Iowa are best preserved along the valley walls of the modern Missouri River, suggesting that a "modern" valley configuration was in place by the Illinoian. The general absence of tills below the Missouri Valley floor, the incision of the valley across the A-and B-till sequence, and the location of thick Illinoian loess all suggest that the modern Missouri River Valley was entrenched following depositon of the A-tills but prior to Illinoian loess deposition. However, as discussed in previous paragraphs, the southern-diversion of eastward-flowing systems in Iowa became regionally apparent during pre-Illinoian time. If the major southward-diversion was pre-Illinoian but the modern Missouri Valley is entirely of Illinoian and Wisconsinan origin, southward drainages analogous to the modern Missouri Valley should have been



GENERALIZED MIOCENE-PLIOCENE DRAINAGE



GENERALIZED QUATERNARY DRAINAGE

Figure 11. Schematic representation of general drainage patterns (heavy lines) for the Miocene-Pliocene and Quaternary (post-B-till) in the central Great Plains region. Rocky Mountains shown along western margin. Arrows over drainages indicate general fluvial transport directions; open arrows show general direction of glacial advance. Dashed lines show approximate extent of glacial tills and Wisconsinan glacial margin.

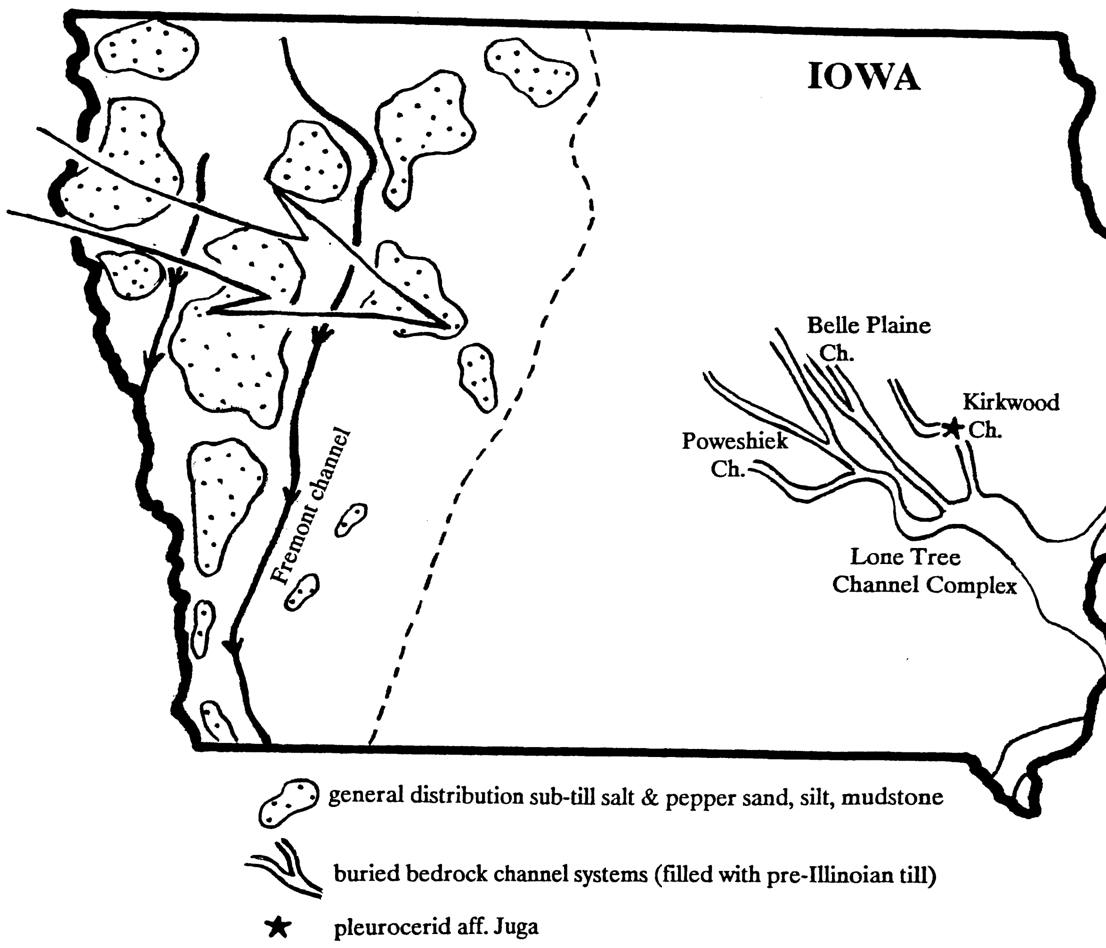


Figure 12. Schematic diagram showing general extent of sub-till fluvial sediments of the "s & p" suite in bedrock upland divides of western Iowa. The Fremont Channel apparently cuts across the older sequence of "s & p" sediments. Location of deep bedrock channels shown for southeastern Iowa. Large arrow shows general eastward transport direction for sediments of the "s & p" suite.

developed outside the area of the modern valley during the pre-Illinoian.

Condra et al. (1950), Reed and Dreeszen (1965), and others discuss potential channel locations developed by southward drainage diversions, and various ice-marginal, moraine-controlled, and bedrock channel positions were considered in eastern Nebraska and western Iowa. A prominent bedrock channel trends southward across western Iowa from Minnesota to Missouri, termed the Fremont Channel (e.g. Sendlein and Gilmore, 1980; Hansen and Runkle, 1986). This channel apparently cuts across a sequence displaying a basal "s & p" unit overlain by one or more tills in the upland bedrock interfluve areas (Fig. 12). The channel is, in turn, filled by a sequence of multiple pre-Illinoian tills and glacigenic alluvial units, and the valley incision is therefore of pre-Illinoian origin (possibly early in the A-till sequence). The additional presence of "s & p" sands in sub-till and inter-till positions within the Fremont Channel suggests that it received western sediments during part of its valley-filling history. The Fremont Channel may have served as the main trunk stream for an earlier pre-Illinoian southward diversion, analogous to the younger valley incision of the modern Missouri Valley.

Prior to regional southward diversion, eastward flowing stream systems brought western-derived sediments into western Iowa. Continuing eastward, where did these streams flow? Occurrences of western-derived sediments are generally absent in eastern Iowa, although descriptions of "s & p" sand units in some deep bedrock valleys of southeast

Iowa deserve additional study. A coalescing network of deep bedrock valleys in that area ("Lone Tree channel complex," Fig. 12) are filled with a sequence of pre-Illinoian tills, and the present drainage cuts across some of these buried valleys. Perhaps western-derived rivers drained eastward towards southeast Iowa during portions of the Miocene, Pliocene, and possibly early Pleistocene, where they would join with a southward-flowing proto-Mississippi drainage. Further study of the buried channels across Iowa is needed. Snail fossils (pleurocerids aff. *Juga*) recovered from the Kirkwood Channel of eastern Iowa (Fig. 12) suggest a possible pre-Quaternary age for the basal alluvium (T.Frest, 1988, pers. comm.).

CONCLUSIONS

Some general stratigraphic, compositional, and historical interpretations are proposed for Neogene alluvial units in western Iowa and adjacent areas. 1) A distinct lithologic suite of sediments, the "salt & pepper suite," is characterized by fine-grained sands and mudrocks that consistently contain dark volcanic lithic grains but typically lack carbonate grains. This suite is interpreted to be derived from western sources headwatered in the Rocky Mountains. This suite of sediments in Iowa generally occupies a sub-till stratigraphic position, but locally occurs in inter-till positions. 2) Granitic sands and gravels (the granitic suite) are also of western origin. They are known to occur above "s & p" sediments and below till in western Iowa. 3) A glacigenic suite includes sediments derived from glacial outwash or eroded tills, and is characterized by an abundance of carbonate grains and northern-sourced lithologies. Sediments of this suite in western Iowa were deposited in generally southwestward flowing streams.

4) "S & p" units in western Iowa lithically resemble various stratigraphic units in eastern Nebraska including the Ogallala Group, "Fullerton" Fm., and modern Missouri and Platte River alluvium. The occurrence of Miocene mammal fossils as reworked bones in Quaternary gravels of Iowa and northern Missouri may suggest that some Ogallala outliers may be present east of the Missouri River. 5) Granite gravels in northwest Iowa have yielded bones of *Stegomastodon*, indicating a Blancan or earliest Irvingtonian age. Similar Plio-Pleistocene granite gravels are known from Nebraska and South Dakota (e.g. "Red Cloud," "Holdredge," Bon Homme gravels), and the Iowa occurrences indicate eastward extension of one or more western-derived gravel units. 6) Glacigenic sands and gravels are the dominant alluvial units in western Iowa following deposition of the B-tills.

7) The occurrence of western-derived alluvium over large areas of western Iowa in a sub-till (probably sub-B-till) position indicates that a southward-flowing Missouri River-type drainage was not permanently established before the early Pleistocene. Streams that headwatered in the central Rocky Mountains drained eastward into western Iowa during portions of the Miocene, Pliocene, and early Pleistocene; these streams may have continued to drain eastward into the deep bedrock valleys of southeast Iowa where they joined a proto-Mississippi drainage system. 8) A southward drainage diversion, which originated during or immediately following deposition of the B-tills, generally bypassed western-derived alluvium from western Iowa. This diversion marked the development of a "proto-Missouri" River drainage in the area, and was undoubtedly a response to incursion of glacial lobes and till deposition across the earlier west-east drainage network. The Fremont Channel in western Iowa may represent a pre-Illinoian trunk pathway for the southward diversion. 9) Entrenchment of the modern Missouri River Valley in western Iowa probably occurred during the Illinoian, and marked the late Quaternary location of the southward diversion.

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CARBON AND OXYGEN ISOTOPIC GEOCHEMISTRY OF PEDOGENIC CARBONATE NODULES IN NEOGENE DEPOSITS IN WESTERN IOWA

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INTRODUCTION

The stable isotopic geochemistry of pedogenic carbonates has become a subject of increasing interest because of their potential to preserve an independent record of paleoclimatic change in continental environments (Magaritz and Amiel, 1980; Magaritz et al., 1981; Cerling, 1983; Rabenhorst et al., 1984; Cerling, 1984; Gardner, 1984; Schlesinger, 1985; Cerling and Hay, 1986; West et al., 1988; Amundson et al., 1988, 1989). Nodular accumulations of secondary carbonate are abundant features in modern and ancient weathering horizons in the Neogene stratigraphic succession of western Iowa. We have initiated an exploratory investigation of the carbon and oxygen isotopic geochemistry of carbonate nodules from several weathering profiles, to evaluate internal variations within and among nodules in individual weathering profiles, and to make comparisons between the isotopic variations recorded by different positions in the Neogene stratigraphic succession.

The relative stratigraphic positions of various nodule horizons that we have sampled are shown in Figure 1. Nodules from the Loveland Loess in the weathering profile associated with the Sangamon Soil have been the most intensively studied. Nodules associated with this weathering profile in two bluff line localities have been studied: Murray Hill (QN-S2) near the Harrison-Monona county line, and the Loveland Paratype Section (78LT1) in northern Pottawattamie County. Matrix isotope data has also been obtained from samples of the Loveland Loess at the Paratype Section. Nodules from the Peoria Loess within the Holocene weathering profile at a site in southcentral Harrison County (43PL), and from Pisgah Formation loess within the Farmdale Soil weathering profile at the Loveland Paratype Section (78LT1-MP) have also been sampled. Together these samples form a preliminary data set encompassing all the major weathering profiles developed in Missouri River-sourced loess units.

Also included in this study are nodules formed in fluvial sand and gravel beneath the Lava Creek B ash at the County Line Ash site. These may or may not be directly associated with a weathering profile related to a specific paleo-landsurface. The oldest carbonate nodule-bearing weathering profile sampled is associated with an unnamed soil developed in Plio-Pleistocene alluvial deposits at the Folsom Quarry in northwest Mills County.

NEOGENE PALEOCLIMATES OF THE UPPER MIDWEST

Detailed reconstructions of climatic and/or vegetation conditions in the Upper Midwest prior to the last glacial maximum are not available. The characteristic feature of the Quaternary paleoenvironment is the periodic variation in the size of northern hemisphere ice sheets, and the climatic and vegetational response to those variations. Environmental changes documented for the late Wisconsinan period are not unique, nor probably even the most extreme to have occurred in the Quaternary (Bartlein, 1988). It is worthy of note that conditions as warm as those of the Holocene have lasted for only about 10 percent of each late Pleistocene glacial/interglacial cycle (Emiliani, 1972). Information from studies of deep sea cores reveal significant variations in global ice

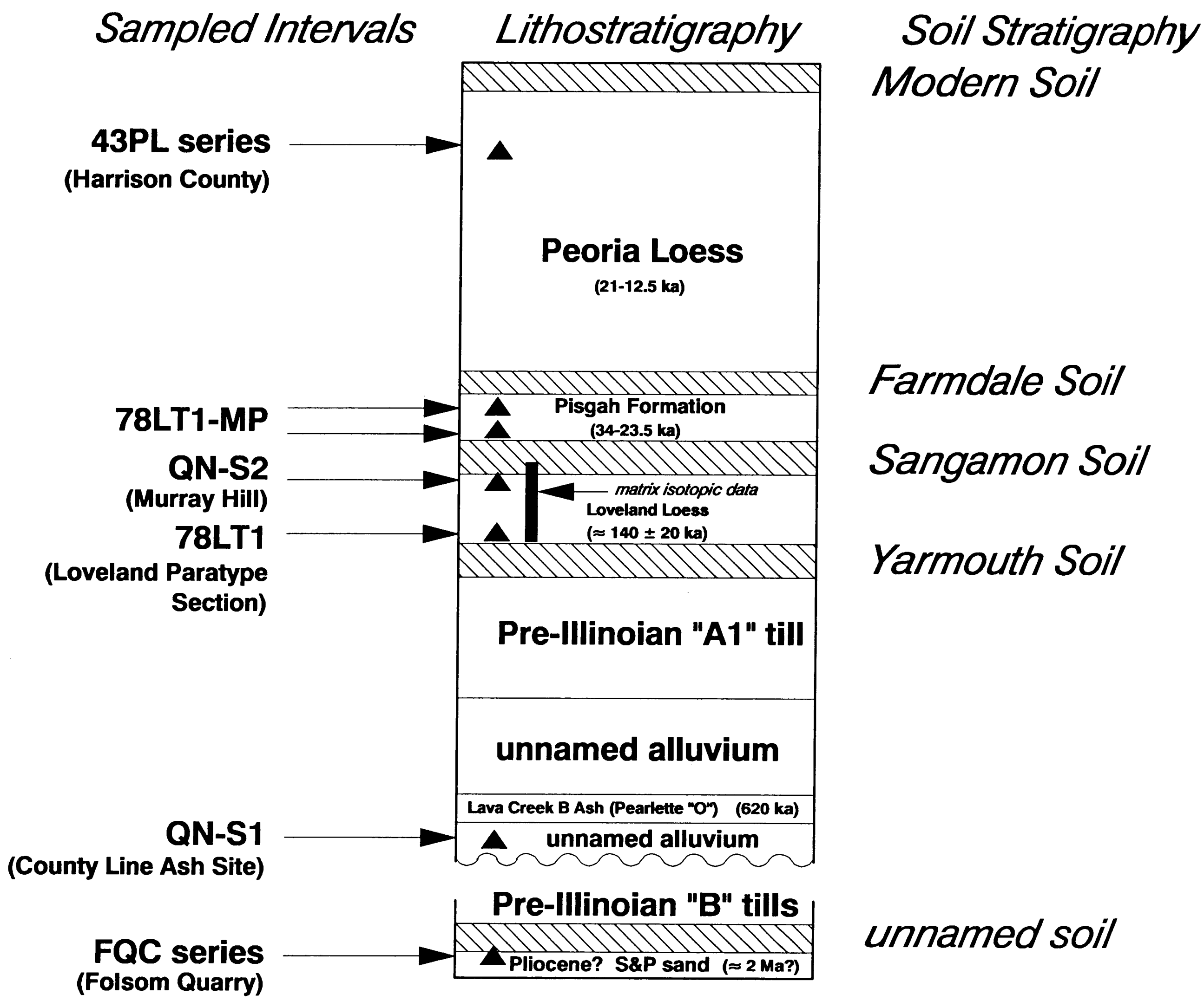

Figure 1. Stratigraphic positions of nodular carbonate horizons sampled for this study.

volume during the Quaternary that appear to be controlled by continuous insolation changes, as determined by orbital parameters (Ruddiman and McIntyre, 1981; Shackelton and Opdyke, 1976). Other atmospheric parameters, such as the concentration of CO_2 gas in the atmosphere have also varied (Broecker, 1982).

Vegetation, as reconstructed from pollen data, has been used extensively to reconstruct Wisconsinan and Holocene paleoclimates of the Upper Midwest (Watts, 1983, and references therein; Webb et al., 1983, and references therein). Conditions of the Sangamon Interglacial are not well known because of a lack of pollen-bearing deposits of this age, as well as an inability to accurately date those that are preserved. It is generally assumed, however, that at least sometime the during the Sangamon, climatic conditions similar to those of the Holocene prevailed (Grüger, 1972). It is not known, however, if grasslands extended as far eastward as during the Holocene. Cool conditions prevailed during the Farmdale Stage (ca. 28-24 ka) and a boreal grassland/parkland occupied western Iowa (Rhodes, 1984). During the coldest conditions of the late glacial between about 20 and 16.5 ka, spruce-dominated coniferous forest was present. After 16.5 ka, the climate followed a general warming trend, culminating around 6.5 ka in western Iowa (Van Zant, 1979). Vegetation shifted from coniferous to deciduous forest around 11-10 ka, and to prairie around 9 ka in western Iowa.

RESEARCH METHODS

All carbonate concretions used in this study were mechanically stabilized by the vacuum injection of epoxide resins, and were slabbed on water-cooled rock saws. Smaller nodules (< 3 cm diameter) were placed in cylindrical polystyrene vials and embedded in resin. Septarian voids in the interiors of the embedded nodules characteristically were filled by epoxide resin during vacuum injection, thus protecting their original fabrics from mechanical destruction during subsequent sample handling. Thin sections were cut from the slabs to evaluate the petrography of the nodules, and matching blank surfaces were polished for later microsample extraction.

Powdered samples of 5-10 mg were drilled from polished surfaces of carbonate nodules using a 1 mm-diameter carbide dental burr on a microscope-mounted microdrill assembly at the Sedimentary Geochemistry Laboratory at the University of Iowa. Powders were loaded into 2 ml borosilicate glass ampules and roasted in vacuum at 200° C for 4 hours to remove volatile organic contaminants. All samples for this study were analyzed at the stable isotope laboratory of Dr. E.M. Ripley at Indiana University, using a Finnigan Delta-E mass spectrometer with a 9 cm deflection radius. Analytical precision for $\delta^{13}C$ and $\delta^{18}O$ values are considered to be less than ±0.05 per mil, and values are reported in per mil relative to the PDB standard.

In order to evaluate the possible significance of the pedogenic translocation of detrital (matrix) carbonates in the formation of the concretions, nodule data from the Loveland Paratype Section were augmented by the collection of isotopic data on matrix carbonates in the loess. Calcite and dolomite weight percentages of loess matrix from closely-spaced samples in stratigraphic succession were determined at the Iowa State University Soil Survey Laboratory with the Chittick apparatus, using the procedure outlined by Walter and Hallberg (1980).

Sample splits from the loess samples that were processed for Chittick carbonate analyses were filled into 2 ml borosilicate glass ampules and roasted in vacuum at 200° C for 4 hours to remove volatile organic contaminants. Each sample split was used to collect data on both calcite and dolomite fractions in the Loveland Loess by stepwise gas generations from the same reaction vessel on a CO_2 gas extraction line. Each sample was reacted with reagent grade phosphoric acid for 24 hours at 25° C to generate CO_2 gas for analysis of the calcite fraction in the loess. After the CO_2 gas from the calcite fraction was trapped, the reaction vessel was recharged with phosphoric acid and reacted for 48 more hours at 50° C to generate CO_2 gas for analysis of the dolomite fraction in the loess.

Petrography of Pedogenic Nodules

Nodules recovered from the Quaternary sections are subspherical in shape, whereas those from the unnamed soil in the Plio-Pleistocene deposits at the Folsom Quarry include both large (10's of centimeters in diameter) elliptically-shaped

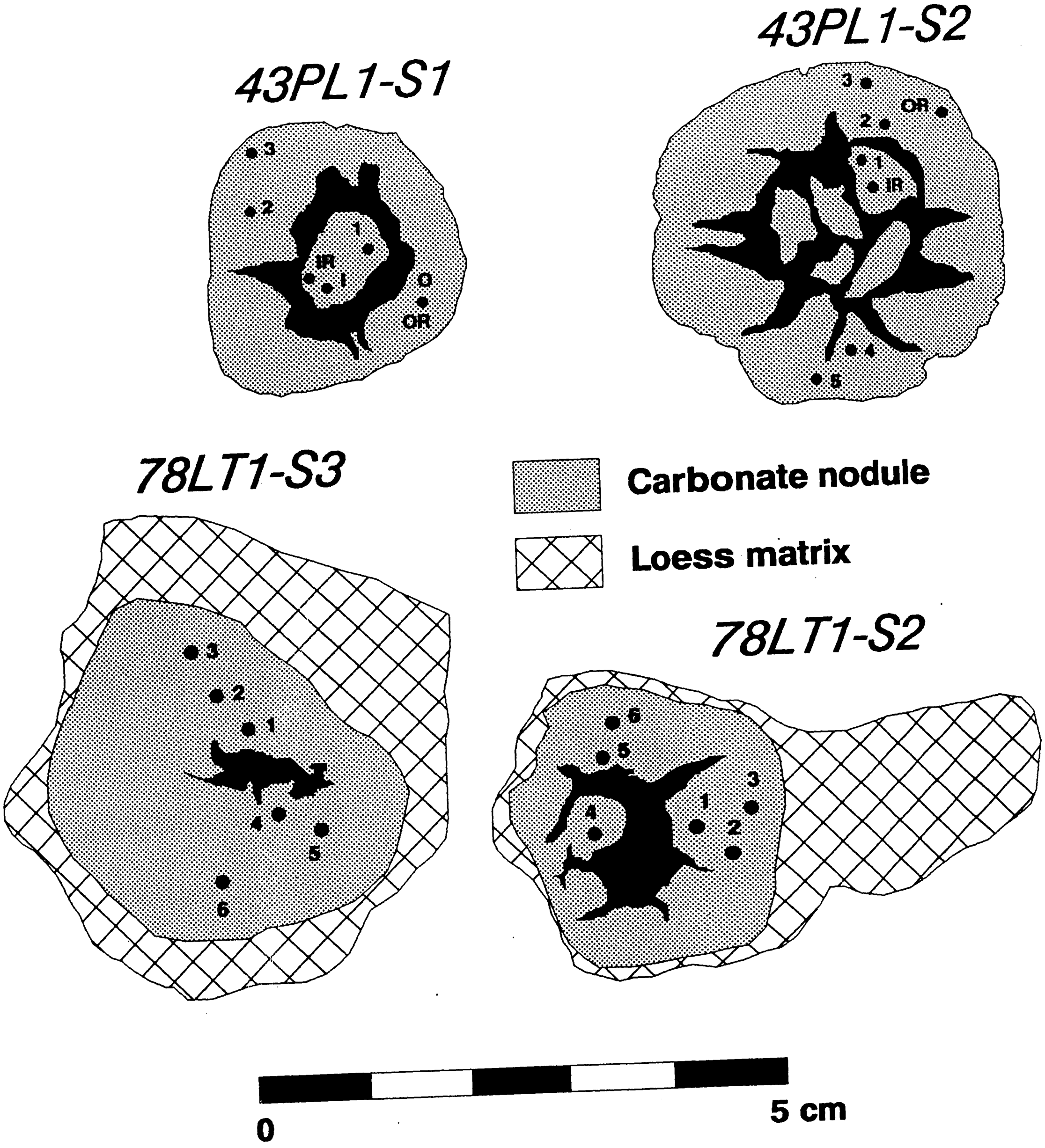

Figure 2. Structure of pedogenic carbonate nodules sampled from the Peoria Loess (43PL1) and the Loveland Loess (78LT1) for this study. Black areas are septarian voids filled by epoxide resin, and the small numbered and lettered circles are drill holes from microsample sites.

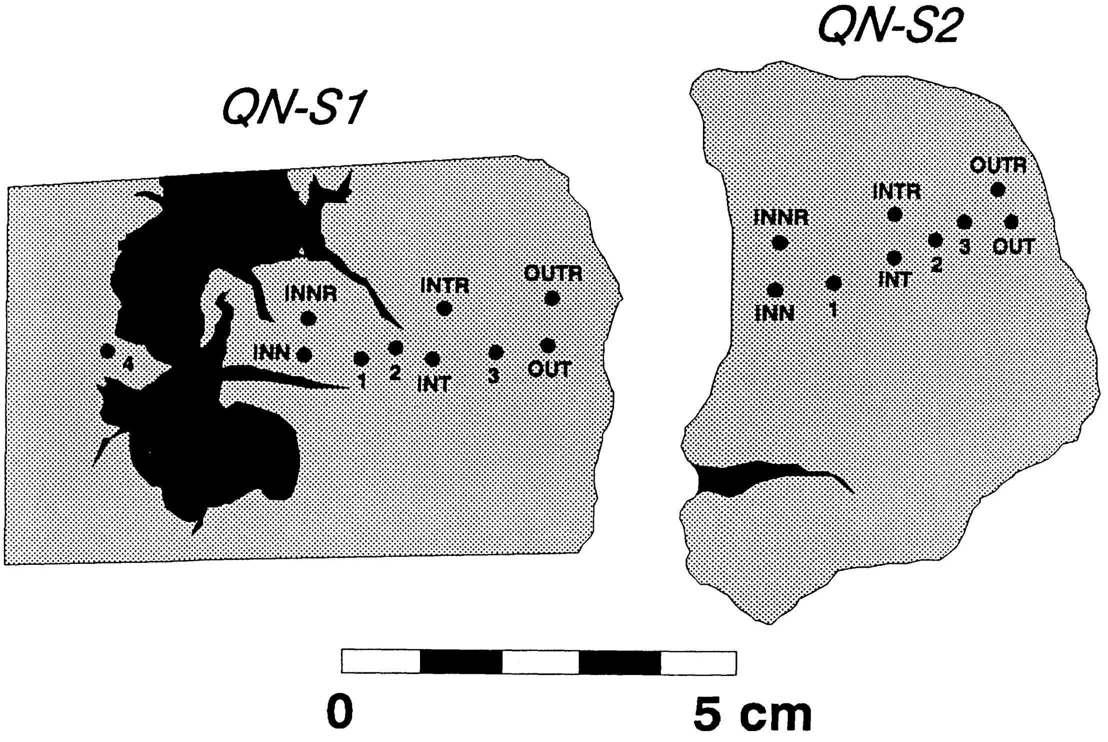

Figure 3. Structure of pedogenic carbonate nodules sampled from Pre-Illinoian alluvium (QN-S1) and the Loveland Loess (QN-S2) for this study. Symbols are as in Figure 2.

nodules that are flattened parallel to bedding, and smaller subspherical nodules. Scattered circumgranular cracks appear to mimic faint concentric growth increments in many of the nodules. Septarian structure is characteristic of all the nodules studied, and only the concretions in the Plio-Pleistocene deposits at Folsom Quarry showed any evidence of sparry vein-filling mineral growth in septarian voids. The shapes, structure, and sample positions of selected nodules are shown in Figures 2 and 3.

Petrographic examination of thin sections of nodules shows that all of the Quaternary samples and the large elliptical nodules from the Plio-Pleistocene (?) deposits grew as micritic (microcrystalline) carbonate cements that engulfed the siliciclastic matrix of the hosting sediment without changing the original sedimentary fabrics. Calcite crystallaria filling microscopic tube-shaped voids are especially prominent features in the nodules collected from the Loveland Loess Paratype Section. The lack of coarse carbonate fabric differentiation within the nodules precluded development of a petrographically-based sampling strategy, so microsampling was based on the assumption of concentric nodular growth histories in order to test for systematic temporal variations within nodules.

Carbonate cements in the small concretions from the Plio-Pleistocene weathering horizon at the Folsom Quarry grew as displacive spherulitic (radial-fibrous) spars that physically rearranged the siliciclastic matrix of the hosting sediment. These spherulitic spars display compositional zoning that appears to be controlled by the abundance of ferric oxide inclusions. Septarian veins are present in these nodules, so spherulitic and septarian vein-filling spars were sampled. No convincing textural evidence was found to show that the smaller nodules at the Folsom Quarry developed as symmetric concentric growths, so no spatial sampling strategy was employed other than to select areas of purer spar and to assure broad coverage of the polished surface.

Cathodoluminescence petrography of polished thin sections of the nodules reveals the following: 1) roughly circular silt-size areas of brightly luminescent carbonate that presumably are detrital

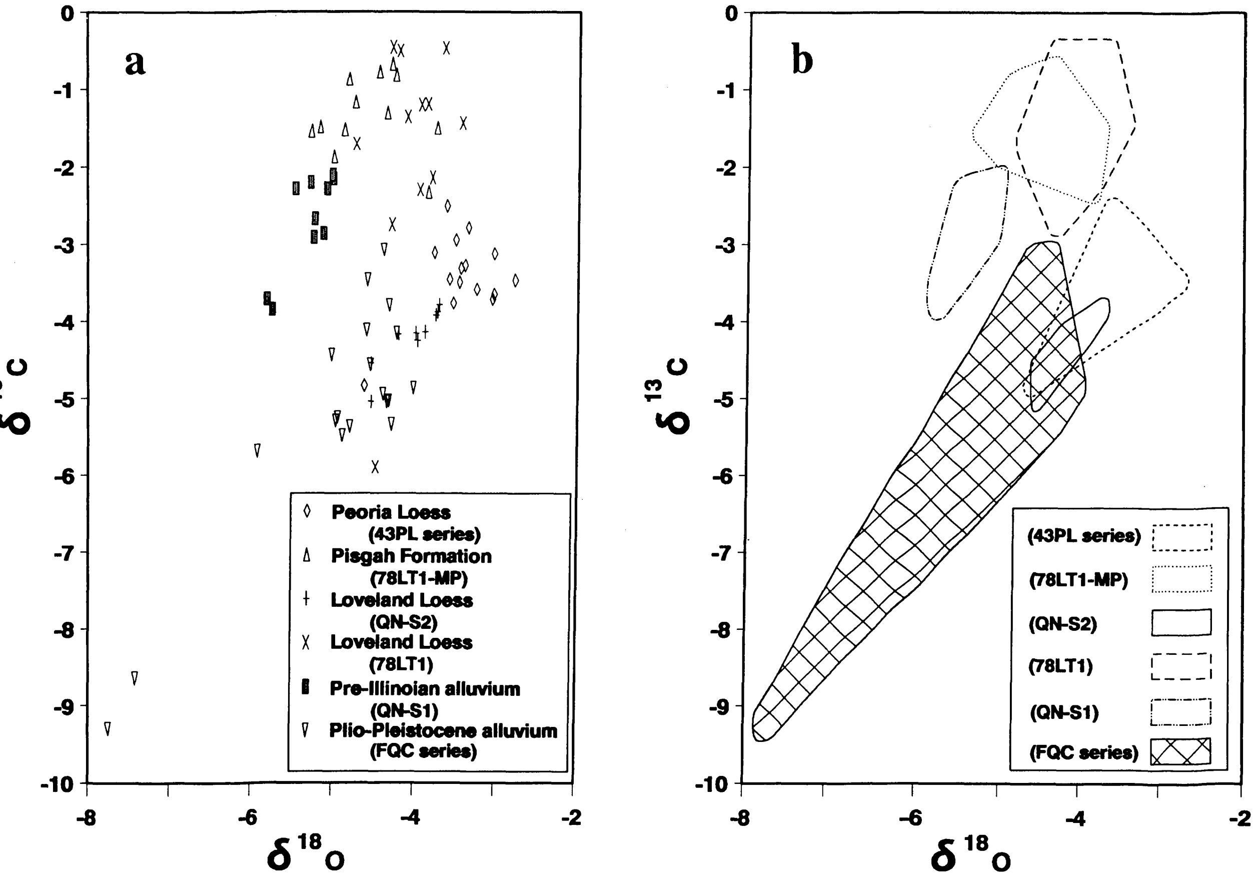

Figure 4. Carbon and oxygen isotope plot of pedogenic carbonates from Neogene deposits in western Iowa. a. Plot of individual analyses, with symbols representing samples from specific sites. b. Shapes of polygonal fields enclosing the data from specific sites.

grains of Paleozoic/Mesozoic sedimentary carbonates, and 2) all other carbonates in the nodules are nonluminescent. The presence of carbonate grains from Paleozoic and Mesozoic source rocks in the Quaternary deposits is expected, since these grain types are known to be prominent detrital components of glacigenic sands in the region (see Witzke and Ludvigson, this guidebook). The significance of the nonluminescent nodule carbonates needs to be evaluated further. It could signify a lack of manganese substitution in the carbonate lattice, as would be expected if the nodules developed in oxidizing vadose environments. However, the presence of manganese oxide growths in some nodules, and the ferric oxide zoning in the spherulitic calcite spars from the nodules at Folsom Quarry suggest that alternations between oxidizing and reducing environments may have controlled the manganese and iron chemistry of the pedogenic carbonates. Studies of the minor and trace element chemistry of the nodules are warranted.

CARBON AND OXYGEN ISOTOPIC DATA

Figure 4 shows the aggregate isotopic data from all of the sample localities. While there is considerable overlap between the isotopic ratios recorded from each sample population, the data from each nodule locality occupies a unique field. All of the carbonate nodules from the Quaternary deposits have $\delta^{18}O$ values that range between -2 to -6 per mil, whereas those from the Plio-Pleistocene deposit at the Folsom Quarry include values of less than -7 per mil. The Quaternary nodules have $\delta^{13}C$

values that range between -0.5 to -5 per mil, whereas those from the Plio-Pleistocene deposit at the Folsom Quarry include values of less than -8 per mil. Clearly, some of the nodule data from the Plio-Pleistocene alluvium at the Folsom Quarry record very different environments of formation than those in the younger Quaternary sections.

EVALUATION OF TEMPORAL TRENDS DURING NODULE GROWTH

Radiometric ages are not currently available for any of the nodules used for this study, and the lengths of time needed for the nodules to grow are not known. The septarian structure of the nodules complicates assessment of temporal changes in physical environments during the growth of the nodules. Since concentric growth histories are generally assumed, the record of early nucleation and concretionary growth is obscured by septarian fracturing. In addition, the opening of fractures in the nodules may possibly lead to changes in the isotopic composition of interior portions, through subsequent water-rock interactions or the deposition of additional micritic cements coating fracture surfaces. The origin of the septarian structure in the Neogene nodules is also problematic. Such features are generally considered to result from the brittle failure of concretionary masses under lithostatic load, frequently in overpressured sediments (Astin, 1986), yet this scenario cannot reasonably be applied to nodules in the Peoria Loess, which also have septarian structure.

We evaluated the temporal evolution of the nodules by using the outermost layer, the latest increment of concretionary growth, as a datum. By assuming approximately symmetric growth histories for the nodules, the relative ages of samples within nodules could be determined by measuring the distance of the sample drillhole to the edge of the nodule along the presumed growth direction of the concretion. Thus, the larger distances presumably represent the earliest record of nodule growth, with the smallest distances representing the latest growth.

The results of this analysis are shown on Figure 5. The larger nodules with radial dimensions of about 4 cm (QN-S1 and QN-S2) appear to record long-term changes in physico-chemical environments. Nodule QN-S2, in particular, seems to record a systematic trend towards depleted $\delta^{18}O$ and $\delta^{13}C$ values. Smaller nodules with radial dimensions of about 1 cm are more difficult to interpret, possibly because the shorter depositional records do not allow discrimination of temporal trends from "noise" in the data. Alternatively, their variability may reflect the influences of multiple mechanisms of carbonate precipitation.

CONTROLS ON COMPOSITIONAL VARIATIONS

As reviewed by Cerling (1983, 1984), the stable isotopic geochemistry of pedogenic carbonates provides paleoclimatic information because: 1) their oxygen isotopic compositions are primarily controlled by climatically-related variations in the isotopic ratios of meteoric (rain) water, and 2) their carbon isotopic compositions are heavily influenced by climatically-zoned floral communities. The very presence of pedogenic carbonates within weathering profiles is indicative of relatively dry climates, and they generally are confined to regions receiving less than 100 cm of precipitation per year (ibid., p. 229).

By convention, oxygen and carbon isotopic compositions of carbonate minerals are reported as per mil variations in $^{18}O/^{16}O$ and $^{13}C/^{12}C$, respectively, relative to the PDB standard (calcite from belemnites in the Cretaceous Pee Dee Formation of South Carolina). The oxygen and carbon isotopic compositions of carbonate mineral precipitates are determined by the isotopic composition of fluids (water oxygen and the dissolved CO_2), temperature, and precipitation rates. For oxygen, colder temperatures lead to greater ^{18}O enrichments. In the temperature range of 0-40° C, every 5° C translates to an approximately one per mil shift in $\delta^{18}O$ of the carbonate (Figs. 6 and 7). Although the carbon isotopic fractionation is also dependent on temperature, this effect is minimal relative to that of oxygen isotopes. In addition, fractionations between the different dissolved carbon species ($CO_3^{=}$, HCO_3^{-}, and H_2CO_3) have different temperature dependencies. Equilibrium fractionations of ^{18}O and ^{13}C occur only under slow precipitation rates, and the magnitudes of fractionation effects decrease with increasing precipitation rates. As the amount of carbon

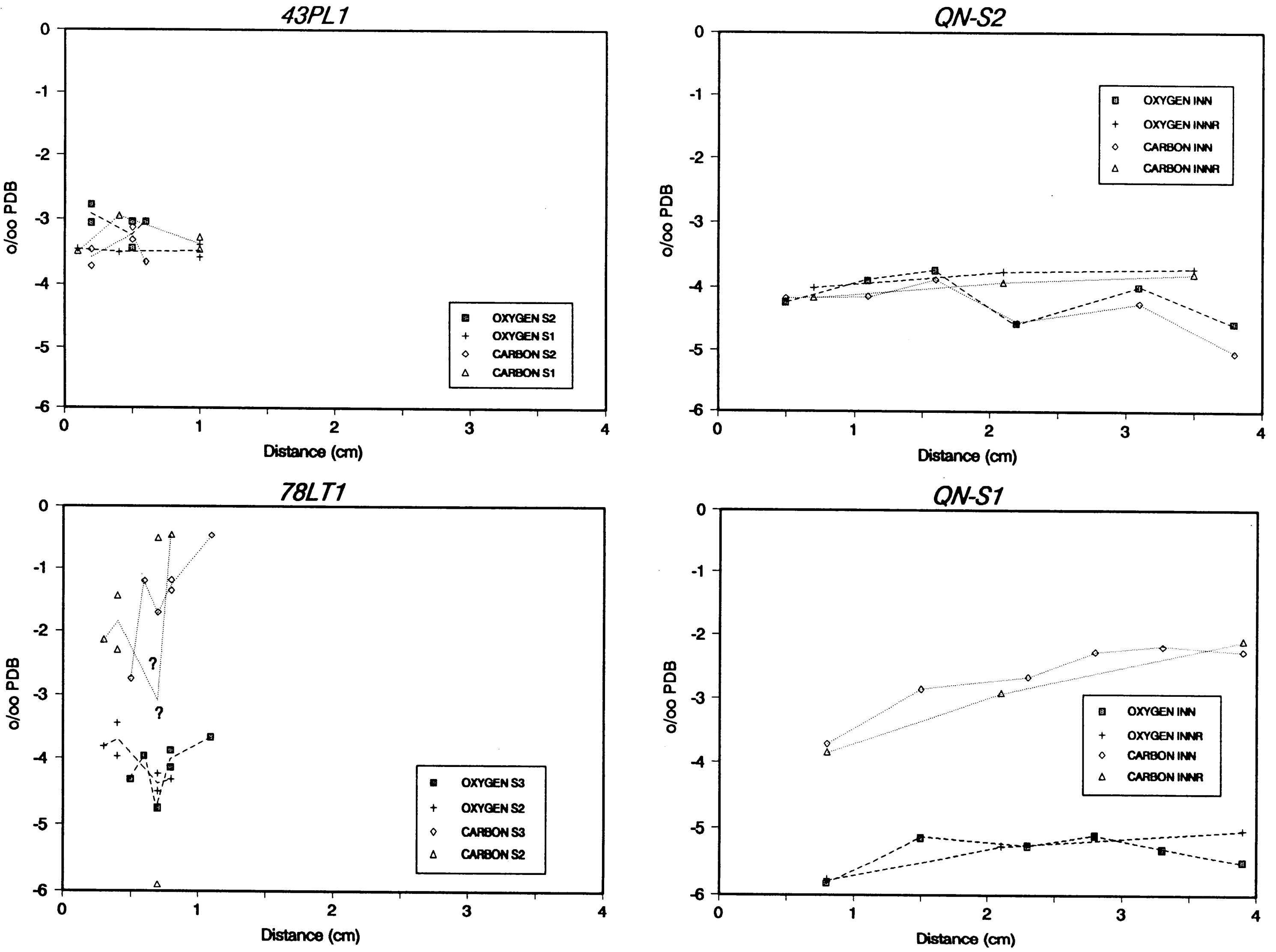

Figure 5. Temporal controls on the composition of pedogenic nodules. Distances record the measured distance between a microsampling site and the outer surface of the nodule along the presumed growth direction. Temporal relationships are interpreted to show older growth increments to the right, and younger growth increments to the left. Dashed lines connect oxygen isotopic data from the same nodule, and dotted lines connect carbon isotopic data from the same nodule. The symbols S1, S2, and S3 each refer to individual nodules from sampling sites (43PL1, 78LT1), whereas INN and INNR refer to separate drilling transects within the same nodule (QN-S1, QN-S2).

(dissolved CO_2) per liter of water is extremely small (micromoles) relative to oxygen, carbon isotopic compositions are more easily altered, and a greater variability in carbon isotopic compositions is expected than in oxygen isotopic compositions.

The oxygen isotopic composition of fluids in soils is controlled by local meteoric (atmospheric) precipitation. The magnitude of seasonal variations in the composition of vadose fluids is damped and homogenized at depth (Yonge et al., 1985). The maximum depth at which seasonal variations can be detected is controlled by numerous factors that include: quantity and frequency of rain, magnitude of seasonal variations, local vegetation and topography, and permeability of the vadose zone. The isotopic composition of atmospheric precipitation is controlled by the isotopic composition of the water that serves as the source of atmospheric moisture (ocean), and the number of fractionation (precipitation and evaporative feedback) events affecting the atmospheric moisture en route to it's final destination. For continental areas, there is a generally good correlation between mean annual temperature and mean annual isotopic compositon of rain and vadose seepage (Yurstsever and Gat, 1981; Yonge et al., 1985). Evaporative isotopic enrichment of seepage water can occur under semi-arid and arid conditions (Craig et al., 1963; Lloyd, 1966). Thus, minor variations in the oxygen isotopic composition of soil fluids can occur in response to wet-dry cycles.

The carbon isotopic composition of the dissolved CO_2 in soil fluids is determined by the composition of soil gas. Soil CO_2 is produced by plant respiration through roots and bacterial oxidation of organic matter. A major controlling factor of the $\delta^{13}C$ of the soil CO_2 is the metabolic photosynthetic pathway used by plants (C_3, C_4, and CAM). On average, the $\delta^{13}C$ composition of C_3 plants ("normal vegetation") is -26 per mil, that of C_4 vegetation is -13 per mil, and that of CAM vegetation ranges from -32 to -15 per mil (Talma and Netterberg, 1983; Cerling, 1984). Thus, the relative abundance of these plant groups is a major determining factor of the $\delta^{13}C$ composition of soil CO_2. Under pronouced seasonal variations, the amount and composition of soil CO_2 will be greatly modified due to temperature controls on the rates of soil respiration as well as available soil moisture. In general, during colder conditions both the oxidation of organic matter and respiration rates are decelerated, resulting in lower CO_2 contents and heavier $\delta^{13}C$ compositions. In addition, C_4 plants are more tolerant of dryer conditions, and their contributions during dry conditions are augmented (Fig. 7; heavier $\delta^{13}C$ compositions). Calculations by Cerling (1984) indicate that changes in respiration rates can result in carbon isotopic variations of up to 12 per mil. Variations in soil gas $\delta^{13}C$ composition due to molecular diffusion of atmospheric CO_2 is only a consideration at depths of less than 10 cm, or at extremely slow respiration rates (Cerling, 1984).

Relationships Between Carbonate Components in the Loveland Loess

Combined Chittick carbonate analyses and carbon and oxygen isotopic analyses of carbonate nodules, matrix dolomite, and matrix calcite from the Loveland Paratype Section are the basis of our preliminary assessment of the interactions between these carbonate components during pedogenesis in the Sangamon Interglacial. Figure 8 shows that the weathering profile in the Loveland Loess is characterized by an approximately 5 meter-thick leached zone. Both the calcite and dolomite fractions increase in abundance at about the 9.5 meter depth interval, and the nodular horizon is located a short distance below at about the 10.5 meter depth interval (Fig. 8).

An important question about these matrix carbonates is what proportion is comprised by the original unleached detrital carbonates in the loess, and what proportion is comprised by secondary pedogenic carbonates that accumulated in the weathering profile? Our preliminary isotopic data from the Loveland Paratype Section suggests that much of the loess matrix calcite in the nodular horizon is of pedogenic origin. The isotopic ratios of the dolomite fraction show negligible changes through the profile, whereas the isotopic ratios of the calcite fraction show much greater changes, including a $\approx$ 3.5 per mil depletion of $\delta^{13}C$ values in the interval containing the nodular horizon. We interpret the isotopically heavier values (ie. more positive; matrix carbonates at the 8 to 8.5 m and 10.5 to 11.3 m intervals; Fig. 8) to indicate loess samples with matrix carbonates dominated by eolian detritus of Paleozoic and Mesozoic sedimentary carbonates. The calcites with depleted carbon isotopic ratios (eg. matrix calcites at the 9.8

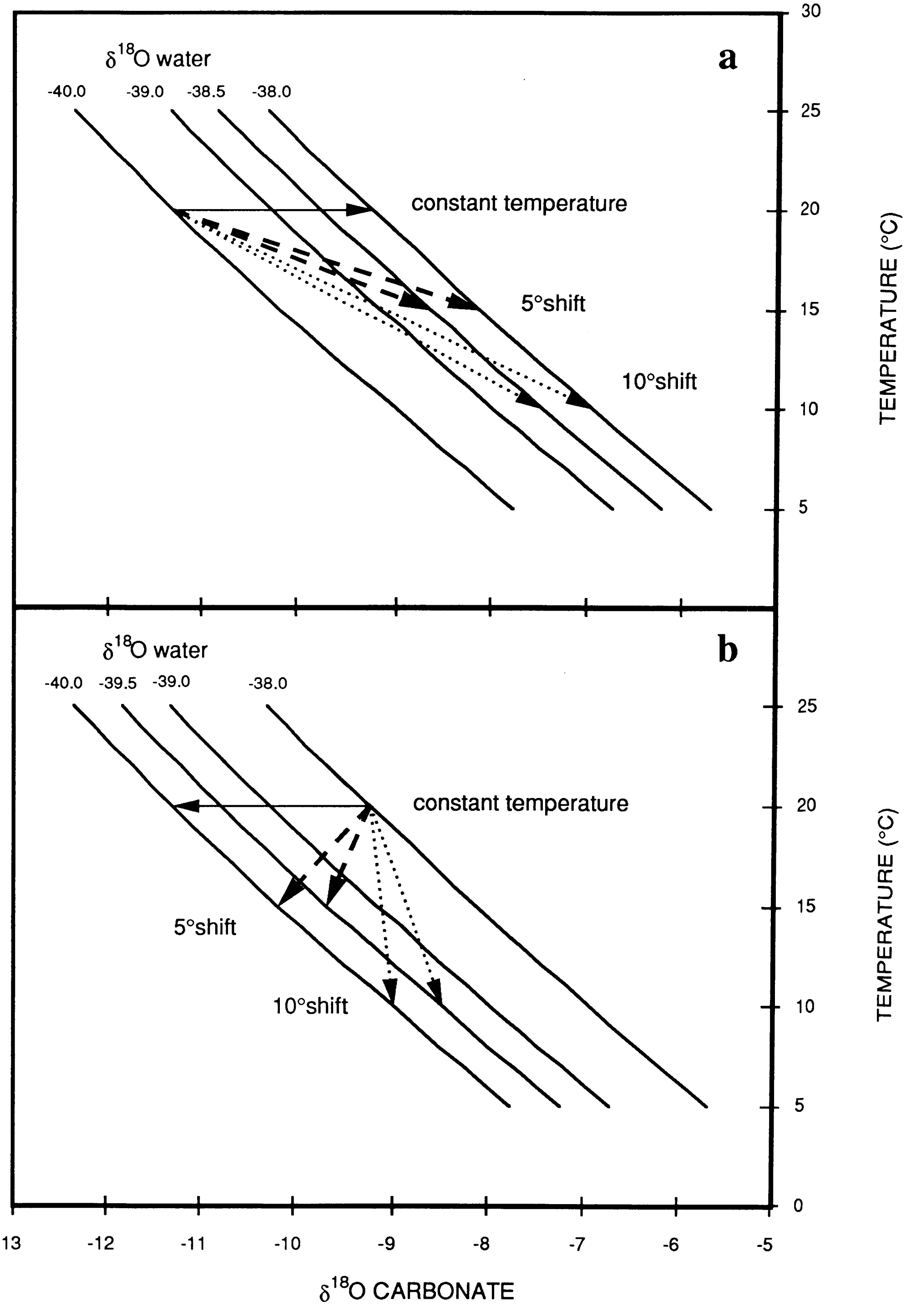

Figure 6. Dependence of oxygen isotopic composition of carbonate (calcite) on temperature and fluid composition. a) Effects of $\delta^{18}O$ enrichment of precipitating fluids and decreasing temperature. Note that every 5°C translates into a 1 per mil enrichment of of the carbonate. b) Effects of $\delta^{18}O$ depletion of precipitating fluids and decreasing temperature. Note that a 5°C temperature decrease buffers a 1 per mil shift in fluid composition. Slight enrichments in carbonate composition can result despite depletion of precipitating fluids if the temperature effect is larger than the fluid compositional effect. Such buffering can also occur with fluid $\delta^{18}O$ enrichments accompanied by temperature increase.

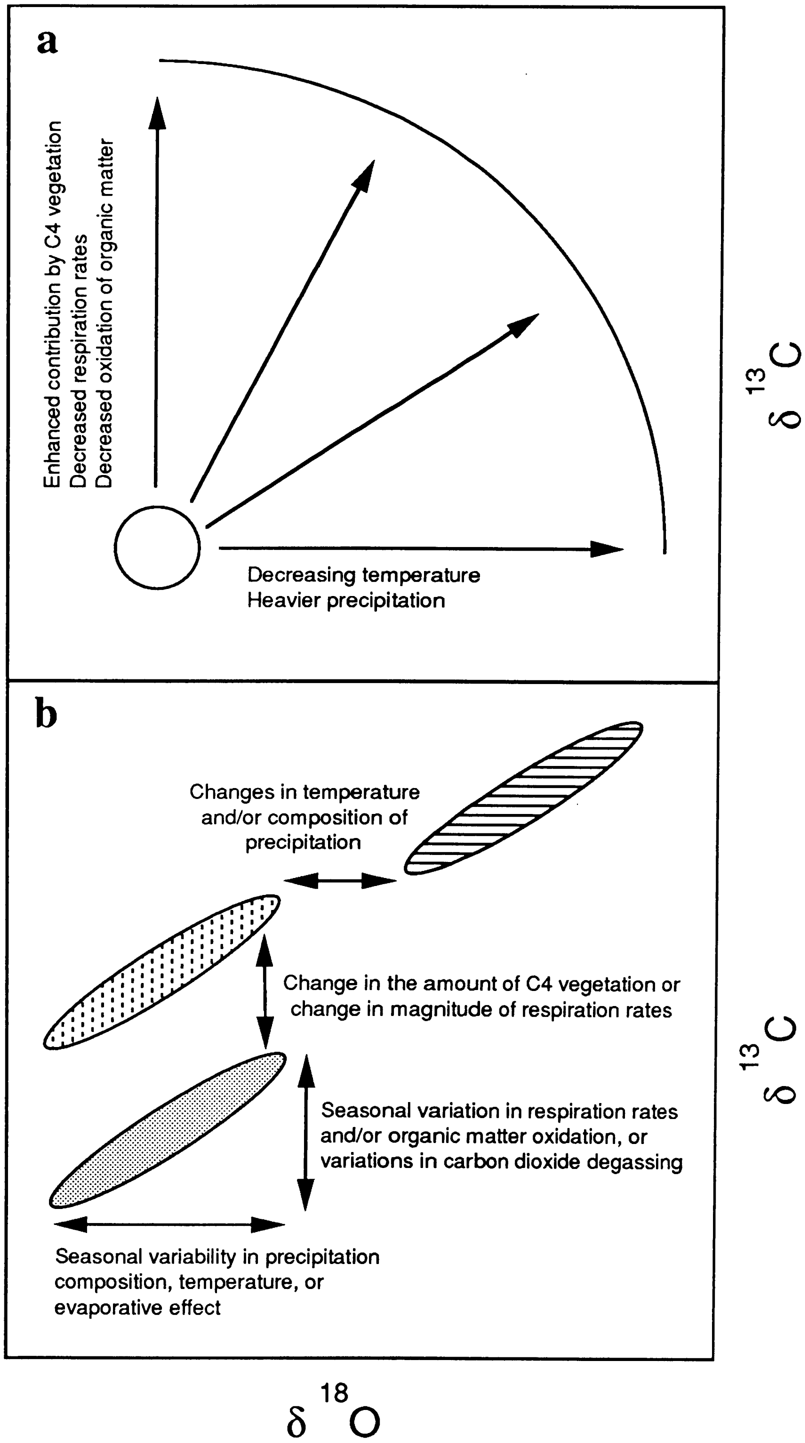

Figure 7. Controls on $\delta^{13}C$ and $\delta^{18}O$ variations in carbonates. a) Factors controlling major shifts in carbonate composition to heavier values. Independent shifts in either carbon or oxygen can occur displacing carbonate composition to heavier values with the actual direction and magnitude of the displacement depending on the relative contributions of the various processes. For changes of equal magnitude in carbon and oxygen, the new compositional field will lie along a 90° arc relative to former compositions. b) Factors controlling compositional variations within and among concretions. Covariance of values argues for seasonally controlled compositionaal changes or compositional cycles such as drought vs. wet regimes on short time scales. Minor displacement of fields could occur in response to changes induced by minor climatic changes.

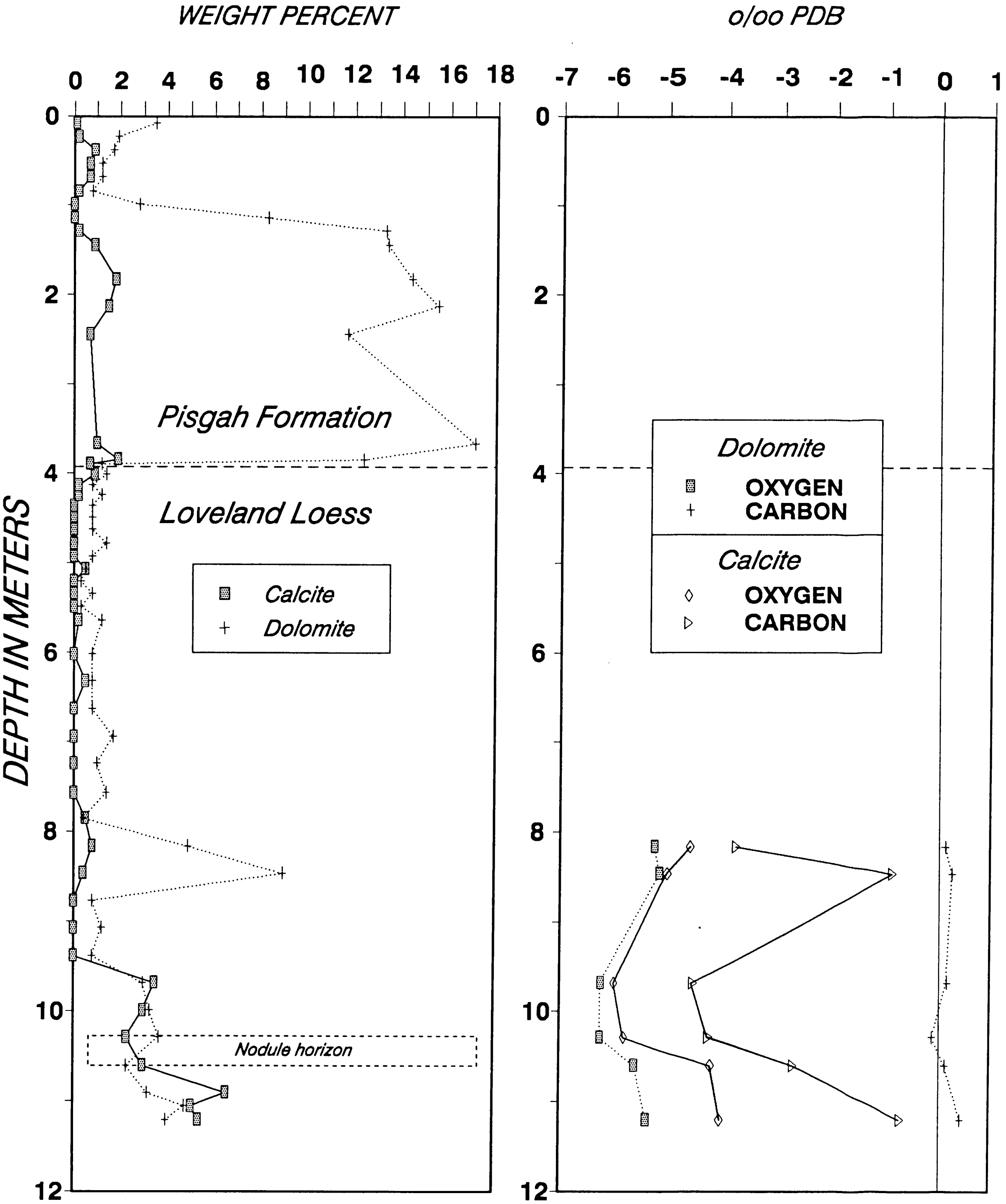

Figure 8. Stratigraphic variations in the abundance of matrix carbonates and their oxygen and carbon isotopic ratios in the Loveland Loess at the Loveland Paratype Section.

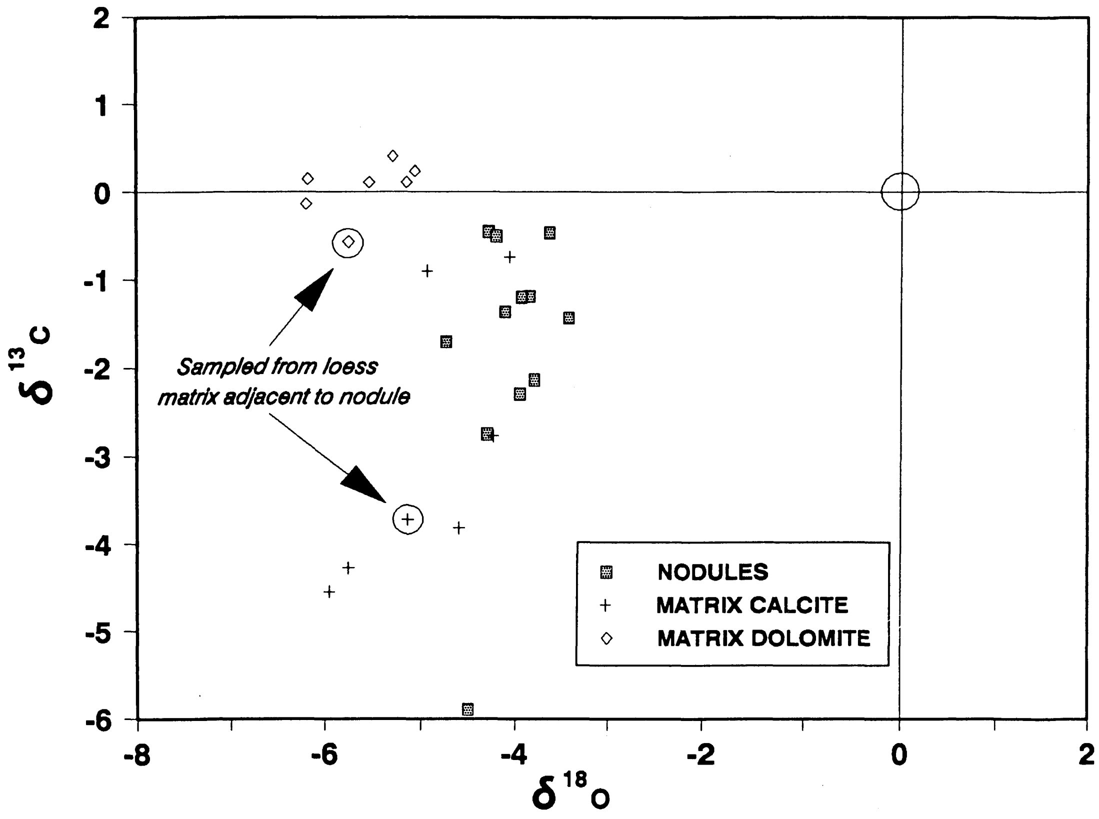

Figure 9. Carbon and oxygen isotope plot of carbonate components in the Loveland Loess at the Loveland Paratype Section. Matrix calcite, dolomite, and carbonate nodules all plot in distinct fields.

to 10.2 m interval) have compositions that were significantly influenced by the ^{12}C-enriched signal that is characteristic of CO_2 generated from soil respiration.

Several important relationships are revealed by examination of the covariation between carbon and oxygen isotopes in Figure 9. Matrix dolomites plot within a small field that is distinct from the other components. Their values are similar to those reported from Silurian marine dolostones (Ludvigson, 1988, p. 54-55) and Ordovician marine carbonates (Ludvigson et al., 1990) in eastern Iowa. Given that loess deposits are regarded as eolian facies of Quaternary glacio-fluvial deposits, the isotopic ratios of their matrix dolomites are in accord with the petrographic observation of abundant echinoderm-replaced dolowackestone grains (a common carbonate rock fabric in Ordovician and Silurian rocks of the Upper Midwest) in the glacigenic sands of western Iowa (see Witzke and Ludvigson, this guidebook). Other than providing a minor source of dissolved carbonate from the leached zone of the Loveland Loess, it is doubtful that the matrix dolomites played a significant role in the formation of the carbonate nodules

The isotopically heaviest matrix calcites in the Loveland Loess, interpreted as detrital components, have values that overlap with the field that encloses the carbonate nodules from the Loveland Paratype Section. The isotopically depleted (presumably pedogenic) matrix calcites from the nodular horizon in the Loveland Loess largely plot outside the field occupied by the carbonate nodules. These matrix calcites plot along a linear covariant trend with a positive slope, a trend that also includes several of the analyses from the carbonate nodules. This relationship may suggest that: 1) the composition of the nodule carbonates has been influenced by the mechanisms of carbonate mineral precipitation (evaporation and CO_2 degassing), or 2) the time interval during which carbonate accumulated in the nodule horizon (Fig. 8) coincided with climatic changes that

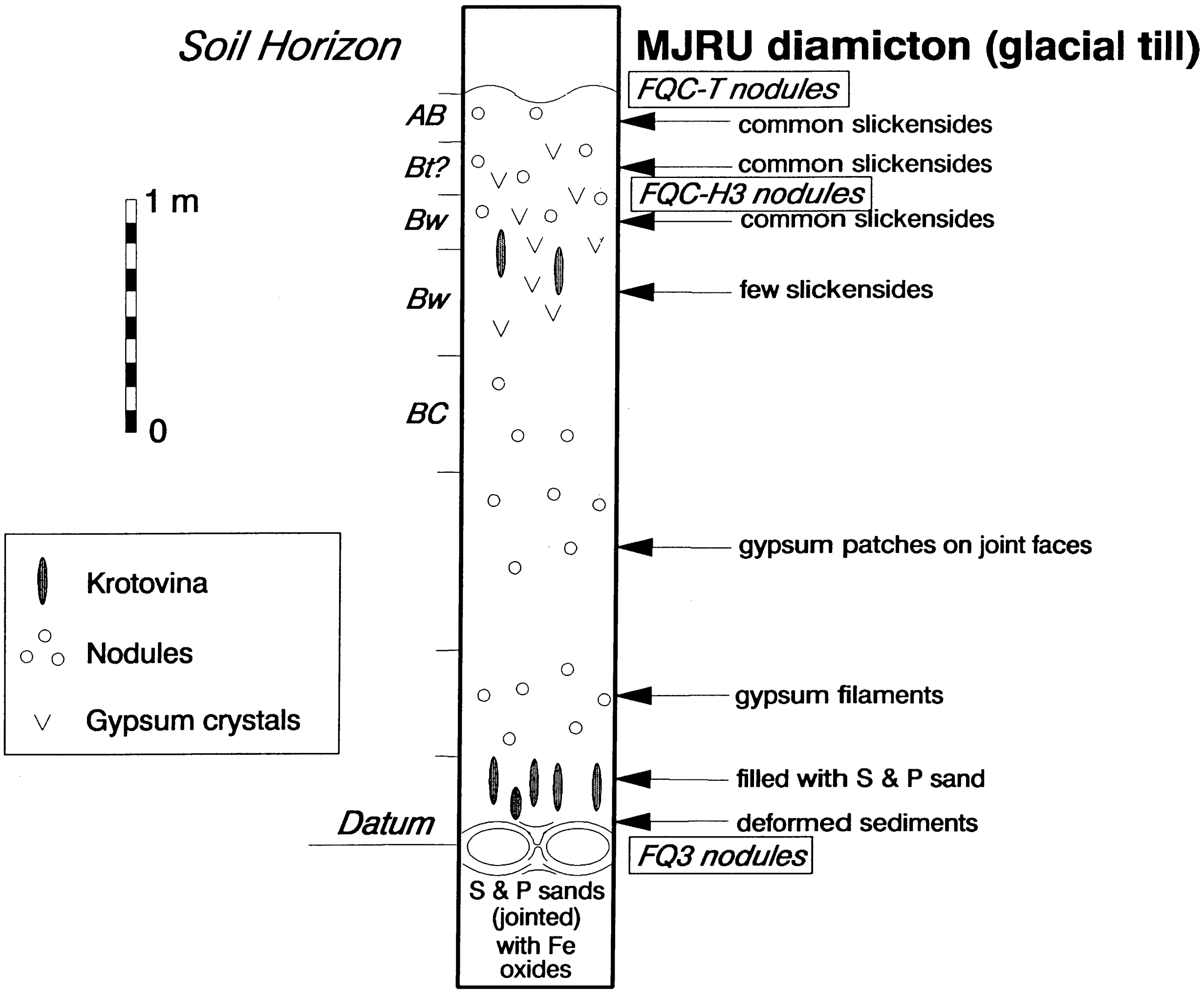

Figure 10. Graphic log of the weathering profile at the top of the Plio-Pleistocene alluvial deposits at the Folsom Quarry. Measured from a road cut section exposed to the north of the quarry workings. Note the positions at which carbonate nodules were sampled.

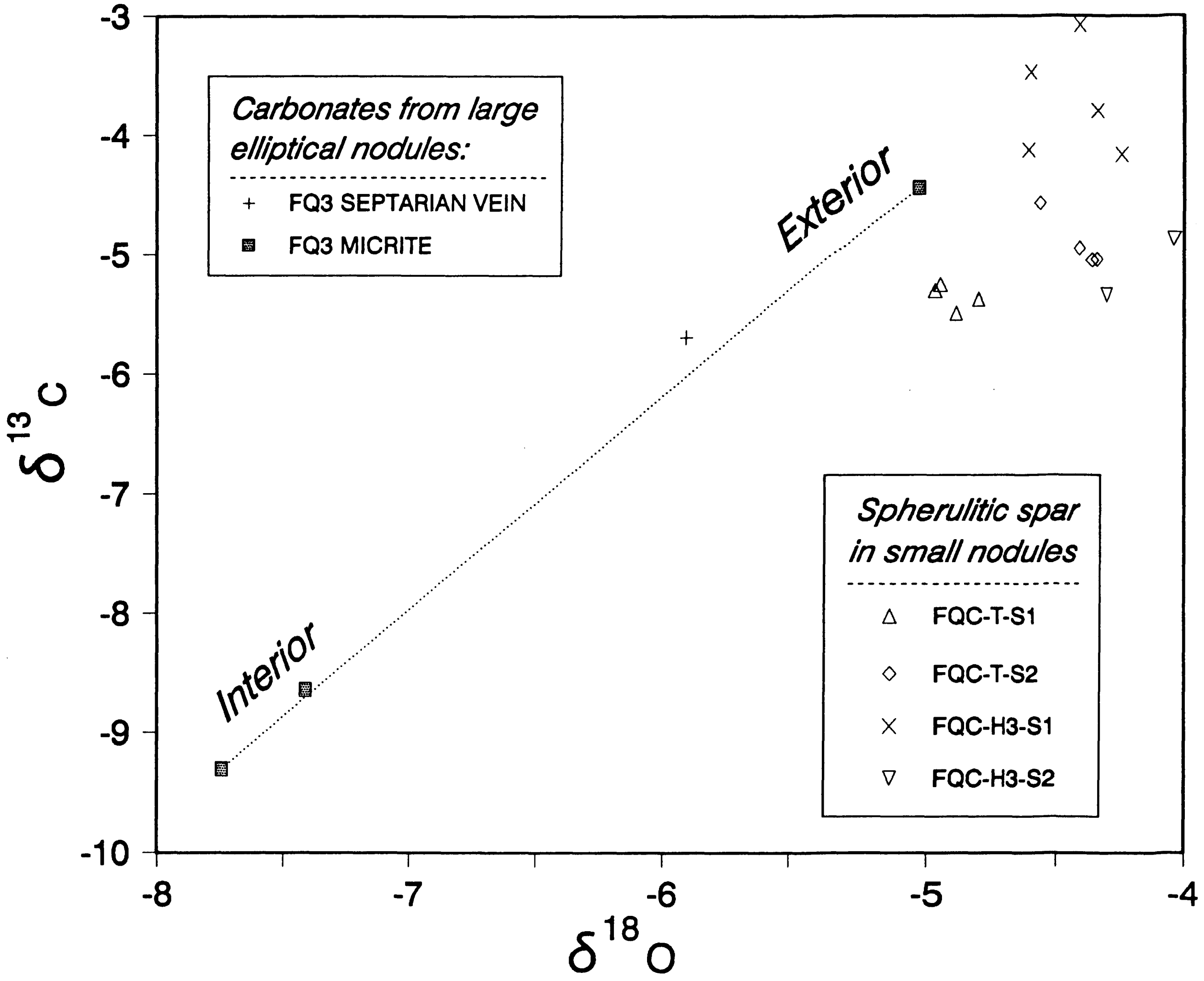

Figure 11. Carbon and oxygen isotope plot of carbonate components from the nodules sampled from the Plio-Pleistocene alluvial deposits at the Folsom Quarry. Nodules FQC-T and FQC-H3 have isotopic ratios that are similar to those from younger Quaternary sections, whereas those from the interior portion of nodule FQ3 have carbon and oxygen isotopic ratios that are depleted by ≥ 2.5 per mil from their younger counterparts, suggesting formation in a warmer paleoclimate.

systematically changed the carbon and oxygen isotopic composition of pedogenic carbonate. Further work is needed to resolve these alternative interpretations.

Relationships Between Authigenic Carbonates in Plio-Pleistocene Deposits at the Folsom Quarry

The most anomalous data set produced by this study was recovered from the large elliptical nodules from the lower part of the weathering profile in the Plio-Pleistocene alluvial deposits at the Folsom Quarry (FQ3; Figs. 10 and 11). Data from this site also included samples from small nodules higher in the profile (FQC-T; FQC-H3; Figs. 10 and 11). Isotopic ratios from the smaller nodules are not remarkably different from those recorded by younger Quaternary nodules, whereas parts of the larger elliptical nodules (FQ3) are depleted in ^{18}O and ^{13}C by greater than 2.5 per mil relative to their overlying counterparts. The most depleted carbonates in the large concretions were sampled from micritic cements in the interior portions, whereas micritic carbonates from the exterior portion and septarian vein-filling spar in the same nodule have isotopic ratios more similar to those of the overlying small nodules.

While our early interpretations are provisional, these data suggest that the nodules may record two successive weathering cycles during which pedogenic carbonates accumulated in the Plio-Pleistocene alluvium at Folsom Quarry. The first weathering cycle apparently was responsible for the initial formation of the large elliptical nodules at the base of the weathering profile. A second weathering cycle was responsible for the formation of the small nodules near the top of the profile, and probably for a late increment of concretionary growth on the exterior portions of the large elliptical nodules from the base of the profile.

The general isotopic similarity between the smaller nodules at the top of the weathering profile and the younger Quaternary nodules from other localities in western Iowa suggests that they may record grossly similar environments, while the isotopically depleted carbonates from the large elliptical nodules evidently record environments that are quite dissimilar to all the others.

Nodules that formed during the first weathering cycle in the Plio-Peistocene(?) deposits may record considerably warmer paleoclimates than those recorded in the younger Quaternary sections, as indicated by their more depleted $\delta^{18}O$ values. They also may record landscapes that were colonized by considerably different floras than those that characterized the Quaternary landscapes, as indicated by their more depleted $\delta^{13}C$ values. Although the meaning of such comparisons are uncertain, it perhaps is worth noting that the isotopic ratios of micritic calcretes from the Oligocene of South Dakota reported by Lander and Anderson (1989) are less depleted than those from the interior of nodule FQ3.

Nodules that formed during the second weathering cycle in the Plio-Pleistocene deposits apparently record a paleoclimate that more closely resembled those of the younger Quaternary paleoenvironments than that of the earlier Plio-Pleistocene weathering cycle. These nodules apparently nucleated close to the surface of an unnamed paleosol that formed in the Plio-Pleistocene deposits preceding their burial by Pre-Illinoian "B" glacial tills. Accordingly, they can be interpreted to preserve a record of Early Pleistocene paleoenvironments in western Iowa.

Paleoclimatic Implications

Two notable characteristics of the isotopic composition of the pedogenic concretions must be addressed. The first of these is the large shift in isotopic compositions between the lowermost Plio-Pleistocene concretions (FQ3 nodules, Figs. 4, 11) and the uppermost Plio-Pleistocene and Quaternary concretions. The second characteristic is the variations within individual concretions and the minor carbon isotope shift between the concretions series QN-S1, 78LT1-MP, and 78LT1 and the concretions of series QN-S2, FQC, and 43PL (Figs. 1, 4b). The nearly 3 per mil difference in $\delta^{18}O$ between the lowermost Plio-Pleistocene concretions and other concretions suggests a significant change in mean annual temperature coupled with a shift in the $\delta^{18}O$ of precipitation (Fig. 6a). The change in the $\delta^{18}O$ of rain could have been produced by either a change in the isotopic composition of oceanic source waters (i.e. ice volume effects due to continental glaciation-deglaciation), or a shift in the major source of atmospheric moisture (Gulf of Mexico vs. Pacific Ocean) during different climatic regimes. For example, a 1.5 per mil increase in the $\delta^{18}O$ of rain, coupled with a 5° C decrease in temperature can produce the nearly 3 per mil shift observed between the lowermost Plio-Pleistocene concretions and the other concretions (Fig. 6a). The nearly 5 per mil difference in $\delta^{13}C$ suggests a major modification of the contributors to the soil CO_2. Such a shift could be achieved in various manners, the simplest of these would be an increase in the abundance of C_4 vegetation, leading to a marked shift in the $\delta^{13}C$ of the soil CO_2 to heavier values (Fig 7). Assuming average compositions for C_3 and C_4 vegetation, a 5 per mil change requires that C_4 vegetation increases by 35%. Alternatively, vegetation could have remained constant, but changes in temperature and perhaps the amount and distribution of atmospheric precipitation could result in lower rates of plant respiration and organic matter degradation. Depending on initial respiration rates, rate reductions of 50% can result in changes of 1 to 3 per mil in soil gas $\delta^{13}C$. It is likely that this 5 per mil shift was achieved by both enhanced contributions by C_4 vegetation and reduced respiration rates induced by colder temperatures.

Minor isotopic variations within the Quaternary concretions could be attributed to either seasonal variations in the isotopic compositions of atmospheric precipitation and soil gas, pre-infiltration evaporative concentration of vadose waters during dryer periods when C_4 contributions were more pronouced, or evaporative enrichment coupled with CO_2 degassing (Fig. 7b). Of these three scenarios, only the first could result in light $\delta^{18}O$ compositions paired with heavy $\delta^{13}C$ values. The last two would result in either positive covariance of $\delta^{18}O$ and $\delta^{13}C$, or invariant $\delta^{18}O$ with variable $\delta^{13}C$ values.

The minor shift to heavier $\delta^{13}C$ compositions of the concretions series QN-S1, 78LT1-MP, and 78LT1 relative to the series QN-S2, FQC, and 43PL (Figs. 1, 4b) suggests that minor climatic fluctuations that affected only the vegetative cover could explain the data. This is an unlikely alternative, as it is difficult to envisage a shift in temperature or a shift in humidity without a concomitant change in the isotopic composition of atmospheric precipitation. It is likely that changes in the $\delta^{18}O$ of precipitation, humidity, and mean annual temperature interacted in such a way that the changes were buffered in the carbonate composition, and only reflected in the carbon isotopic compositions (Fig. 6b). An alternative scenario would be a decrease in precipitation without any accompanying changes in temperature, so that the $\delta^{18}O$ of the soil fluid was not affected, but that stressed conditions favored an enhanced contribution by C_4 vegetation.

DISCUSSION

While the data reported here do show intriguing differences between the different collection sites/intervals, detailed interpretations of paleoclimatic changes in western Iowa during the Neogene are not yet warranted. Further data collection is needed to more thoroughly document the spatial and temporal variability recorded within individual nodule horizons. Special attention should be focused on the pedogenic carbonates of the Peoria Loess and Pisgah Formation, because of the availability of a variety of other data sets that can be used to constrain environmental interpretations of that sequence.

Differences between data sets from the Loveland Loess at two different localities (QN-S2, 78LT1; Figs. 4 and 5) are illustrative of some fundamental interpretive problems in need of further attention. Do the data sets independently record the environments of two separate weathering cycles during the Sangamon Interglacial, or merely reflect spatial variations controlled by formation in different positions within the same weathering profile? Could development in different landscape positions with variable interactions with the groundwater table be a controlling factor? What effect has landscape evolution had on the position of the groundwater table and the movement of meteoric water through the deposits at a given locality? Are the nodule horizons all preserved in complete weathering profiles, or from partially eroded paleosol sequences? The issue of varying stabilities of ancient landscapes needs to be considered, especially in the Loess Hills area. Systematic description and sampling at each site will be required to resolve these problems.

CONCLUSIONS

The results of this exploratory study suggest that carbonate nodules in the Neogene deposits of western Iowa do preserve a record of paleoclimatic change. However, much further work at each collecting site is needed in order to derive unique interpretations of those paleoclimates.

Preliminary data suggest that the oldest of the studied concretions (from the Plio-Pleistocene alluvium at the Folsom Quarry) preserve a record of a warmer climate that probably coincided with greatly contracted (or missing) continental ice sheets. The Plio-Pleistocene environment was also characterized by a landscape that was colonized dominantly by vascular plants using the C_3 photosynthetic pathway.

The heavier $\delta^{18}O$ values recorded by concretions from the Quaternary deposits in western Iowa suggest formation in cooler climates. Their heavier $\delta^{13}C$ values suggest that Quaternary plant communities had lower respiration rates, and that Quaternary soil gases received greater contributions from plants using the C_4 photosynthetic pathway.

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THERMOLUMINESCENCE AND RADIOCARBON CHRONOLOGY OF LOESS DEPOSITION AT THE LOVELAND PARATYPE, IOWA.

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INTRODUCTION

There is a clear need for the development of a technique that can determine accurately the timing of eolian/glacial depositional events during the middle and late Pleistocene in the central U.S. The thermoluminescence (TL) technique, which directly dates silicate mineral grains from sediments has the potential of providing detailed chronologic control on loess deposition for the Wisconsinan and perhaps older stages. During the past decade the TL technique has provided temporal constraint on loess deposition on many continents (i.e. Europe: Wintle, 1987; China: Lu, 1986; Pakistan: Rendell and Townsend, 1988). Only recently has the technique been extended to the extensive loess sequences in the American midwest thus, providing some of the first numeric age estimates on Late Pleistocene loess deposition (Norton and Bradford, 1985; Canfield, 1985; Pye and Johnson, 1988). These studies demonstrate the general usefulness of the TL method in dating late Quaternary loess deposits in the Central U.S. However, there is some uncertainty on the accuracy of TL ages greater than 30 ka and thus, not a clear consensus on timing of loess deposition prior to the Wisconsinan. Careful and consistent application of a variety of dating methods (^{14}C, TL, amino acid racemization) to the loess record in the Mississippi and Missouri River valleys may provide a "critical mass" of geochronologic data to decipher the timing of loess deposition during the last 250 ka.

A series of samples for TL and ^{14}C dating were collected from the Loveland Paratype to test the stratigraphic consistence and concordance of ages produced by these techniques. TL samples were taken from oxidized calcareous loess that showed little or no signs of pedogenesis. Chemical weathering can alter both the original TL signal in mineral grains and the radioactivity status of the sediment, thus most buried soil horizons are not suited for TL dating. Radiocarbon dating was completed on disseminated organic matter by conventional methods at Beta-Analytic, Coral Gables, Florida, and on individual snails by accelerator mass spectrometry (AMS) at the University of Arizona. The AMS ages are determined on a fragment from the inner whorl of a snail shell. Prior to radiocarbon analyses this fragment was cleaned by ultrasonification and the outer 50% was removed by soaking in dilute acetic acid. I believe that this carefully cleaned carbonate material is more chemically specific than unidentified organic matter from the loess and thus, yields more accurate ^{14}C ages.

We report nine TL and six ^{14}C age estimates from the Loveland Loess, Pisgah Formation (Roxana Loess equivalent) and the Peoria Loess that provide new data to constrain the timing of loess deposition during the late Pleistocene. The TL and ^{14}C age estimates provide a firm foundation for the development of chronologic hypothesis on loess deposition that will be tested by future field and laboratory studies.

BACKGROUND: THERMOLUMINESCENCE DATING

The TL technique directly dates silicate mineral grains, reflecting the time since the sediment was last exposed to sunlight (cf. Wintle and Huntley, 1980). Exposure to full sunlight for at least 8 hours eliminates (bleaches) any inherited TL signal, thus resetting the TL clock to time "zero". If the sediment is buried and shielded from further light exposure, nuclear radiation, mostly from the radioactive decay of potassium and uranium and thorium and their daughters, progressively imparts a TL signal. This radiation ionizes electrons in mineral grains, which are subsequently trapped at lattice-charged disequilibrium sites, called electron traps. Heating during laboratory analysis or exposure of the sediment to natural sunlight causes vibration of the mineral lattice and eviction of electrons from traps. A number of these electrons are conducted to recombination sites from which light is emitted. This light signal is proportional to the time since burial of the mineral grain.

Quartz and feldspar grains within sediment act as long-term radiation dosimeters, with the TL signal being a measure of the radiation exposure during burial. In the laboratory, this radiation induced TL signal is calibrated to a known radiation level, which is called the equivalent dose ED; measured in grays (100 rads = 1 gray (Gy)). Determining an ED is one half of the TL age-equation (1). The other half of the equation is the dose rate, which is an estimate of the environmental radioactivity for the sediment during the burial period. For a more thorough treatment of thermoluminescence dating see Aitken (1985).

$$\text{TL Age Estimate (ka)} = \frac{\text{Equivalent Dose(Gy)}}{\text{Dose Rate (Gy/ka)}} \quad (1)$$

Sediment that receives at least 8 hours of sunlight exposure prior to deposition is preferred for TL analysis because the TL signal can be assumed to be reduced to a low level, i.e. essentially time "zero". Previous studies of modern eolian silts or loess deposits of known age indicate that wind transported silt grains receive sufficient exposure to light to be dated accurately by the TL technique (cf. Wintle, 1981).

THERMOLUMINESCENCE LABORATORY METHODS

The thermoluminescence dating methods utilized herein are the same that were employed by Forman et al., (1989). TL determinations were completed on the 4-11 μm fraction. All samples were preheated for 16 hours at 150° C prior to analysis; after a three week storage period post-preheating samples exhibited no instability in the TL signal, (termed anomalous fading; Wintle, 1973), within analytical resolution of 5%. If this possible instability in the TL signal remains unrecognized, it can lead to an underestimate in TL age estimates.

Samples were analyzed by the three most often used TL methods: the total bleach (Singhvi et al., 1982), partial bleach (Wintle and Huntley, 1980), and the regeneration (Wintle and Proszynska, 1983) methods (Fig. 1). The partial bleach method is capable of dating sediments that have received limited (i.e. <8 hours) as well as extended light exposure. The total bleach and regeneration methods are useful principally for dating sediments that received extended (> 8 hours) exposure to light prior to deposition. However, a recent study of the TL age structure of a loess sequence in Pakistan indicates that the regeneration technique yields significantly younger ages than the total bleach technique, especially for loess >40 ka (Fig. 2). This underestimate in age by the regeneration method reflects a sensitivity change in the rate of TL acquisition in the laboratory after elimination of the geological TL signal by exposure to light. This sensitivity change is specific to the regeneration technique; total and partial techniques do not suffer from this effect. Thus, TL age estimates determined by the regeneration technique should be considered minimum estimates of age.

A recent major advance in TL dating is the rigorous statistical treatment of non-linear TL data. Empirical (Berger et al., 1987; Forman, 1988) and theoretical (Huntley, et al., 1987) studies indicate that the TL growth function is most faithfully modelled as a saturating exponential. These new procedures allow the extension of the total and partial bleach techniques beyond ca. 30 ka, when the TL growth function is distinctively non-linear. The total and partial techniques, particularly for sediments >30 ka, supplant the regeneration technique and offer a more accurate measure of geologic time (Table 1).

One of the major uncertainties in TL dating is the moisture content of the sediment during the burial period. Moisture absorbs ionizing radiation, and thus a variable moisture content causes corresponding variations in dose rate (Table 2). A moisture content of 20 ± 5% was assumed for all dated sediments. Another critical assumption is one of secular equilibrium in the uranium decay-series for the calculation of the dose rate during the burial period. Although there are no data to evaluate this assumption, disequilibrium of <30% would result in a <10% difference from the "equilibrium" value dose rate. This possible difference in dose rate is within existing analytical uncertainty and would have a negligible effect on the TL age estimates.

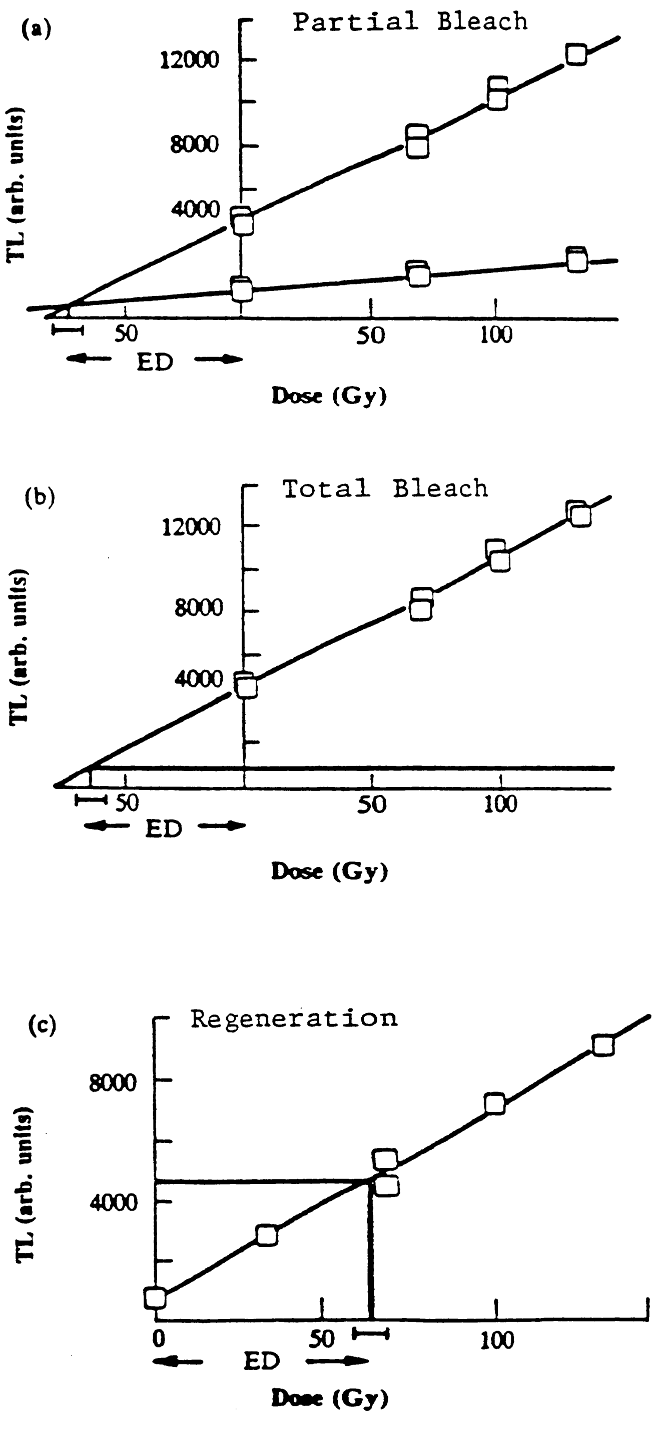

Figure 1. Three often used methods in determining an equivalent dose. The total bleach and partial bleach methods involve extrapolation of the (N+beta) growth. The regeneration method determines an equivalent dose by comparing the natural TL to a laboratory reproduced TL signal. (From Wintle and Prøszynska, 1983).

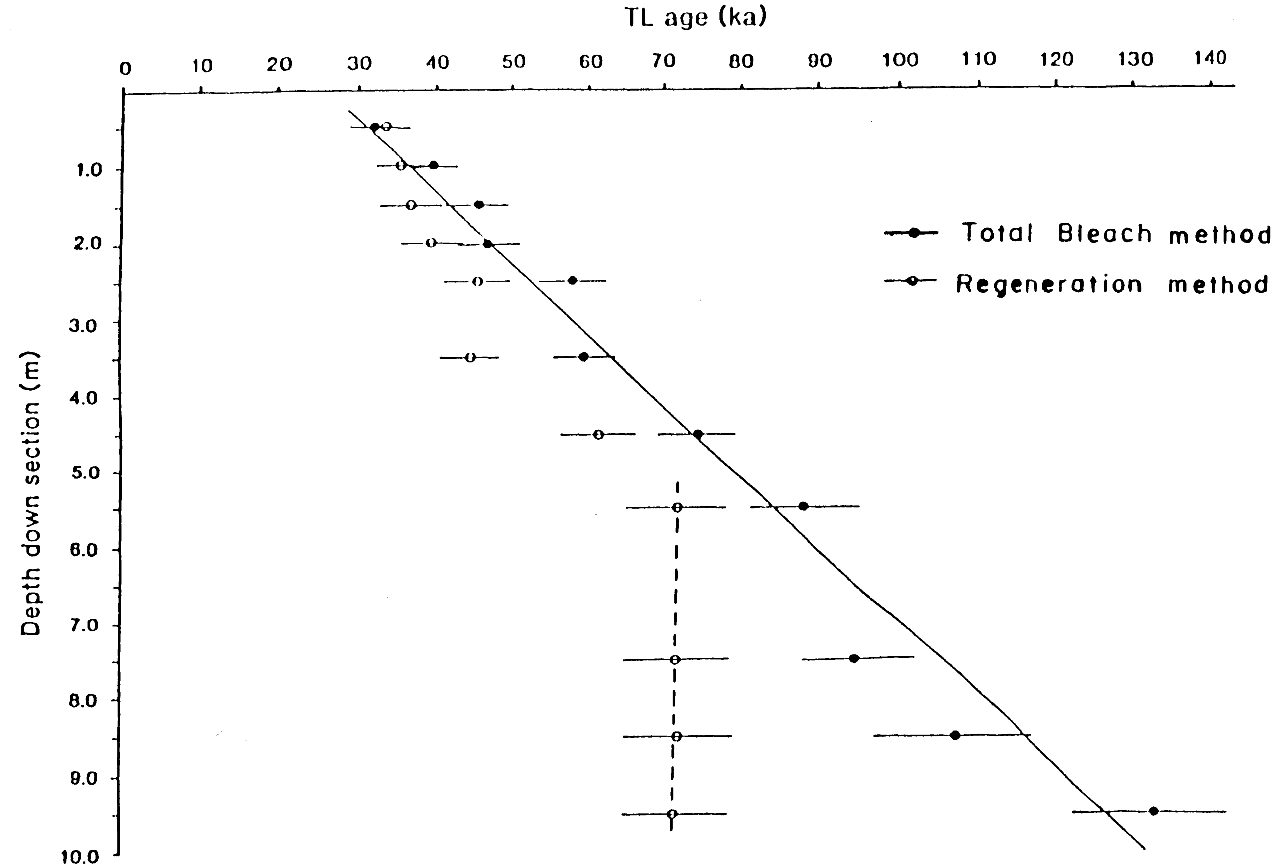

Figure 2. Variation of TL age estimates by the regeneration and total bleach method for a 10 m thick loess section in Pakistan (From Rendell and Townsend, 1988).

CORRESPONDENCE OF THERMOLUMINESCENCE AND RADIOCARBON AGE ESTIMATES

TL age estimates are generally stratigraphically consistent and differentiate three episodes of eolian deposition in the late Pleistocene at the Loveland Paratype (Fig. 3). However, there are substantial differences in age for the Loveland Loess by the regeneration and total/partial methods. The regeneration method yields age estimates of 77 ± 9 ka, 56 ± 5 ka and 60 ± 7 ka, which are considerably younger than partial and total bleach ages of ca. 140 ± 20 ka on the same loess. This difference in regeneration and total/partial bleach TL age estimates is similar to TL dating results for a loess section in Pakistan where the TL ages by the regeneration technique are considered minimum estimates of age (see Fig. 2). Thus, TL ages for the Loveland Loess by the total and partial bleach technique of ca. 140 ± 20 ka are considered finite age estimates. Previous TL determinations by the regeneration method on the Loveland Loess or presumably correlative Illinoian loess of 90 to 60 ka are probably minimum estimates on loess deposition (Norton and Bradford, 1985; Canfield, 1985). Corrections to compensate for the under-estimation in age by the regeneration technique are inappropriate because the calibration curve is not well constrained and is not universally applicable (cf. Canfield, 1985).

Concordant TL and ^{14}C age determinations were obtained on materials from the basal 10 cm of loess deposited on top of the Sangamon Soil. An inner whorl of a snail shell from this level yielded the AMS ^{14}C age of 34,400 ± 700, yr B.P. (AA-4827) which is in agreement with a previous ^{14}C age of 31,080 +5600/-3200 yr B.P. (FRL-1444) on disseminated organic matter. A TL age estimate of 30 ± 3 ka (ITL-198) on the surrounding loess is

Table 1. Thermoluminescence data and age estimates for samples collected from the Loveland Paratype, Iowa.

Field No.	Lab sample No.	Strat. Unit	Equivalent Dose Method[1]	Light Exposure[2]	Temperature (°C)[3]	Equivalent Dose (grays)	TL Age Estimate (ka)
F89-I1	ITL194	Loveland Loess	Total Bleach	16h sun	250-370	664.3 ± 79.7	164 ± 18
			Partial Bleach	2h sun	250-320	706.3 ± 92.6	172 ± 22
			Regeneration	16h sun	250-370	312.3 ± 43.5	77 ± 9
F89-I2	ITL208	Loveland Loess	Total Bleach	16h sun	250-370	398.9 ± 47.8	110 ± 15
			Partial Bleach	2h sun	250-360	402.8 ± 56.8	111 ± 20
F89-I3	ITL197	Loveland Loess	Total Bleach	16h sun	250-370	644.0 ± 69.3	138 ± 14
			Partial Bleach	2h sun	250-320	601.6 ± 101.0	129 ± 24
			Regeneration	16h sun	250-370	262.8 ± 20.7	56 ± 5
F89-I4	ITL200	Loveland Loess	Total Bleach	16h sun	250-350	631.3 ± 121.4	124 ± 20
			Regeneration	16h sun	250-370	246.7 ± 26.9	60 ± 7
F89-I7	ITL198	Pisgah Formation	Total Bleach	16h sun	250-370	118.5 ± 13.4	30 ± 3
			Partial Bleach	2h sun	250-370	132.6 ± 35.7	34 ± 7
F89-I9	ITL206	Pisgah Formation	Total Bleach	16h sun	250-370	82.6 ± 13.0	23 ± 3
			Partial Bleach	2h sun	250-370	94.2 ± 24.6	25 ± 5
F89-I10	ITL201	Peoria Loess	Total Bleach	16h sun	250-370	76.6 ± 13.7	18 ± 2
			Partial Bleach	2h sun	250-370	69.7 ± 22.6	16 ± 4
F89-I12	ITL207	Peoria Loess	Total Bleach	16h sun	250-370	88.0 ± 11.7	22 ± 3
			Partial Bleach	2h sun	250-370	80.5 ± 14.5	20 ± 3
F89-I13	ITL195	Peoria Loess	Total Bleach	16h sun	250-370	88.4 ± 15. 2	21 ± 3
			Partial Bleach	2h sun	270-330	88.6 ± 16.0	21 ± 3

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[1] All TL measurements were made with a Schott UG-11and HA-3 filters in front of the photomultiplier tube. Samples were preheated to 150 °C for 16 hrs prior to analysis.

[2] Hours of light exposure to define residual level. "Sun" is natural sunlight in Boulder, Colorado.

[3] Temperature range used to calculate equivalent dose.

[4] All errors are at one sigma and calculated by averaging the errors across the temperature range.

Table 2. Dose rate data for samples from the Loveland Paratype, Iowa.

Lab Sample Number	Bulk Alpha Count Rate (ks/cm2)[1]	Th (ppm)	U (ppm)	Unsealed/ Sealed[2]	%K[3]	A Value[4]	Dose Rate (Gray/ka)[5]
ITL194	0.57 ± 0.01	7.3 ± 1.0	2.6 ± 0.3	1.00	2.10 ± 0.06	0.15 ± 0.01	4.05 ± 0.20
ITL195	0.69 ± 0.01	8.5 ± 1.1	3.3 ± 0.4	1.04	2.12 ± 0.05	0.12 ± 0.02	4.21 ± 0.21
ITL197	0.53 ± 0.01	7.1 ± 1.0	2.4 ± 0.3	0.99	2.22 ± 0.05	0.23 ± 0.01	4.67 ± 0.21
ITL198	0.62 ± 0.01	7.1 ± 1.1	3.1 ± 0.3	1.03	2.20 ± 0.10	0.11 ± 0.01	3.97 ± 0.18
ITL200	0.56 ± 0.01	8.3 ± 0.8	2.3 ± 0.3	0.99	2.25 ± 0.02	0.11 ± 0.02	5.01 ± 0.24
ITL201	0.62 ± 0.01	6.5 ± 0.8	3.3 ± 0.2	1.04	1.98 ± 0.06	0.16 ± 0.01	4.30 ± 0.13
ITL206	0.65 ± 0.01	8.1 ± 1.2	3.0 ± 0.4	0.99	1.82 ± 0.08	0.12 ± 0.01	3.67 ± 0.11
ITL207	0.63 ± 0.01	6.7 ± 1.0	3.3 ± 0.3	0.98	2.25 ± 0.10	0.11 ± 0.01	4.00 ± 0.17
ITL208	0.54 ± 0.01	6.9 ± 1.0	2.5 ± 0.3	1.00	2.18 ± 0.04	0.16 ± 0.02	3.63 ± 0.16

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[1] U and Th ppm values calculated from alpha count rate, assuming secular equilibrium.

[2] Ratio of bulk alpha count rate under sealed and unsealed counting conditions. A ratio of >0.95 indicates little or no radon loss.

[3] % potassium determined by atomic absorption spectrophotometry after digestion in HF.

[4] The measured alpha efficiency factor as defined by Aitken and Bowman (1975).

[5] Dose rate value includes a contribution from cosmic radiation of 0.12 ± .01 gray/ka and assuming

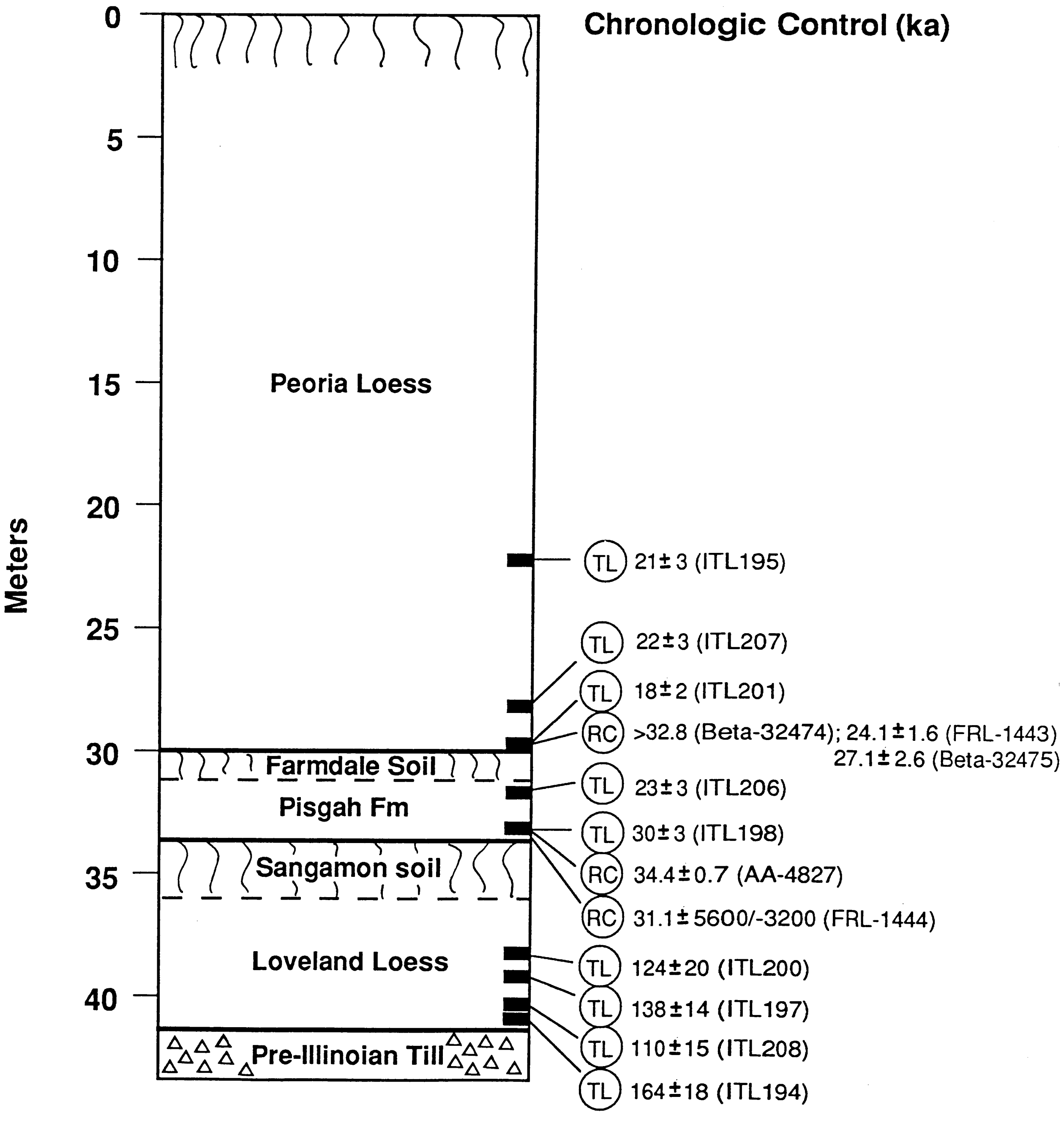

Figure 3. Stratigraphy at the Loveland Paratype and corresponding thermoluminescence and radiocarbon age estimates.

in general agreement with the ^{14}C ages. These geochronologic data indicate that deposition of the Pisgah Formation (Roxana Loess equivalent) at this site started 35 to 30 ka.

TL and ^{14}C age estimates from the basal part of the Peoria Loess provide chronologic control on the timing of loess deposition during the Late Wisconsinan. Radiocarbon ages on unidentified organic material from the top of the Farmdale Soil yielded ages of >34,820 yr B.P. (Beta-32474), 24,100 1650 yr B.P. (FRL-1443) and 27,090 ± 2600 yr B.P. (Beta-32475) and the surrounding loess yielded the TL age estimate of 18 ± 2 ka (ITL201). I consider the infinite ^{14}C age spurious because below this level there are four ^{14}C ages <34 ka and three TL ages <30 ka. The remaining ^{14}C and TL ages estimates from the top of the Farmdale Soil overlap at two standard deviations and are stratigraphically consistent, and thus provide a better estimate on loess deposition. The majority of geochronologic data at this level indicate that the Farmdale Soil was buried by loess deposition 25 to 20 ka ago. The early phase of Peoria Loess deposition was rapid, indicated by three statistically identical TL age estimates from the bottom 7 m of this unit.

CHRONOLOGY OF LATE PLEISTOCENE LOESS DEPOSITION : A HYPOTHESIS

Though there are methodological and diagenetic effects that erode the accuracy the technique, the full potential of the TL technique to date the timing of loess deposition in the Midwest has yet to be fully realized. This study indicates that combined ^{14}C and TL dating can provide new and more secure constraints on the timing of loess deposition in the Midwest. Four TL ages on the Loveland Loess indicate that this sediment was deposited ca. 140 ± 20 ka. The penultimate loess depositional event, represented by the Pisgah Formation, started 35 to 30 ka, as indicated by ^{14}C and TL ages from this unit. The majority of geochronologic data indicates that the latest episode of loess deposition at this site probably started 25 to 20 ka ago. The available dates from the Loveland Paratype indicate that there were three periods of loess deposition ca. 140 ± 20 ka, 35 to 25 ka, and 25 to 12 ka.

Recent TL dating of loess from the New Pleasant Grove School Section indicates that there may have been a period of loess deposition during the early Wisconsinan. At this site the Teneriffe Silt, below the Sangamon Soil, yielded a TL age estimate of ca. 70 ± 10 ka (by the total and partial bleach techniques). The overlying Roxana Loess gave TL age estimates of ca. 30 ± 5 ka, similar to the Pisgah Formation of the Loveland Paratype. The TL age of the Teneriffe Silt is similar to TL ages (by the partial and total bleach techniques) for a loess below a major paleosol, near Vicksburg, Mississippi (Pye and Johnson, 1988). The TL ages from the New Pleasant Grove School Section suggest that the loess in which the Sangamon Soil is developed may vary in age and that the Loveland site may have undergone erosion during the early Wisconsinan.

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AMINO-ACID ANALYSIS OF FOSSIL GASTROPOD SHELLS FROM LOESS AT THE LOVELAND PARATYPE SECTION, POTTAWATTAMIE COUNTY, IOWA

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Fossils gastropod shells were sampled from the Peoria Loess and the Pisgah Formation loess (Roxanna Silt equivalent) at the Loveland Paratype in Pottawattamie County, Iowa, for the purpose of amino-acid analysis. The ratio of two amino acids, alloisoleucine:isoleucine (AIle/Ile), measured in fossil snail shells has been used throughout the Mississippi Valley as a tool for correlating and differentiating loess units of different ages (Oches et al., in press; Clark et al., 1989), and it is hoped that the developing aminostratigraphy can be extended to loess deposits in this region.

The extent of isoleucine epimerization in a given genus of shell is a function of the age and temperature history of the sample. The aIle/Ile ratio is commonly used as a relative-age indicator, but with appropriate calibration it can be used to suggest numerical ages of paleotemperatures.

Sample LLD-1 was taken from near the middle of the Pisgah Formation, and sample LLD-2 was removed from immediately above the base of the Peoria Loess. The Loveland Loess at this section was not found to be fossiliferous, however, it is hoped that further studies will reveal gastropods in the Loveland Loess at or near the type locality in order that we may extend aminostratigraphic correlations of pre-Wisconsinan loess units into this region.

A radiocarbon age of 24,100 ± 1650 yr. B.P. (FRL-1443) has been determined on disseminated charcoal flecks from the top six centimeters of the Pisgah Formation loess, and an age of 31,080 +5600/-3200 yr. B.P. (FRL-1444) has been obtained on disseminated organic carbon flecks from 30 centimeters above the base of the Pisgah Formation loess (W.H. Allen and others, unpublished). The statistically indistinguishable aIle/Ile values in the total acid hydrolysate (Table 1) measured on samples from the Peoria and Pisgah Fm. loess units support these radiocarbon age

Table 1. AIle/Ile ratios from shell samples collected from the Peoria Loess and the loess of the Pisgah Formation at the Loveland Paratype Section, Pottawattamie County, Iowa.

LLD-2 PEORIA LOESS

Sample #	Genus	Hydrolysate	N	Free Fraction	N
AGL0613	*Hendersonia*	0.07±0.01	2	0.11±0.01	2
AGL1214	*Succinea*	0.11±0.01	5	0.11±0.01	2

LLD-1P PISGAH FORMATION

Sample #	Genus	Hydrolysate	N	Free Fraction	N
AGL1215	*Hendersonia*	0.07±0.01	5	0.12±0.01	2
AGL0612	*Succinea*	0.12±0.01	3	0.15±0.01	2

estimates as well as thermoluminescence age determinations by S. Forman (included in this field guide) in the sense that they suggest a relatively short period of time with little or no warming between the end of deposition of the Pisgah Formation and the onset of accumulation of the Peoria Loess.

It is expected that aIle/Ile ratios on shells from the Loveland Loess would be considerably higher, if the Loveland Loess is, in fact, Illinoian in age. The epimerization reaction would be greatly accelerated during the relatively warm Sangamon Interglacial, resulting in significantly higher aIle/Ile values for pre-Wisconsinan samples.

The "Third loess" at Wittsburg Quarry, Crowley's Ridge, Arkansas, has been correlated by some workers with the Loveland Loess of western Iowa (West and others, 1980; Rutledge and others, 1985; Guccione and others, 1985). AIle/Ile values measured on *Hendersonia* from this locality average about 0.30, compared with ratios of about 0.12 on *Hendersonia* from the Peoria Loess at the same latitude (Clark and others, 1989; Oches and others, in press). McCoy and others (in press) conclude that the "Third loess" is Illinoian in age.

Hopefully, additional research will discover fossiliferous loess of the Loveland Loess in western Iowa so that we may contribute additional independent evidence as to its age and test correlations of the Loveland Loess with the "Third loess" at Crowley's Ridge and units elsewhere.

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MORPHOLOGICAL CHARACTERIZATION OF A SUITE OF BURIED AND EXHUMED SANGAMON PALEOSOLS IN POTTAWATTAMIE COUNTY, IOWA

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Buried, exhumed, and relict paleosols offer earth scientists an opportunity to decipher paleoclimatic and paleoenvironmental conditions from the terrestrial record. Present in both buried and exhumed forms, the Sangamon Soil was early recognized in the Midwest as a distinct stratigraphic zone with important implications for interpretations of events that occurred between the Illinoian and Wisconsinan glacial stages. Its widespread distribution has contributed to the appreciation of the significance of buried soils throughout the Quaternary record (Follmer, 1978).

In Illinois, Ohio, and southeastern Iowa, the Sangamon Soil is primarily developed in Illinoian till and glaciolacustrine sediments (Follmer, 1983; Ransom et al., 1987; Hallberg et al., 1980), and in Indiana it occurs developed both in Illinoian glacial drift and in Pennsylvanian and Mississippian bedrocks (Ruhe et al., 1974). In southwestern Iowa the Sangamon Soil is recognized to have developed in the upper part of the Loveland Loess (Hallberg, 1986). Ruhe and Cady (1967) showed that, in a west-to-east traverse from the Missouri River, the thickness of Loveland Loess decreased, the thickness of the Sangamon Soil's solum increased, and the clay content of the Sangamon Soil's B horizon increased. The reddish colors of many Sangamon paleosol B horizons have suggested to many investigators that the period of Sangamon weathering was either longer or more intense (or both) than that of the Holocene. Ruhe et al. (1974) concluded that the Sangamon environment in the Midwest was a "uniformly warm, humid forest and woodland," similar to the contemporary southern United States.

Micromorphological studies of paleosols are often useful for the interpretation of both pedogenic and diagenic features (Finkl and Gilkes, 1976; Fedoroff et al., 1990). There are few reports of micromorphological examinations of Sangamon paleosols. Moreover, few investigators have explicitly studied the effects of exhumation on the morphology of Sangamon paleosols. Therefore, the objectives of the present article are (1) to present micromorphological observations of a buried Sangamon paleosol in Pottawattamie County, Iowa and (2) to compare morphological characteristics of two exhumed paleosols to those of the buried Sangamon paleosol. The location of the study pedons was about 25 km east of the Missouri River, so the investigation also documents the extent of Sangamon-Soil development in the Loveland Loess not far from its source.

MATERIALS AND METHODS

Buried and exhumed examples of a Sangamon paleosol developed in Loveland Loess were sampled on a 9% hillslope near Oakland in Pottawattamie County, Iowa (NW 160, NE 40, SE 10, E 5 of Sec. 20, T76N, R40W). The site corresponds to Cut 36 of Ruhe's railroad-cut traverse across southern Iowa (Ruhe et al., 1967). Undisturbed cores that included the Sangamon paleosol developed in Loveland Loess were sampled by an hydraulic probe at three locations on the hillslope. Macromorphological characteristics of the cores were described according to the Soil Survey Manual (Soil Survey Staff, 1951), and subsamples were collected for the determination of organic carbon content (Walkley-Black method; Nelson and Sommers, 1982), particle-size distribution (pipette method; Gee and Bender, 1986), and pH (1:1 soil-to-water ratio). Undisturbed sections of each core were air-dried, impregnated with a polyester resin by using the methods of Murphy (1987), and processed into thin sections about 30 μm thick. Thin-section analysis was performed with a petrographic microscope. Concepts and nomenclature followed the International Soil Science Society handbook of

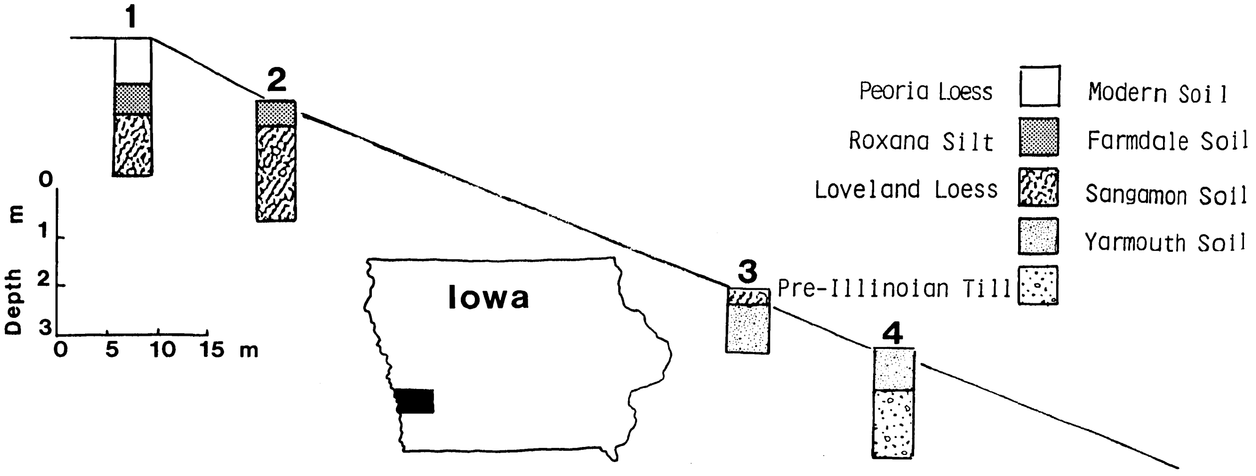

Figure 1. Schematic diagram of hillslope transcect sampled in Pottawattamie County, Iowa.

Bullock et al. (1985) and Murphy et al. (1985) (related distribution patterns). The c/f cutoff was set at 20 μm. Porosity estimates refer to pores >50 μm effective diameter.

RESULTS

Macromorphological Characteristics

Figure 1 presents the stratigraphic context of the pedons examined. Macromorphological descriptions are given in Table 1, and Table 2 shows the chemical and physical data determined for the pedons sampled. The descriptions and data were used to identify lithologic discontinuities and genetic horizons as presented in Table 1. Ruhe et al. (1976) reported that the Loveland Loess was 3 m thick at Cut 36.

Site 1 was located at the top of the hillslope (Fig. 1). Although there was some evidence that the Peoria Loess in which the modern soil was developed had been truncated during construction of the railroad immediately to the north of Site 1, the buried surfaces appeared to be uneroded. At this location, the Sangamon paleosol was covered by 64 cm of a Farmdale paleosol developed in Wisconsinan loess (the proposed Pisgah Formation) that was a light silty clay loam to silt loam with brown (10YR 4/3) matrix colors and prominent light gray (10YR 7/2) silt coatings. The Farmdale paleosol was, in turn, overlain by 96 cm of Peoria Loess (dark grayish brown (10YR 4/2), brown (10YR 5/3), and grayish brown (2.5Y 5/2) silt loam) that was oxidized in the upper part and deoxidized in the lower part.

At Site 1, the 3Ab horizon of the Sangamon paleosol was a 59-cm-thick zone, brown (10YR 4/3 and 4/4) silt loam and silty clay loam, with moderate, fine, subangular blocky structure and common silt coatings. It was underlain by a 31-cm-thick 3BAb horizon that had a silty clay loam texture and continuous silt, clay, and manganese oxide or organic coatings. The 3Btb horizon of the Sangamon paleosol extended for at least 48 cm (i.e., to the base of the core). It was a silty clay and brown (7.5YR 4/4), with strong, fine, subangular blocky structure, discontinuous silt and clay coatings, and continuous manganese oxide or organic coatings.

At Site 2, down slope from Site 1, the exhumed Sangamon paleosol was covered by 58 cm of exhumed Farmdale paleosol. At this location the Sangamon 2Ab horizon was 42 cm thick and had a silty clay loam texture. The 2Btb horizon was a brown (7.5YR 4/ 4) silty clay, with generally strong, fine, subangular blocky structure and continuous clay coatings. The 2Btb horizon extended for at least 140 cm (i.e., to the base of the core).

At Site 3, farther down slope from Site 2, the exhumed Sangamon paleosol extended from the soil surface to a depth of 28 cm where it overlay the truncated B horizon of a Yarmouth paleosol. The Sangamon paleosol consisted of (1) a brown (10YR 3/3) silty clay loam Ap horizon with moderate, medium, platy and subangular blocky structure and

Table 1. Macromorphological descriptions of Pottawattamie County hillslope transect.

Horizon	Depth cm	Color moist	Texture	Structure	Mottles	Coatings	Fecal pellets	Boundary
Site 1								
A1	0-5	10YR4/2	sil	m-1-gr				c
A2	5-16	10YR4/2 10YR5/3	sil	s-1-gr				g
Bw1	16-48	10YR5/3	sil	w-1-sbk m-1-gr			many	c
Bw2	48-96	2.5Y5/2	sil	w-1-sbk	c-1-d 7.5YR4/6	c-1-disc 7.5YR3/2	common	c
2Ab1	96-129	10YR4/3	sicl	m-1-sbk		f-1-disc 10YR7/2	few	d
2Ab2	129-160	10YR4/3	sil	m-1-sbk		c-1-disc 10YR7/2	few	d
3Ab1	160-195	10YR4/3	sil	m-1-sbk		c-1-disc 10YR7/2	common	c
3Ab2	195-219	10YR4/3 10YR4/4	sicl	m-1-sbk		c-1&2-disc 10YR7/2	few	c
3BAb	219-250	10YR4/3	sicl	s-1-sbk		m-1&2-cont 10YR7/2 f-1-cont 7.5YR3/0 m-1-cont 7.5YR4/4	few	g
3Btb1	250-280	7.5YR4/4	sic	s-1-sbk		f-1-disc 10YR7/2 c-1-cont 7.5YR3/0 f-1-disc 7.5YR4/6	few	g
3Btb2	280-298	10YR4/3	sic	m-1-sbk		c-1-disc 7.5YR5/6 m-1-cont 7.5YR5/2 c-1-disc 7.5YR3/0&3/2	few	-
Site 2								
Ap1	0-6	10YR3/3	sil	m			many	c
Ap2	6-34	10YR4/3	sicl	m				g
A	34-58	10YR4/3	sil	m		f-1-disc 10YR7/2	common	c
2Ab	58-100	10YR4/4 7.5YR4/4	sicl	w-1-sbk		c-1-disc 10YR7/2	common	c
2Btb1	100-137	7.5YR4/4	sic	s-1-sbk		c-1-cont 10YR4/3 c-1-cont 10YR4/3 c-1-disc 10YR3/0&3/2	few	c
2Btb2	137-190	7.5YR4/4	sic	s-1-sbk		m-1-cont 10YR4/3 m-1-disc 7.5YR3/0		c
2Btb3	190-240	7.5YR4/4	sic	m-1-pr m-2-sbk		m-2-cont 10YR4/3 m-1-disc 10YR2/1		-
Site 3								
Ap	0-13	10YR3/3	sicl	m-2-pl m-2-sbk				a
Bt1	13-28	7.5YR4/4	sic	m-2-sbk m-1-sbk	f-1-d 10YR3/2	c-1-disc 10YR4/3&4/2	few	c
2Bt2	28-46	10YR5/2	sic	m-1-sbk	f-1-d 7.5YR5/6	c-1-disc 10YR4/3 f-1-disc 10YR4/2	few	c
2Bt3	46-62	10YR5/2	sic	m-1-sbk	c-1-p 10YR3/2	c-1-cont 10YR4/2 f-1-cont 7.5YR5/6		c
2Bt4	62-120	10YR5/2	sicl	m-2-sbk	f-2-p 7.5YR5/6	m-1&2-cont 7.5YR4/2		-

Table 2. Particle-size distribution, organic C, and pH of the soils studied.

Site and horizon	Depth	Particle size distribution†				Organic C	pH
		sand	c.silt	f.silt	clay		
	cm	%				g kg^{-1}	
Site 1							
A	0-16	2	47	25	25	11.5	6.6
Bw1	16-48	2	42	33	23	3.4	6.8
Bw2	48-96	2	40	37	21	2.3	7.2
2Ab1	96-129	3	37	33	27	3.3	7.7
2Ab2	129-160	4	37	33	26	2.3	7.7
3Ab1	160-195	5	33	33	29	1.8	7.7
3Ab2	195-219	4	36	28	32	1.7	7.6
3BAb	219-250	5	29	27	39	1.5	7.5
3Btb1	250-280	5	27	26	42	0.8	7.5
3Btb2	280-298	4	28	25	42	0.5	7.5
Site 2							
Ap	0-6	3	39	32	26	9.7	6.2
A1	6-34	3	41	27	30	4.6	6.5
A2	34-58	3	41	30	26	3.0	6.8
2Ab	58-100	5	33	32	31	1.7	7.3
2Btb1	100-137	5	29	24	42	1.5	7.3
2Btb2	137-190	5	30	24	41	0.6	7.4
2Btb3	190-210	5	26	26	43	0.6	7.3
2Btb3	210-240	5	29	23	44	0.4	7.4
Site 3							
Ap	0-13	5	36	24	36	13.5	5.6
Bt1	13-28	4	32	23	41	4.3	5.3
2Bt2	28-46	4	28	28	40	2.1	6.3
2Bt3	46-62	3	24	31	42	1.2	6.5
2Bt4	62-100	4	27	31	38	0.4	6.8

†Sand = 2-0.05 mm; coarse silt = 50-20 µm; fine silt = 20-2 µm; clay = <2 µm.

(2) a brown (7.5YR 4/4) silty clay Bt horizon with moderate, fine and medium, subangular blocky structure, and discontinuous clay coatings.

Micromorphological Characteristics.

In the following paragraphs, a summary of micromorphological characteristics of the Sangamon Soil at Sites 1, 2, and 3 is given. Percentages in parentheses are estimates of area-percentage in thin section. Thin sections of materials above and below the Sangamon paleosols at each site were also described, but these will only be referred to when relevant to interpretation of the Sangamon paleosols. Micrographs for key features observed in thin section will be presented in discussions at Stop 7 of the 1990 Midwest Friends of the Pleistocene field conference.

Site 1. The buried Sangamon 3Ab horizon had a microstructure that was both spongy and granular; a single-spaced, embedded-grain related distribution pattern (RDP); and a stipple-speckled birefringence fabric (b-fabric). Porosity (15-20%) was dominated by irregularly shaped, compound packing pores of varying size and by channels that were generally 150-800 μm in diameter.

No roots or decomposing organic fragments were observed in the Sangamon 3Ab horizon. On the other hand, several pedological features were present. For example, infillings of silt (3-4%), as large as 5 mm X 0.5 mm, occurred in compound packing pores near the top of the A horizon. Microlaminated clay coatings (1-3%, depending on depth) occurred on walls of planar pores and channels. They were generally 90-120 μm thick, with wavy to sharp extinction and moderate birefringence. A few nodules of micritic calcite were observed in the buried Sangamon 3Ab horizon. They ranged from 1 to 40 cm^2 and included some needle-shape calcite in places. Fecal pellets (2-5%), probably derived from earthworms, ranged from about 275 μm to about 1 mm in diameter. Fe oxide nodules (2-3%) were moderately to strongly impregnative, were both rounded and irregularly shaped, and ranged from about 10 to about 900 μm in diameter.

The buried Sangamon 3Btb horizon had subangular blocky microstructure; single-spaced, embedded RDPs; and both stipple-speckled and porostriated b-fabrics. Porosity (15-20%) was dominated by zig-zag planar pores, 150-1250 μm wide, but compound packing pores, channels, and chambers were also present.

In the upper part of the 3Btb horizon, 15-20% of the pores had 15-80-um-thick, discontinuous hypocoatings of oriented clay. In the lower part of the Bt horizon, microlaminated clay coatings (2-5%) were 20-200 μm thick and had wavy extinction and moderate birefringence. A few crescent-shaped accumulations of microlaminated clay that averaged about 400 X 1000 μm also occurred in the 3Btb horizon. One prolate, sparitic, calcite nodule, 310 X 170 μm, was observed, with individual crystals 20-60 μm in diameter. Fe oxides (2-3%) consisted of both impregnative nodules and coatings. The nodules ranged from about 30 to about 500 μm in diameter, and they ranged from translucent to strongly impregnated. Fe oxide coatings on pore walls were 10-130 μm thick and discontinuous. They occasionally overlay microlaminated clay coatings.

Site 2. The upper 58 cm of material at the second site of the hillslope transect were interpreted to be an exhumed Farmdale paleosol. In thin section, this material exhibited spongy and channel microstructure in the upper and lower portions (i.e., at depths of 0-6 cm and 24-58 cm) and fissure/platy microstructure in the middle portion (14-20 cm depth). The related distribution pattern was dominantly single-spaced, coated-and-bridged or embedded grain, and the b-fabric was undifferentiated or weakly stipple-speckled.

Root fragments in varying stages of decomposition occurred to a depth of about 30 cm. Porosity (10-15%) consisted mainly of packing pores and channels, except in the 14-20-cm zone where subhorizontal planar pores were dominant. Fecal pellets in the exhumed Farmdale paleosol appeared to be derived mainly from potworms and (rarely) mites. Their abundance was about 2% in the 0-6-cm zone, decreased to <1% in the 6-29-cm zone, and increased to about 3-4% in the 34-58-cm zone. In this lowermost zone, fecal pellets appeared to be derived from earthworms. Throughout, Fe oxides were typic and irregular impregnative nodules (1-2%), ranging from about 5 to about 500 μm in diameter. Fe oxide hypocoatings of pores also occurred but were rare.

The 58-100-cm zone at Site 2 was interpreted from macromorphological, chemical, and physical data to be a 2Ab horizon, i.e., a remnant of the Sangamon Soil. In thin section it had spongy microstructure; single-spaced, embedded grain

RDP; and stipple-speckled b-fabric. Porosity (18-20%) was mainly packing pores between aggregates.

Rare microlaminated clay coatings (1%), 10-100 μm thick, with wavy extinction patterns and moderate birefringence occurred both in pores and embedded in the groundmass. Infillings of medium silt grains (20-30 μm)(1-2%) were observed in vughs and were 200-400 μm in diameter. Fecal pellets, probably derived from both potworms and earthworms accounted for about 12-15% of the thin sections from this zone. The pellets were strongly aged. The potworm fecal pellets occurred largely as loose, discontinuous infillings of channels that were 2-5 mm in diameter. Typic, impregnative Fe oxide nodules (1-2%) were generally discrete, equant individuals, 100-500 μm in diameter, with sharp boundaries.

There was a distinct break in the continuity of micromorphological features at about 100 cm depth. At that depth a band of fine silt separated the spongy microstructure of the overlying horizon from subangular blocky structure in the underlying horizon. In fact, the silty band, which was 3-4 mm thick and exhibited some internal bedding, appeared to be draped over the uppermost subangular blocky peds. The upper part of the underlying 2Btb horizon had a single-spaced, embedded-grain RDP and a mosaic-speckled b-fabric. Porosity (20%) consisted mainly of packing pores and vughs that were irregularly shaped but roughly 1-2 mm in diameter.

Textural pedological features included both clay coatings and silt coatings and infillings. The clay coatings (5%) were weakly microlaminated, dusty, and 50-100 μm thick, with wavy to sharp extinction and moderate birefringence. They were generally embedded in the groundmass, but some were associated with pores as well. The silt coatings and infillings (2%) were associated with pores of various sizes. One silt coating was observed to overlie a clay coating. Rare, typic, impregnative Fe oxide nodules (<1%) that were opaque and 100-800 μm in diameter also occurred in the upper 2Btb horizon.

The lower part of the 2Btb horizon at Site 2 had subangular blocky microstructure; a double-spaced, embedded RDP; and b-fabrics that were porostriated and mosaic speckled. Porosity was significantly less than in overlying horizons, consisting largely of planar pores (5%) and channels (2%). Weakly to moderately microlaminated clay coatings, 25-100 μm thick, with wavy to diffuse extinction and moderate to high birefringence, were associated primarily with channels, not cracks. Both Fe oxide nodules and coatings were present. The nodules (1%) were typic impregnative nodules, 200-1100 μm in diameter, and moderately to completely opaque. The coatings and hypocoatings were generally 10-50 m thick and opaque. They were associated with both channels and planes.

Site 3. At Site 3, the uppermost 21 cm of soil were interpreted to be a remnant of the Sangamon paleosol. The Ap horizon (0-13 cm) had both platy and subangular blocky microstructure in thin section, so porosity (15%) was dominated by planar pores , with fewer compound packing pores and fewer still channels. The RDP was single- and double-spaced embedded grain, and b-fabrics were stipple-speckled. Decomposing root and tissue fragments accounted for 2% of the thin sections described. Both irregular and typic, impregnative Fe oxide nodules (2%) (5-450 μm in diameter) occurred, along with organic matter fragments that were strongly impregnated with Fe oxide.

The exhumed Sangamon Bt horizon had subangular blocky microstructure. Similar to the A horizon, porosity was low and was dominated by planar pores (100-800 μm wide). The RDP was open- to double-spaced embedded grain, and the b-fabric was largely stipple-speckled with some poro- and mono-striated portions. Rare hypocoatings of clay (<1%), 5-30 μm thick, with wavy extinction and low to moderate birefringence also occurred in this horizon. Fe oxides (2%) consisted of typic impregnative nodules that were translucent to opaque and 60-600 μm in diameter.

DISCUSSION

Site 1 affords the best opportunity to document which pedological features in the Sangamon paleosol have or have not been preserved after burial. In the 3Ab horizon, organic tissues likely to have been present at the time of burial were not preserved. It is difficult to determine whether fecal pellets, porosity, and structure in the buried A horizon represent faunal activity before or after burial. Faunal activity in the overlying Pisgah Formation and Peoria Loess was clearly evidenced by fillings in of fecal pellets and by channel microstructure. Yet it seems unlikely that significant activity of modern earthworms, potworms, and insects would be so concentrated as much as 2 m below the present land surface. On the other hand, in the buried Sangamon 3Btb horizon at Site 1, subangular blocky structure, dominantly planar pores, and textural pedological features such as well-developed, microlaminated clay coatings appeared to be little altered by burial. The abundance of clay coatings in the 3Btb horizons suggested that during the period of soil formation the soil was on a relatively stable landscape position and that both climatic and pedological conditions were conducive to translocation of clay (Bullock and Thompson, 1985).

Some of the clay coatings may have been composed of clay neoformed in the 3Btb horizon (and not translocated from overlying horizons). X-ray diffraction studies of the clay fraction (<2 μm) of the paleosols at this location indicate the presence of both montmorillonite and beidellite (M.L. Thompson and A.L. Steinwand, unpublished data). Because beidellite is commonly found to be a mica weathering product, its formation within the solum would be consistent with either a long or moderately intense period of weathering. On the other hand, neoformation of montmorillonite typically occurs under conditions of high base status, high Si activity in the equilibrating solution, and restricted drainage. At this point, it is not clear whether clay mineralogy can be used to infer soil climate and soil solution characteristics during formation of the Sangamon paleosol, but they do allow some interesting hypotheses to be developed for further testing.

A number of pedological features in the buried Sangamon paleosol appeared to be post-burial, diagenic features. For example, most of the Sangamon paleosol horizons at Site 1 contained a few isolated nodules of secondary calcite. The most reasonable interpretation of these data is that calcite was dissolved and leached from the overlying, initially calcareous Pisgah Formation and/or Peoria Loess. That secondary carbonates were not more widely disseminated in the buried Sangamon horizons could be because the dissolved ions simply continued to move with water that leached through the paleosols. If the Sangamon paleosol had been strongly acid at the time of burial, calcite would not have precipitated. Alternatively, the Sangamon paleosol could have been resaturated with Ca by leaching from the loess and then leached again as water continued to move through the soil. With the present data, one cannot choose between these hypotheses. Mausbach et al. (1982) have argued that base saturation is a characteristic that adjusts rather rapidly when a soil is buried by a calcareous deposit.

Other features of the buried Sangamon paleosol were probably also derived from the loess that buried the soil. These include the silt infillings and thin clay coatings that occurred in the Sangamon AB horizon. In addition, the coatings of Fe oxides that occurred on pore walls of the 3Btb horizon were probably derived from the overlying materials. Above the Farmdale paleosol at Site 1, the Peoria Loess included a 48-cm zone of "deoxidized" loess (the Bw2 horizon at 48-96 cm depth). With matrix colors of 2.5Y 5/2, this zone had clearly lost much Fe, presumably during one or more periods of saturation and reduction.

Many of the Fe oxide coatings in the 3Btb horizon overlay clay coatings on pore walls, and others appeared to have entirely engulfed clay coatings as the Fe oxides precipitated. Therefore, Fe oxide precipitation must have postdated the period of clay illuviation (and, by implication, the period of soil development) for the Sangamon paleosol. This observation suggests that the strong brown to reddish matrix colors typically noted for the Sangamon Soil may not always be good evidence of drainage regime and weathering intensity during soil development but instead may indicate diagenic, postburial processes. Such a model needs to be tested at other sites where a Sangamon paleosol is buried by Wisconsinan deposits. Further characterization of the particular Fe oxide minerals that occur in the paleosol is also needed.

The effects of exhumation on morphological properties of the Sangamon paleosol depended on how close to the present land surface the exhumed soil occurred. At Site 2, the micromorphological identification of a textural discontinuity (a band of silt) at about 100 cm depth suggested that the 58-100 cm zone did not represent the buried A horizon of the Sangamon paleosol, as interpreted from the macromorphological, textural, and chemical data. Instead, the original Sangamon A horizon appeared to have been removed and the Btb horizon buried by a colluvial deposit. Besides truncation, the most significant difference between the shallowly buried Sangamon Bt horizon at Site 2 and the deeply buried Bt horizon at Site 1 was the absence of even isolated nodules of calcite. Proximity to the land surface may have allowed more efficient leaching of secondary carbonates after exhumation.

At Site 3, materials derived from the Sangamon paleosol occurred in the upper 28 cm of the solum. The effects of exhumation on soil properties were inferred by comparison of the properties of the Sangamon materials at Site 3 with those at Site 1. Exhumation appeared to result in truncation and complete leaching of any secondary carbonates derived from previously overlying loess, as at Site 2. Moreover, total porosity was estimated to be only about half that estimated for the Sangamon Btb horizons at Sites 1 and 2, and microlaminated clay coatings were not observed in thin section. These observations suggested that the Sangamon materials at Site 3 consisted not of a Sangamon paleosol in situ but rather a colluvial deposit derived from the Sangamon paleosol-- probably from immediately up slope.

In summary, an integrated morphological characterization of a Sangamon paleosol developed in Loveland Loess in southwestern Iowa has allowed the effects of several pedogenic, diagenic, and geomorphic processes to be distinguished in buried and exhumed forms of the paleosol. Insights gained from this sort of investigation can inform interpretations of soil formation during Sangamonian time as well as help to develop and test more refined models of paleosol diagenesis following burial and exhumation.

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FOSSIL ASSEMBLAGES ASSOCIATED WITH THE LAVA CREEK B ASH (HARTFORD ASH) FROM LITTLE SIOUX, IOWA

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INTRODUCTION

Between 1966 and 1969, middle Pleistocene molluscs, mammals and other vertebrate remains were collected from silts associated with the Lava Creek B ash (Izett and Wilcox, 1982) exposed south of the Harrison-Monona County line, near Little Sioux, Iowa (Figure 1). Only the molluscs and mammals are considered in the report.

The southernmost of the two study sites, the Yard Locality, has contributed the Wright local fauna and the Little Sioux local fauna from sediments immediately above and below the Lava Creek B ash, respectively (Figure 2). The northern most site (Shimek Locality, Figure 3) has yielded the Kraft assemblage from above and the Little Sioux local fauna from immediately beneath the Lava Creek B ash (= Hartford ash of Boellstorff, 1976). The Shimek Locality is the "County-line exposure" illustrated in Shimek, 1910 (Plate XXIV). On the basis of stratigraphic and faunal evidence, the Kraft assemblage is considered the youngest of the three faunas (Figure 4).

FAUNAL ANALYSIS AND COMPOSITION

A total of 13 taxa of mammals (Table 1) and 55 nominal gastropod and pelecypod species and forms (Table 2) have been identified from the four collections sites. The mammals, all small species, include four shrews and nine rodents. The molluscan assemblages include three species of pisidiid clams, 12 pulmonate and three prosobranch aquatic gastropods species, but are dominated in both individual abundance and species diversity by small terrestrial taxa. Only in the Little Sioux local fauna (Shimek Locality) are the molluscs predominantly aquatic species. Similarly the vertebrates are predominantly fish and frog (the Bog Lemming and the ubiquitous vole *Microtus paroperarius* are the only mammals present). No vertebrates have been recovered from above the ash (unit 6) at the Shimek Locality although the molluscan fauna is mostly terrestrial.

Fourteen of the 38 terrestrial molluscs no longer live in the Loess Hill region of western Iowa (Frest and Dickson, 1986). One of the 14 species is represented by the extinct taxon, *Deroceras aenigma*. A second group include seven extralimital species (*Hendersonia occulta, Pupilla muscorum, Vertigo elatior, V. gouldi, Striatura milium, Pomatiopsis lapidaria* and *Zonitoides nitidus*) that now have modern distributions that approach the Loess Hills area in central and northeastern Iowa (Hubricht, 1985). *Vertigo alpestris oughtoni* is a boreal species that now lives in northern Ontario and Manitoba (Oughton, 1948). *Vertigo binneyana* is a species of the western United States and Canada (Hubrich, 1985). *V. nylanderi* and *V. modesta* now have geographic distributions in the Central Lowlands that are well to the north of the Loess Hills in northern Minnesota (Dawley, 1955) and northern Michigan. Although *Vallonia perspectiva* and *V. gracilicosta* are not recorded as extant by Frest and Dickson (1986) in the Loess Hills, *V. perspectiva* is present in central Iowa, northwest Missouri, central Minnesota and southeastern South Dakota, and *V. gracilicosta* has been reported from the Lake Okoboji region of Iowa (Shimek, 1910, 1915). With the possible exception of *Acella haldemani*, most of the aquatic species now have reported geographic ranges that include the study area (Baker, 1920; Shimek, 1910; Clarke, 1981; Burch, 1975; Burch and Tottenham, 1980).

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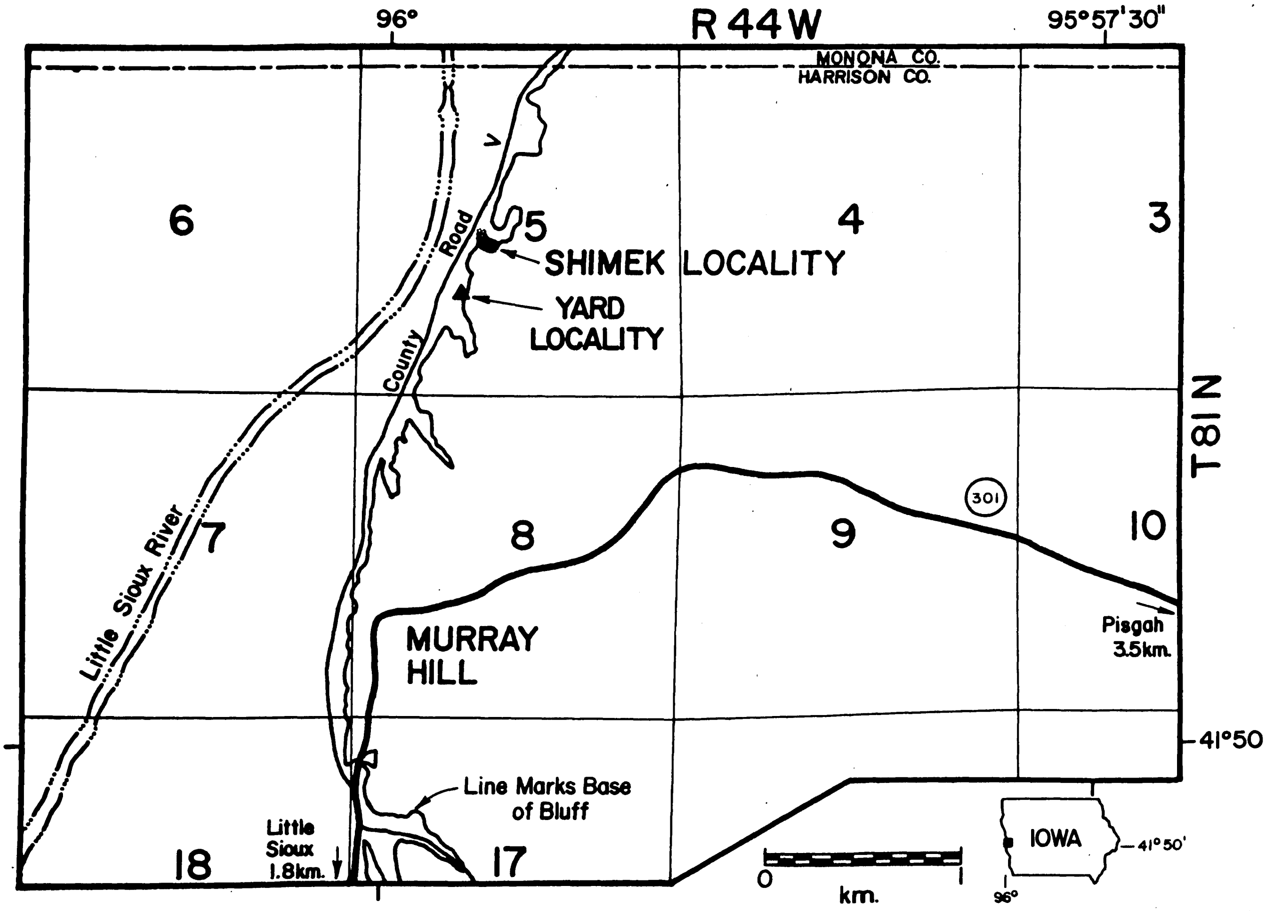

Figure 1. Map showing location of Shimek and Yard localities.

DISCUSSION

Age

Alloisoleucene/isoleucine (aIle/Ile) in fossil gastropod shells recovered from the Little Sioux and Wright local faunas at the Yard Locality provide some insight into the temporal differences between these two assemblages. The results of these analyses (summarized in Table 3) suggest that there is little or no significant difference in age between the faunas at the Yard Locality. Since the rate of isoleucine epimerization varies among different taxa, only aIle/Ile ratios between like genera can be compared. The aIle/Ile values in both the free fraction and the total acid hydrolysate appear to overlap at one standard deviation for *Deroceras, Discus* and *Succinea*. Overall the aIle/Ile values appear similar to other ca. 620,000-year-old shell samples found at similar latitudes and with similar current mean annual temperature (McCoy, 1987; and unpublished data).

Habitat Groupings

Environmental interpretations have been facilitated by assigning the molluscs to habitat groupings (Table 2). Although most species are not restricted to one habitat, there is a tendency for many species to occur most frequently within certain habitats. The habitat groupings to which a given species has been assigned is believed to reflect these preferences.

Yard Locality

Ninety-seven percent of the >10,000 individuals and 76% of the 42 species of molluscs identified from the Little Sioux local fauna at this locality are represented by terrestrial taxa (Table 2). In terms

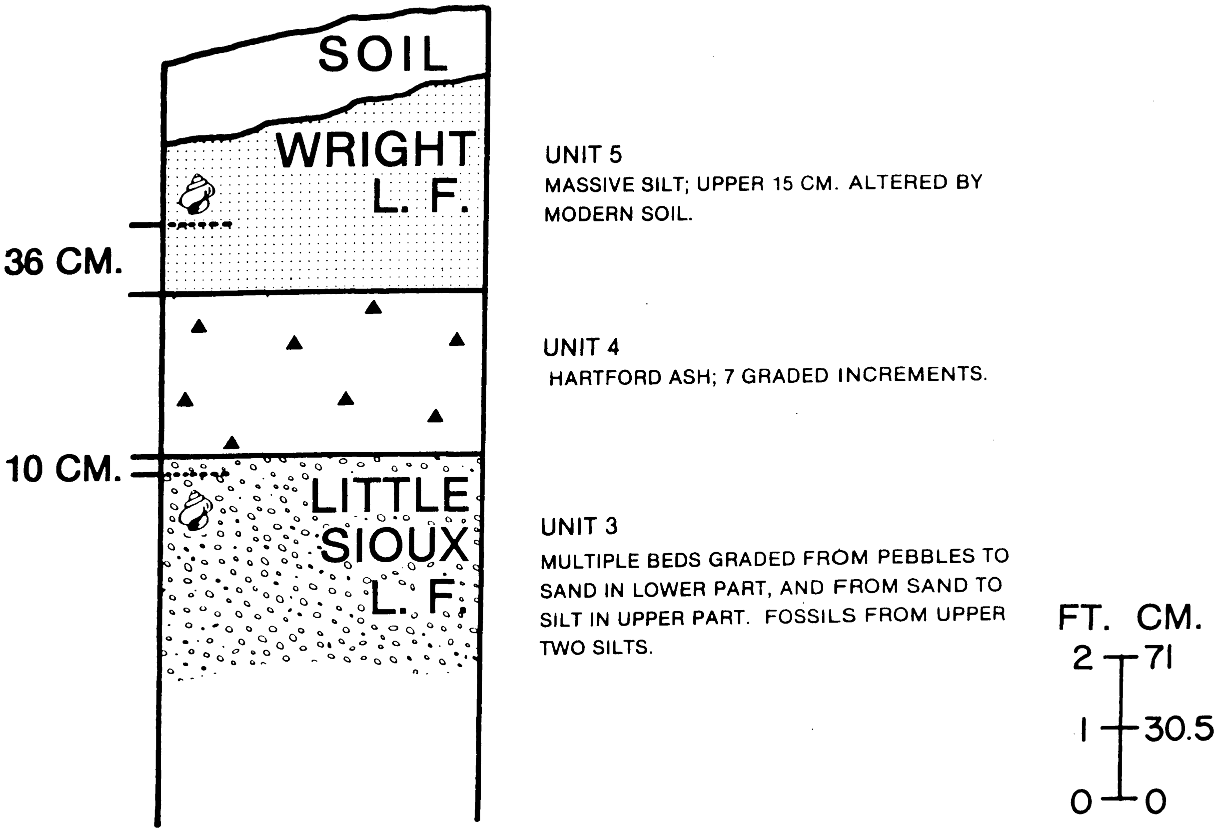

Figure 2. Description of lithologic units at Yard Locality.

of numerical abundance, the terrestrial species are dominated by hygrophiles. This group includes *Carychium exiguum, Gastrocopta tappaniana, Vertigo elatior, V. nylanderi, Discus cronkhitei, Euconulus fulvus, Nesovitrea electrina,* and *Zonitoides nitidus*, species that prefer moist, shaded situations under leaf litter, near water. This association of terrestrial taxa, combined with the fining-upward sequence of sediments, imply a floodplain overbank sequence in which the channel migrated away from the depositional site through time.

A more xeric association of terrestrial molluscus, represented by *Gastrocopta armifera, Pupilla muscorum*, and *Vallonia gracilicosta*, would have lived in better drained areas on the valley slope. Shells from this assemblage were concentrated after death at the base of the valley wall by mass-wasting processes.

The most abundant of the aquatic molluscs are *Bakerilymnaea dalli*, a species that lives in marginal situations near water and *Aplexa hypnorum*, a species that is almost always associated with water bodies that dry-up seasonally (Clarke, 1981). The occurrence of these two species imply the presence of vernal water on the floodplain. The few shells of *Valvata tricarinata* and *Pisidium adamsi,* which are permanent water dwellers, probably represent faunal elements that were brought to the depositional site during occasional flooding. In summary, the faunal and sedimentary evidence support the interpretation that the Little Sioux local fauna at the Yard Locality probably accumulated on the distal part of a floodplain away from the main stream channel and near the base of the valley slope.

The Wright local fauna molluscs from the massive silt above the ash at the Yard Locality (Figure 2) includes 12 aquatic and 27 terrestrial taxa identified to species. Thirty-one of the taxa

Table 1. Mammals from the Little Sioux and Wright local faunas.

TAXON	MODERN ANALOG	LITTLE SIOUX	WRIGHT
**Sorex lacustris*	Arctic Shrew	x	--
**Phenacomys* sp.	Spruce-Heather vole	x	--
Tamiasciurus cf.*hudsonicus* (small)	Red Squirrel	x	--
Thomomys sp.	Northern Pocket Gopher	x	--
**Microtus paroperarius* +	Vole	x	x
**Synaptomys meltoni* +	Northern Bog Lemming	x	x
Sorex cinereus	Masked Shrew	x	x
**Blarina* aff. *ozarkensis* (large)	Short-Tailed Shrew	--	x
Spermophilus sp. (small)	Ground Squirrel	--	x
Onychomys sp.	Northern Grasshopper Mouse	--	x
Geomys sp.	Plains Pocket Gopher	--	x
Peromyscus sp.	Uncertain	--	x
**Sorex* sp. nov.	Uncertain	--	x

* Extinct

\+ Recovered from below the ash at both localities.

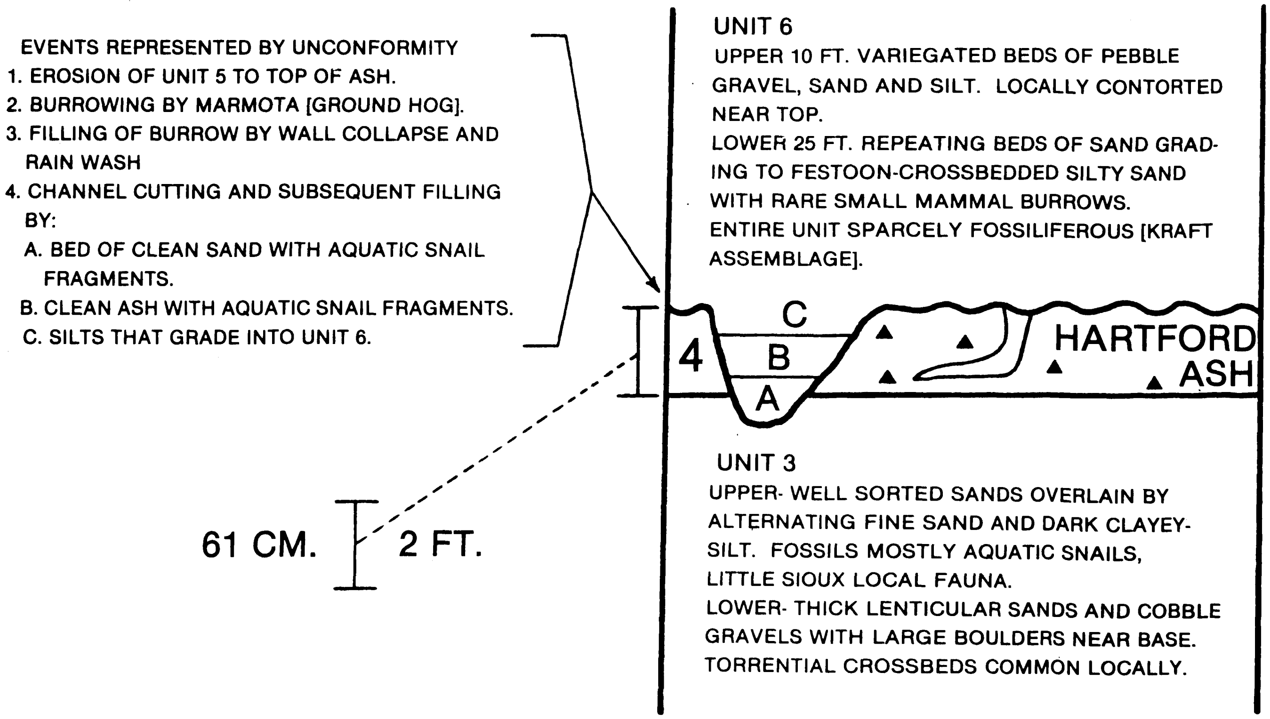

Figure 3. Description of lithologic units and events recorded at Shimek Locality.

found in the Little Sioux local fauna at this locality are also present in the Wright local fauna (Table 2). These similarities indicate little change in habitats between the intervals represented by the two assemblages. With the exception of *Valvata sincera* most of the aquatic taxa have modern distributions that include the Little Sioux River (Shimek, 1915) and may approach or reach the Monona-Harrison County area of western Iowa. Terrestrial taxa comprise 96% of the individuals and are dominated by four small hygrophilous species (*Carychium exiguum, Gastrocopta tappaniana, Vertigo elatior* and *V. milium*) usually found in moist, shaded areas not far from water.

With several exceptions all of the terrestrial species have been reported extant in the Loess Hills (Frest and Dickson, 1986). These "exceptions" include: 1) *Deroceras aenigma,* an extinct species; 2) the extralimital species *Striatura milium, Vertigo elatior, Zonitoides nitidus* and *V. gouldi*, which are reported in central and northeast Iowa by Hubricht (1985); and 3) *V. nylanderi*, which now most closely approaches the study area in northern Minnesota (Dawley, 1955).

Shimek Locality

Molluscs from the Little Sioux local fauna at this locality were collected from the alternating fine sand and dark clayey silt that overlay thick lenticular sands and gravels, the latter often with local torrential crossbedding and containing large boulders. The fluvial origin suggested by the sediment geometry is compatible with the fauna which is dominated both in species (71%) and individual abundance (99%) by aquatic taxa (Table 2), Five aquatic species (*Gyraulus deflectus, G. parvus, Planorbula armigera, Stagnicola elodes,* and *Valvata tricarinata* comprise 94% of the individuals. The aquatic assemblage implies the presence of a perennial-water habitat, with areas of shallow, quiet water supporting dense submerged vegetation.

The terrestrial shells from this locality include several small pupillids, *Gastrocopta tappaniana, G. armifera, Vertigo elatior,* and *V. ovata*, that probably inhabited moist areas under sticks and leaf litter. Although *G. armifera* is generally found in drier areas than the other three species, all could have found suitable sites on the floodplain.

The Kraft assemblage occurs above an unconformity representing: 1) erosion of unit 5 to

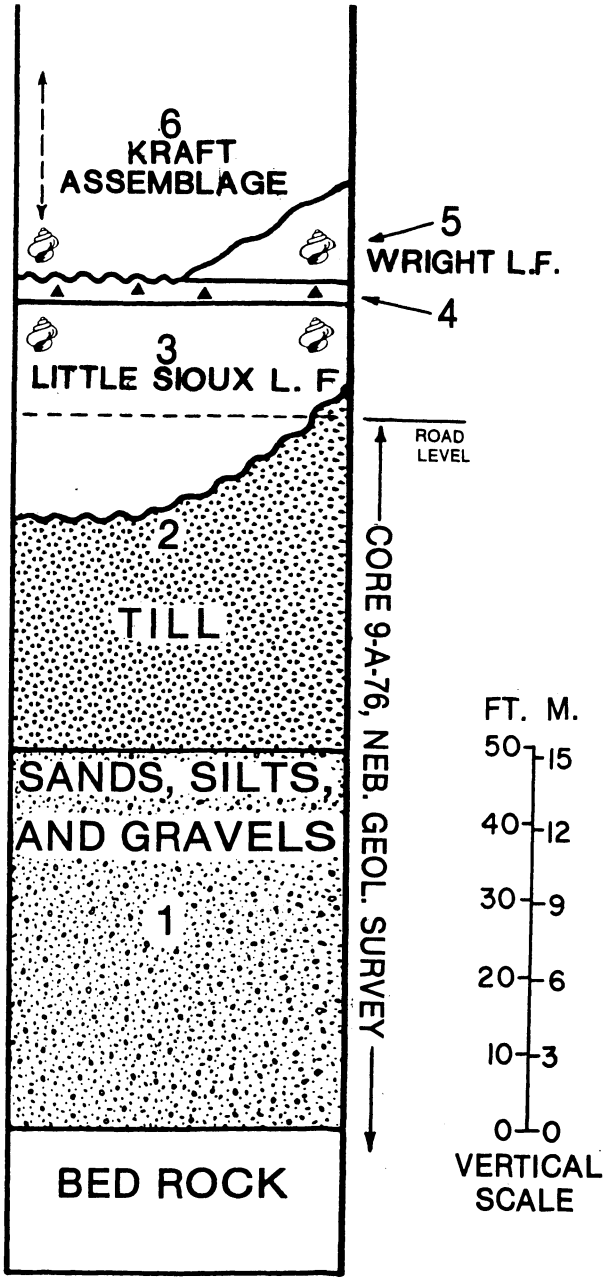

Figure 4. Composite section showing interpreted age relationships. The vertical dashed line in unit 6 marks the zone from which the Kraft assemblage was recovered.

Table 2. Molluscan taxa identified from Little Sioux, Wright and Kraft assemblages. The numerals under the Habitat column refer to the following: 1) Semiaquatic; among vegetation and debris near water's edge, 2) Hygrophilic; moist situations in leaf mold, under sticks and debris; shaded areas not far from water, 3) Moist areas under leaf litter, logs, among tall marsh grass, 5) Open woodland and shrubs, 6) ephemeral small stream, pond, slough or marsh, 7) Small bodies of water on floodplain; no significant seasonal drying; with dense stands of submerged aquatic vegeation, 8) Perennial, non-stagnant water bodies: slow to moderate current; areas of still water; shallow spots with soft sand or mud substrate.

Species	**Habitat**	**Little Sioux**		**Wright**	**Kraft**	**Climate Group**
		Yard Loc.	**Shimek Loc.**			
TERRESTRIAL						
**Catinella avara*	1	344	0	151	0	General
Pomatiopsis lapidaria	1,2	0	0	1	0	Eastern
Carychium exiguum	2	3990	0	1504	26	Eastern
Striatura milium	2	1	0	15	0	Eastern
**Strobilops affinis*	2	0	8	5	0	Eastern
**Succinea ovalis*	2	198	0	0	0	Eastern
Vertigo alpestris oughtoni	2	2	0	0	0	Northern
Vertigo Binneyana	2	3	0	0	0	Northern
Vertigo elatior	2	2013	3	1608	0	Northern
Vertigo gouldi	2	69	0	37	0	General
**Vertigo milium*	2	17	1	644	10	General
**Vertigo ovata*	2	8	1	60	11	General
Vertigo nylanderi	2	64	0	7	0	Northern
**Vertigo tridentata*	2	11	0	6	0	Eastern
Deroceras aenigma	2?,3?	81	0	392	0	General
**Euconulus fulvus*	2,3	153	0	2	0	General
Cionella lubrica +	2,3	181	0	21	0	Northern
**Discus cronkhitei*	2,3	252	0	252	0	Northern
**Helicodiscus parallelus*	2,3	0	0	157	13	Eastern
**Hawaiia minuscula*	2,3,4	312	0	52	26	General
**Zonitoides arboreus*	2,3,4	3	0	6	0	Northern
**Nesovitrea electrina*	3	251	0	21	0	Northern
**Punctum minutissimum*	3	16	0	7	0	Northern
**Strobilops labyrinthica*	3	4	0	0	0	Northern
Zonitoides nitidus	3	132	0	2	0	Northern
Hendersonia occulta	3,4	210	0	0	0	Northern
Vertigo modesta	3,4	15	0	0	0	Northern
**Gastrocopta armifera*	4,5	110	0	35	157	Eastern
**Gastrocopta contracta*	4,5	0	0	708	12	Eastern
**Gastrocopta holzingeri*	4,5	6	0	23	11	Northern

(continued on following page)

\+ Not counted or used in compilation of Table 4.

* Reported as living in Loess Hills by Frest and Dickson, 1986.

Table 2. Continued.

Species	Habitat	Little Sioux		Wright	Kraft	Climate Group
		Yard Loc.	Shimek Loc.			
**Gastrocopta procera*	4,5	0	0	2	197	Southern
**Helicodiscus singleyanus*	4,5	0	0	0	7	Southern
Pupilla muscorum	4,5	247	0	0	0	Northern
**Pupoides albilabris*	4,5	3	0	16	93	General
**Vallonia gracilicosta*	4,5	235	0	267	0	Northern
**Vallonia parvula*	4,5	0	0	0	49	General
Vallonia perspectiva	4,5	8	0	0	0	Southern
**Vallonia pulchella*	4,5	13	0	102	4	Northern
Polygyrid (fragments) +	?	x	0	x	0	?
Stenotrema (fragments) +	?	0	0	x	0	?
Oxyloma sp. +	?	x	0	0	0	?
AQUATIC						
Aplexa hypnorum	6	41	0	8	0	Northern
Stagnicola caperata	6	0	0	49	0	Northern
Gyraulus circumstriatus	6	0	0	58	0	Northern
Bakerilymnaea bulimoides techella	6,7,8	0	0	0	1	General
Bakerilymnaea dalli	6,7,8	172	10	18	0	General
Gyraulus parvus	6,7,8	5	279	16	6	General
Pisidium casertanum	6,7,8	20	3	176	0	General
Promenetus exacuous kansasensis	6,7,8	1	0	0	3	Eastern
Stagnicola elodes	6,7,8	4	100	0	0	Northern
Acella haldemani	7	0	2	0	0	Northern
Gyraulus deflectus	7	2	184	0	0	Northern
Planorbula armigera	7	0	0	9	0	General
Ferrissia rivularis	7,8	1	0	0	0	General
Pisidium adamsi	7,8	14	0	8	0	General
Helisoma anceps	7,8	0	2	0	0	General
Pisidium compressum	7,8	0	22	2	0	General
Valvata sincera	7,8	0	0	4	0	Northern
Valvata tricarinata	7,8	154	3	8	0	Northern
Physa (fragments) +	?	0	4	10	0	?
Musculium (fragments) +	?	0	x	0	0	?

+ Not counted or used in compilation of Table 4.

* Reported as living in Loess Hills by Frest and Dickson, 1986.

Table 3. Ratios of alloisoleucine/isoleucine (aIle/Ile) in the free fraction (FREE) and total acid hydrolysate (HYD) of fossil gastropod shells recovered from sediments at the Yard and Shimek localities.

SAMPLE AGL#*	GENUS	FAUNA	FREE	HYD
YARD LOCALITY				
1382	*Deroceras*	WRIGHT	0.65 ± 0.02	0.44 ± 0.01
1383	*Deroceras*	LITTLE SIOUX	0.63 ± 0.01	0.42 ± 0.01
0204	*Discus*	WRIGHT	---	0.48 ± 0.02
0205	*Discus*	LITTLE SIOUX	---	0.51 ± 0.03
0206	*Succinea*	WRIGHT	0.83 ± 0.04	0.61 ± 0.02
0203	*Succinea*	LITTLE SIOUX	0.82 ± 0.02	0.65 ± 0.03
1380	*Hendersonia*	LITTLE SIOUX	0.71 ± 0.01	0.53 ± 0.02
SHIMEK LOCALITY				
1381	*Fossaria*	LITTLE SIOUX	0.77 ± 0.02	0.53 ± 0.01

* AGL refers to University of Massachusetts Amino Acid Geochronology laboratory number.

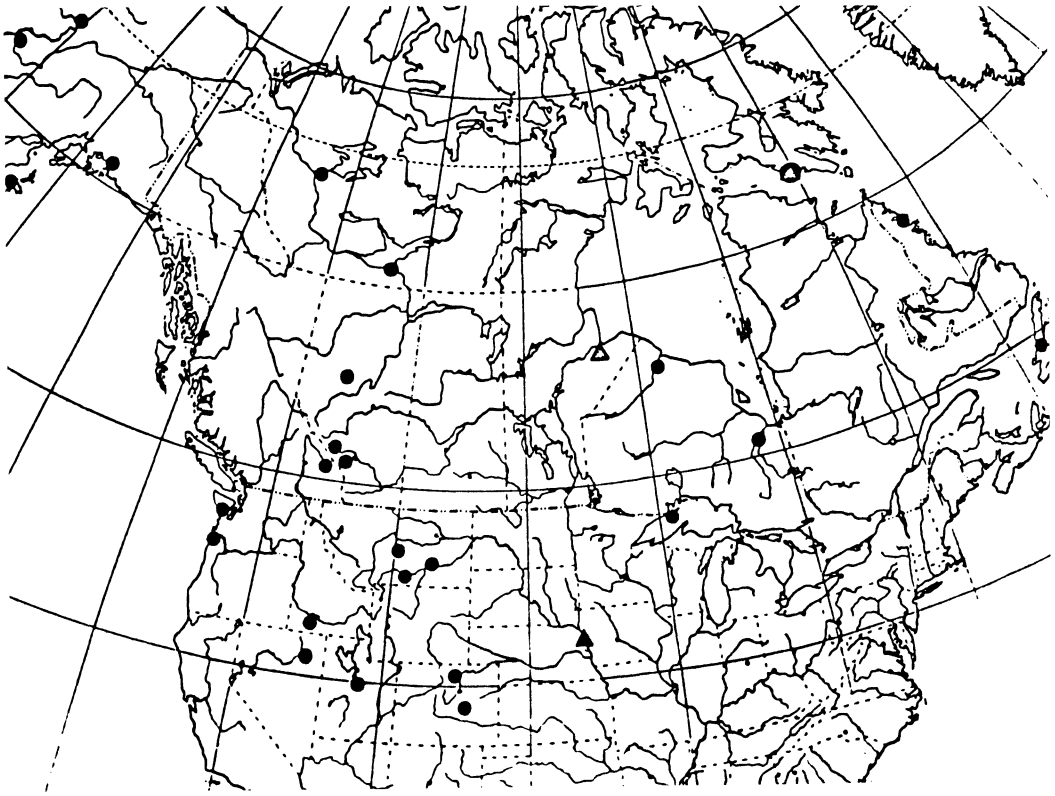

Figure 5. Map showing modern distribution records for *Vertigo modesta*, a member of the northern distribution group. The triangle in figures 5,6,7,8,9 marks the Shimek and Yard localities.

Table 4. Comparison by climatic groupings of Little Sioux, Wright, and Kraft molluscan assembages.

CLIMATE GROUP	LITTLE SIOUX TER #	%	AQ #	%	WRIGHT TER #	%	AQ #	%	KRAFT TER #	%	AQ #	%
Northern	16	47	5	36	10	38	5	42	2	14	0	0
Southern	1	03	0	0	1	04	0	0	2	14	0	0
Eastern	7	21	1	07	8	31	2	16	5	36	0	0
General	10	29	8	57	7	27	5	42	5	36	3	100

the top of the ash bed; 2) development of a burrow in the ash by a woodchuck (*Marmota*); and 3) channel cutting through the ash into unit 3 (Figure 3). The Kraft molluscan assemblage indicates that significant environmental changes occurred during the interval represented by the hiatus. With the exception of *G. parvus* and *Promenetus exacuous kansasensis*, all of the aquatic species that were present below the ash are missing. The almost total absence of aquatic taxa imply the probable absence of any truly aquatic habitats near the immediate depositional site. The terrestrial molluscs are primarily species that favor drier areas than the majority of the terrestrial species from below the ash.

Climate

For purposes of climatic analysis the molluscs also have been categorized into climatic groups (Table 2) based on their modern geographic distributions. The rationale for these groupings is discussed elsewhere (Miller, 1975; Miller and Kay, 1981). One group includes northern species that have the southern limits of their range in the Interior Lowlands controlled by high summer temperature (Figure 5). A second grouping includes species that are usually limited to the eastern United Sates and Canada (Figure 6). Their westward range into the Interior Lowland appears to be controlled by available moisture. Southerly distributed species that are restricted in their northern range by the length and severity of the winters, comprise a third group (Figure 7). A fourth grouping includes species for which: 1) there is either inadequate distribution data; 2) the species is extinct ; or 3) the species is so widely distributed that it is not possible to infer what factors control its distribution. In general, species in this group cannot be used for making interpretations about climate.

Table 4 contrasts the Little Sioux, Wright and Kraft molluscan assemblages by climatic grouping. The almost total absence of aquatic taxa from the Kraft assemblage, however, discourages direct comparisons of the assemblages. The discussion that follows, therefore, is limited to the terrestrial components of the assemblages.

The Little Sioux local fauna contains the greatest number and percentage of both mammal and snail taxa belonging to the northern distribution grouping. Included in this group are *Vertigo alpestris oughtoni, V. nylanderi, V. modesta, Zonitoides nitidus, Pupilla muscorum*, and fossil forms related to *Tamiasciuris hudsonicus, Sorex arcticus, Phenacomys intermedius* (Figure 8) and *Synaptomys borealis* (Figure 9) which together imply a cool, moist, boreal climate. The Wright local fauna, although sharing taxa in common with the Little Sioux assemblage, differs in several important ways. These changes involve either apparent disappearance (e.g., *P. muscorum, V. a. oughtoni, V. modesta, Phenacomys, Tamiasciuris* and the form related to *S. arcticus*) or diminution (e.g. *V. nylanderi and Zonitoides nitidus*) of some species belonging to the northern distribution grouping. Accompanying these changes are increases in the percentage abundance of molluscan species from the eastern geographic grouping (e.g., *Gastrocopta contracta*, and *Helicodiscus parallelus*). To this group may be added the modern analog of the fossil Short-Tail Shrew, *Blarina brevicauda*, which in the eastern part of its range is usually considered an inhabitant of moist, deciduous forest debris. However, there is no faunal evidence to support the presence of an extensive deciduous woodland. Indeed, the first appearance of *Geomys* sp., *Onchcomys* sp., and

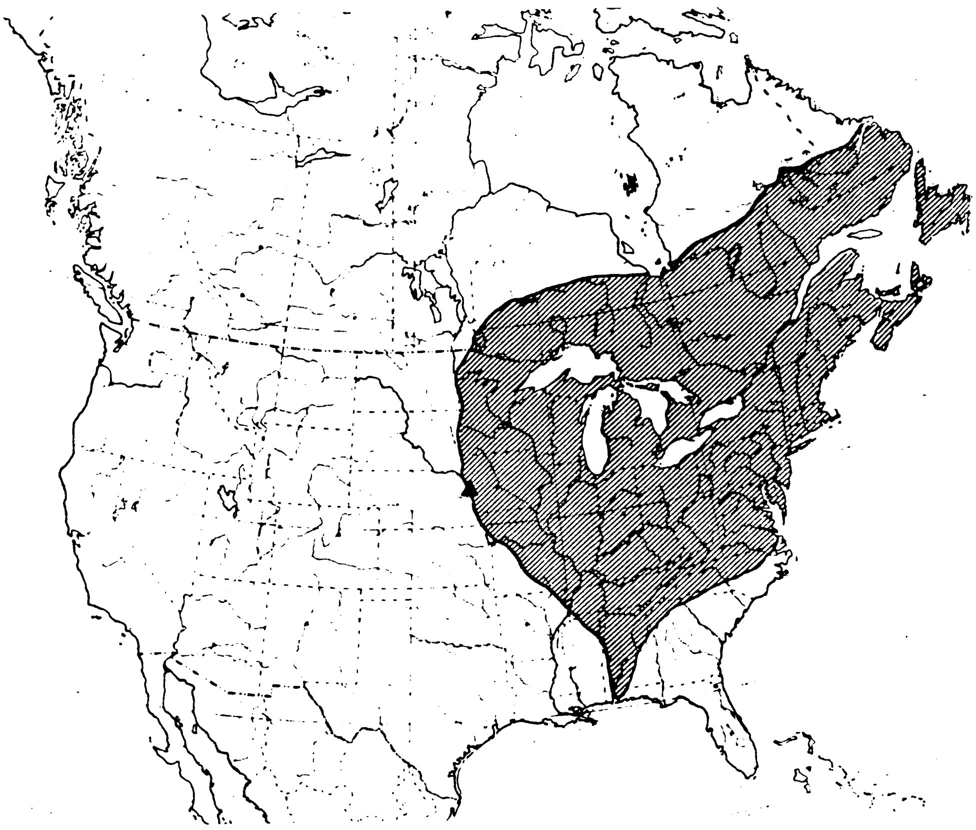

Figure 6. Map showing modern distribution records for *Succinea ovalis*, a member of the eastern distribution group.

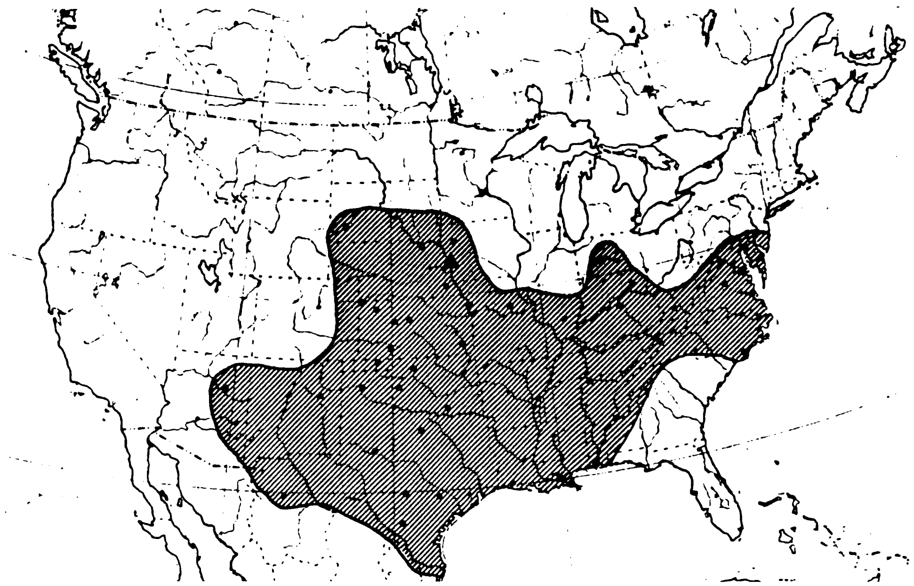

Figure 7. Map showing modern distribution records for *Gastrocopta procera*, a member of the southern distribution group.

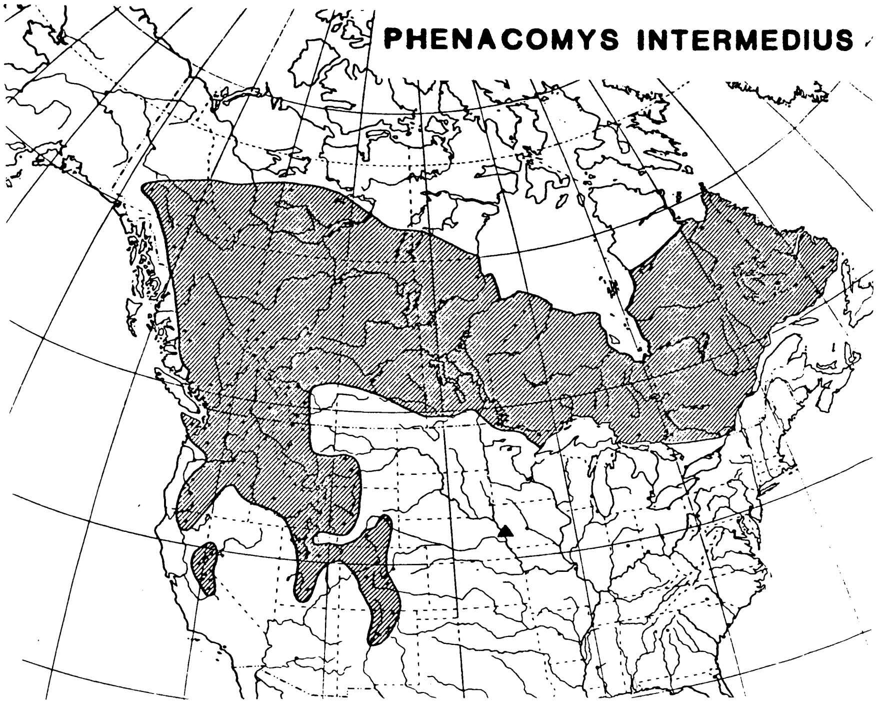

Figure 8. Map showing distribution of *Phenacomys intermedius*, the modern analog for the *Phenacomys* of the Little Sioux local fauna. (Modified from Hall and Kelson, 1959.)

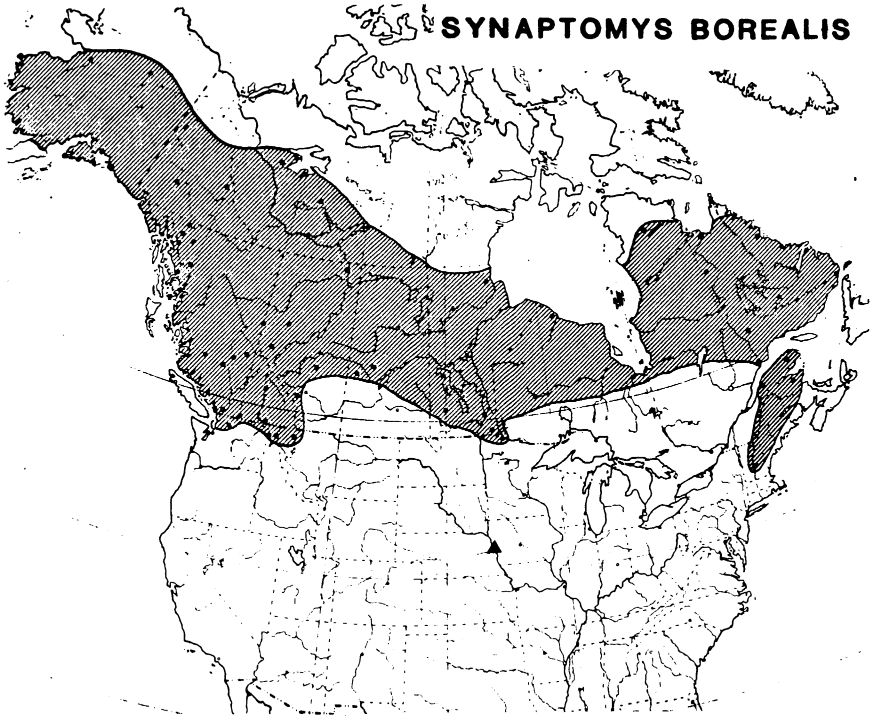

Figure 9. Map showing distribution of *Synaptomys borealis*, the modern analog of the *Synaptomys* from the Little Sioux and Wright local faunas. (Modified from Hall and Kelson, 1959.)

Spermophilus sp. in the Wright assemblage indicates open parkland conditions. These faunal changes represent a warmer and drier climate than that interpreted for the Little Sioux local fauna, but cooler and moister than the climate now characterizing western Iowa. The third assemblage (Kraft assemblage), consists entirely of molluscs recovered from sediments unconformably overlying the ash bed. The Kraft assemblage only includes molluscs that show a further decrease in the percentage of northern distribution taxa relative to the Little Sioux and Wright local faunas, suggesting a climate similar to that now occurring in this area of Iowa.

CONCLUSIONS

Three fossil assemblages in close proximity to the Lava Creek B ash have been studied from exposures near Little Sioux, Iowa. The Little Sioux local fauna from just beneath the ash yielded climatically significant forms such as *Vertigo alpestris oughtoni, V. modesta, Pupilla muscorum*, and fossil mammals related to the Spruce-Heather Vole, Red Squirrel, Arctic Shrew, and Northern Bog Lemming, which together imply a cool, moist boreal climate. The Wright local fauna, although sharing many taxa in common with the underlying Little Sioux local fauna, differs in several important respects. These include the disappearance and/or diminution of certain northern taxa and the appearance of new forms that suggest a warmer, less moist climate. The third assemblage (Kraft assemblage), consists entirely of molluscs recovered from sediments unconformably overlying the ash bed. This assemblage has still fewer taxa typically found in cool, moist situations and, hence, suggests climatic/habitat conditions even more closely approaching those presently found in western Iowa.

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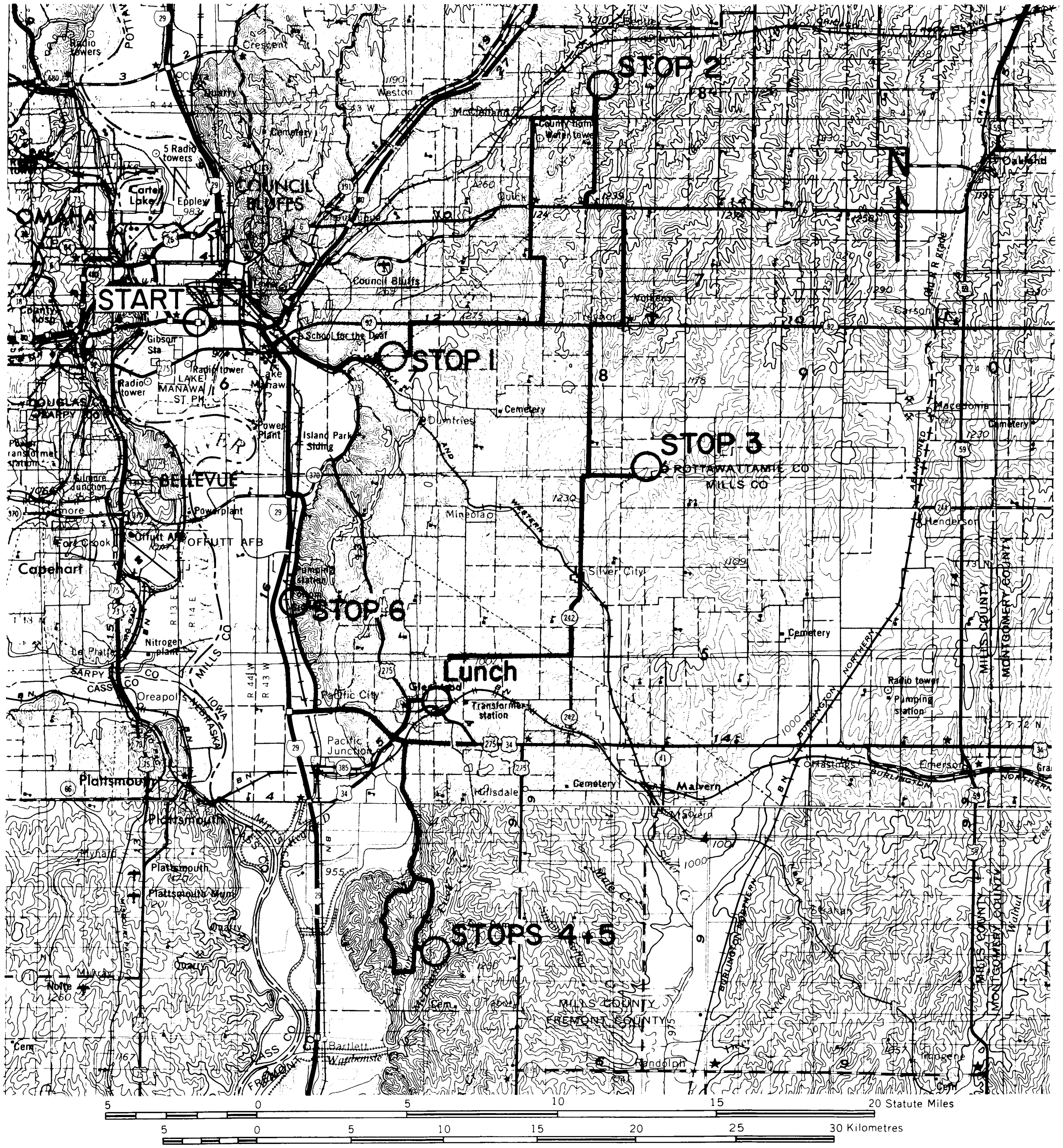
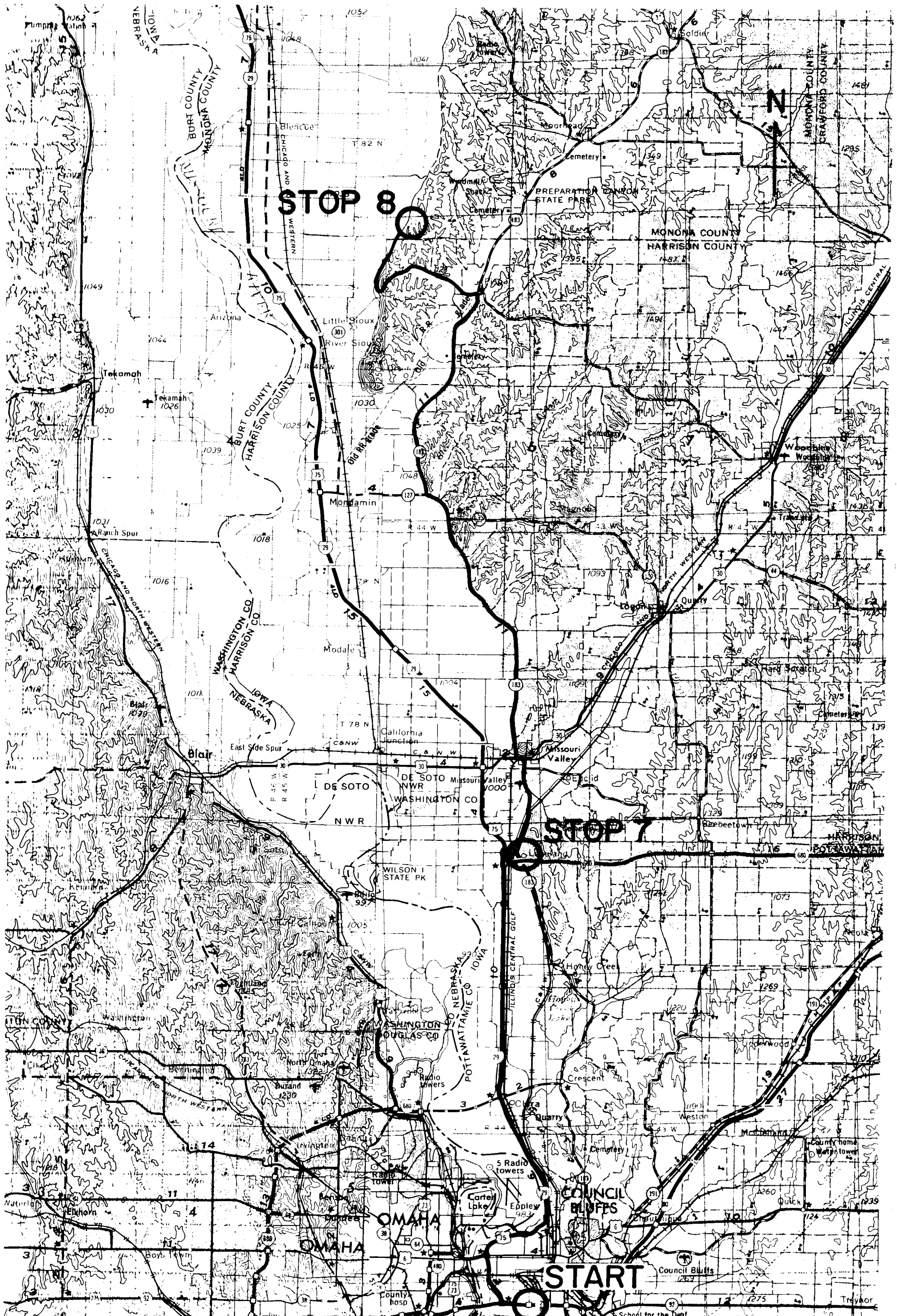


Map showing Day 1 fieldtrip route and stops.
Base taken from USGS Omaha, Nebraska; Iowa 1:250,000 scale topographic map (NK 15-7).



Map of Day 2 fieldtrip route and stops.
Base taken from USGS Omaha and Fremont, Nebraska;
Iowa 1:250,000 scale topographic maps (NK 15-7 and 14-9).