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THE DEFOREST FORMATION OF WESTERN IOWA:

LITHOLOGIC PROPERTIES, STRATIGRAPHY, AND CHRONOLOGY

Iowa Department of Natural Resources
Larry J. Wilson, Director
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ABSTRACT

The western Iowa fluvial system is characterized by an entrenched drainage network that presents unique management problems and land-use hazards. The drainage system is developed in easily-eroded materials and the streams are characterized by flashy flow and high sediment discharge. Bed and bank instability problems are widespread and costly to local, state, and federal agencies, as well as individuals.

A repeatable and mappable sequence of Holocene alluvial fills is present in western Iowa valleys. These alluvial fills comprise the DeForest Formation and are recognizable on the basis of easily observed lithologic characteristics and stratigraphic position. Investigations in six watersheds demonstrate that the stratigraphic sequence is traceable across the region and that the alluvial fills have distinctive distribution patterns and age relationships in the drainage network.

The record of Holocene drainage system behavior recorded in the DeForest Formation provides a perspective on the long-term behavior of fluvial systems dominated by easily eroded material, high sediment load, and dramatically fluctuating conditions of flow. This perspective allows for assessment of factors important in influencing the Holocene-scale behavior of this fluvial system and places its Historic behavior in a geologic framework.

INTRODUCTION

The fluvial system is of importance and interest to everyone in one way or another: the engineer designing levees, foundations, and bridges; the geologist characterizing deposits in a river valley and attempting to reconstruct the history of a fluvial landscape; the farmer concerned about spring flooding, summer drought, or a river eroding portions of his cornfield; and the executive drinking a cup of coffee made from the water pumped from a nearby alluvial aquifer.

The fluvial system is one of the most dynamic and diverse physical systems acting on the earth's surface today. On the broadest scale, the system consists of an upstream zone of sediment and water production--the drainage basin, a transfer zone--the drainage network, and downstream zones of deposition (Schumm, 1977). These three zones can be envisioned on a continental scale, such as the Mississippi River Basin, drainage network, and delta; or on a local scale--a small drainage basin, the stream flowing through it, and the alluvial fan and floodplain where alluvium is stored temporarily.

The fluvial system, when viewed in detail, is extremely diverse. Drainage basins are composed of a hierarchy of drainages of increasing size and historical complexity. Processes do not necessarily operate at the same time or with the same intensity throughout a given basin. This complexity may be reflected in the stratigraphic record, and in some cases, influenced by complexities in the stratigraphy. Because of varying geology and climate the characteristics of drainage basins can vary considerably from one physiographic region to another. On this scale the diversity of drainage basins and networks can be striking. In Iowa, for example, drainage systems range from the rock-controlled, deeply incised drainage network of the Paleozoic Plateau Region of northeast Iowa to the low-gradient, poorly integrated network developed on the Des Moines Lobe Region of northcentral Iowa (Bettis et al., 1985). This diversity injects a great deal of complexity into the quest for understanding the past and present workings of streams and rivers.

Most people studying the fluvial system work with only limited portions of it. Hydrologists, engineers, soil conservationists, and geomorphologists tend to be most concerned with the dynamic zones of sediment and water supply and transfer (the channel area, the land surface of the basin, etc.). Stratigraphers and sedimentologists, on the other hand, focus mostly on the end product in zones of deposition (sedimentary structures, deposits comprising landforms, etc.). Because sediment is derived from a source area and transported to an area of deposition, one cannot understand fluvial sedimentary deposits or their related river without an understanding of upstream and downstream controls. This necessitates a clear comprehension of the fluvial system as a whole.

Several factors interact to supply the water, sediment, and topographic relief which drive the fluvial system. These can be grouped into two broad categories; 1) extrinsic--those external and independent of the system such as climate, vegetation, diastrophism, and eustasy, and 2) intrinsic--those internal and dependent within the fluvial system, factors such as increases in elevation resulting from aggradation or increased sediment supply produced by upstream incision (Schumm, 1975; 1977). It is also important to realize that the fluvial system operates within an historical framework. The present relief, valley, and deposits developed during the past, yet they exert a profound influence on the present response of the fluvial system to the modern climate, vegetation, and land use systems. The combined effects of extrinsic and intrinsic factors acting within the historical framework of the drainage basin, drainage network, and alluvial stratigraphy account for the modern behavior of the fluvial system. Reconstruction and study of the past behavior of the fluvial system as revealed in the stratigraphic record provides a perspective on long-term behavior of the system. An appreciation of long term behavior is of utmost importance for accurate flood frequency and channel stability forecasting and the land use planning and engineering dependent on such forecasting (Patton et al., 1979; Meade, 1982).

Opportunities to study the stratigraphy of entire drainage basins or large portions of drainage basins in order to characterize the fluvial deposits and reconstruct the history of the drainage system do not arise often because of time, interest, and funding constraints. Such an opportunity arose in 1979, however, when the USDA-Soil Conservation Service requested geologic investigations of the alluvial stratigraphy of portions of the Western

Iowa Rivers Basin Project as part of the cultural resource (archaeologic) evaluation of the project (Thompson and Bettis, 1980, 1981; Bettis and Thompson, 1981). These investigations focused on Holocene-age (< 10,500 years before present-YBP) alluvium in first- through fourth-order (Horton system as modified by Strahler) drainages in western Iowa. Surficial deposits in this region are dominated in the uplands by thick late Wisconsinan-age Peoria Loess, and in the valley bottoms by loess-derived alluvium. A well-integrated dendritic drainage network with first- and second-order drainages constituting a major portion of the landscape is present. Most western Iowa drainages larger than first-order contain deep, nearly vertical-walled gullies or entrenched streams. Headward extension of these gullies coupled with downstream alluviation and gully wall degradation is the dominant fluvial style.

Pioneering work on the alluvial stratigraphy and chronology of small western Iowa valleys was undertaken by Daniels and co-workers during the late 1950s and early 1960s (Daniels et al., 1963; Daniels and Jordan, 1966). They recognized a consistent lithostratigraphy in the Willow River and Magnolia watersheds in Harrison County. All the silty and loamy alluvium filling these valleys was named the DeForest Formation. The DeForest Formation encompassed six lithologically and temporally distinct alluvial fills. Five of these were designated as members of the formation while the youngest fill, which buried surfaces younger than the time of the first Euroamerican settlement of western Iowa (approximately 1850 A.D.), was informally referred to as "postsettlement alluvium" (Daniels et al., 1963). Radiocarbon dating of wood within the DeForest Formation indicated that its accumulation spanned the late Wisconsinan through Holocene, and that at least three of the formation's members were late Holocene (< 3000 YBP) in age. These investigations demonstrated that the western Iowa drainage network had experienced several cut-and-fill episodes during the last 11,000 years and that several lithologically distinct alluvial fills could be traced from one drainageway to another.

Although the investigations of Daniels and co-workers outlined the lithostratigraphy and chronology of alluvium in the Willow River and Magnolia study areas of Harrison County, three important questions raised by the investigations were left unanswered: 1) can the stratigraphy identified in Harrison County be recognized in other parts of western Iowa?; 2) is the temporal framework for the DeForest Formation members also applicable in other valleys in the area? and; 3) what is (are) the mechanism(s) responsible for the several cut-and-fill episodes recognized in the DeForest Formation?

Investigations begun by the author in 1979 focused on answering the first two questions but also generated data important for addressing the third. The primary purpose of the investigations was to characterize, map, and date Holocene alluvium in ten watershed projects distributed throughout western Iowa. This information was then used to assist archaeologists in assessing the potential of proposed impact areas (primarily earthen dam sites and their pool areas) for containing buried cultural resources not discernible using traditional archaeological exploration methods [surface survey, shallow (1.5 m deep) test pitting, etc.] (Thompson and Bettis, 1981). Although aimed at providing information useful to archaeologists, the investigations were geological in nature. Three groups of information concerning western Iowa valleys were produced as a result of the investigations: 1) revision of the DeForest Formation lithostratigraphy including the exclusion of late Wisconsinan alluvium from the formation, recognition of a new member (the Corrington Member), formalization of "postsettlement alluvium" as the Camp Creek Member, introduction of two new members that encompass four of Daniels et al.'s DeForest Formation members in western Iowa, and a change in status from member to bed of the Watkins, Hatcher, Mullenix, and Turton; 2) the collection and collation of over 100 radiocarbon dates from within the DeForest Formation, complete revision of the chronologic framework for the various units comprising the formation, and recognition of a significant gap in the fluvial depositional record (the DeForest Gap) in upper portions of the drainage system; and 3) a model of late Wisconsinan and Holocene valley landscape evolution which addresses the mechanisms by which gully systems and valley fills evolve on a Holocene time scale, and the interactions among extrinsic and intrinsic factors influencing the evolution of gully systems.

Diverse interest groups will benefit from information on the small valley systems of western Iowa presented herein. Discussions of the lithologic properties and temporal relationships of the DeForest Formation will prove useful to geologists and civil engineers concerned with predicting the short-and-long-term behavior of alluvial deposits and channels in their natural state as well as under altered conditions at bridges, pipeline crossings, artificially straightened reaches, and beneath foundations and berms. This information has already greatly assisted archaeologists in assessing the geological controls on the archaeological record of western Iowa (Thompson and Bettis, 1981; Bettis and Thompson, 1982) and will continue to be of utility in managing known and discovering presently unknown cultural resources in the area (Thompson and Benn, 1985; Benn, 1986).

Discussions of the relationships among alluvial landforms and the deposits of which they are comprised will be useful to soil scientists, geomorphologists, and civil engineers, as well as archaeologists. A large percentage of the modern (and buried) soils in alluvial landscapes are cumulic in nature; pedogenesis and accumulation of sediment have occurred through time producing a relatively thick soil profile. Although recognized as such, little attention has been devoted to investigating the genesis and distribution of soils in these landscape positions. This report provides the geologic and sedimentologic framework for such an investigation.

Finally, the valley landscape evolution/gully development model will be of interest to those concerned with the long-term (Holocene time scale) behavior of low-order drainage systems. Of special interest is the relationship between factors significant in short-term (years or decades) gully growth and degradation, and factors judged to be significant in the long-term development of gully networks.

This report summarizes existing data on the DeForest Formation (Holocene alluvium) of western Iowa and presents a model aimed at understanding the causative factors behind long-term behavior of the fluvial system in the area. Investigations in six western Iowa watersheds are summarized and results are compared in order to gain an appreciation for both the overall stratigraphic and geomorphic similarity across the region, as well as the degree of local variability resulting from loess thickness patterns, geologic history, and stream size.

METHODS

Detailed study areas were all located within SCS watershed projects, usually in and around proposed detention structure localities. The primary method of investigation was coring using a Giddings hydraulic soil coring machine. Usually 7.6 cm (3 in) diameter cores were extracted. A total of 2,090 linear meters (6,870 linear ft) of core from 301 holes was drilled during the project. Gully walls and man-made exposures were also examined. All cores and exposures were described in the field using standard USDA procedures and nomenclature (Soil Survey Staff, 1975). Soil horizon nomenclature follows that outlined by Guthrie and Witty (1982) and in Chapter 4 of the new Soil Survey Manual (Soil Survey Staff, 1981). Standard weathering zone terminology is applied to deposits not altered by pedogenesis (Hallberg et al., 1978). Standard USDA-SCS textural classes and terms are also used (Soil Survey Staff, 1975; Hallberg et al., 1978). The Horton stream ordering system as modified by Strahler is used, but applied to valleys rather than channels. A scale of 1:24,000 was used for the valley ordering.

Laboratory data is presented in order to quantify the physical characteristics of the deposits. The pipette method as outlined in Walter et al. (1978) was used for particle-size analysis. In addition, several samples were analyzed for particle-size distribution at the USDA-SCS Midwest Technical Center, Lincoln, NE using the hydrometer method. Selected samples were analyzed for pH using a combination electrode emerged in the supernatant liquid of a 1:1 soil: distilled water mixture.

Soil engineering data was obtained from Shelby tube samples collected by the USDA-SCS during foundation investigations for proposed structures. The samples were analyzed by the Soil Engineering Laboratory at the USDA-SCS Midwest Technical Center in Lincoln, Nebraska and the Soil Engineering Laboratory of the USDA-SCS State Office in Des Moines. A statistical summary of these analyses is presented in Table 1 of this report and a complete set of the data is on file at the USDA-SCS office in Des Moines, Iowa.

Organic materials encountered in drill holes or outcrop were collected and submitted to Beta-Analytic, Inc. and the University of Wisconsin Radiocarbon Laboratory for radiocarbon dating.

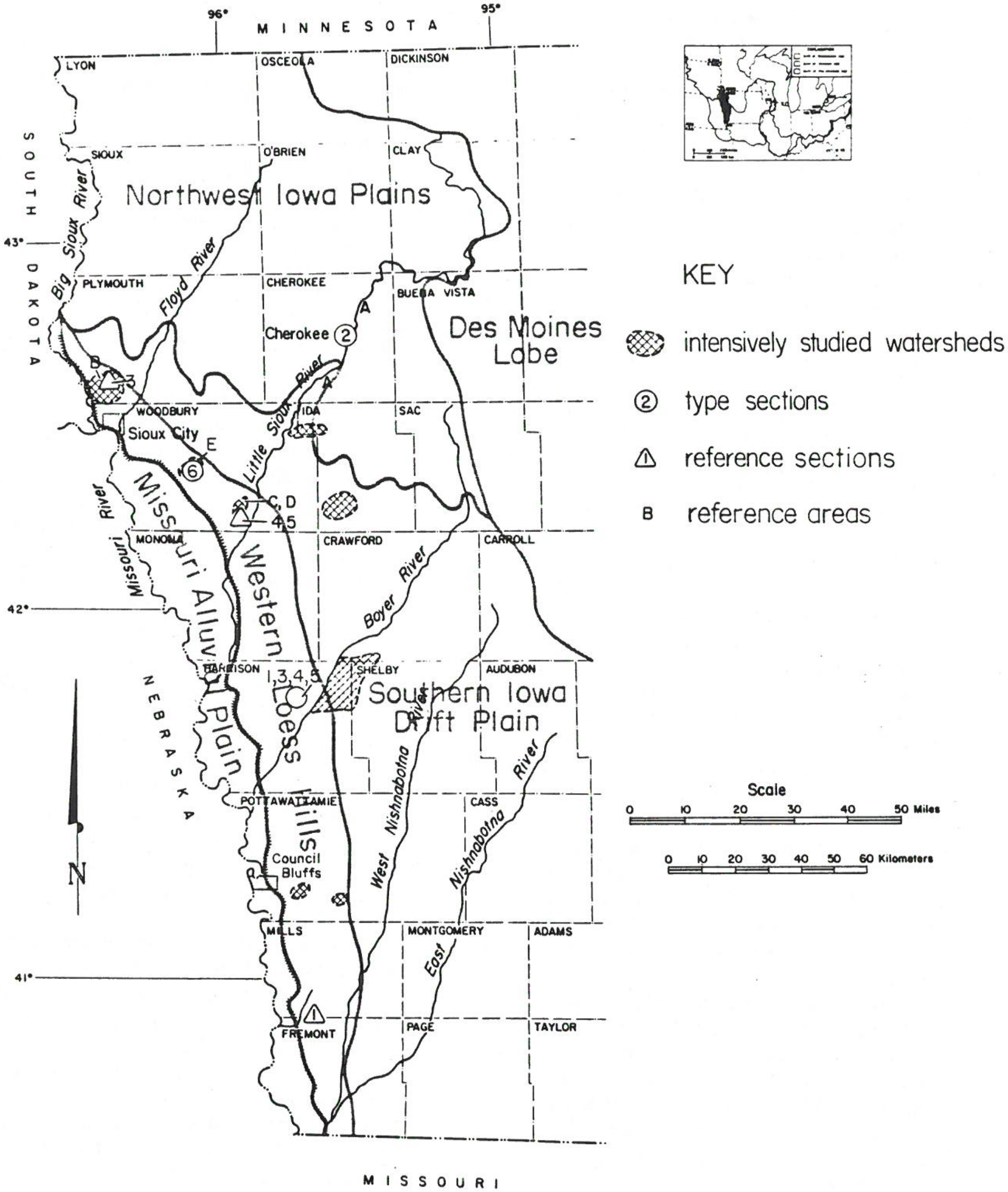


Figure 1. Location of watersheds discussed in the text, type sections, reference areas, reference sections, and landform regions in western Iowa.

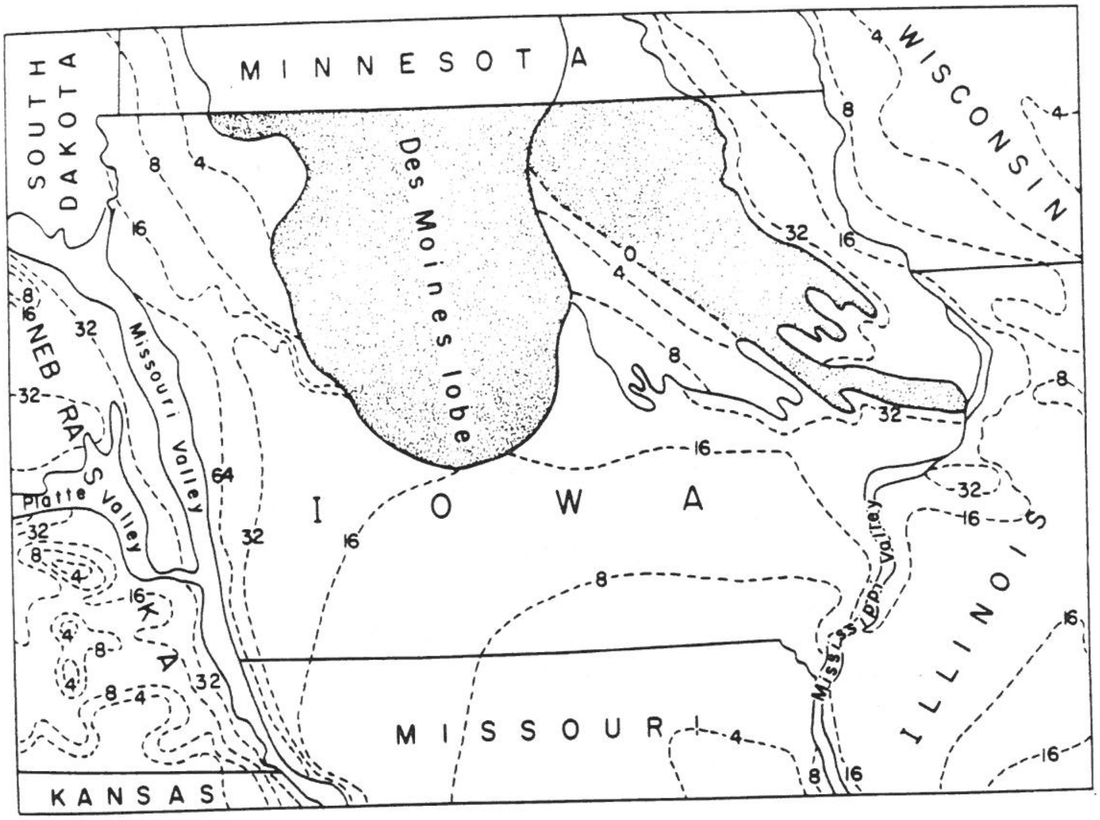


Figure 2. Map showing Peoria Loess thickness in Iowa and adjacent areas (contours in feet). Note the decrease in thickness to the southeast from the Missouri Valley source area. Taken from Ruhe 1969, Fig. 22.

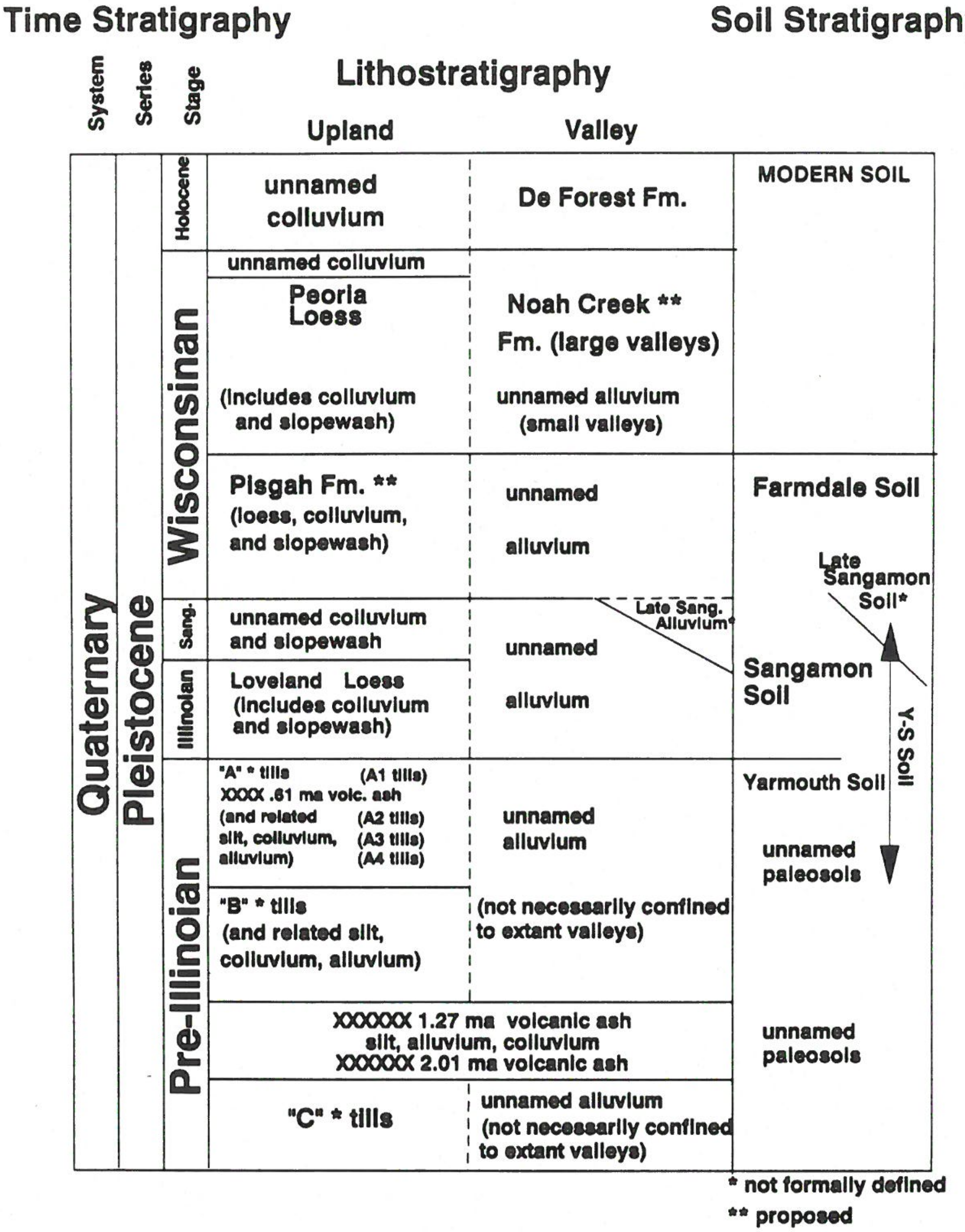


Figure 3. Stratigraphic column for the Pleistocene Series of western Iowa.

REGIONAL STRATIGRAPHIC SETTING

The study area encompasses that portion of western Iowa which drains to the Missouri River within the state's boundaries (Fig. 1). Uplands in this area are dominated by a thick mantle of Peoria Loess that was deposited between about 25,000 and 12,500 years ago (Bettis et al., 1986). The loess is in excess of thirty-five meters (115 ft) thick at some locations adjacent to the Missouri River valley source area, and decreases in thickness to the southeast across the southern two-thirds of the region (Fig. 2) (Ruhe, 1969). In the northern one-third of western Iowa the loess thins from five meters (16 ft) to one meter (3 ft) in a northeasterly direction away from the Missouri and Big Sioux valleys (ibid.). Older Wisconsinan loess, hillslope sediment, and colluvium, collectively referred to as the Pisgah Formation are buried by the Peoria Loess (Fig. 3) (Bettis and Kemmis, in preparation). These deposits have previously been referred to informally as the basal Wisconsinan loess and basal loess sediment (Hallberg et al., 1978) and are in the same stratigraphic position as the Gillman Canyon Formation in Nebraska (Reed and Dreezen, 1965) and the Roxana and Robein silts in Illinois (Willman and Frye, 1970).

The Peoria Loess and Pisgah Formation bury a complex sequence of pre-Wisconsinan deposits in western Iowa. Adjacent to the Missouri River valley, Illinoian-age Loveland Loess is buried by the Wisconsinan deposits (Daniels and Handy, 1959). The Loveland Loess is as much as eight meters (24.7ft) thick adjacent to the Missouri River source area in western Iowa and thins rapidly to the southeast (Ruhe, 1969). Pre-Illinoian glacial deposits and interbedded fluvial and eolian deposits are present beneath the Illinoian and Wisconsinan deposits in western Iowa. Formerly these deposits were recognized as two till units designated both litho-and chronostratigraphically as Kansan and Nebraskan (Kay and Apfel, 1928; Ruhe, 1969). Recent work, however has shown that at least seven Pre-Illinoian glacial sequences, ranging in age from greater than 2.2 million years B.P. to less than 500,000 years B.P., are preserved in the stratigraphic record of southwestern Iowa (Hallberg and Boellstorff, 1978; Boellstorff, 1978; Hallberg, 1986).

Recent investigations indicate that Tertiary rocks are preserved on bedrock upland areas beneath the Quaternary sequence in western Iowa (Witzke and Ludvigson, 1988). These rocks (fluvial sequences dominated by sand, silt, and clay) contain volcanic rock fragments and lack Paleozoic carbonate grains, in sharp contrast to the overlying Quaternary sequence. The Tertiary assemblage compares closely with various western-source pre-Quaternary fluvial units in eastern Nebraska, and has been interpreted as distal outliers of the Pliocene-age Ogallala Group. The presence of these rocks on bedrock uplands in western Iowa indicates that Pliocene drainage was to the east and southeast, and that the Missouri River system was not present at that time. Available evidence suggests that the development of the Missouri system and the south-southwest drainage in the area today took place during the Pleistocene, possibly around 1.2 million years ago (Witzke and Ludvigson, 1988).

Pre-Tertiary bedrock is rarely exposed in western Iowa because of the thick cover of Quaternary deposits. Most bedrock exposures in the area are found along the Missouri Valley and its tributaries in the Sioux City and Council Bluffs areas where deep entrenchment of the streams has exposed the bedrock. Cretaceous limestone (Greenhorn Limestone), shales (Graneros Shale and Carlile Shale), and interbedded siltstone, claystone, and sandstone (Dakota Formation) crop out extensively along the Missouri and Big Sioux valleys in the Sioux City area (Brenner et al., 1981). Bedrock outcrops in the Council Bluffs area and southward are dominated by Pennsylvanian limestone, coal, and shale (Missourian and Virgilian Series; Hershey et al., 1960; Miller, 1964). Outcrops of Pennsylvanian bedrock are also found along lower reaches of some of the major tributary valleys, such as the Boyer and Nishnabotna. Cretaceous Dakota Formation rocks, dominated by sandstones, also crop out intermittently throughout southwestern Iowa (Witzke and Ludvigson, 1982). The oldest exposed rocks in Iowa, the Pre-Cambrian Sioux Quartzite, crop out in extreme northwestern Iowa along the Big Sioux Valley (Beyer, 1896; Koch, 1969).

REGIONAL PHYSIOGRAPHIC SETTING

Four major Iowa landform regions occur in western Iowa: The Missouri Alluvial Plain, the Western Loess Hills, the Northwest Iowa Plains, and the Southern Iowa Drift Plain (Fig. 1) (Prior, 1976).

Missouri Alluvial Plain

The Missouri Alluvial Plain forms the western border of the study area. Relief is quite subdued on the alluvial plain, usually less than two to five meters (6.5-16 ft) across a given valley reach. Low-relief Holocene alluvial landforms such as oxbow lakes, abandoned channels, large point bars, natural levees, etc. dominate this landscape. Topographically higher, older loess-mantled terraces are intermittently present along the margins of this landform region, but they are most prevalent in the Sioux City and Omaha-Council Bluffs areas. Between Sioux City and Missouri Valley, where the valley is cut into Cretaceous sandstone and shale, the width of the alluvial plain varies from thirteen to twenty-nine kilometers (8.2 to 18.3 mi). South of Missouri Valley, where the valley is cut into more erosionally resistant Pennsylvanian rocks, the alluvial plain is narrower, ranging from six to thirteen kilometers (3.7 to 8.2 mi) in width. The low-relief landscape typical of the Missouri Alluvial Plain extends up major tributary valleys throughout western Iowa. Terraces, both loess-mantled and younger ones without a loess mantle, are more prominent and better preserved in the tributaries than they are in the Missouri Valley.

Northwest Iowa Plains

The Northwest Iowa Plains landform region occupies the northern third of western Iowa, north of a line from Westfield in western Plymouth County to Wall Lake in southcentral Sac County. The landscape in this region is gently rolling with broad U-shaped valleys. Valley floors gently merge with lower slopes that ascend by several steps to broad interstream divides. Level, relatively stable upland summits in the Northwest Iowa Plains are mantled with one to five meters (3 to 16 ft) of Peoria Loess which thins to the northeast (Ruhe, 1969). This landform region owes much of its distinctive character to the presence of an extensive late Wisconsinan upland erosion surface (the Iowan Erosion Surface of northwestern Iowa) that is buried by Peoria Loess.

Western Loess Hills

The Western Loess Hills region lies directly east of the Missouri Alluvial Plain. It extends from Westfield southward to the Iowa-Missouri state line. The Western Loess Hills landscape is rugged with narrow, deep V-shaped valleys bordered by steep slopes leading to narrow divides. The region is composed of very dissected loess topography with small, steep valleys occupying a large percentage of the landscape. This landform region varies in width. It is approximately 32 km (20 mi) east to west in Monona and Harrison counties, and about 3 km (1.9 mi) wide in the northern and southern portions of the area. These width variations are a function of loess thickness and drainage density variations (Ruhe, 1969; Handy, 1976). Within the Western Loess Hills, loess thickness on upland divides is in excess of ten meters. The thickest loess deposit occurs adjacent to the Missouri River valley, where up to thirty-five meters (115 ft) is present at some locations. The boundary between the Loess Hills and the Northwest Iowa Plains is sharp (occurring over a distance of about 0.8 km; 0.5 mi) and the western boundary with the Missouri Alluvial Plain is abrupt.

Southern Iowa Drift Plain

The Southern Iowa Drift Plain lies south of the Northwest Iowa Plains and east of the Western Loess Hills. Approximately five to ten meters (16.4 to 32.8 ft) of Peoria Loess, thinning to the southeast, mantles relatively level upland divides in this landform region. Pre-Illinoian drift, formerly referred to as Kansan and Nebraskan, usually crops out on sideslopes where erosion during the Holocene has removed the original cover of Peoria Loess. The landscape in this region is steep to moderately rolling with broad and deeply entrenched U-shaped valleys, relatively steep, stepped interfluves, and broad upland divides (Ruhe et al., 1967). The northeastern border of this region with the Des Moines Lobe landform region is abrupt. The northern border with the Northwest Iowa Plains appears lobate on a broad scale, and occurs over a distance of about 0.8 km (0.5 mi). The border with the Western Loess Hills is gradational and directly related to the eastward thinning of the Peoria Loess.

PRE-HOLOCENE QUATERNARY HISTORY

The pre-Wisconsinan (> 60,000 B.P.) Quaternary history of western Iowa is poorly understood. Radiometric dates from the area indicate a complex history of glacial and interglacial episodes extending back to at least 2.2 million years ago (Hallberg and Boellstorff, 1978; Boellstorff, 1978; Hallberg, 1986). Numerous episodes of erosion, both subglacial and subaerial, affected the region to various degrees. The combined effect is an extensive, though discontinuous Quaternary stratigraphic record. Attempts to reconstruct the pre-Wisconsinan history of western Iowa are further confounded by the thick cover of late Wisconsinan loess which buries the pre-Wisconsinan deposits. In spite of these problems, available evidence from relatively recent investigations in the area permit a sketchy outline of the development of the Quaternary stratigraphic record, and the pre-Wisconsinan landscape which conditioned subsequent landscape development in western Iowa.

Pre-Illinoian Glaciations

By 2.2 million years ago continental glaciers had invaded western Iowa. Pre-Illinoian glaciers advanced over the area several times and deposited at least seven tills separated by alluvium, loess, volcanic ash, and paleosols (Bettis et al., 1986). The youngest till in the area lies above a Pearlett Family, Lava Creek B volcanic ash dated at 620,000 Y.B.P. (Izett and Wilcox, 1982). The glacial advance during which this till was deposited is estimated to have occurred about 500,000 Y.B.P. (Hallberg and Boellstorff, 1978, Hallberg, 1986).

Loveland Loess

Major drainage lines in western Iowa, as we know them today, were in existence by Illinoian time. Deposition of the Illinoian-age Loveland Loess took place during this time (Ruhe, 1969). The sedimentary system of the Loveland Loess is similar in kind to that of the late Wisconsinan Peoria Loess and it is inferred that both deposits have a similar origin and source (Ruhe and Olson, 1980). During and following accumulation of the Loveland Loess soils formed on stable landscape positions. Today these soils are collectively referred to as the Sangamon Soil (Ruhe, 1969; Follmer, 1983).

Late Sangamon Interval

Following development of the Sangamon Soil and before the onset of Wisconsinan loess deposition an erosion episode, or episodes, truncated the Sangamon Soil developed on slopes and, in the process, produced a stepped landscape with progressively older surfaces lying at higher elevations along a given interfluve. During development of this "Late-Sangamon" landscape (Ruhe et al., 1967) material eroded from the slopes was deposited at the base of the slopes and in valleys. Periods of slope erosion and valley alluviation were punctuated by stability and soil formation. Soils developed on eroded slopes during periods of stability as well as those soils developed on alluvium deposited during this interval have been referred to as "Late-Sangamon" (Ruhe et al., 1967; Hallberg et al., 1978). Because these soils are buried by Wisconsinan-age Pisgah Formation deposits, just as the Sangamon Soil in its Type Area is buried by the correlative Roxana Silt (Follmer, 1983 and references therein), pedostratigraphically they should be referred to as the Sangamon Soil (North American Commission on Stratigraphic Nomenclature, 1983).

Pisgah Formation

After development of the Sangamon Soil and prior to the onset of Wisconsinan loess deposition extensive upland and valley erosion removed portions of the Late-Sangamon landscape, and increased local relief throughout western Iowa (Ruhe et al., 1967). This was followed by deposition of the first increment of Wisconsinan loess (Pisgah Formation) beginning around 31,000 B.P. in extreme western Iowa (Allen, 1971). This loess deposit, as well as colluvium and hillslope deposits associated with it have been informally referred to as basal Wisconsinan loess, Farmdale Loess, and basal loess sediment (Hallberg et al., 1978). Bettis and Kemmis, (in preparation) now refer to this package of Wisconsinan loess and associated deposits buried by Peoria Loess as the Pisgah Formation. This package of deposits occupies the same stratigraphic position as the Roxana Silt of Illinois (Willman and Frye, 1970) and the Gillman Canyon Formation of Nebraska (Reed and Dreezen, 1965).

Sometime shortly before or during accumulation of the Pisgah Formation in western Iowa, major streams entrenched and the Late-Sangamon floodplains were isolated as a terrace. Late-Sangamon terraces are prominent features in major tributaries to the Missouri Valley today; but they have been mapped and described only in the Boyer River valley (Daniels and Jordan, 1966).

As deposition of the Pisgah Formation waned soil formation altered the upper part of the deposits. These soils have been informally referred to as the basal loess paleosol in Iowa (Hallberg et al., 1978). They are equivalent pedostratigraphically to the Farmdale Soil in Illinois (Willman and Frye, 1970) and are hereafter called the Farmdale Soil (Bettis and Kemmis, in preparation).

Iowan Erosion Surface of Western Iowa

During development of the Farmdale Soil another erosion cycle began to affect landscapes in the Upper Midwest (Ruhe et al., 1968). Erosion was most pronounced in northern Iowa where a low-relief, stepped landscape began to develop. This erosion surface, actually a series of coalescing surfaces, has been called the Iowan Erosion Surface (IES) (Ruhe et al., 1968; Ruhe, 1969, Hallberg et al., 1978). The Northwest Iowa Plains landform region of western Iowa owes its distinctive character to extensive and intensive development of the IES in that area.

"Tazewell" Glaciation

The first Wisconsinan glacier(s) to directly affect Iowa entered the north-central part of the state between 29,000 and 25,000 B.P. (IGS, unpublished data; Ruhe, 1969). This glaciation, the "Tazewell" (ibid.), extended as far west as western O'Brien and eastern Cherokee Counties (Ruhe, 1950; 1969). Valley train outwash was deposited in major valleys, such as the Boyer, Maple, Little Sioux, and Floyd, which drained the "Tazewell" ice (Daniels and Jordan, 1966; Hoyer, 1980a). By 20,000 B.P. "Tazewell" ice had retreated from Iowa and the IES began to develop on the recently exposed "Tazewell" surface (Ruhe, 1969). Drift (till, outwash, and associated deposits) associated with the "Tazewell" glaciation in Iowa is included in the Sheldon Creek Formation (Bettis and Kemmis, in preparation).

Peoria Loess

After 20,000 Y.B.P. development of the IES continued in the northern and eastern parts of western Iowa, but to the south and west the rate of deposition of the Peoria Loess far exceeded the rate of slope erosion and the landscape became deeply buried by loess fall. Deposition of the Peoria Loess was not at a uniform rate, but instead occurred in a series of pulses with intervening periods of very slow or no deposition during which incipient soils ("dark bands") developed (Daniels et al., 1960; Ruhe et al., 1971). Peoria Loess deposition continued from about 25,000 to 12,500 Y.B.P. in western Iowa. During that time local relief was significantly increased by loess accumulation on divide areas. Many small valleys remained active during loess deposition (Rhodes, 1984) while others were overwhelmed by loess fall and buried (Bettis et al., 1986). The combined effects of extreme loess fall, mass movement produced by undercutting of thick loess deposits along valley margins, and stream capture resulting from migration of the major streams into their valley walls (Tiffany et al., 1988) produced a latest Wisconsinan Loess Hills landscape which bore little resemblance to the preceding sub-loess landscape. Elsewhere in western Iowa, IES development and increases in local relief produced by deposition of the Peoria Loess altered the appearance of the landscape, but not to the same degree as in the Loess Hills landform region.

Shortly after about 18,000 Y.B.P. major upland erosion on the IES of northwestern Iowa ceased and a final increment of Peoria Loess buried the stripped late Wisconsinan surfaces of the Northwest Iowa Plains. Loess also buried "Tazewell" valley train deposited in the major valleys of western Iowa. Loess deposition continued until around 12,500 Y.B.P.

Wisconsinan Terrace Deposits

Many western Iowa valleys which did not drain the "Tazewell" glacier, such as the East and West Nishnabotna, and Soldier also contain loess-mantled terraces that are Wisconsinan in age (Corliss and Ruhe, 1955; Daniels and Jordan, 1966). Paleosols are not developed in the top of the alluvium comprising these terraces. In addition, where these Wisconsinan terraces and Late-Sangamon terraces are both present along a valley reach, the Late-Sangamon terraces are at higher elevations. The Wisconsinan terraces were formerly thought to be outwash associated with the "Iowan" glaciation (Corliss and Ruhe, 1955). With the demise of the concept of an Iowan glaciation (Ruhe et al., 1968) and the realization that the "Iowan Lobe" was an extensive upland erosion surface (IES) the temporal placement of these terraces became problematic. The Wisconsinan alluvium in these terraces is not outwash because a Wisconsinan glacier was not issuing meltwater into these river systems. The logical explanation is that these terrace deposits are analogous to those making up the Late-Sangamon terraces and were derived from intensive erosion of the landscape during development of the IES.

Sometime during the latest Wisconsinan, probably around 14,000 Y.B.P. major streams entrenched and loess-mantled valley train alluvium, as well as other Wisconsinan alluvium in large valleys, was isolated as a terrace (Daniels and Jordan, 1966). This entrenchment was associated with advance of the Des Moines Lobe glacier into northcentral Iowa and other lobes of the Laurentide ice sheet into the upper Missouri River Basin.

Impacts of the Des Moines Lobe Advance

The Des Moines Lobe had a profound effect on the headwater areas of the Little Sioux and Boyer Rivers. As the glacier pushed southwestward it blocked the Ocheyedon River, originally a tributary of the ancestral-Raccoon River which flowed to the Mississippi River in Iowa (Hoyer, 1980a). Blockage of the Ocheyedon River resulted in the formation of Glacial Lake Spencer upstream of the ice dam. Lake Spencer's water level rose until it topped a divide southward into Waterman Creek. The lake water cut through the divide quickly along what is now the Clay-Buena Vista County line, carved a deep narrow channel, and established the current drainage pattern of the Little Sioux Basin southwestward to the Missouri River. These events resulted in the addition of 4,250 km^2 (1,641 mi^2) of drainage area to the Little Sioux Basin that only encompassed 2,550 km^2 (985 mi^2) prior to 14,500 Y.B.P. The Little Sioux River responded to this nearly two-fold drainage area increase with a complex sequence of rapid cutting and filling. This response produced a series of terraces which dominate the valley above Correctionville.

The late Wisconsinan history of the Boyer River valley has not been worked out in the detail which that of the Little Sioux Valley has, but the two valleys appear to share similar effects of Des Moines Lobe glaciation. From its mouth to the Des Moines Lobe terminus at Wall Lake, in Sac County, the Boyer Valley trends northeast to southwest, as do all other major western Iowa valleys. At Wall Lake the valley turns abruptly to a north-south course and parallels the western terminus of the Des Moines Lobe to its headwaters west of Storm Lake in Buena Vista County. It appears that, like the Little Sioux Valley, the Boyer captured the upper part of its basin, above Wall Lake, as a result of blockage of southeast flowing tributaries of the ancestral-Raccoon Valley by advancing Des Moines Lobe ice around 14,000 Y.B.P. Unlike the Little Sioux, however, the Boyer River did not develop a prominent terrace sequence during its adjustment to addition of a larger drainage area.

Des Moines Lobe valley train outwash forms a low, gravelly terrace above Wall Lake in the Boyer Valley. Below Wall Lake the outwash is buried by Holocene terrace and floodplain deposits. Outwash deposits associated with the Des Moines Lobe glaciation are the Noah Creek Member of the Dows Formation (Bettis and Hoyer, 1986; Bettis and Kemmis, in preparation).

By about 11,000 Y.B.P. glacial meltwater no longer entered streams flowing through western Iowa, although the Missouri and Big Sioux rivers still acted as meltwater channels. At that time the floodplain level in large valleys was several meters lower in elevation than it is presently (Hoyer, 1980a: Dahl, 1961).

DEFOREST FORMATION

The DeForest Formation as originally defined (Daniels, et al., 1963) consisted of silty and loamy Holocene and late Wisconsinan alluvial and colluvial deposits found in small valleys in western Iowa. The name of the formation is taken from a tributary of Thompson Creek in Harrison County. Our definition of the formation differs from that of Daniels, et al. (1963) in three ways: 1) we expand the DeForest Formation to include all silty, loamy, clayey, and sandy Holocene alluvium in Iowa. Presently, the formation is subdivided into four members, all of which occur in western Iowa, 2) as originally defined the formation included a basal member (Soetmelk) deposited during the late Wisconsinan. We propose that the Soetmelk be excluded from the DeForest Formation and included in an as yet unnamed lithostratigraphic unit encompassing Wisconsinan fluvial deposits in Iowa. Our studies have indicated that the Soetmelk is related lithologically, biostratigraphically, and temporally to coarse-textured alluvial fills in large valleys. The large valley alluvial fills originated from the influx of glacial outwash into the headwater areas of these streams. Deposition of the Soetmelk was controlled, in part, by events taking place in the larger valleys and the Soetmelk is therefore stratigraphically related to these large valley fills; in addition, it frequently differs lithologically from the DeForest Formation alluvial fills. 3) We recognize and herein define two additional members (Corrington and Camp Creek), redefine the former Watkins and Hatcher members as beds in the newly defined Gunder Member, and likewise redefine the former Mullenix and Turton members as beds in the newly defined Roberts Creek Member. These changes allow a logical and simple lithostratigraphic classification of all Holocene alluvium in Iowa and adjacent states.

As formally defined here, the DeForest Formation includes silty, clayey, loamy, and sandy alluvium in Iowa valleys. Throughout Iowa the formation overlies Wisconsinan and older deposits. The formation is divided into four members; Gunder, Corrington, Roberts Creek, and Camp Creek. The formation and its members are extensive, mappable, lithostratigraphic units. By definition a lithostratigraphic unit is a body of strata "distinguished and delineated on the basis of lithic characteristics and stratigraphic position" (North American Commission on Stratigraphic Nomenclature, 1983:855). "Distinctive lithic characteristics include chemical and mineralogical composition, texture, and such supplementary features as color, primary sedimentary or volcanic structures, fossils... or other organic content" (ibid.:858). The DeForest Formation is distinguishable from other Quaternary deposits on the basis of particle-size (grain-size) distribution, sedimentary structures, stratigraphic position, and fossil content.

The DeForest Formation is usually significantly finer-grained than older Quaternary alluvium. The formation and its members usually fine upward as opposed to most outwash deposits which do not (Kemmis et al., 1985). Sedimentary structures within DeForest Formation alluvium are dominantly small scale and usually indicative of high frequency, low magnitude events; the opposite is often the case for sedimentary structures in Wisconsinan and older alluvium. The DeForest Formation buries and/or cuts out older deposits and lacks a loess cover. Members within the formation are separated on the basis of lithologic differences (color, sedimentary structures) and bounding unconformities (either fluvial erosion surfaces or paleosols). Extinct forms of vertebrates or invertebrates do not occur in primary context within the DeForest Formation, but extinct forms do occur in older deposits (Rhodes and Semken, 1986; Frest and Dickson, 1986). Artifacts and earthen features produced by humans occur within the Deforest Formation, but not within older deposits in Iowa.

Daniels, et al. (1963: 475 and 484-485) described two type sections for the DeForest Formation in Thompson Creek Watershed. Both sections have now been obliterated by inundation and slumping. Because of the short-lived nature of exposures in gullies and entrenched streams, and the fact that all of the formation's units are not exposed in one vertical section, we will identify two type areas, one reference area, several reference sections, and two additional type sections for the DeForest Formation. The formation's members, beds, type sections, reference areas and sections, are discussed in the following pages.

Gunder Member

The Gunder Member is proposed for oxidized, and occasionally reduced, (as defined in Hallberg et al., 1978) silty and loamy alluvium throughout Iowa. This member encompasses the Watkins and Hatcher members of Daniels et al., (1963) as described by Bettis and Thompson (1982). The Watkins and Hatcher are now included as beds within the Gunder Member. The Type Area for the Gunder Member is located in northeastern Iowa (Bettis and Littke, 1987). Gunder Member deposits overlie coarse-grained or organic-rich older alluvium, glacial till, loess, or bedrock. Gunder Member deposits include alluvium as well as colluvial and slope deposits along valley margins. Gunder Member deposits often underlie low terraces in valleys larger than first-order. The Gunder Member is separated from younger members of the DeForest Formation by a fluvial erosion surface or an unconformity marked by a buried soil. Surface soils developed in the upper part of the Gunder Member in western Iowa are thick Mollisols with dark-colored surface horizons, and brown or yellowish brown (10YR4/3-5/3) cambic (Bw) or argillic (Bt) subsurface horizons.

Watkins Bed

The Watkins Bed is the basal unit of the formation and is named after a tributary of Thompson Creek in Harrison County (Daniels, et al., 1963:478). The Watkins Bed is usually stratified, calcareous silt loam with occasional sandy and loamy zones. It is usually reduced and ranges in color from dark greenish gray (5GY4/1) to olive brown (2.5Y4/4), usually with 7.5YR hue secondary accumulations of iron oxides. The Watkins Bed rarely crops out in gully walls and has been examined primarily in borings. It is buried by younger alluvial fills of the DeForest Formation. The thickness of the bed ranges from one half to four meters (1.6-13 ft). Pre-Holocene alluvium beneath the Watkins Bed is usually finer-grained in small valleys and coarser-grained in large valleys, and is usually separated from the Watkins Bed by a fluvial erosion surface. A fluvial erosion surface also separates Watkins from younger units of the formation although Daniels recorded an A-C soil profile developed in the top of the Watkins Bed at its type section in Harrison County, Iowa (Daniels and Jordan, 1966:19-20). We propose a reference section for the Watkins Bed in southern Mills County along the west bank of McPherron Creek just upstream from a bridge on county road L-45 (Fig. 1:1; Fig. 4). At this section the Watkins Bed is exposed in the lower two meters (6.5 ft) of the gully wall beneath 9.78 m (32.1 ft) of Hatcher Bed alluvium. A detailed description of the Watkins Bed reference section is presented in Appendix A. Particle-size data for the Watkins Bed reference section are presented in Figure 5.

Four radiocarbon dates, all from southwest Iowa, are available from within the Watkins Bed. These indicate that the Watkins Bed was deposited after 10,500 and before 8,000 RCYBP. Daniels and Jordan (1966: 27-28) reported a date of 11,600$\underline{+}$200 B.P. from a log collected 38 cm (1.25 ft) above the base of the Watkins Bed at its type section. They noted that this was equivalent to dates from within the Soetmelk member at other localities in Thompson Creek and suggested that wood from the Soetmelk member could have been eroded and incorporated into the Watkins Bed. It is also possible that Watkins Bed deposition was time transgressive and that the unit began accumulating during latest Wisconsinan time in some areas. The time transgressive nature of DeForest Formation sedimentation is elaborated on later in this report.

Hatcher Bed

The Hatcher Bed is named after a tributary to Thompson Creek in Harrison County (Daniels et al., 1963). A fluvial erosion surface (the DeForest Gap) separates the Hatcher Bed from the Watkins Bed or sub-DeForest Formation deposits (Fig. 6). The Hatcher Bed ranges in thickness from one to over fifteen meters (3.2-49 ft) and is usually a massive, calcareous, brown to yellowish brown (10YR4/3-5/4) silt loam. Lower portions of this unit are often stratified and are occasionally loam or coarser texture. Noncalcareous sections have been recorded. Weathered exposures of the unit usually exhibit columnar structural units one to two meters high (3.2-6.6 ft) and one half meter (1.5 ft) wide with secondary carbonate and silt coatings along their surfaces. Secondary carbonate concretions similar to those in the Peoria Loess are often found within the unit. Within the Hatcher Bed, however, these concretions are weathered, abraded, and oriented with their long axis horizontal to subhorizontal, indicating that they have been fluvially transported to their present location.

The Hatcher Bed encompasses the greatest volume of the DeForest Formation sediments in valleys smaller than third-order. The Hatcher Bed usually crops out at the present surface, often as a terrace above the Roberts Creek Member (Fig. 6). The top of the Hatcher Bed merges with the footslope of the valley walls in a smooth, concave upward profile. Cumulic or Typic Hapludolls are usually developed in this unit where it is the surficial deposit. These are relatively thick soils with a dark-colored surface horizon (mollic epipedon). Weakly expressed buried soils are occasionally encountered within the Hatcher Bed (see the description of the Watkins reference section, for example). Most alluvial fans found within valleys draining less than 10 km^2 (3.9 mi^2) are included in the Hatcher Bed. Deposits making up these fans are lithologically indistinguishable from other portions of the Hatcher Bed and are distinctly different in lithology, geomorphic setting, and age, from Corrington Member alluvial fans described in the following section. Thin, weakly expressed paleosols are occasionally found within

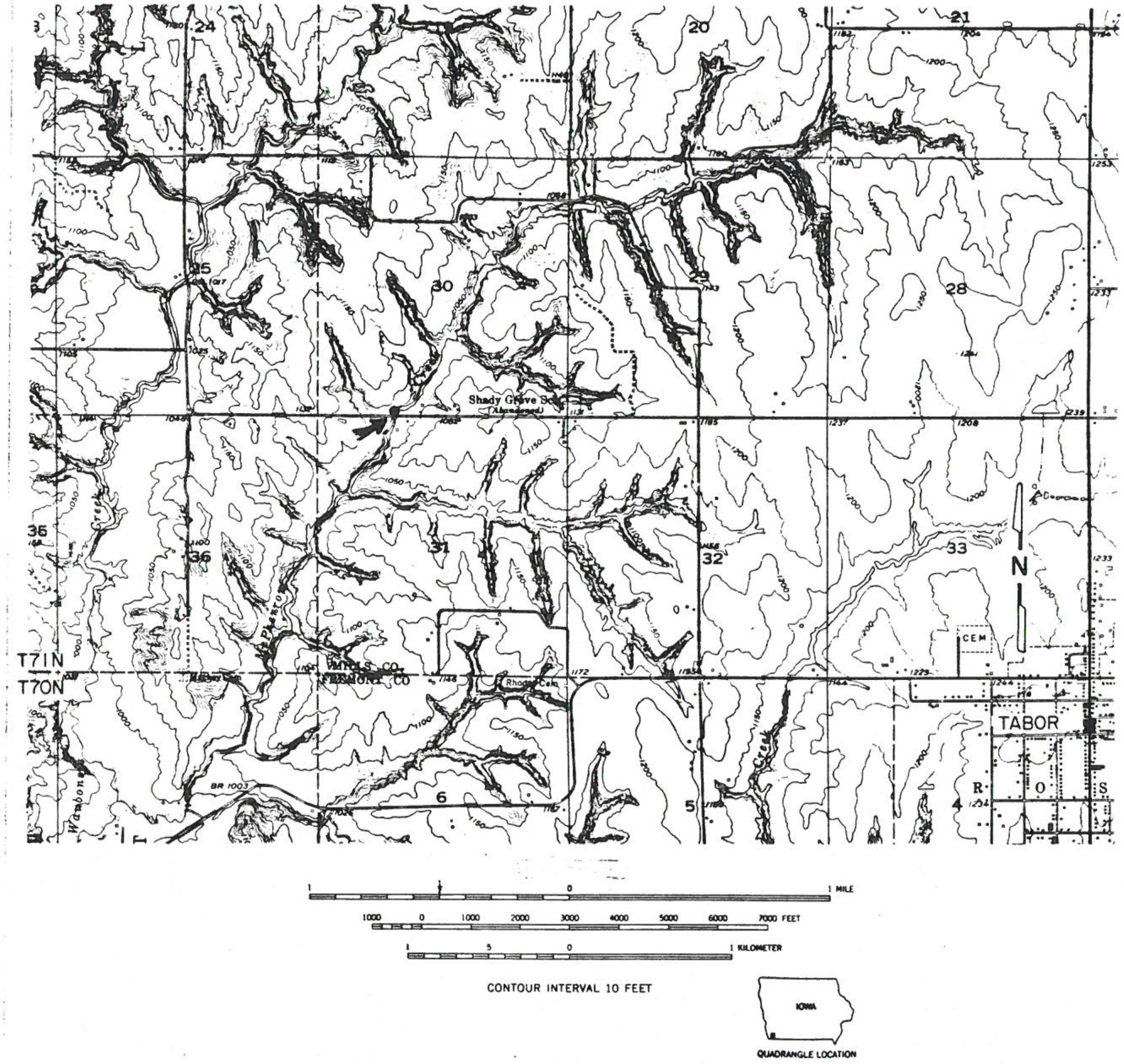


Figure 4. Topographic map showing the location of the reference section for the Watkins Bed of the Gunder Member along McPherron Creek in southern Mills County. Base taken from U.S.G.S. 7.5 minute Tabor, Iowa quadrangle.

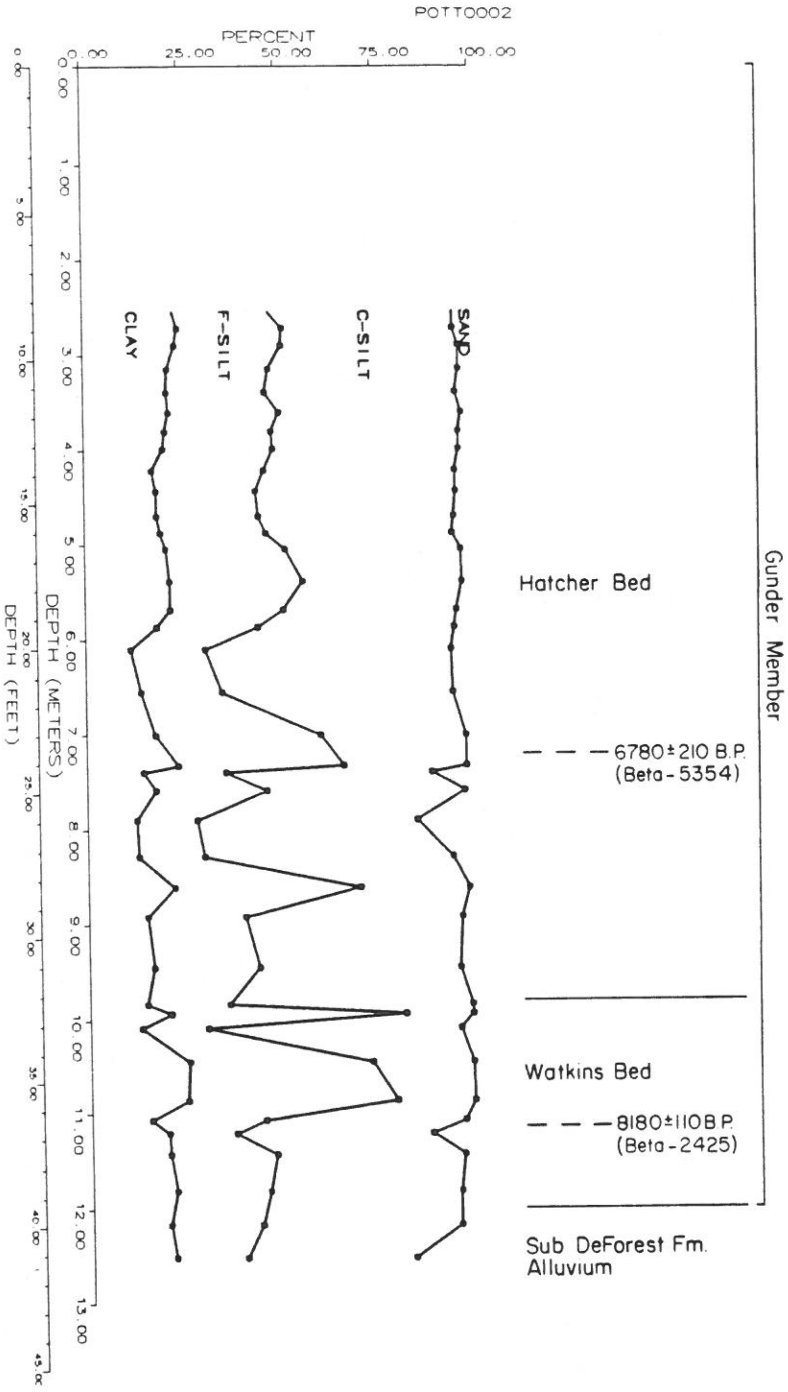


Figure 5. Particle-size profile and radiocarbon ages from the Watkins Bed reference section.

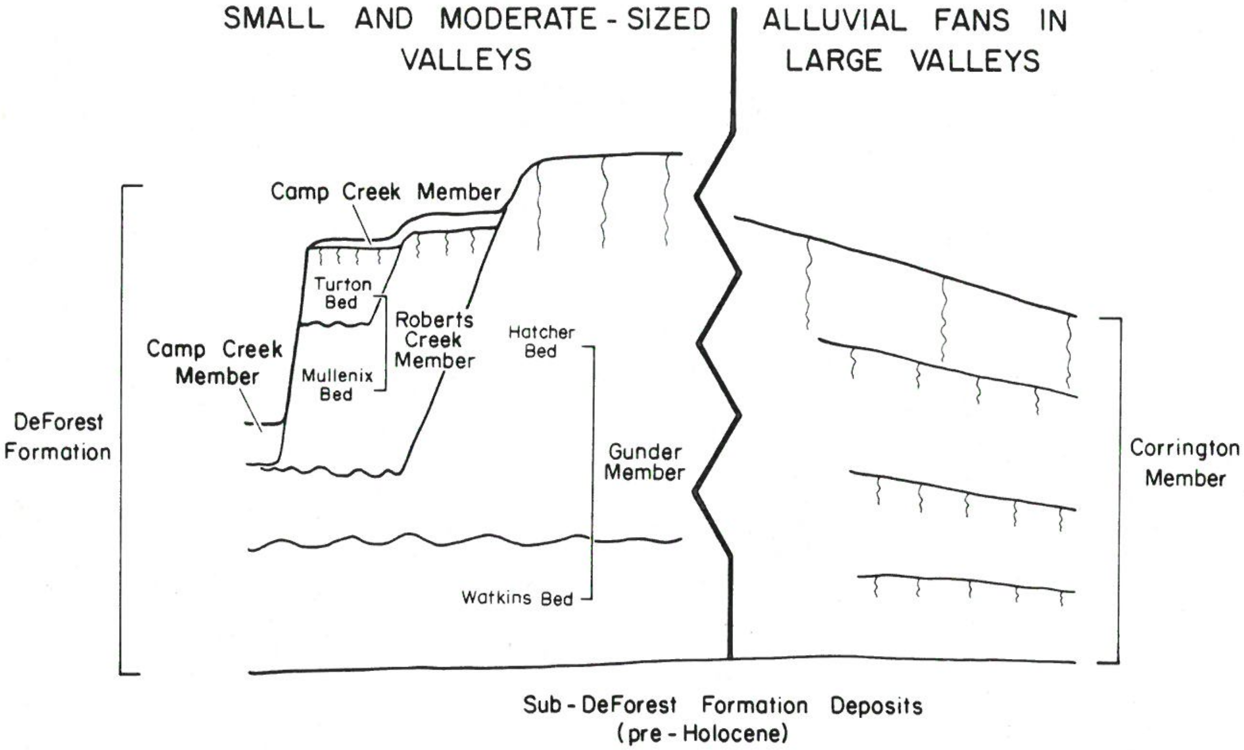


Figure 6. Schematic of stratigraphic relationships among subdivisions of the DeForest Formation. See Figure 11 for the relationship between the Corrington Member and other units.

the Hatcher fans. Hatcher Bed fans differ from Corrington Member alluvial fans in that the latter usually contain lenses of sand and gravel, exhibit more prominent stratification, and contain more well-expressed paleosols than those found within Hatcher Bed alluvial fans (Bettis and Thompson, 1982).

The reference area for the Hatcher Bed is Beaulieu Valley, a tributary of the Big Sioux River in southwestern Plymouth County (Fig. 1: B). In downstream portions of Beaulieu Valley the Hatcher Bed forms a two to four meter (6.6-13.1 ft) high terrace. Numerous exposures of the Hatcher Bed are present where small sidevalleys join the main valley. The reference section is a core taken from the east side of Beaulieu Valley (SW 1/4 NE 1/4 sec. 24 T90N R48W; Fig. 7). A detailed description of the Hatcher Bed reference section is presented in Appendix A. Figure 8 presents particle-size data for the Hatcher Bed reference section.

Detailed drilling and examination of gully exposures indicate that the Hatcher Bed accumulated as a result of several episodes of gully cutting and filling. Gullies in which the Hatcher Bed accumulated were usually two to four times larger than those presently occupying modern valleys in western Iowa and, in many cases, occupied the entire breadth of the valley. During gully filling Hatcher Bed alluvium accumulated as channel fill (gully fill), gully wall debris, as well as sheetwash from adjacent loess-mantled slopes.

Over much of western Iowa, especially in the Western Loess Hills area, the Hatcher Bed grades into Peoria Loess in the valley wall. The boundary between the two units is often imperceptible. Examination of numerous exposures along the Missouri River bluffline shows that the Peoria Loess contains bedded zones. Many of these appear to be zones of reworked loess either overlying or buried by primary loess. Stratigraphic position beneath primary Peoria Loess or the presence of an angular unconformity allow separation of this reworked loess from the Hatcher Bed.

The Hatcher Bed has been dated extensively. Chronologic relations of DeForest Formation alluvial fills, such as the Hatcher Bed, are complex. Daniels et al. (1963:482) indicated a maximum age of 2,020 RCYBP based on a single date from the base of the unit. Our study indicates an earlier commencement of Hatcher alluviation than was suggested by Daniels et al. (1963). In valleys with drainage areas up to 10 km^2 (3.9 mi^2), Hatcher Bed alluviation began shortly after 3,500 RCYBP and terminated prior 1,800 RCYBP. In larger valleys accumulation of the Hatcher Bed was underway before 8,000 RCYBP and had ended by 3,000 RCYBP. Chronologic relationships in the DeForest Formation of western Iowa will be discussed in detail later in this report.

Corrington Member

The Corrington Member is a newly defined member of the DeForest Formation, named after the Corrington alluvial fan (Hallberg, et al., 1974; Hoyer, 1980a, 1980b), located four kilometers (2.5 mi) south of the town of Cherokee, Iowa along the western wall of the Little Sioux River valley in Cherokee County. This member is restricted to alluvial fans located where small- and moderate-sized valleys enter major valleys. The Corrington Member is the most internally variable member of the formation and consists of very dark brown to yellowish brown (10YR2/2-5/4) loam to clay loam with occasional sand and gravel lenses. The unit is stratified and contains several buried soils (Hoyer, 1980b). This member is usually not buried by younger alluvium except in fan head trenches. Surface soils developed into this member are usually Cumulic Hapludolls. These are relatively thick soils which have a mollic epipedon and an irregular decrease in organic carbon content with depth. Most of these soils have argillic (Bt) subsurface horizons.

The type area for the Corrington Member is the Little Sioux River valley between Sioux Rapids and Correctionville (Fig. 1: A). The type section is the Corrington alluvial fan (W 1/2 SW 1/4 SE 1/4 sec. 4, T91N R40W; Fig. 9). At the type section approximately eleven meters (36 ft) of the member overlie late Wisconsinan alluvium (Hoyer, 1980b). Hoyer identified fifteen buried soils (Entisols and Inceptisols) within the Corrington Member at the type section. A composite description of the Corrington Member Type Section is presented in Appendix A. A composite section showing laboratory data from the type section is shown in Figure 10.

Corrington Member deposits were derived from the low-order contributory basins draining to the alluvial fans. These deposits accumulated by channeled flow, sheetwash and debris flow (Hoyer,

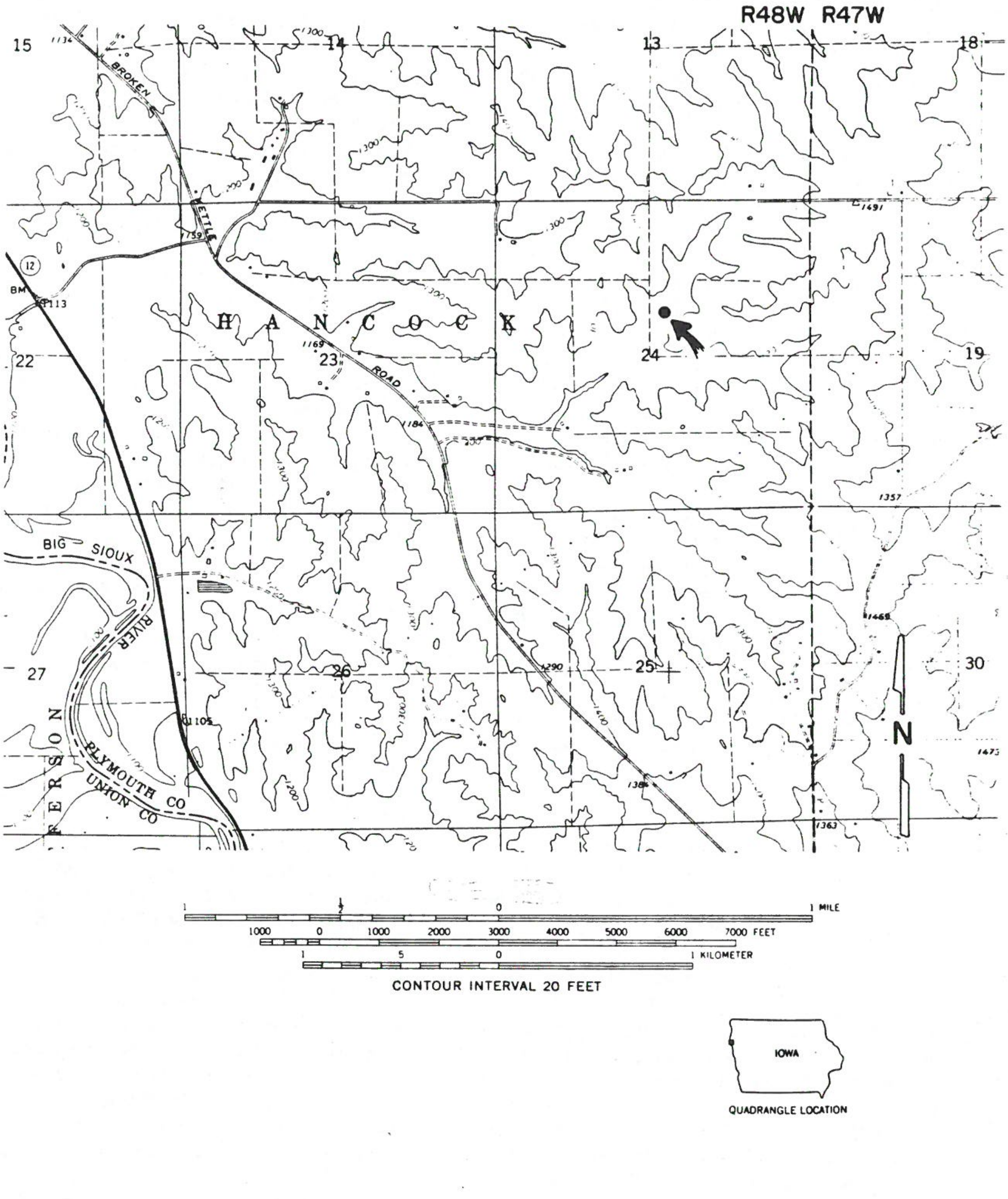


Figure 7. Topographic map showing the location of the reference area and reference section for the Hatcher Bed of the Gunder Member along Beaulieu Valley in Plymouth County. Base from U.S.G.S. Sioux City North, Iowa 7.5 minute quadrangle.

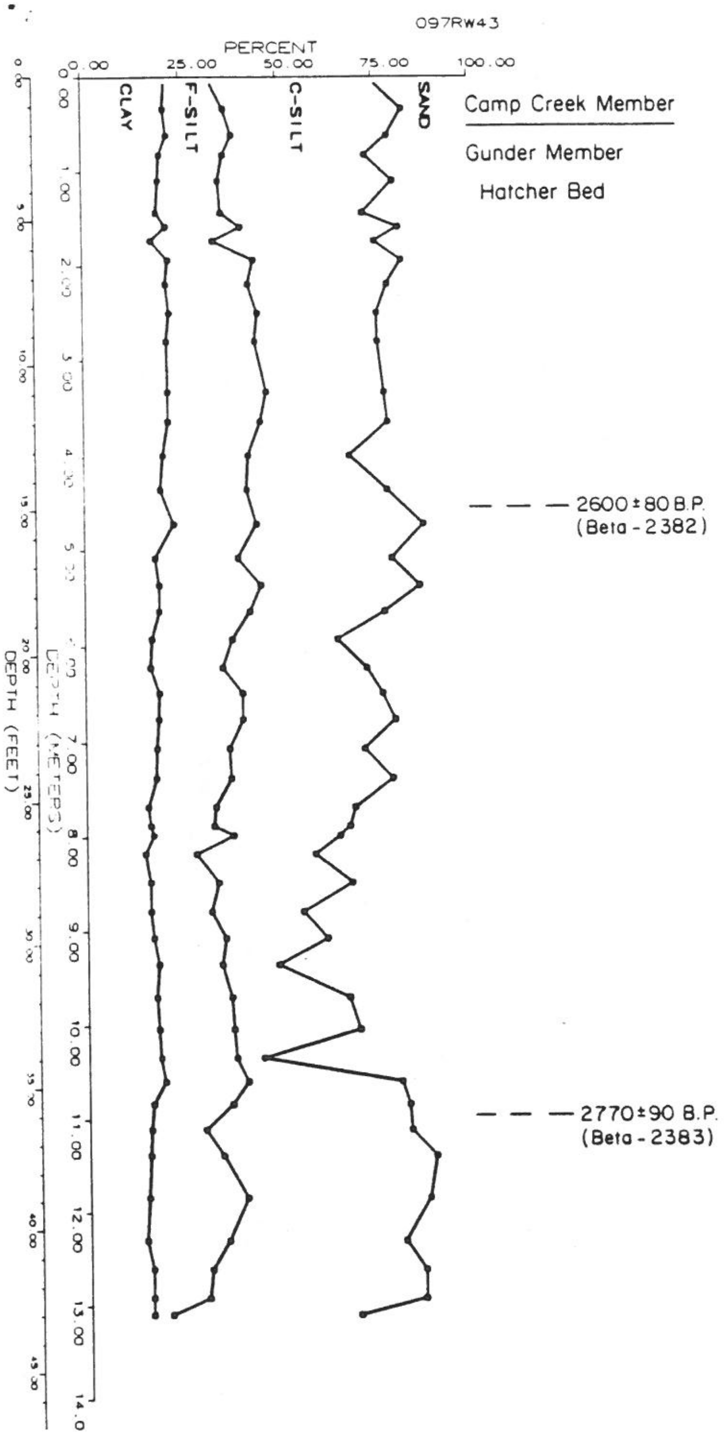


Figure 8. Particle-size profile and radiocarbon dates from the Hatcher Bed reference section along Beaulieu Valley in northwest Iowa.

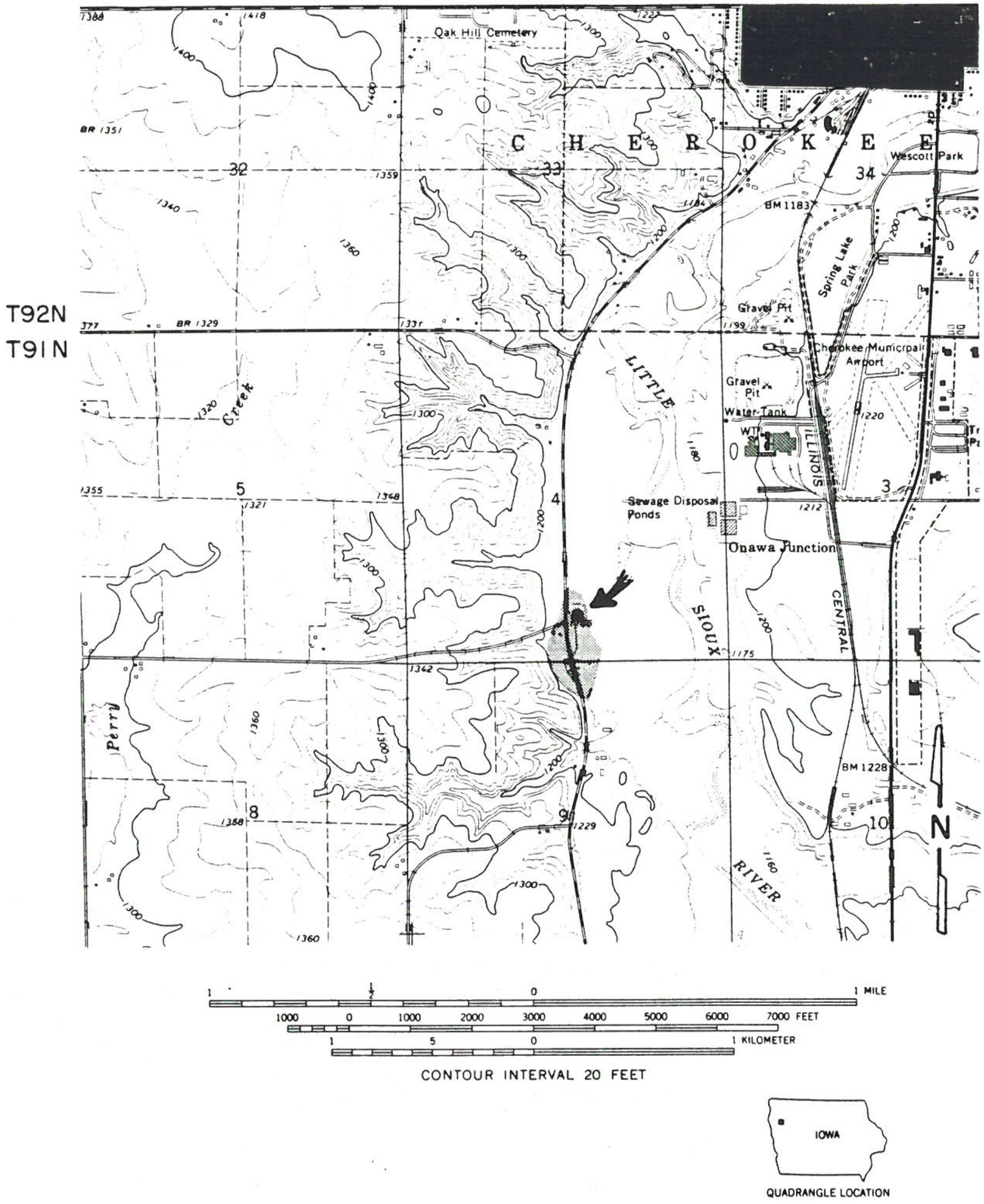


Figure 9. Topographic map showing the location of the Corrington Member Type Section along the Little Sioux Valley in Cherokee County. Base taken from U.S.G.S. 7.5 minute Cherokee South, Iowa quadrangle.

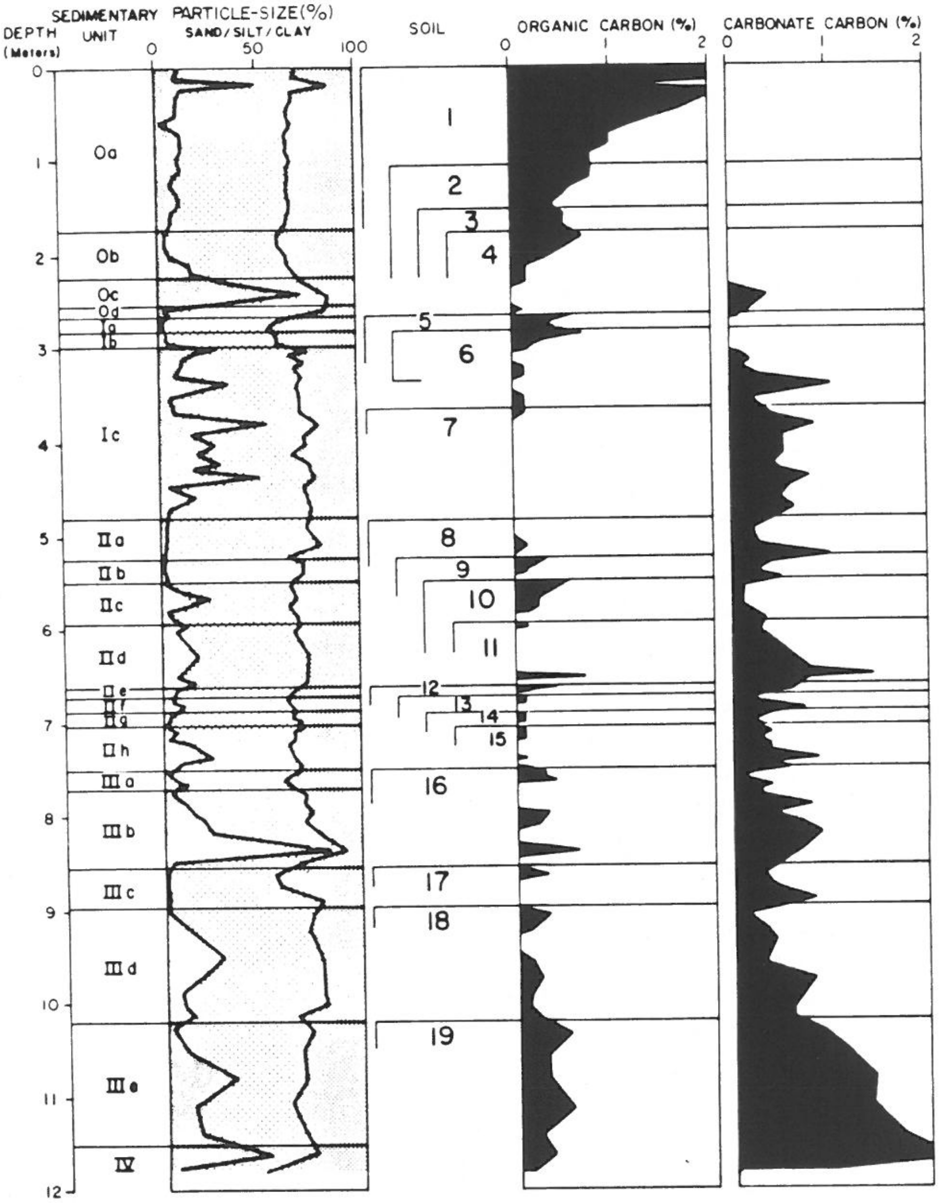


Figure 10. Laboratory data from a composite geologic section of the Corrington Member Type Section at the Corrington alluvial fan south of Cherokee, Iowa. Repeated upward-fining sequences of sedimentation are revealed by the grain-size data and increases in carbonate occur beneath each solum. Adapted from Hoyer, 1980b, Figure 2.13.

1980b). Studies at the Type Section and at other Corrington Member fans along the Boyer River valley near Dennison, Iowa have shown that the Corrington Member interfingers with Gunder Member alluvium in large valleys, and is separated from late Holocene alluvium by an angular unconformity (Hoyer, 1980b: Fig. 2.6; Bettis, 1981).

Hoyer (1980b) presented a model of alluvial fan sedimentation which applies to the Corrington Member throughout its extent (Bettis and Hoyer, 1984; 1986). Fan deposits accumulate episodically with intervening periods of relative stability and soil formation across most of the fan surface. The first increments of sediment in a sedimentation episode are quite coarse, often sandy loam or loam with some pebbles in western Iowa. As sedimentation progresses the deposits fine, eventually producing a normally graded bed. Near the end of the episode sedimentation slows because of stability in the contributory basin, and pedogenesis proceeds in the recently deposited material on the fan.

Several buried soils are developed in the Corrington Member. This indicates numerous episodes of fan sedimentation (to bury the soils) and relative stability (during which the soils develop). Soils developed rapidly in these deposits because the materials were well-drained and "pre-weathered", having been derived from former soils and alluvium in the contributory basin. The thick Mollisols found as surface soils on fans throughout the area owe their origin to relatively slow, episodic sedimentation concurrent with pedogenesis.

During the early to mid-Holocene, low-order drainageways were sites of net erosion. The products of this erosion were deposited at the junction of the low-order drainageways with major river valleys as Corrington Member alluvial fan deposits (Fig. 11). In low-order drainages there is an erosional unconformity, referred to as the DeForest Gap, within the Gunder Member separating the Watkins Bed and the next youngest, overlying alluvial fill, the Hatcher Bed. The Corrington Member contains a depositional record corresponding to development of the DeForest Gap in the small contributory basins.

Twenty-four radiocarbon dates from the Type Section and other Corrington Member sections in western Iowa place Corrington Member alluviation between about 8,500 and 2,500 RCYBP (Hoyer, 1980a). Stratigraphic relationships between dated Holocene alluvium and Corrington Member alluvial fan deposits in other portions of the Upper Midwest indicate that major alluvial fan development was an early to mid-Holocene phenomenon throughout the region (Bettis and Thompson, 1982; Bettis et al., 1984; Benn and Bettis, 1985; Wiant et al., 1983; Bettis and Mandel, in review).

Roberts Creek Member

The Roberts Creek Member is proposed for dark-colored clayey, silty, and loamy alluvium throughout Iowa. This member includes the Mullenix and Turton members of Daniels et al. (1963) as described by Bettis and Thompson (1982). The Mullenix and Turton are now included as beds within the Roberts Creek Member. The Type Area for the Roberts Creek Member is located in northeastern Iowa (Bettis and Littke, 1987). Roberts Creek Member deposits can overlie a wide variety of deposits including Gunder Member deposits, coarse-grained older alluvium, loess, and glacial till. In western Iowa Roberts Creek Member deposits are usually found beneath the floodplain in small and large valleys. The Roberts Creek Member is separated from younger DeForest Formation deposits (Camp Creek Member) by either a fluvial erosion surface or an unconformity marked by a buried soil. Surface soils developed in the Roberts Creek Member are dark-colored Entisols, Mollisols, and Inceptisols.

Mullenix Bed

The Mullenix Bed was described by Daniels et al. (1963) from exposures in a tributary of Thompson Creek. This unit is inset unconformably as a gully fill into the Hatcher Bed of the Gunder Member and often cuts into other older deposits as well (Fig. 6). The Mullenix Bed is composed of very dark gray to dark grayish brown (l0YR3/l-4/2) stratified silt loam and clay loam which commonly exhibits medium to coarse columnar structure. Thin, lenticular bodies of sand and gravel, marking paleo-channels, usually occur in lower portions of the unit. Typically, the Mullenix Bed is one to four meters (3.2-13.1 ft) thick. Usually the upper one to three meters (3.2-9.8 ft) is noncalcareous and the remainder is calcareous. Where it is exposed at the surface, Cumulic Hapludolls and Typic Udifluents are developed into this unit. These soils have thick, dark-colored surface horizons and, in the later case,

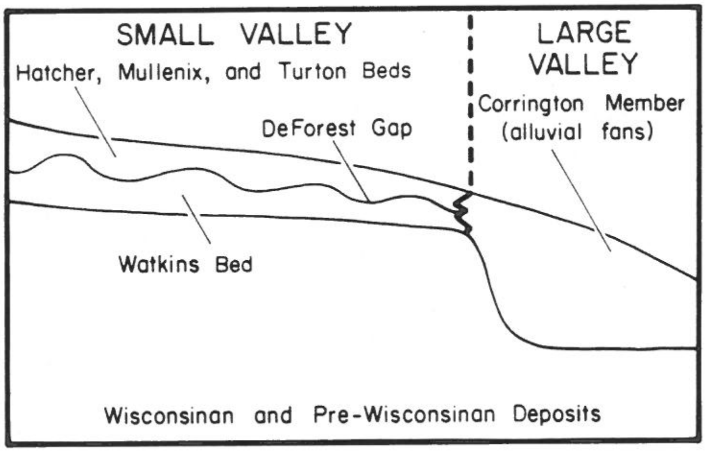


Figure 11. Schematic diagram showing relationships of Holocene alluvial fills in small-and moderate-size valleys with alluvial fans in large valleys.

lack a B horizon and are stratified below the A horizon. Soils developed into the Mullenix Bed are morphologically less well expressed and have darker B and C horizons than those developed into the Gunder and Corrington Members.

The reference area for the Roberts Creek Member in western Iowa is Smokey Hollow valley, a tributary to the Little Sioux River in southern Woodbury County (Fig. 1, C). The reference section for the Mullenix Bed is a core taken on the west side of the valley (SE 1/4 NW 1/4 sec. 22, T8N, R44W) (Fig. 12). At this location gully erosion prior to deposition of the Turton Bed truncated the upper portion of the Mullenix Bed. A detailed description of the reference section for the Turton and Mullenix beds of the Roberts Creek Member is presented in Appendix A. Figure 13 presents particle-size data for the Roberts Creek Member reference section in Smokey Hollow.

The Mullenix Bed accumulated in gullies similar in size and extent to those occupying many western Iowa valleys today. These gullies were smaller than those in which the Hatcher Bed of the Gunder Member was deposited. Detailed investigations at the Rainbow Site along Held Creek in Plymouth County, indicate that Mullenix Bed sedimentation rates varied dramatically through time in response to shifting channel locations and evolving gully morphology (Bettis, in press).

Twenty-four radiocarbon dates from materials within the Mullenix Bed in valleys with drainage areas less than 10 km^2 (3.9 mi^2) indicate it accumulated between 1,800 and about 1,000 RCYCB. This is in agreement with the chronology proposed by Daniels, et al. (1963). In contrast, two dates from southwestern Iowa (in large valleys draining 100-700 km^2; 38.6-270.3 mi^2) suggest that Mullenix Bed alluviation was underway in moderate-sized valleys by 3,500 radiocarbon years ago.

Turton Bed

The Turton Bed of the Roberts Creek Member is named after a tributary of Thompson Creek in Harrison County (Daniels, et al., 1963). The unit is inset into older units and often overlaps the Mullenix Bed. The Turton Bed is usually a very dark gray to dark grayish brown (10YR3/1-4/2) stratified, silty clay loam to loam. The entire unit may be calcareous or the upper one to two meters (3.3-6.6 ft) may be noncalcareous. The Turton Bed typically ranges from one to four meters (3.3-13.1 ft) in thickness. Surface soils developed into this unit are usually Typic Udifluents. These soils lack a B horizon and usually exhibit stratification below the solum. Soils developed into the Turton Bed are morphologically less well expressed than nearby soils developed into the Mullenix Bed. Soil development in the Turton Bed usually consists solely of organic matter accumulation in a surface horizon. The reference area and section are given in the description of 93SHB-2 (Appendix A).

Turton Bed accumulated in gullies generally smaller and less extensive than those present in these valleys today. Often Turton Bed alluvium completely filled the paleo-gullies and overlapped adjacent areas, burying former surface soils developed into the upper part of the Mullenix Bed.

Six radiocarbon dates are available for the Turton Bed (Appendix A). These indicate that deposition of the unit in valleys draining less than 10 km^2 (3.9 mi^2) began around 700 Y.B.P. and terminated sometime after 250 Y.B.P. but prior to 100 years ago. A date from a southwestern Iowa stream draining about 700 km^2 (270.3 mi^2) places commencement of Turton Bed alluviation at 1,300 Y.B.P., while another basal Turton date from a stream draining 27 km^2 (10.4 mi^2) in western Crawford County indicates that alluviation of the unit began there about 840$\pm$80 Y.B.P.

Camp Creek Member

The Camp Creek Member, a newly named member, encompasses deposits formerly designated as "postsettlement alluvium" (Daniels and Jordan, 1966; Bettis and Thompson, 1981). The member is named from exposures along Camp Creek which drains to the Garretson Drainage Ditch in section 3, T87N, R46W, Woodbury County, Iowa about 24 km (15.1 mi) southeast of Sioux City. The Camp Creek Member is usually a calcareous to noncalcareous, very dark gray to brown (10YR3/1-5/3), stratified silt loam to clay loam. This member is inset into or unconformably overlies the Gunder, Corrington, and Roberts Creek members, depending on the local geomorphic setting and history of landuse. Thickness of the Camp Creek Member is quite variable ranging from a few centimeters to over five meters (16.4 ft). Surface soils developed into the Camp Creek Member are Typic Udifluvents. These soils consist of an organically enriched surface horizon (A horizon) grading to unaltered parent material.

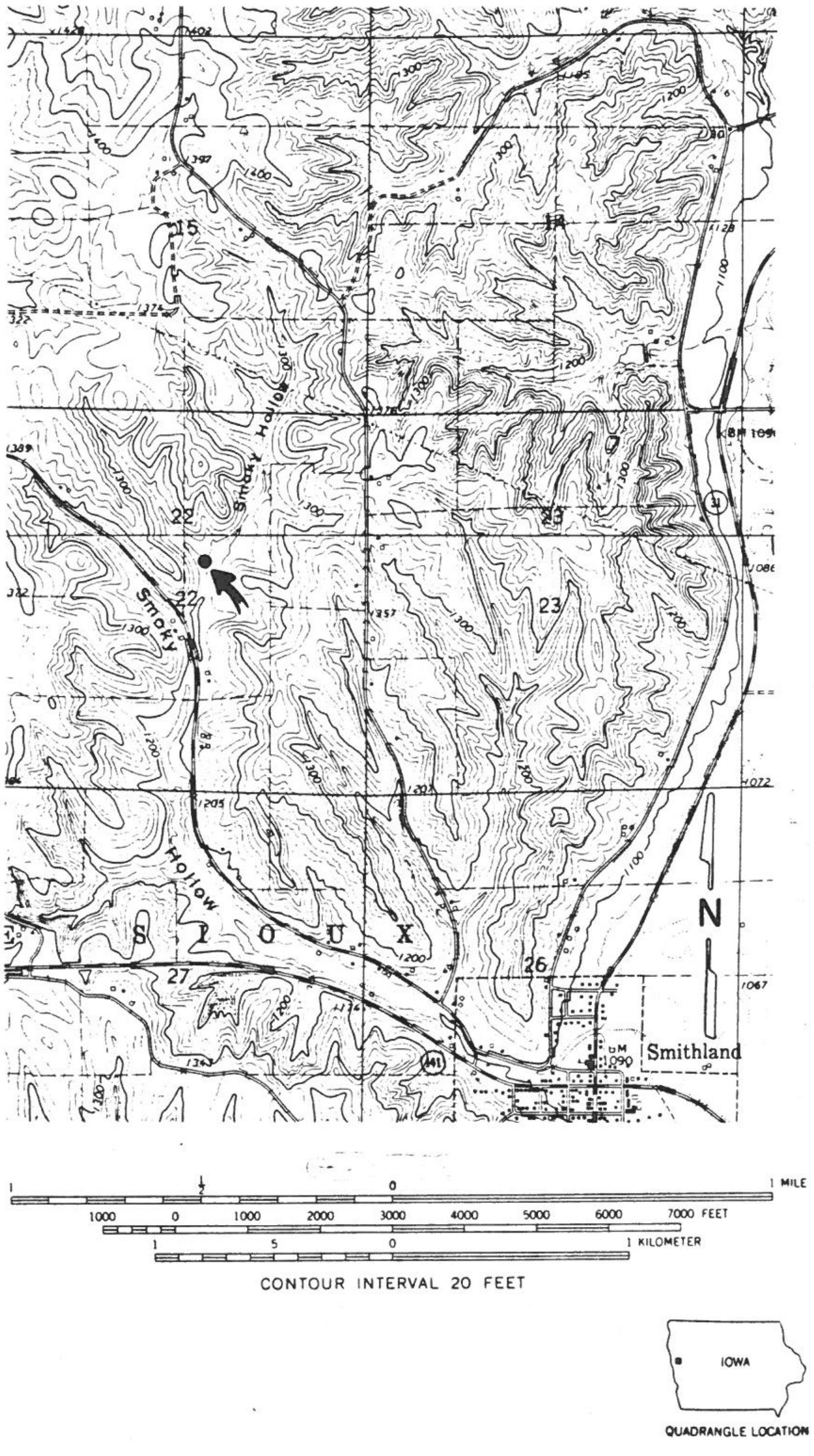


Figure 12. Topographic map showing the location of the reference area for the Roberts Creek Member in western Iowa and the reference section for the Mullenix and Turton beds in Smokey Hollow valley in southern Woodbury County. Base taken from U.S.G.S. 7.5 minute Smithland and Oto, Iowa quadrangles.

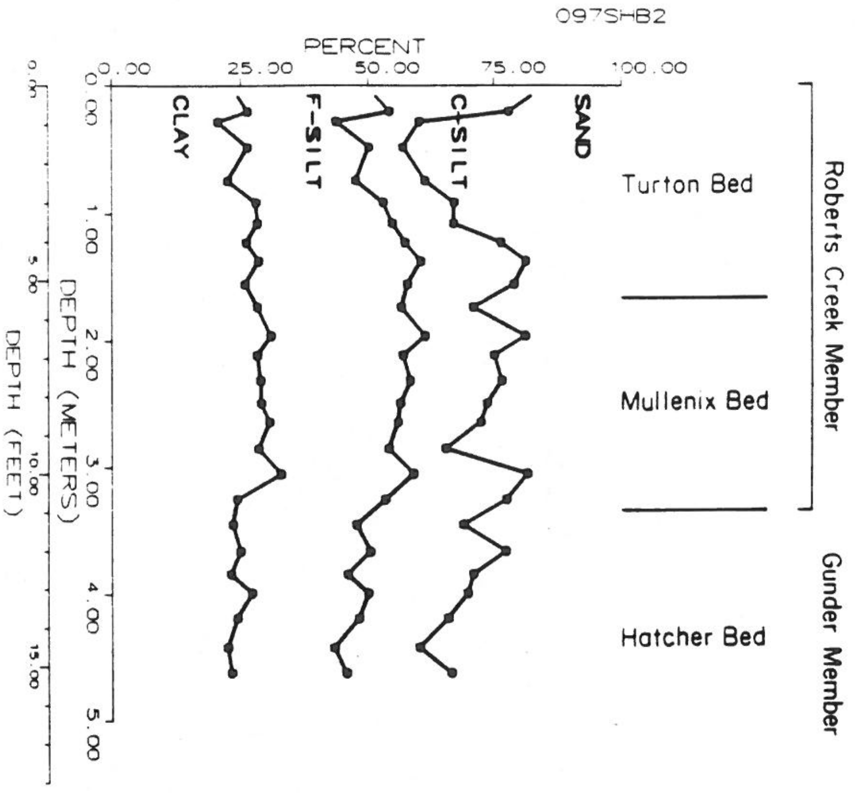


Figure 13. Particle-size data for the Roberts Creek reference section in western Iowa.

Stratification is usually evident beneath the A horizon. However, many Camp Creek sections do not have soils developed into them.

The Type Area for the Camp Creek Member is that portion of Camp Creek passing through section 2, T87N, R46W (Fig. 1; E). Numerous exposures of the member are present along this reach. The Type Section for the Camp Creek Member is a core taken along the west bank of Camp Creek (NW 1/4 SW 1/4 sec. 1 T78N R45W) (Fig. 1, 6; Fig. 14). A detailed description of the Camp Creek Member Type Section is presented in Appendix A.

Historic objects (glass, cans, farm implements, etc.) within and at the base of several Camp Creek Member exposures indicate that it began accumulating after Euroamerican settlement of western Iowa about 150 years ago in valleys smaller than third-order. In larger valleys radiocarbon dates indicate that the Camp Creek Member was aggrading as early as 400 B.P. This member is still accumulating.

Table 1 provides a summary of the lithologic properties of units comprising the DeForest Fomation in western Iowa.

GEOTECHNICAL PROPERTIES OF THE DEFOREST FORMATION

As part of their subsurface investigations for grade stabilization and erosion control structures the Soil Conservation Service has analyzed a large number of samples for standard geotechnical properties. On the advice of Dr. R. Lohnes, Iowa State Univ. Engineering Dept. three properties were examined: unit weight, liquid limit, and plasticity index. These analyses were determined on disturbed and undisturbed samples collected by SCS geologists. The stratigraphic scheme used for alluvial deposits during their investigations was not the same as outlined in this report but conversations with SCS personnel, comparison of investigations in the same study areas, and correlations suggested by Conrad Kilian (SCS file) permit a preliminary correlation of geotechnical properties determined by the SCS with units of the DeForest Formation described in this report. Table 2 presents means and standard deviations of values for three geotechnical properties determined for DeForest Formation units. The stratigraphic units used by the SCS at the time the samples were collected are given in parentheses and the results are separated according to DeForest Formation lithounits as well as geographically into samples collected in the Western Loess Hills (thick loess) and the Southern Iowa Drift Plain (thinner loess). Several of the analyses from the Southern Iowa Drift Plain region were collected outside of the western Iowa study area.

Unit weight, or body force per unit volume, is density multiplied by the acceleration of earth's gravity. The liquid limit is the water content at which a material changes from a liquid to a plastic state of consistency. The plastic limit is the minimum water content above which a soil changes from the plastic to the semi-solid state of consistency . The plasticity index is the numerical difference between the liquid limit and the plastic limit of a material. The plasticity index (LL-PI) represents the range of moisture content within which the material exhibits the properties of a plastic solid (Spangler and Handy, 1984).

Several trends are apparent in the data. Unit weight is greatest in the Gunder Member, less in the Roberts Creek Member, and least in the Camp Creek Member. This is an age sequence and may be a product of more compaction of the alluvium with increasing age. The Roberts Creek Member also contains a higher percentage of organic carbon than the Gunder Member which would result in a lower unit weight for the former. Unit weight is also greater in the Southern Iowa Drift Plain than in the Western Loess Hills area. This trend is probably a product of greater clay content of the Southern Iowa Drift Plain alluvium.

The liquid limit of the Roberts Creek Member is greater than the liquid limit of other members in the formation. This probably results from the high total carbon content and slightly greater average clay content of the Roberts Creek Member relative to the other members. The liquid limit of all DeForest Formation units is slightly greater in the Southern Iowa Drift Plain than in the Western Loess Hills. This is probably a result of a greater average clay content for the DeForest Formation in the Southern Iowa Drift Plain.

The plasticity index of the Roberts Creek Member is greater than that of the Gunder Member, which is greater than that of the Camp Creek Member. This trend probably reflects a decrease in average clay content from the Roberts Creek to the Camp Creek members. The standard deviation (s) of the plasticity and liquid limit values is greater for all DeForest Formation units in the Southern Iowa Drift Plain than in the Western

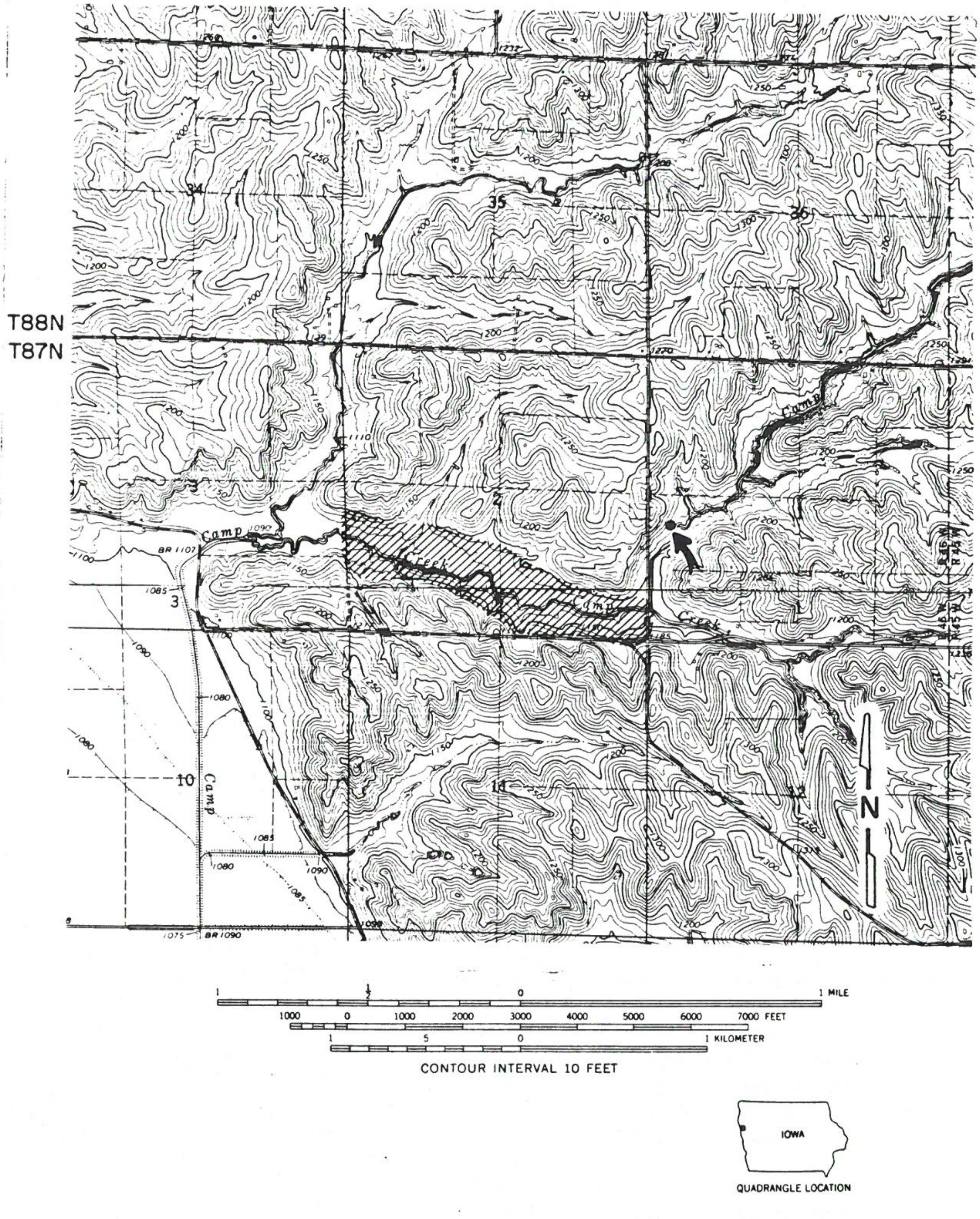


Figure 14. Topographic map showing the location of the Type Area and Type Section for the Camp Creek Member along Camp Creek in Woodbury County. Base taken from U.S.G.S. 7.5 minute Luton and Lawton, Iowa quadrangles.

Table 1. Lithologic characteristics of DeForest Formation units in western Iowa.

MEMBER	BED	LITHOLOGIC PROPERTIES
Camp Creek		stratified silt loam to clay loam (texture varies according to local source material); calcareous to noncalcareous; very dark gray to brown (10YR 3/1-5/3); no surface soil to very poorly expressed surface soil developed in upper part of unit.
Roberts Creek	Turton	stratified silty clay loam to loam; calcareous to noncalcareous in upper part; very dark gray to dark grayish brown (10YR 3/1-4/2); thin dark colored surface soils developed in upper part.
	Mullenix	stratified silt loam and clay loam with thin lenticular sand and gravel bodies in lower part; noncalcareous grading downward to calcareous, very dark gray to dark grayish brown (10YR 3/1-4/2); coarse columnar structural units evident on weathered sections; thick dark-colored surface soils in upper part.
Corrington		stratified to massive; calcareous to noncalcareous; loam to clay loam with lenses of sand and gravel; very dark brown to yellowish brown (10YR 2/2-5/4); several buried soils; thick well horizonated surface soils with brown B horizons developed in upper part; found in alluvial fans in large valleys.
Gunder	Hatcher	massive (to planar bedded in its lower part), calcareous to noncalcareous silt loam; brown to yellowish brown (10YR 4/3-5/4); prominent coarse columnar structural units evident on weathered sections; thick, moderately well horizonated surface soils with brown B horizons developed in upper part.
	Watkins	stratified, calcareous silt loam with sandy and loamy interbeds; dark greenish gray (5GY 4/1) to olive brown (2.5 Y4/4); often exhibits 7.5YR hue secondary accumulation of iron oxides; deeply buried.

Table 2. Unit weight, liquid limit, and plasticity index of DeForest Formation alluvium in western Iowa.

CAMP CREEK MEMBER (Modern Alluvium)	N		UNIT WT. (g/cc)	N	LL	PI
Western Loess Hills	6	x̄	1.30	6	37.5	23.0
		s	0.80		5.24	4.67
Southern Iowa Drift Plain	1		1.40		38.0	15.0

ROBERTS CREEK MEMBER-TURTON BED (Recent Alluvium)	N		UNIT WT. (g/cc)	N	LL	PI
Western Loess Hills	1	x̄	1.41	3	41.7	20.7
		s	—		1.15	2.08
Southern Iowa Drift Plain	14	x̄	1.44	19	43.4	23.0
		s	0.99		8.95	7.56

ROBERTS CREEK MEMBER-MULLENIX BED (Older Recent Alluvium)	N		UNIT WT. (g/cc)	N	LL	PI
Western Loess Hills	10	x̄	1.36	10	40.0	17.7
		s	0.90		3.37	5.25
Southern Iowa Drift Plain	12	x̄	1.47	12	41.2	20.5
		s	0.08		9.79	7.76

GUNDER MEMBER-HATCHER BED (Hatcher Alluvium)	N		UNIT WT. (g/cc)	N	LL	PI
Western Loess Hills-terrace	28	x̄	1.43	35	37.8	15.2
		s	0.12		3.96	4.62
-non-terrace	33	x̄	1.38	34	41.7	20.9
		s	0.10		4.82	7.68
Southern Iowa Drift Plain	12	x̄	1.54	12	35.5	17.8
		s	0.10		6.95	5.37

SUB-GUNDER MEMBER-HATCHER BED INCLUDES WATKINS BED AND WISCONSINAN ALLUVIUM (Sappa)	N		UNIT WT. (g/cc)	N	LL	PI
Western Loess Hills	14	x̄	1.40	14	38.1	14.2
		s	0.09		5.72	5.70
Southern Iowa Drift Plain	13	x̄	1.50	13	33.6	13.8
		s	0.18		10.8	7.15

Loess Hills. This reflects greater textural variability of the formation in the Southern Iowa Drift Plain area.

GEOMETRY AND DISTRIBUTION OF THE DEFOREST FORMATION IN SELECTED STUDY AREAS

In the previous section the characteristics and age of the lithostratigraphic units comprising the DeForest Formation were outlined. This section presents cross-sectional and distributional data on the DeForest Formation units in selected study areas. Also discussed in this section are variations in the lithologic characteristics of the formation's members and beds produced by local variation in source materials. All the areas investigated in western Iowa will not be discussed, but those discussed encompass the variability observed during our investigations.

Smokey Hollow

Smokey Hollow is a right bank tributary of the Little Sioux River located in southern Woodbury County within the Western Loess Hills landform region (Fig. 1; B, C, D). The study area is located in the upper reaches of Smokey Hollow about 3 km (1.9 mi) north of the town of Smithland. This part of Smokey Hollow includes a north-south trending third-order valley with eight first- and second-order sidevalleys (Figs. 15 and 16). A discontinuous gully occupies the mainstem while the sidevalleys are presently ungullied. Drainage area at the studied reach is approximately 128 hectares (315 ac). East-facing slopes are steeper and shorter than the west-facing slopes. Hardwoods (oak, hickory, walnut) dominate east-facing slopes while west-facing slopes are covered with prairie and pasture grasses which interdigitate with softwoods on the valley floor along the modern gully. Less than ten percent of the valley floor in the study area has ever been cultivated.

Sixty five holes were drilled in the Smokey Hollow project area. The depth and density of the borings were sufficient to allow construction of a series of isopach maps showing the thickness and distribution of the various DeForest Formation lithounits.

Over most of the watershed thick Peoria Loess (>15 m; 49.2 ft) is the surficial deposit on valley slopes and uplands. Smokey Hollow Valley is cut into a sequence of interbedded Pre-Illinoian till and sand and gravel (Thompson and Bettis, 1980). At some locations along the valley slopes Late Sangamon paleosols are developed into the Pre-Illinoian deposits, indicating that the valley is pre-Wisconsinan in age. The Pre-Illinoian deposits crop out at the modern surface only in the downstream one-third of the study area.

Dark greenish gray (5GY 4/1) and dark gray to dark grayish brown (2.5Y 4/0-4/2) silty clay loam late Wisconsinan alluvium, formerly referred to as the Soetmelk member, truncates Peoria Loess in the mainvalley and underlies the Holocene alluvium in much of the study area (ibid.). This alluvium commonly contains organics and, in Smokey Hollow usually has an organic zone at or near its surface. Daniels and Jordan (1966) reported an organic zone from the top of a similar unit in Thompson Creek Watershed in Harrison County, but considered it a deposit rather than an incipient soil. In Smokey Hollow, however, this zone occasionally exhibits weak soil structure accompanied by a decrease in reaction with dilute HCl. These characteristics suggest that this is probably a weakly-expressed soil in Smokey Hollow and that a period of time passed between accumulation of this alluvium and deposition of the overlying Gunder Member of the DeForest Formation. The organics in this weakly expressed soil include abundant spruce (Picea sp.) needles and a spruce log (F. Manwiller, Iowa State University Forestry Department, personal communication).

All DeForest Formation members, except the Corrington Member, are present within the Smokey Hollow study area. The Hatcher Bed of the Gunder Member, the Mullenix and Turton beds of the Roberts Creek Member, and the Camp Creek Member are the surficial deposits. The Watkins Bed of the Gunder Member is buried beneath some of the younger units. Late Wisconsinan alluvium and Pre-Illinoian deposits underlie the Holocene alluvium in Smokey Hollow.

The DeForest Formation alluvial fills accumulated in paleo-gullies and therefore the isopachs of the various units show the extent of the gully network that the fills accumulated in, provided that a subsequent gullying episode was not more extensive. Areas of a given fill which have a buried paleosol developed in their upper part were not gullied (eroded) prior to accumulation of the alluvium which buries them.

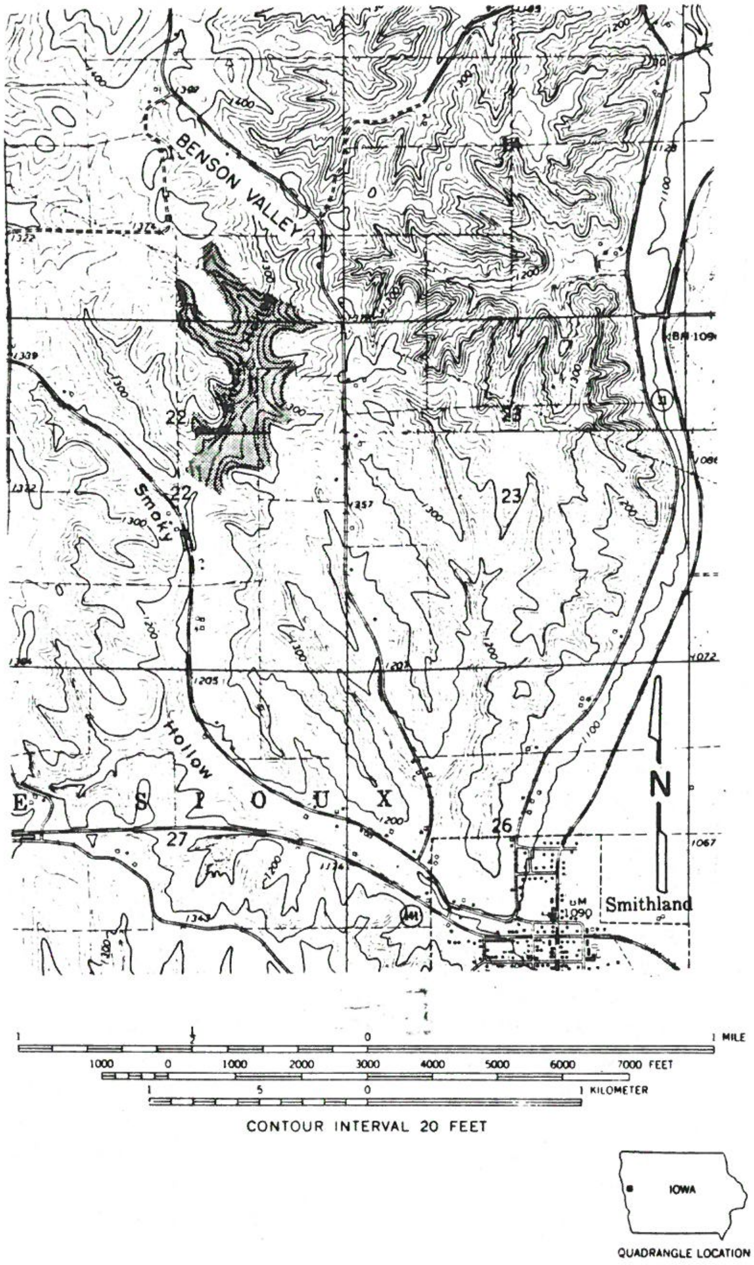


Figure 15. Topographic map showing the location of the Smokey Hollow study area in southern Woodbury County. Base taken from U.S.G.S. 7.5 minute Smithland and Oto, Iowa quadrangles.

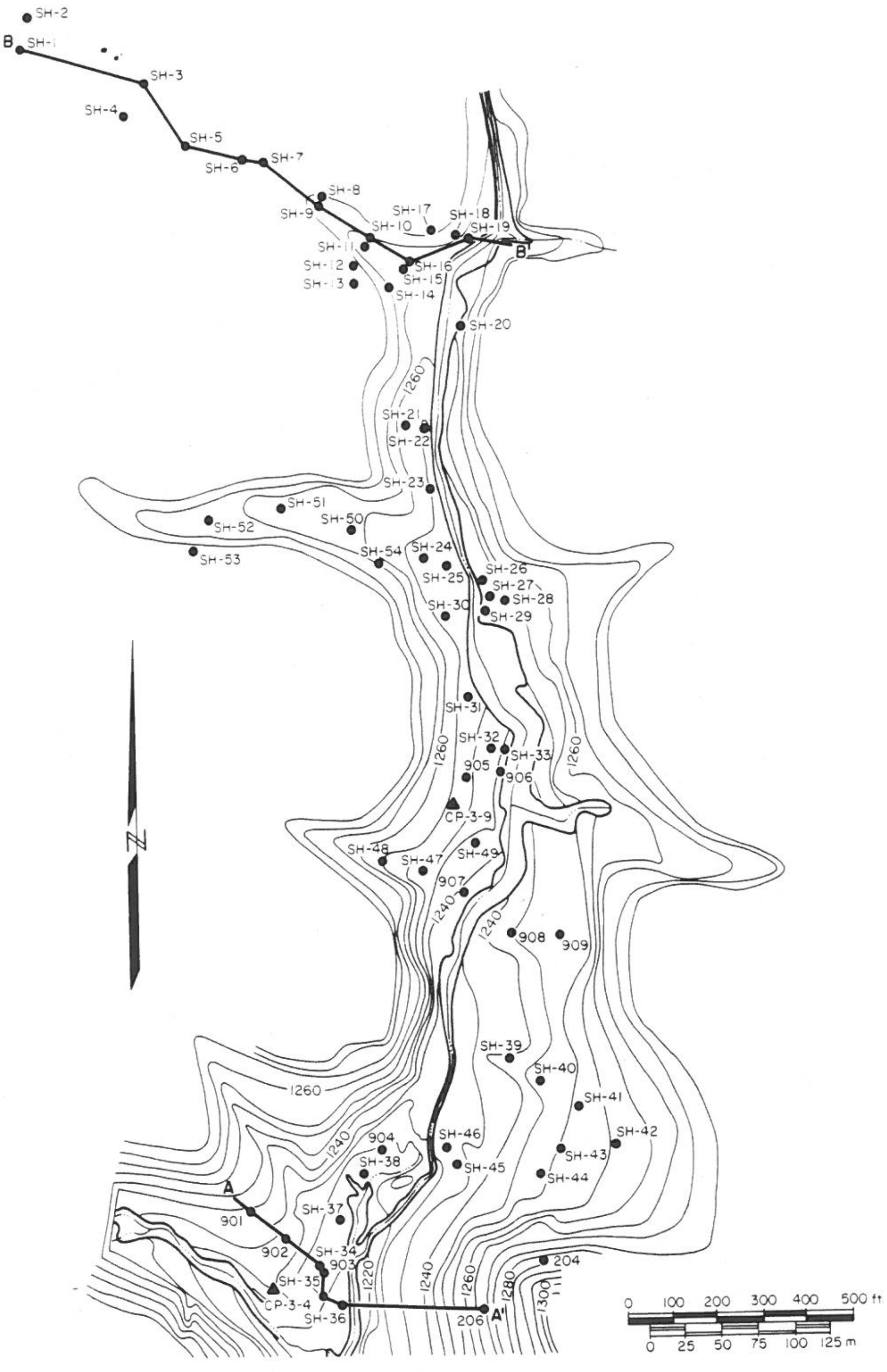


Figure 16. Topographic map of investigated portion of Smokey Hollow Watershed showing locations of drill holes and cross-sections discussed in the text. Contour interval is five feet (1.5 m).

Figure 17 presents isopachs of the Watkins and Hatcher beds of the Gunder Member, the Mullenix and Turton beds of the Roberts Creek Member, and the Camp Creek Member in the studied portion of Smokey Hollow. The distribution of the Watkins Bed indicates that the pre-Watkins gully extended along the entire mainstem of the present valley and up the three second-order tributaries along the western side of the valley (Fig. 17a). A pre-Watkins plunge pool is evident where a first-order tributary joins the mainstream from the east about midway between the southern two second-order tributaries. The patchy distribution of a soil developed in the top of the Watkins Bed indicates that post-Watkins gullying voided large areas of the Watkins Bed. The Watkins Bed is best preserved in the upper portion of first- and second-order tributaries where it was not affected by subsequent gullying.

Charcoal recovered 3.3 m (10.8 ft) below the modern land surface from within an A-C soil profile developed in the top of the Watkins Bed in the central east-flowing tributary yielded a radiocarbon date of 2,340+80 B.P. (Beta-2426). This dates the time of burial of the soil surface and not the age of the alluvium into which the paleosol developed. No other datable material was found within the Watkins Bed in Smokey Hollow.

A fluvial erosion surface (the DeForest Gap) or a paleosol surface separates the Watkins from the overlying Hatcher Bed. In Smokey Hollow the calcareous, thinly bedded, dark-colored (l0YR3/2-4/4 and 2.5Y3/2) silt loam and sandy loam Watkins Bed is easily distinguished from the less calcareous, massive, lighter-colored (l0YR3/4-4/4) silt loam Hatcher Bed. The Hatcher Bed is present throughout the drainage network in Smokey Hollow (Fig. 17b). Along the mainstem the Hatcher Bed forms a terrace standing one to three meters above younger fills (Fig. 18). Hatcher Bed underlies most of the younger alluvium along the mainstem where gullying subsequent to deposition of the Hatcher Bed removed upper portions of the unit.

Soils are developed in the top of the Hatcher Bed in all the east-flowing sidevalleys (Fig. 17b). These areas were not gullied after deposition of the Hatcher Bed. Most of the west-flowing sidevalleys are filled only with Hatcher Bed and the surface soil is developed in the upper part of the unit.

The isopach shows the location of plunge pools at the junction of some sidevalleys with the mainstem and also in the southeastern portion of the mainstem (Figs. 17 and 19). Hatcher Bed alluvium is present across the entire valley floor and merges with the base of the valley slopes in a smooth, concave profile. This relationship with the valley slope, the fact that Hatcher Bed is present throughout the drainage network, and the loess-like characteristics of the Hatcher Bed, indicate that much of the Hatcher Bed was derived from erosion of the valley slopes.

Five radiocarbon dates were collected from within the Hatcher Bed in the Smokey Hollow area. Two were collected from the mainstem in the southern part of the basin, while two others were collected in Benson Valley, a second-order tributary in the headwaters of Smokey Hollow upstream of the study area (Fig. 15). Charcoal collected two meters (6.6 ft) below the surface of a Hatcher terrace in the study area yielded a date of 2,690+90 B.P. (Beta-2381), while charcoal collected 4.1 m (13.4 ft) below the land surface within the Hatcher Bed overlain by the Mullenix Bed of the Roberts Creek Member was dated at 3,400+70 B.P. (WIS-1144). Charcoal from near the base of the Hatcher Bed in a first-order portion of Benson Valley was dated at 3,640+90 B.P. (Beta-7230), while wood from near the base of the Hatcher Bed at the junction of Benson Valley with the mainstem of Smokey Hollow yielded a radiocarbon date of 3,180+80 B.P. (Beta-5358; Thompson and Benn, 1985). Charcoal collected from a prehistoric hearth two meters (6.6 ft) below the top of the Hatcher Bed at the junction of Benson Valley with the mainstem was radiocarbon dated at 1,860+110 B.P. (Beta-5356). A previously discussed date of 2,340+80 B.P. from a soil developed in the top of the Watkins Bed in the main study area indicates that Hatcher Bed alluvium began to accumulate in that sidevalley after that date.

Gullying that preceded accumulation of the Mullenix Bed (Roberts Creek Member) was not as extensive as that which preceded accumulation of the Hatcher Bed (Fig. 17c). This gully system did not extend up first-order drainages and was restricted to the mainstem of the drainageway and sidevalley junctions. An interesting feature of the pre-Mullenix gully is that it was discontinuous between the junction of the two northernmost east-flowing tributaries. This pattern is expressed in all subsequent gully systems in the valley.

Mullenix Bed alluvium is the most extensively

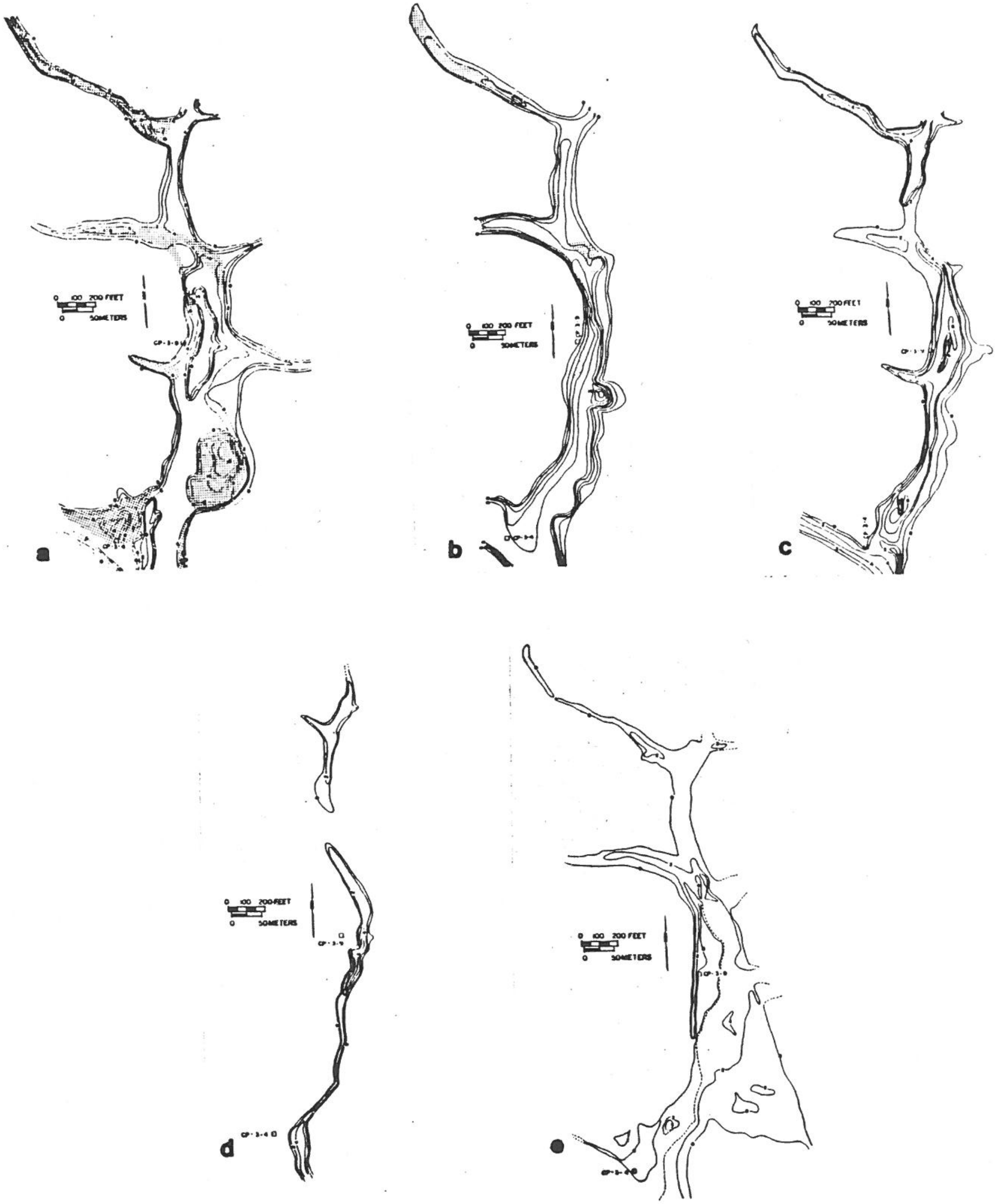


Figure 17. Isopachs of DeForest Formation litho-units in Smokey Hollow. Contour interval is two feet (0.6 m). Density pattern indicates soil developed in upper part of unit; a - Watkins Bed, b - Hatcher Bed, c - Mullenix Bed, d - Turton Bed, e - Camp Creek Member.

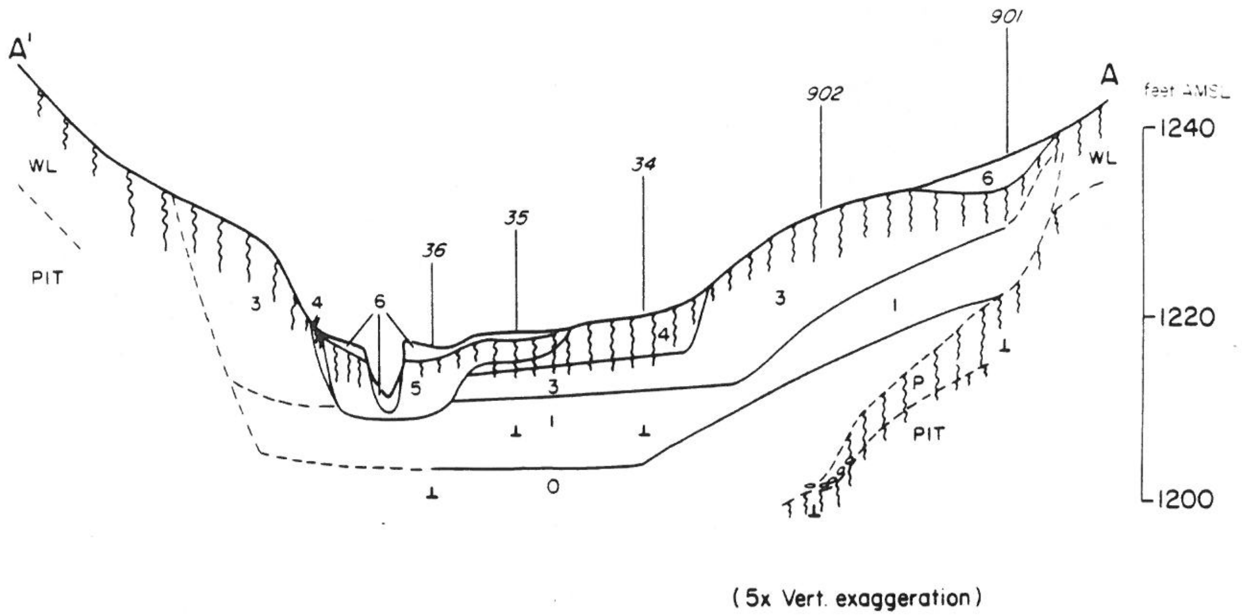


Figure 18. Cross-section A-A' in Smokey Hollow. The Hatcher Bed underlies a terrace in this part of the valley.

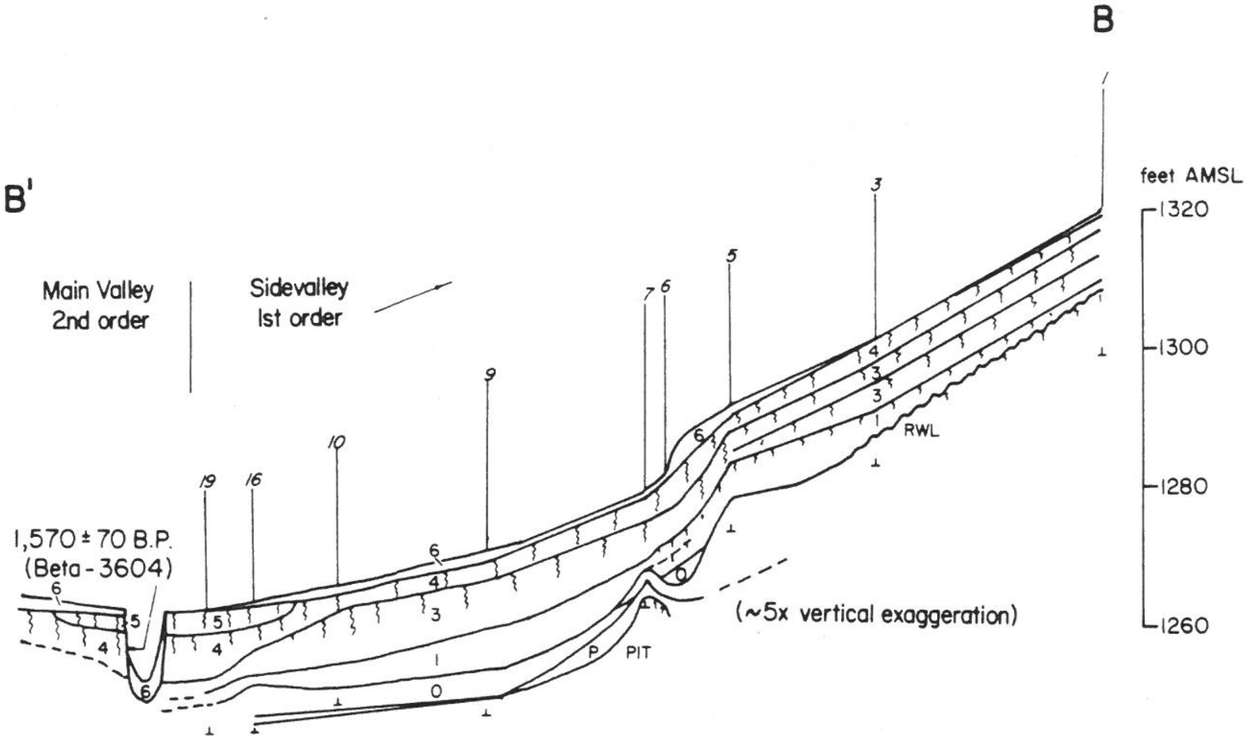


Figure 19. Cross-section B-B' in Smokey Hollow. Note soils developed in the upper part of most units in this east-flowing second-order tributary.

exposed unit of the DeForest Formation in Smokey Hollow's gully walls. Along some of the main valley floor the upper surface of the Mullenix Bed stands about one meter (3.3 ft) above the surface of the younger Turton Bed. Although pre-Mullenix gullies did not extend into sidevalleys in this area, the Mullenix Bed is found in the sidevalleys. In these areas it generally buries a paleosol developed in the top of the Hatcher Bed. Mullenix Bed is easily distinguished from older units of the formation by its low value and chroma 10YR-hue colors, medium to weak, coarse columnar structure, and the presence of stratification, including small scale (usually less than 2 m; 6.6 ft in cross-section) sandy and gravelly channel fill structures in the lower portion of the unit.

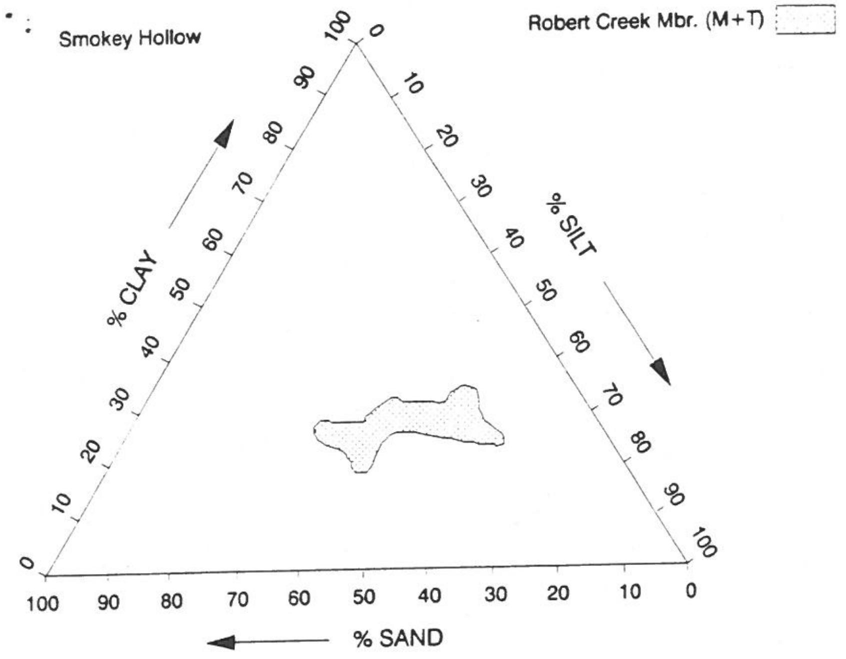
Radiometric dates from Smokey Hollow indicate that the Mullenix Bed began accumulating after 2,000 B.P. A radiocarbon date from within the Mullenix Bed at the junction of the northernmost west-flowing sidevalley (1,570 ±70 B.P.; Beta-3604; Fig. 19) and a thermoluminescence age determination on a Middle Woodland pottery vessel contained within the Mullenix Bed in Benson Valley (1,360±60 B.P.; Alpha-676; Thompson and Benn, 1983) conform to the regional chronologic framework for the Mullenix Bed in valleys of this size in western Iowa (Bettis and Thompson, 1982).

The pre-Turton gully system was discontinuous and restricted to the mainstem (Fig. 17d). Turton Bed is extensively exposed along the modern gully in Smokey Hollow. Turton Bed is inset into the Mullenix Bed, and a short, one meter (3.3 ft) high scarp usually separates the two fills where they are adjacent to each other. Texturally, the Turton Bed is very similar to the Mullenix Bed but the Turton does not exhibit the columnar structure characteristic of the Mullenix. Turton Bed is calcareous and usually contains abundant broken mollusc shells in its upper one to two meters. Lower portions of the Turton Bed are very thinly planar bedded. No radiometric dates were obtained on materials contained within the Turton Bed in Smokey Hollow.

Camp Creek Member is present within and adjacent to the present gully, on the floors of most sidevalleys, at the foot of steep slopes, and along most fence lines (Fig. 17e). This unit is the surficial deposit throughout most of the study area and is variable in lithology, depending on the source of the deposit. Commonly it is a light-colored silt loam that may be either calcareous or noncalcareous. Historic objects such as glass, barbed wire, and farm implements are incorporated within this unit, indicating its Historic age.

Surface soils are developed in the Hatcher, Mullenix, and Turton beds, and in some cases, the Camp Creek Member. In the Soil Survey of Woodbury County, Iowa the entire valley floor of Smokey Hollow in the studied reach is mapped as the Napier series, a Cumulic Hapludoll (Worster et al., 1972). This series consists of well-drained silty soils with a thick, dark surface horizon and a brown Bw horizon. They are calcareous below the solum and are developed in local alluvium. Soils within the range of the Napier series are developed on Hatcher terraces in this area. Some soils developed into the Hatcher Bed, however, have an argillic horizon, a subsurface accumulation of illuvial clay, and therefore do not fall within the range of the Napier series. Surface soils developed where the Mullenix, and Turton beds, and Camp Creek Member are the surficial deposit do not fall within the range of the Napier series because either they are not well drained, do not have a Bw horizon, are stratified in the lower part of the solum, or are buried by thick Camp Creek Member deposits. Surface soils in these areas are Typic Udifluvents, Aquic Udifluvents, and Cumulic Haplaquolls. The first two kinds of soils do not have a B horizon and are stratified below the A horizon. The last kind has a Bw horizon, an irregular decrease of organic carbon with depth, a thick, dark surface horizon and is poorly drained. No soil series used in the Soil Survey of Woodbury County encompass these areas adequately. The Kennebec series (Cumulic Hapludoll) is close, but stratification is not permitted in the lower solum of that series. In Smokey Hollow, soils developed into the Mullenix Bed have a dark brown or dark grayish brown Bw horizon, while those developed into the Turton Bed often do not have a Bw horizon. The McPaul series (Typic Udifluvent) encompasses those areas where 50 to 100 cm (20-29 in) of Camp Creek Member bury the Roberts Creek Member.

The distribution and properties of the DeForest Formation units in Smokey Hollow are typical for a valley of its size in the Western Loess Hills landform region. Texturally, the fills overlap considerably (Fig. 20). All contain less than about 40 percent sand and clay. Hatcher Member tends to be the siltiest of the units. Hatcher Bed has a bimodal textural distribution with samples from the central portion of the valley trending toward loam,



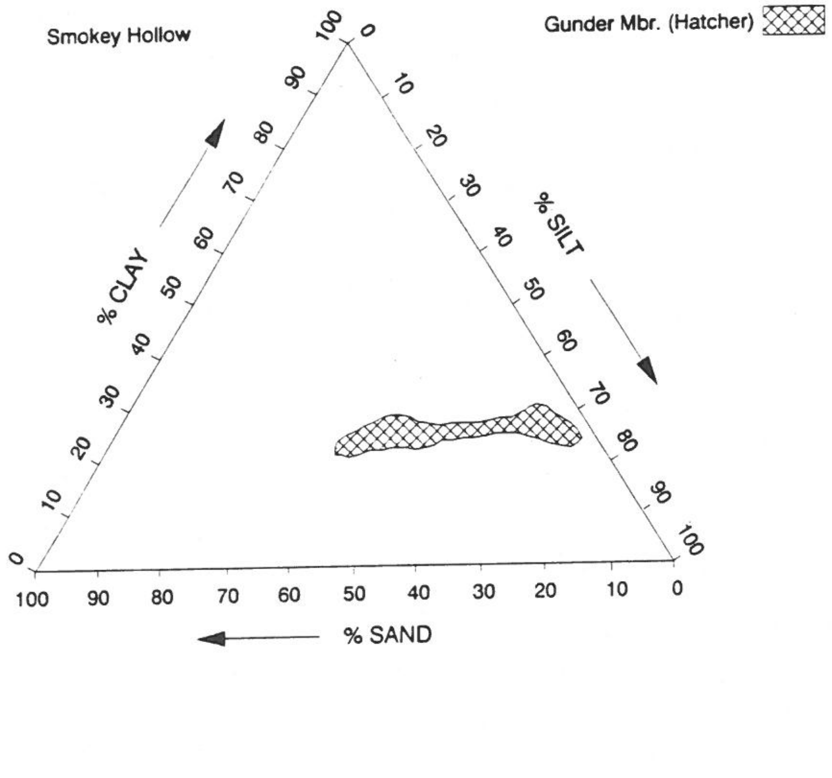


Figure 20. Plot of DeForest Formation textures from Smokey Hollow on textural triangles. Note the considerable overlap of the units' textural ranges.

sand samples from the valley margins being much siltier. This probably results from the presence of coarser channel fill (water-sorted) deposits making up the Hatcher Bed in the central part of the valley and primarily loess-derived slopewash deposits comprising the bed on the valley margins. Both the Mullenix and Turton beds of the Roberts Creek Member exhibit stratification in their lower parts and are darker-colored (less oxidized) than the Hatcher Bed. In Smokey Hollow the Watkins Bed is readily distinguished from all other units except the Mullenix Bed on the basis of lithology. Stratigraphic position and abrupt cross-cutting field contacts between these two units allowed them to be distinguished.

The major landscape elements in the Smokey Hollow area appear to have been in place by at least "Late-Sangamon" time and local relief was significantly increased by loess fall during the late Wisconsinan. The presence of late Wisconsinan alluvium beneath the Holocene fill in first- and second-order tributaries indicates that the present drainage network was established by that time.

The Holocene depositional record is most complete, but accumulation was the slowest, in upper parts of the drainage system; first- and second-order valleys. In larger parts of the system, repeated episodes of gully extension and widening removed large volumes of older deposits. Episodes of gully growth during the Holocene were concentrated in the mainstem and at the junction of second-order valleys with the third-order mainstem. These episodes decreased in intensity through time. Five distinct episodes of gully stability and valley alluviation occurred during the Holocene in Smokey Hollow. The second of these, during which the Hatcher Bed was deposited, produced the most extensive valley fill remaining today. Extensive slope erosion also contributed significant amounts of oxidized silt loam sediment to this valley fill.

Beaulieu Valley, Ross Watershed

Beaulieu Valley is located within Ross Watershed just west of the Perry Creek-Big Sioux Valley drainage divide in southwestern Plymouth County within the extreme northern portion of the Western Loess Hills (Fig. 1, B; Fig. 21). The drainage area of this study area is about 71 hectares (176 ac). Several short, steep first- and second-order valleys join the southwest-trending third-order mainstem in this area (Fig. 22). In the southern (downstream) portion of the study area a west-trending third-order tributary joins the mainstem. A deeply-incised active gully extends about half way through the study area along the mainstem. Local relief is about 76 meters (249 ft). Valley slopes are steep (14-40%) and descend to the valley floor in a series of steps. The study area has never been cultivated. Although Peoria Loess in excess of 10 m (32.9 ft) thick is present in some parts of Ross Watershed, our investigations revealed that the loess cover is generally less than 6 meters (19.7 ft) and often only two or three meters (6.60 or 9.8 ft) throughout most of the watershed. A complex array of Cretaceous bedrock and Pre-Illinoian Quaternary deposits are found beneath the Peoria Loess (Bettis and Thompson, 1982). Seventy-one holes were drilled in the Beaulieu Valley study area. Most of these terminated in Pre-Illinoian-age till or Cretaceous bedrock. Late Wisconsinan alluvium is buried beneath Holocene alluvium in the extreme upstream portion of the mainstem (Bettis and Thompson, 1982). The Watkins Bed was encountered only in the upstream portion of one west-trending sidevalley. Most likely, this unit was removed from the rest of the drainage system during development of the DeForest Gap erosion surface prior to deposition of the Hatcher Bed.

Nearly all the Holocene alluvium in the upper portion of Beaulieu Valley is the Hatcher Bed (Gunder Member). In this area the Hatcher Bed consists of massive, dark brown to yellowish brown (lOYR 3/3-5/3) calcareous, silt loam. Lower portions of the unit are usually deoxidized or reduced, are often stratified, and contain clasts of local bedrock and thin, discontinuous organic zones. The reference section for the Hatcher Bed in western Iowa is a core (75RW43) taken along the east side of Beaulieu Valley at cross-section A-A' (Figs. 22 and 23). Figure 24 presents an isopach of the Hatcher Bed in the valley. The isopach shows that the Hatcher Bed fills a relatively broad gully cut into pre-Holocene deposits. Plunge pools developed during development of the DeForest Gap are evident in several of the sidevalleys. Holes drilled across the valley at cross-section A-A' encountered stratified silt loam and gravel composed of local carbonate bedrock (Greenhorn Limestone) filling one of these paleo-plunge pools (Fig. 23).

Within this section of Beaulieu Valley, the Hatcher Bed occupies 521,844 cubic meters

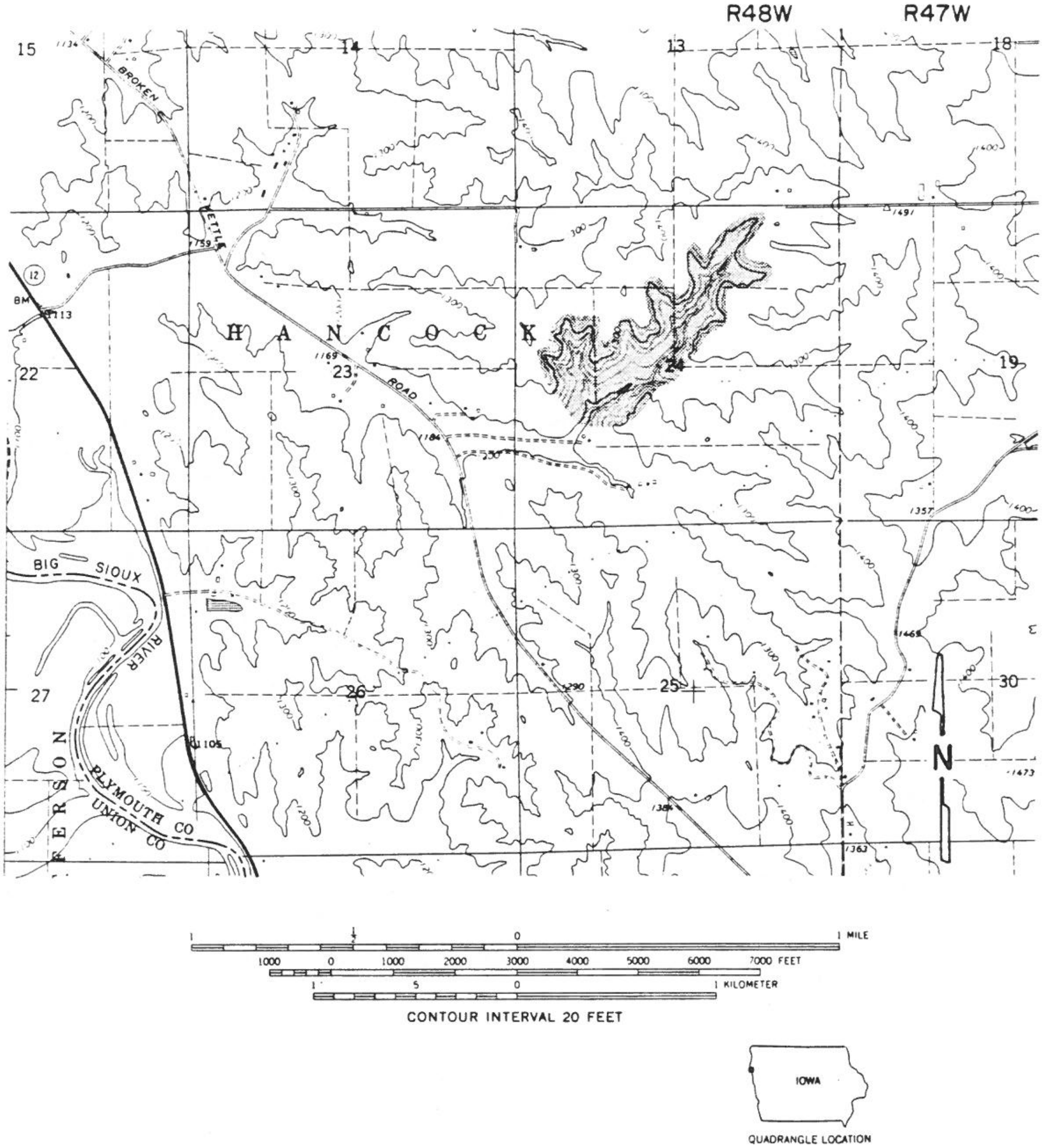


Figure 21. Topographic map showing the location of the Beaulieu Valley study area in Ross Watershed, Plymouth County. Base taken from U.S.G.S. 7.5 minute Sioux City North, Iowa quadrangle.

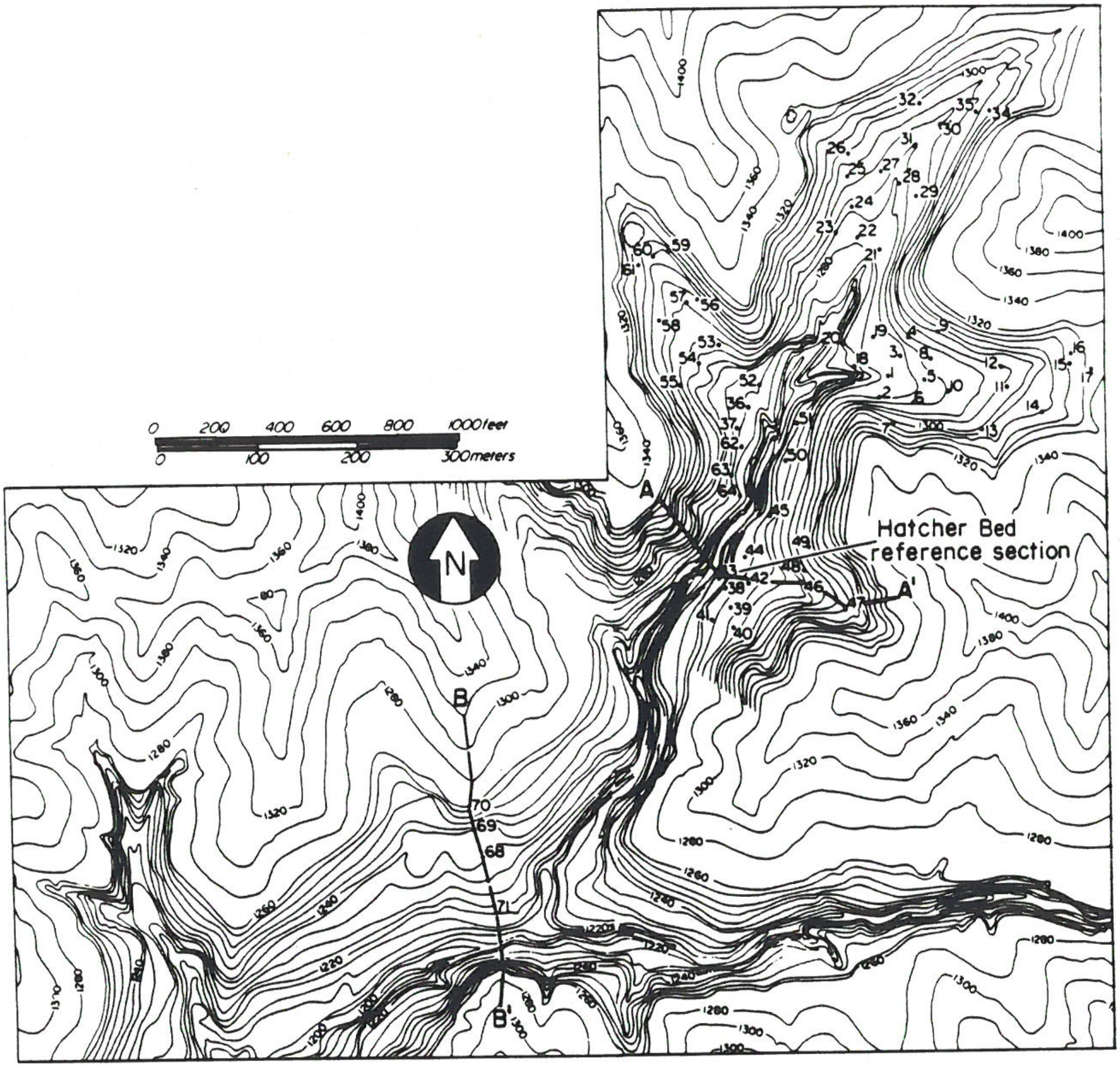


Figure 22. Topographic map of Beaulieu Valley showing location of drill holes and cross-section discussed in the text. Contour interval is four feet (1.2 m).

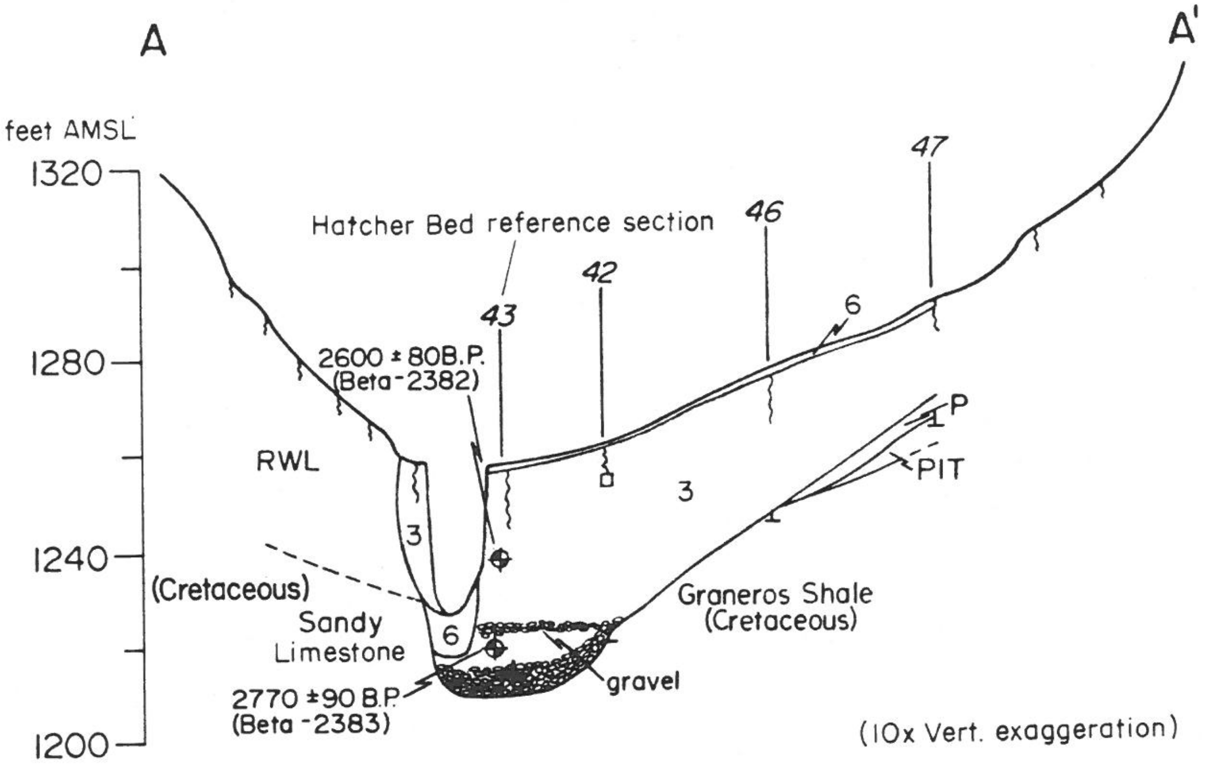


Figure 23. Cross-section A-A' in Beaulieu Valley showing stratigraphic relationships at the Hatcher Bed reference section.

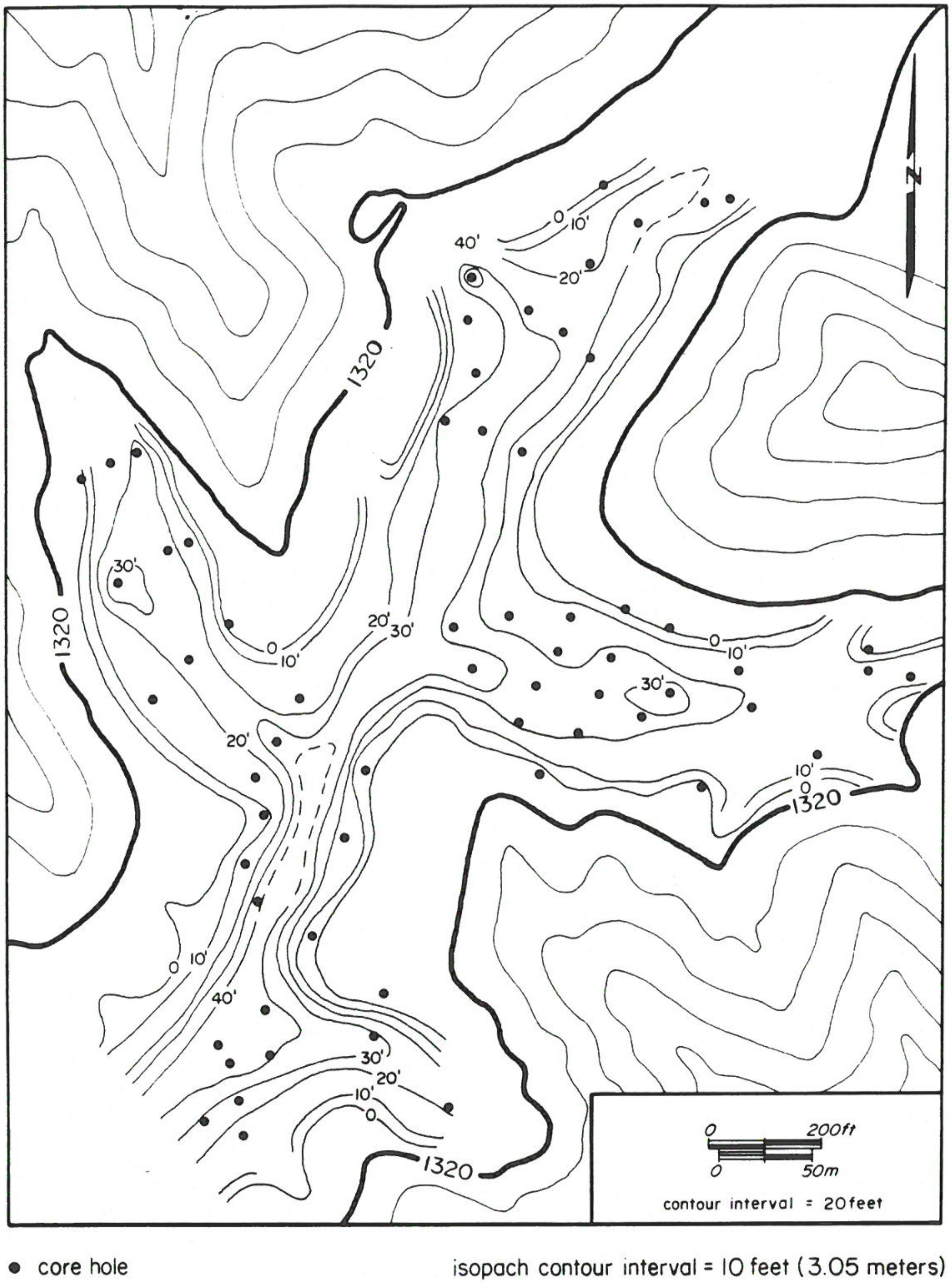


Figure 24. Isopach of the Hatcher Bed in upper portion of Beaulieu Valley. Dots are drill hole locations.

($18,421,093 ft^3$), amounting to 492,306 m^3 ($17,378,402 ft^3$) of loess (density of Hatcher Bed deposits 1.17 gm/cm; density of loess 1.24 gm/cc). This is equivalent to 68 cm (26.7 in) of loess eroded off the entire 71 hectare (176 ac) watershed. This is a minimum value since it does not consider the volume of Hatcher Bed upstream of the isopach area, nor does it account for an unknown amount of material transported out of this valley reach during accumulation of the Hatcher Bed.

Downstream of the junction of sidevalley E with the mainvalley the Hatcher Bed forms a prominent terrace along the western valley wall. The modern gully in this area is narrower and less deep than farther up the valley. The Hatcher Bed overlies eroded Pre-Illinoian till in the downstream part of Beaulieu Valley (Fig. 25).

Three radiocarbon dates were obtained from wood and charcoal enclosed in the Hatcher Bed in Beaulieu Valley. Wood collected at the base of the Hatcher Bed resting on bedrock at the mouth of sidevalley B yielded a radiocarbon date of 3,300±120 B.P. (Beta-3230). Two other dates were obtained, one on wood (lower) and another on charcoal (upper) collected from the wall of a pipe next to the reference section (Fig. 23). The lower sample (7.6m; 24.9 ft below land surface) was dated at 2,770±90 B.P. (Beta-2383), while the upper sample (4.6 m; 15.1 ft below land surface) yielded a date of 2,600±80 B.P. (Beta-2382). These dates, in conjunction with several others from Ross Watershed and elsewhere, demonstrate that in small western Iowa valleys Hatcher Bed alluviation began around 3,500 RCYBP and ended by about 2,000 RCYBP.

The Mullenix Bed of the Roberts Creek Member has a very limited distribution in the upper part of this study area. It is present in the extreme upstream portion of the main valley as well as the middle portion of sidevalley C, a southeast-flowing second-order tributary. In both these areas it is separated from underlying deposits by a fluvial erosion surface. Mullenix Bed is a very dark gray to dark brown (10YR 3/1-3/3), noneffervescent, silt loam in this portion of Beaulieu Valley. Stratification is not evident and the entire unit appears to have been pedogenically modified.

Downstream of sidevalley E the Mullenix Bed is inset into the Hatcher Bed which stands as a two to three meter (6.6-9.8 ft) high terrace above the floodplain where younger units of the formation are present (Fig. 25). In this area Mullenix Bed is buried by the Turton Bed. Over most of the floodplain Inceptisols are developed in the upper portion of the Mullenix Bed. These soils are about one meter thick (3.3 ft) and have dark grayish brown (10YR 4/2) Bw horizons. Below the solum the Mullenix Bed is massive, dark grayish brown to brown (2.5Y 4/2-10YR 4/3) calcareous, silt loam. Lenses of carbonate gravel are present in the lower portions of the unit.

Turton Bed is present only in the downstream portion of Beaulieu Valley where it buries the Mullenix Bed on the floodplain. The presence of a soil developed in the upper part of the underlying Mullenix Bed indicates that gullying did not precede deposition of the Turton Bed in this area. Turton Bed is easily separated from the Mullenix Bed since the Turton is stratified while the Mullenix is not. The buried soil in the top of the Mullenix Bed also permits easy separation of the two beds. Surface soils developed in the Turton Bed in Beaulieu Valley are Fluvents with A-C profiles and stratification below the A horizon.

The Camp Creek Member is present throughout the Beaulieu Valley study area. It is discontinuous and has a distribution similar to that in Smokey Hollow; along fence lines, at the base of steep slopes, and in and along the modern gully. In all these areas it is silt loam texture. Outside of gully areas A horizons have developed in the Camp Creek Member. Buried soils in the upper part of older members of the DeForest Formation permit easy recognition of the Camp Creek Member in these areas.

The Napier soil series is mapped on the valley floor throughout the upper portion of Beaulieu Valley (Worster and Harvey, 1976). This is the same soil series mapped on the valley floor at Smokey Hollow. Soils described during our investigations in Beaulieu Valley generally conform to the Napier series but are much thicker (average solum thickness 3-3.5 m; 9.8-11.5 ft) than the 1.5 meter (4.9 ft) solum described for the series. A soil complex, the McPaul-Napier complex, is mapped in the lower part of Beaulieu Valley. Napier-like soils are present on the Hatcher terraces in this area while McPaul-like soils are present adjacent to the modern gully where greater than 50 cm (1.6 ft) of Camp Creek Member bury the Turton Bed. No soil series used in the Soil Survey of Plymouth County adequately encompasses surface soils developed into the Turton Bed in Beaulieu Valley.

The lithology, geographic distribution, and

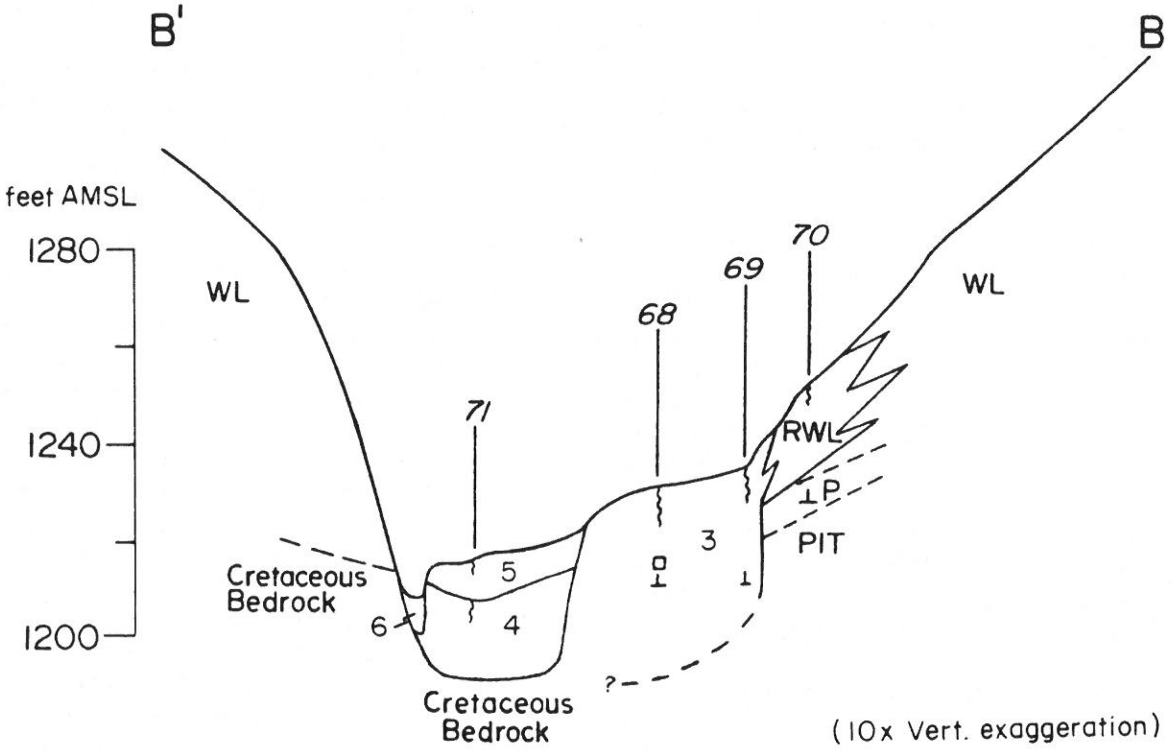


Figure 25. Cross-section B-B' across the lower portion of Beaulieu Valley. The Hatcher Bed underlies a prominent terrace in this part of the valley.

stratigraphic relationships of DeForest Formation deposits in Beaulieu Valley are very similar to those in Smokey Hollow. Hatcher Bed occupies a greater proportion of the Beaulieu Valley fill, but the drainage area of Beaulieu Valley is about half that of Smokey Hollow, and therefore Beaulieu Valley is much higher in the drainage network than the Smokey Hollow study area. In both areas the depositional record is most complete in first- and second-order valleys. The magnitude of gully growth episodes appears to have decreased through time, although the modern gully system is more extensive then either the pre-Mullenix or pre-Turton gully systems.

Figure 26 presents textural triangles showing the textural range of the DeForest Formation units in all the Ross Watershed study areas (see Bettis and Thompson, 1982 for detailed descriptions of the additional areas). Overall, individual units are siltier in Ross Watershed than in the Smokey Hollow study area. This is probably a result of the presence of more Pre-Illinoian deposits, which contain abundant sand and clay, in the Smokey Hollow area in contrast to the relatively sand-free Cretaceous Dakota Formation siltstones which dominate the sub-DeForest Formation deposits in Ross Watershed. The sandy "tail" on the plots of the Watkins and Hatcher beds is produced by samples collected from channel fill areas at the base of the unit. Watkins Bed tends to be more clayey than the rest of the formation in Ross Watershed. Texturally, the Mullenix Bed and Camp Creek Member are indistinguishable from the bulk of the Hatcher Bed.

Middle Silver Creek

Middle Silver Creek is a major tributary of the West Nishnabotna River located in Shelby, Pottawattamie and Mills counties in southwestern Iowa (Fig. 1). This valley passes through a transition area between the Western Loess Hills and the Southern Iowa Drift Plain landform regions. The study area is along the east bank of Middle Silver Creek (NC 1/4 sec. 13, T74N, R42W) in southcentral Pottawattamie County approximately 2 km (1.3 mi) south-southwest of the town of Treynor (Fig. 27). Middle Silver Creek has a drainage area of approximately 161 km^2 (62 mi^2) at the study area. In most years Middle Silver Creek flows year-round, although flow can be very low during the late summer. The present stream occupies a channel incised 4 to 5 meters (13.1-16.4 ft) into the floodplain. The valley ranges from 0.5 to 0.8 km (0.3-0.5 mi) in width in this area. Valley wall slopes are relatively steep (approximately 12-15%) and ascend to the upland by several steps. A large tributary, Little Silver Creek joins Middle Silver Creek about .8 km (.5 mi) upstream (north) of the study area. Two smaller east-trending tributaries join the main valley within the study area while a southwest-trending sidevalley enters the main valley at the southern end of the study area. Peoria Loess is the surficial deposit over the majority of the upland and valley slopes. It attains a maximum thickness of about 10 meters (32.8 ft) on uplands in this area (Allen, 1971). Currently, the study area is partially in row crops and partially in pasture. The entire area has been cultivated in the recent past.

Fourteen holes were drilled in the study area. A few of the holes penetrated the entire alluvial sequence and terminated in Pre-Illinoian till. In addition, stream bank exposures were described and sampled along Middle Silver Creek and at the junction of a southwest-flowing tributary with the main valley in the southern part of the study area.

The Gunder Member (Watkins Bed) lies directly above Pre-Illinoian till and is buried by younger DeForest Formation alluvium in this area (Fig. 28). An angular unconformity overlain by a gravel lag marks the contact between the till and alluvium. In this area the Watkins Bed is olive gray to dark greenish gray (5Y4/1 - 5G4/1) stratified, calcareous, heavy silt loam. A buried soil is present in the top of the Watkins Bed throughout the study area. The soil is thin (< 35 cm; 13.8 in), has a Bw horizon and exhibits colors which indicate that it developed on a poorly-drained landscape position. The presence of a buried soil developed in the top of the Watkins Bed where it is overlain by the Hatcher Bed indicates that entrenchment did not precede deposition of the Hatcher Bed in the area of the cross-section. It is possible that pre-Hatcher gullying occurred on the opposite (west) side of the present channel location but that area was not investigated.

Two radiocarbon dates were obtained on material collected from the Watkins Bed in this area. Organic materials (leaves, twigs, etc.) collected from the A soil horizon at the top of the Watkins Bed in hole 78TR5 were dated at 10,000±230 B.P. (Beta-5182). Charcoal collected from within the Watkins Bed in a stream exposure

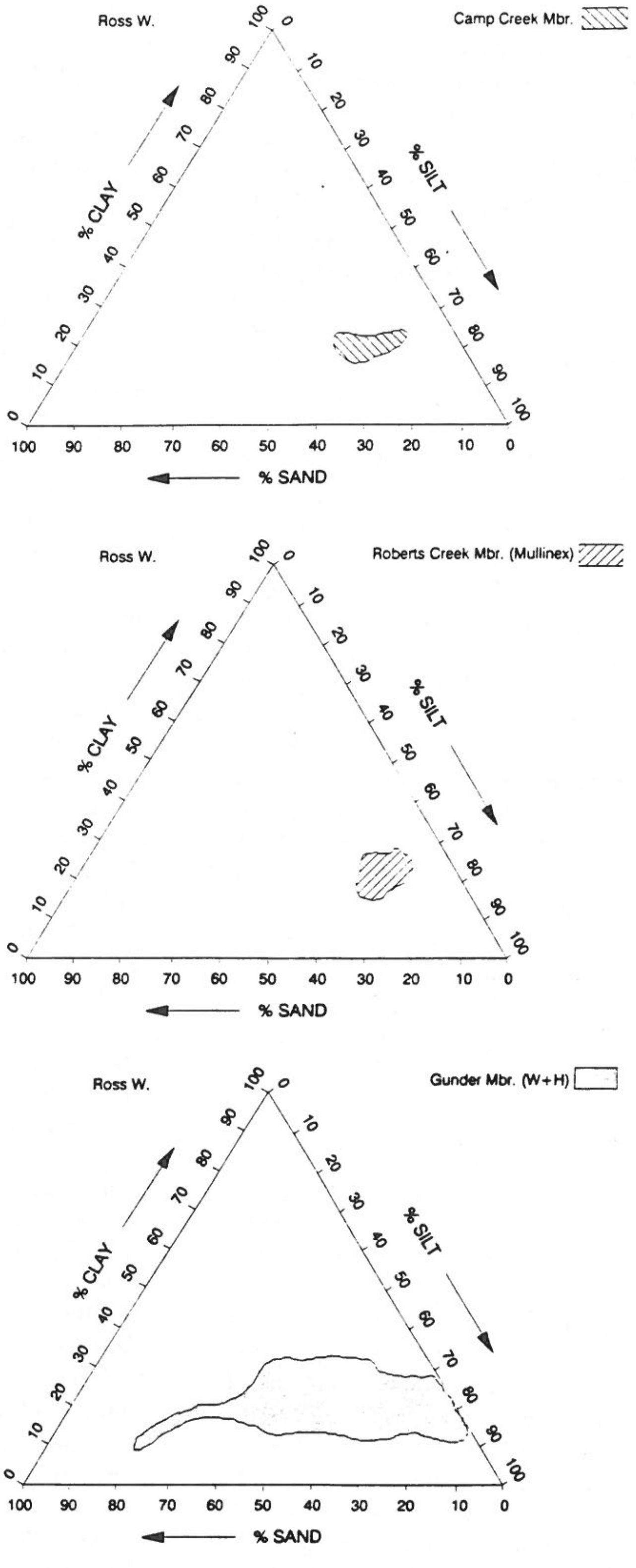


Figure 26. Plot of Ross Watershed DeForest Formation textures on textural triangles. Note overlap of the ranges of the units.

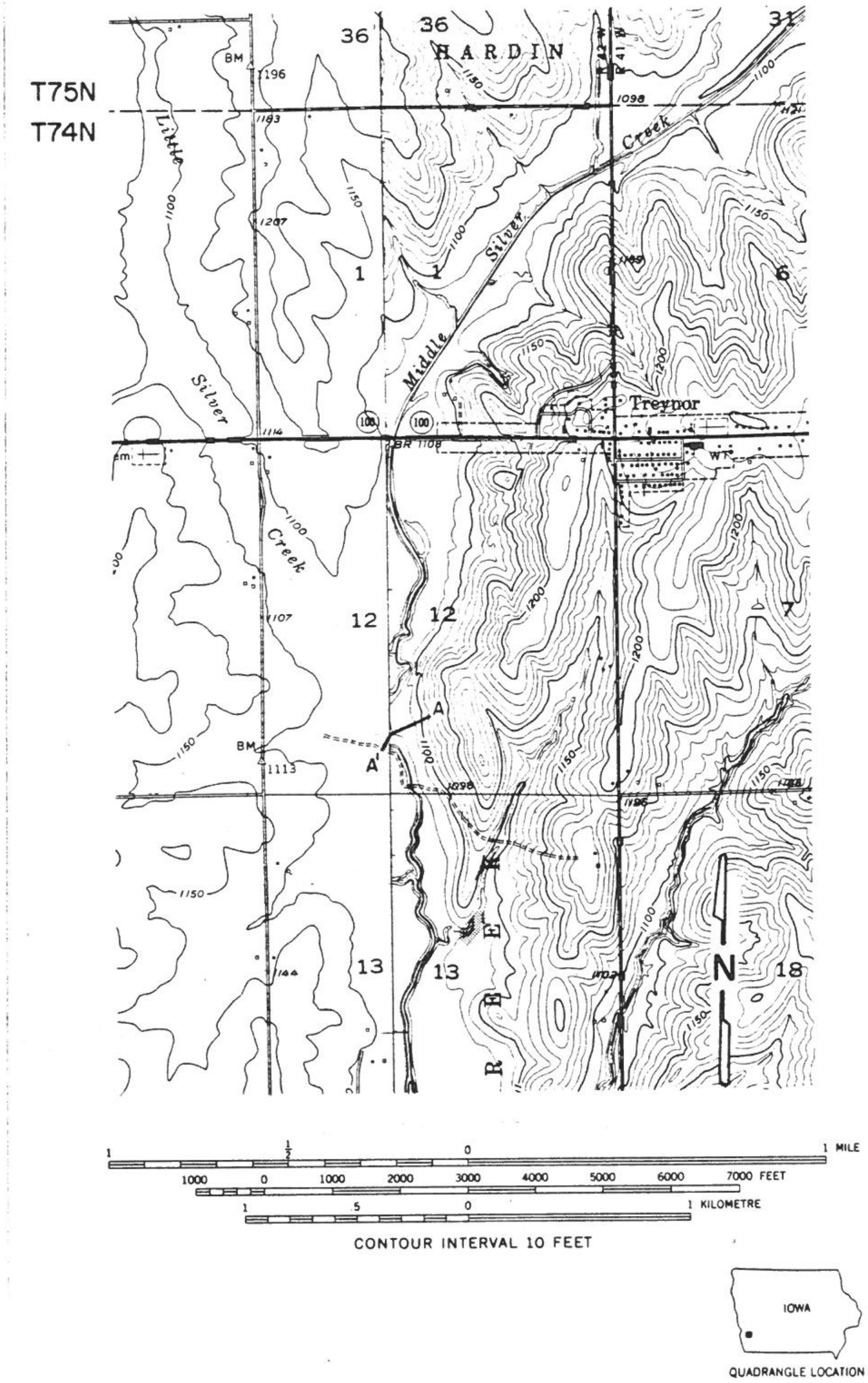


Figure 27. Topographic map showing the location of the Middle Silver Creek study area in southern Pottawattamie County. Base taken from U.S.G.S. 7.5 minute Treynor and Mineola, Iowa quadrangles.

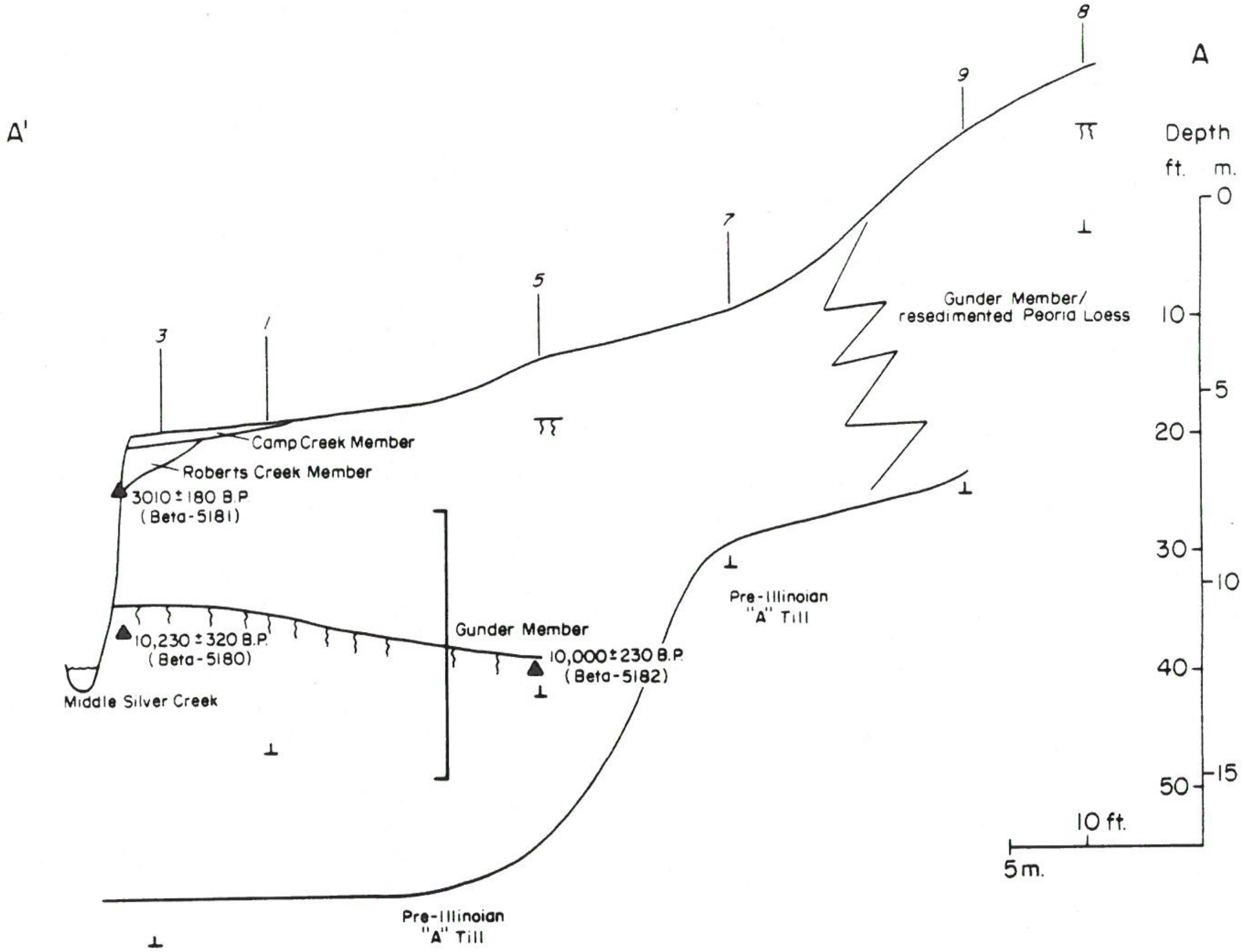


Figure 28. Cross-section along the east side of Middle Silver Creek showing the distribution of DeForest Formation alluvial fills and radiocarbon dates described in the text.

along Middle Silver Creek yielded a date of 10,230±320 B.P. (Beta-5180) (Fig. 28). Both dates are approximately 2,000 years older than dates from equivalent stratigraphic positions in small western Iowa valleys. This suggests that accumulation of a given unit of the DeForest Formation began significantly earlier in large valleys (lower portions of the drainage network). This, in turn, indicates that entrenchment preceding the gully fill episodes represented by the units was initiated in large valleys and then proceeded into upper parts of the system.

The Hatcher Bed of the Gunder Member buries the Watkins Bed throughout the study area and extends to the footslope position along the valley wall. It is the dominant surficial deposit along this valley reach. Within the area the Hatcher Bed is a dark brown to grayish brown (lOYR3/3 -2.5Y5/2) massive, weakly calcareous to neutral silt loam. It ranges up to 8 meters (26.2 ft) in thickness, has an unconformable contact (soil) with the Watkins Bed, and is separated from Pre-Illinoian till in the footslope position by an angular unconformity (erosion surface) with a lag of eroded carbonate concretions resting on the contact. A thick Mollisol (Cumulic Hapludoll) is developed in the upper part of the Hatcher Bed. This soil would probably be mapped as the Kennebec series. At hole 5 a buried soil was recorded within the upper portion of the Hatcher Bed. This is not an atypical occurrence and, it seems likely that in many areas the thick surface soils noted in the Hatcher Bed may in fact be more than one soil now welded together into a single discernable solum.

The Roberts Creek Member (Mullenix Bed) is present within a former meander belt, now evident as an inset terrace, along the modern incised channel of Middle Silver Creek. In the study area a remnant of this former meander belt is evident as a lower surface inset approximately 60 cm (23.6 in) below adjacent areas where the Hatcher Bed is the surficial deposit. The Mullenix Bed is a dark gray to very dark gray (lOYR 4/1-3/1) massive, calcareous, light silty-clay loam. The entire unit has been pedogenically altered, probably because of a relatively slow accumulation rate. It exhibits coarse columnar structure in the lower portion of the solum. The contact with underlying units is an angular unconformity (fluvial erosion surface).

Wood and organics collected from the base of the Mullenix Bed in a stream exposure within the study area yielded a radiocarbon date of 3,010±80 B.P. (Beta-5181). This date is 1,200 years older than the time of commencement of Mullenix Bed accumulation in small western Iowa valleys. Previously discussed dates from the upper part of the Watkins Bed also indicated that accumulation of a given DeForest Formation bed began significantly earlier in this large valley than in smaller valleys such as Smokey Hollow.

The Turton Bed is present intermittently along the incised channel of Middle Silver Creek. It was not encountered in holes drilled in the project area but was observed and described in the southern part of the area where the incised channel of the southwest-trending tributary joins Middle Silver Creek (Fig. 27). In this area the Turton Bed is present as a thin strip (< 8 m; 26.3 ft wide) paralleling the modern gully. Here the Turton Bed is grayish brown (lOYR 3/1 to 5/2) noncalcareous to weakly calcareous, stratified silt loam with a few medium and fine sand interbeds. The lower part of the unit is usually gleyed. An angular unconformity separates the Turton Bed from older units. Wood collected from the base of the Turton Bed in this area was radiocarbon dated at 1,300±80 B.P. (Beta-5179). Just as with other dates obtained in large valley areas, this date from the Turton Bed is significantly older than those collected from similar stratigraphic positions in small valleys.

Soils developed in the upper part of the Mullenix and Turton beds are Cumulic Hapludolls or Cumulic Haplaquolls. These soils have thick, dark surface horizons and have irregular decreases of organic carbon with depth. The former are moderately well drained while the latter are poorly drained.

Camp Creek Member is present adjacent to the present channel of Middle Silver Creek and its tributaries throughout the study area. In most places the thickness of the unit is less than 30 cm (11.8 in) but thicker sections were recorded in bank exposures and along the southwest-trending tributary. Where the unit is more than one meter (3.3 ft) thick it consists of very dark grayish brown and brown (lOYR 3/2 and 3/3) noncalcareous, stratified silt loam. The unit is massive where it is less than one meter (3.3 ft) thick. An erosional unconformity or a buried soil surface mark the contact of the Camp Creek Member with underlying units.

Distribution and geometry of the units, lithologic characteristics, and stratigraphic relationships of the DeForest Formation units in the large valley at Middle Silver Creek are very similar to those in small valleys elsewhere in the Western Loess Hills landform region. Figure 29 presents textural data for this study area plotted on a textural triangle. Samples of the Mullenix and Turton beds, and the Camp Creek Member were collected from the junction of the southwest-trending tributary with Middle Silver Creek. The Hatcher Bed in this area exhibits a textural distribution similar to that in Smokey Hollow. In both areas pre-Hatcher entrenchment cut into older Quaternary deposits containing more sand and clay than is present in the Peoria Loess forming the surficial deposit. The result is alluvium containing more sand and clay than is typical of the Hatcher Bed in areas such as Ross Watershed where the materials into which the pre-Hatcher entrenchment occurred are not as sandy and clayey.

The Roberts Creek and Camp Creek members sampled at the tributary junction contain less sand than those in Smokey Hollow or Ross Watershed. This phenomenon probably results form the fact that these deposits are dominated by tributary valley alluvium derived from erosion of Peoria Loess and/or Hatcher Bed alluvium that was derived primarily from erosion of Peoria Loess.

Radiocarbon ages of the Middle Silver Creek fills are significantly older than the same fills in small valleys. These age relationships indicate that gullying (downcutting) episodes, were initiated in lower parts of the drainage network and proceeded into upper parts of the system through time. The named units of the formation, therefore, are lithostratigraphic units but not chronostratigraphic units (North American Commission on Stratigraphic Nomenclature, 1983).

Westside Subwatershed

Westside subwatershed is located in northwestern Ida and northeastern Woodbury counties on the eastern side of the Little Sioux River valley in a transition area between the Northwest Iowa Plains and the Southern Iowa Drift Plain (Fig. 1). The study area in this subwatershed is located in northwestern Ida County 2.8 km (1.75 mi) east of the town of Corretionville (Fig. 30). The study area is located along an unnamed southwest-flowing third-order tributary of Bacon Creek (SE 1/4 sec. 30 and NE 1/4 sec. 31 T89N R41W; Fig. 31). Drainage area at the study area is 230 ha (568 ac). Several short, steep first-and second-order valleys join the mainstem in this area (Fig. 30). Two second-order valleys join in the northern part of the study area to form the mainstem. The stream occupying the mainstem is located in a 1.2 to 1.8 m (4-6 ft) deep incised channel. Local relief in this drainage basin is approximately 61 m (200 ft). Valley slopes range from 10 to 15% and descend to the valley floor in a series of steps. Slopes in the southern half of the drainage basin are less steep than those in the northern half of the basin.

A complex mosaic of Quaternary deposits crop out on the valley slopes. In the northern half of the basin Peoria Loess and interbedded eolian sand (Parkland Sand) are the surficial deposits. These deposits exceed 7 m (23 ft) in thickness. Pre-Illinoian till crops out on the lower portions of slopes in the southern half of the basin. Peoria Loess and Parkland Sand are the surficial deposits farther up the slopes in this area. Pedisediment, ranging in texture from loam to gravel, rests on the surface of the Pre-Illinoian till. This pedisediment does not have a paleosol developed into it which suggests that it is probably Wisconsinan in age. The pedisediment may have accumulated in lower portions of the landscape during cutting of the Iowan Erosion Surface.

In the southern part of the basin a gravelly "terrace" occupies the eastern part of the valley. This feature is elevated approximately 2 meters (6.6 ft) above adjacent Holocene-age valley fills. We were not able to penetrate the gravel making up this "terrace" and therefore we do not know its thickness or its relationship with underlying units. The "terrace" lacks a loess cover and is therefore very late Wisconsinan or Holocene in age. Deposits making up this landform may have accumulated during the later stages of cutting of the Iowan Erosion Surface. These deposits may be correlative with the pedisediment resting on the till surface farther up the valley slopes.

Thirty-three holes were drilled in this project area. About half of these penetrated the entire Holocene sequence. Hole 47W-5 was sampled for laboratory analysis.

Late Wisconsinan alluvium is buried beneath the Holocene alluvium throughout most of the project area. No radiocarbon samples were collected during this investigation but macrofossils of coniferous trees (needles) were noted in several of the cores removed from the late Wisconsinan alluvium. This alluvium ranges in texture from silt

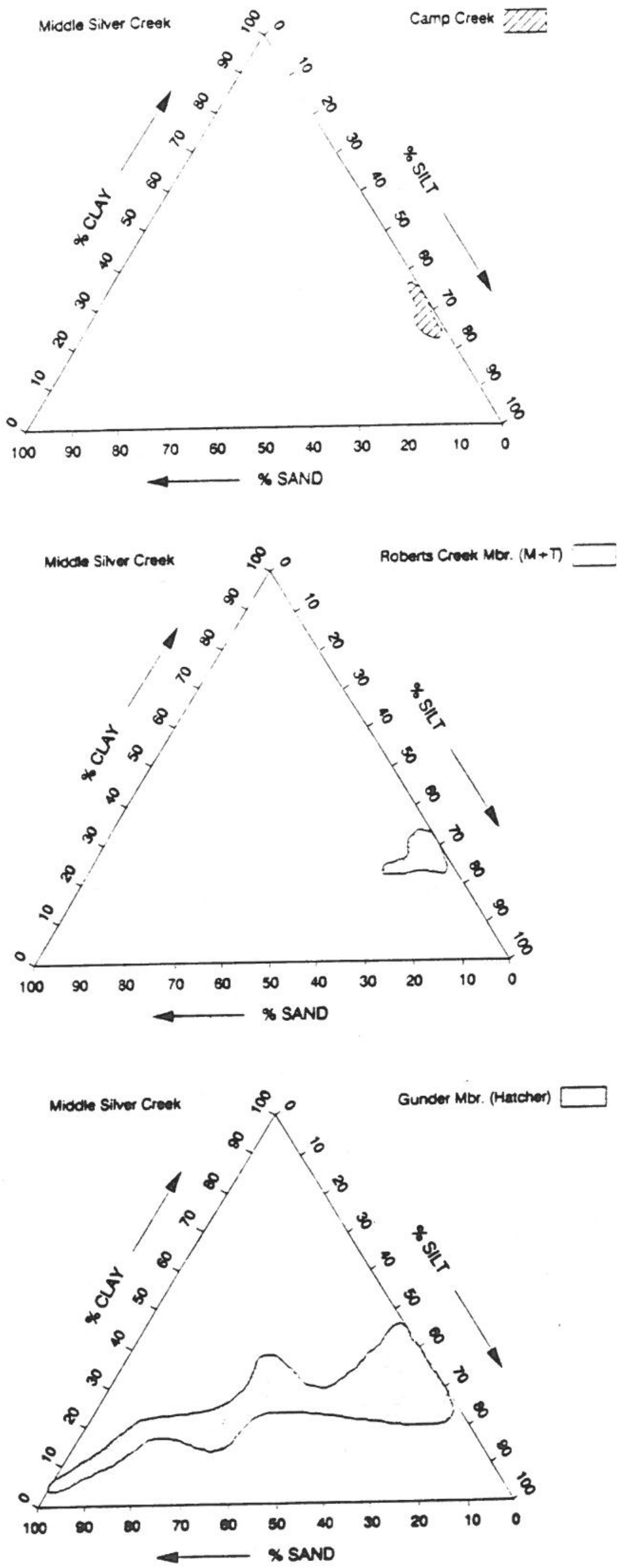


Figure 29. Textural triangle plots of DeForest Formation textures from the Middle Silver Creek Study area. Note the wide range of Gunder Member textures in this large valley.

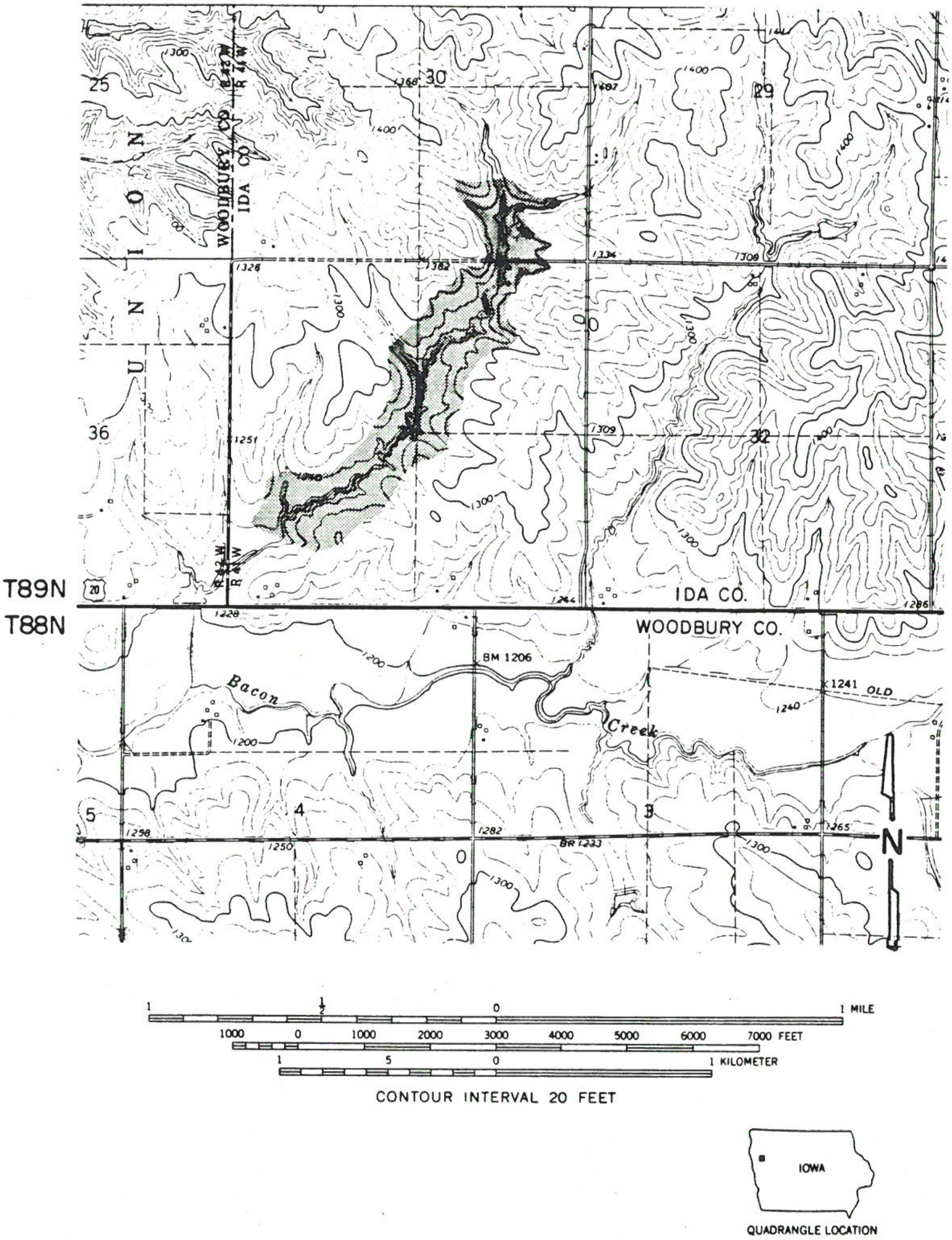


Figure 30. Topographic map showing the location of the Westside Subwatershed study area in Ida and Woodbury counties. Base taken from U.S.G.S. 7.5 minute Cushing, Iowa quadrangle.

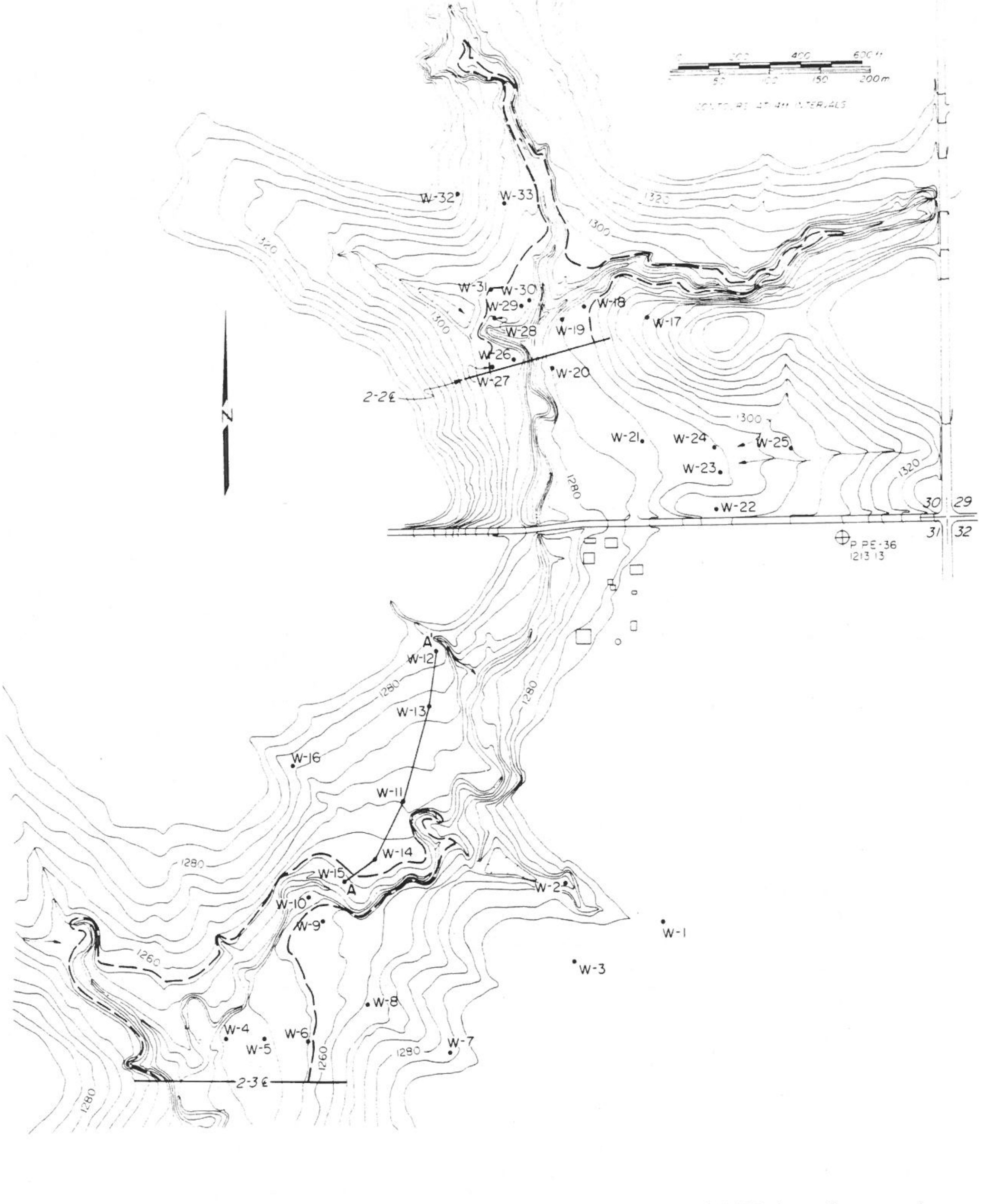


Figure 31. Topographic map of the Westside study area showing the location of drill holes and cross-sections discussed in the text. Contour interval is four feet (1.2 m).

loam to silty clay loam, is highly calcareous, and is usually gleyed (dark gray to dark greenish gray--5Y4/1-5G4/1). A fluvial erosion surface, marked by an abrupt color and textural change, separates the late Wisconsinan alluvium from overlying Holocene-age alluvium. A gravel lag occasionally rests on top of the late Wisconsinan alluvium.

The Watkins Bed was encountered buried beneath younger DeForest Formation alluvium throughout the project area. In this area the Watkins Bed is usually a calcareous, stratified, pebbly loam or silty clay loam which exhibits 2.5Y or 5N hue colors. A fluvial erosion surface (the DeForest Gap) separates the Watkins Bed from overlying, younger units of the formation throughout the mainstem. In upper portions of first-order tributaries a paleosol with an A-Bw-C soil profile is usually developed in the top of the Watkins Bed. In these areas entrenchment did not precede deposition of younger units of the formation.

Hatcher Bed is intermittently present throughout the valley in the study area. Its distribution is patchy as a result of erosion during later downcutting episodes. In contrast to the distribution of this unit in the previously discussed study areas, the Hatcher Bed only crops out in a relatively narrow band along the footslope and toeslope in the Westside study area. Elsewhere in this valley it is buried by younger DeForest Formation alluvium.

Small alluvial fans are present where some first-order tributaries join the mainstem. Lower portions of these features are composed of the Hatcher Bed. Stratigraphic relationships along cross-section C-C' indicate that these fans began accumulating during the period of time the Watkins Bed was being deposited, and their deposition continued into the time that the Hatcher Bed was accumulating elsewhere in this valley (Fig. 32). Paleosols with A-Bw-C profiles are developed in the upper part of the Hatcher Bed comprising the fans. These soils are buried by the Roberts Creek Member (Mullenix Bed).

In this project area Hatcher Bed of the Gunder Member is a noncalcareous, massive silt loam to silty clay loam that ranges in color from very dark grayish brown to brown or grayish brown to light olive brown (10YR3/2-4/3; 2.5Y5/2-5/4). Occasionally the lower few decimeters of the unit are stratified and contain sandy loam beds.

Where the Hatcher Bed is at the land surface Mollisols with A-Bt-C soil profiles are developed into the upper part of the unit. A buried soil developed in the upper part of the Hatcher Bed where it is overlain by younger alluvium was only encountered in a few locations outside of alluvial fan areas. In these areas the buried soil exibited an A-Bw-C soil profile.

The Mullenix Bed of the Roberts Creek Member occupies the greatest volume of the Holocene alluvium in the Westside area. It is found along the mainstem and second-order tributaries. Its distribution in first-order valleys is patchy. In all first- and most second-order valleys entrenchment did not precede deposition of the Mullenix Bed and the unit buries soils developed in the upper part of underlying units.

In the Westside area the Mullenix Bed is a very dark grayish brown to brown (10YR 3/2-4/3) loam to clay loam. The unit is usually noncalcareous in its upper one to two meters and moderately calcareous below that depth. Lower portions of the unit are stratified and often contain lenses and troughs of medium to fine sand and gravel.

Soils are developed in the upper part of the Mullenix Bed where it has not been truncated by later entrenchment. Many of these are surface soils. These soils usually have A-Bw-C profiles with a mollic epipedon and a thick dark-colored Bw horizon. Most of these soils would probably fall within the range of the Kennebec soil series (Cumulic Hapludoll) but are thicker and have darker B horizons than is typical for the series.

The Turton Bed of the Roberts Creek Member is discontinuous in its distribution in the Westside area. It is found in narrow patches along the modern entrenched stream. Most of the original Turton Bed deposit was removed by Historic stream activity.

Turton Bed is a very dark gray to very dark grayish brown (10YR 3/1-3/2) noneffervescent to weakly effervescent loam. The entire unit has been pedogenically altered. Thick dark-colored soils with A-C or A-Bw-C profiles are developed into this bed. These soils would probably fall within the range of the Kennebec soil series.

Camp Creek Member is present throughout the southern half of this project area. In this area it buries all older alluvium. This member has a patchy distribution in the northern half of the watershed where it is restricted to a strip along the mainstem and along fence lines.

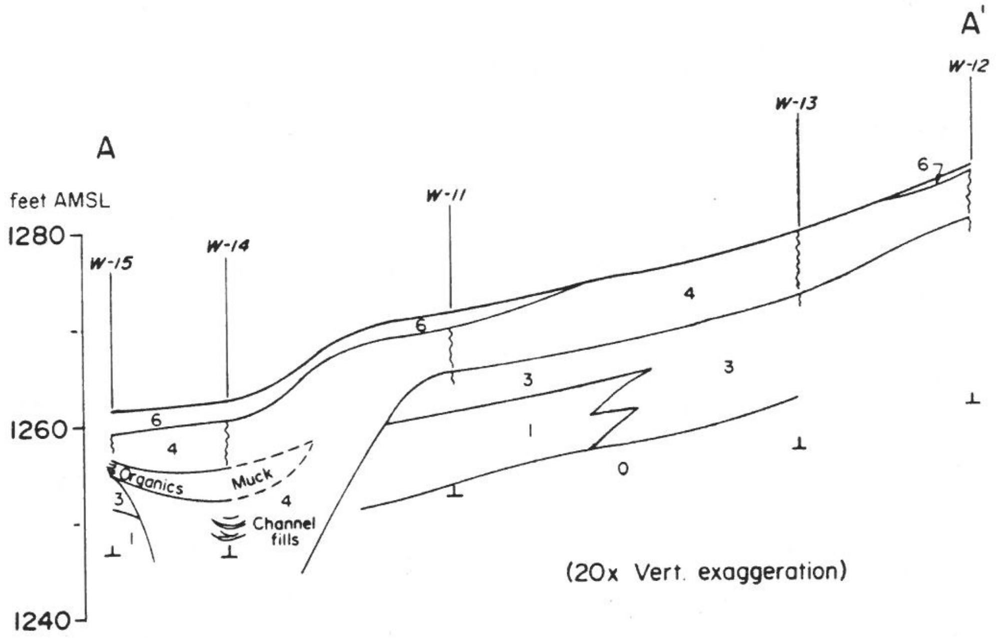


Figure 32. Cross-section A-A' in the Westside study area. Note that the Hatcher Bed grades laterally into the Watkins Bed between holes 13 and 11.

Throughout the Westside area the Camp Creek Member is a very dark grayish brown, brown, or grayish brown (l0YR 3/2, 3/3, 5/2) massive silt loam to sandy loam. Depending on the source of the alluvium, it ranges from noneffervescent to moderate in effervescence. Historic objects are often encountered within this unit.

Stratigraphic relationships among DeForest Formation units in the Westside area are the same as they were in the previously discussed study areas. The depositional record is most complete in upper portions of the drainage network. Throughout the mainstem area a fluvial erosion surface (the DeForest Gap) separates the Watkins Bed from the overlying Hatcher Bed. The Hatcher Bed is not as widely distributed in the Westside area as it is in the previously discussed areas. This is probably a result of more extensive pre-Mullenix entrenchment and lateral stream erosion in the Westside area compared with that in the thicker loess area. In the Westside area the Mullenix Bed is the most voluminous of the DeForest Formation alluvial fills. This is in sharp contrast to the Western Loess Hills area where the Hatcher Bed occupies the greatest volume of the Holocene valley fill.

Mill-Picayune Creek Watershed

This study area is located in extreme southern Crawford County, northeastern Harrison County, and northwestern Shelby County on the east side of the Boyer River valley in a transition between the Western Loess Hills and the Southern Iowa Drift Plain (Fig. 1). The Thompson and Magnolia watershed study areas of Daniels and Jordan (1966), where the DeForest Formation was originally described, are located approximately 16 km (10 mi) southeast of this area. Two proposed structure sites were investigated in this watershed (M-24-17 and P-90-1). Only the investigations at site M-24-17 will be discussed in this report.

The study area is located in extreme northern Shelby County along a south-trending third-order tributary of Mill Creek (E 1/2 sec. 3 T8lN R40W; Fig. 33). Drainage area at the proposed structure site's centerline is 92 ha (227 ac). Several first-order tributaries join the mainstem in the study area. The mainstem is occupied by a 3-4 m wide, 2-3 m deep gully. This gully meanders through the study area (Fig. 34). Small alluvial fans are located where the first-order tributaries descend to the main valley floor. Local relief in the watershed is approximately 49 meters (160 ft). Valley slopes are relatively steep (10-15%) and descend to the valley floor in a series of steps. Within the study area the valley is noticeably asymmetrical with west-facing slopes gentler and longer than east-facing slopes (Fig. 34).

Peoria Loess is the surficial deposit on uplands and valley slopes. Loess thickness on uplands in this area ranges from 10.6 to 13.7 meters (35 to 45 ft) (Ruhe et al., 1971; Fig. 2). The Pisgah Formation with the Farmdale Soil developed in its upper part is buried beneath the Peoria Loess. In some parts of Mill-Picayune Watershed the Pisgah Formation descends down the valley slopes toward the present valley floor. This indicates that these valleys had attained essentially their present form prior to deposition of the Pisgah Formation.

In both study areas loamy and sandy loam Late-Sangamon alluvium is inset into Pre-Illinoian till and buried by Wisconsinan and Holocene deposits. This alluvium has been inferred to be pre-Wisconsinan in age on the basis of stratigraphic relationships (Ruhe et al., 1967; Daniels and Jordan, 1966; Ruhe, 1969). As discussed previously, Late-Sangamon alluvium probably accumulated during cutting of Late-Sangamon erosion surfaces on the valley slopes. The presence of Late-Sangamon alluvium in small valleys in this watershed indicates that these valleys were in existence prior to deposition of the Pisgah Formation. This is consistent with observations elsewhere in Iowa (Ruhe et al., 1967; Hallberg et al., 1978; Bettis and Littke, 1987). Extensive loess-mantled Late-Sangamon terraces are present along the Boyer Valley (Daniels and Jordon, 1966). These are elevated approximately 30 meters (100 ft) above the Boyer River floodplain in the vicinity of the town of Dunlap on the western edge of Mill-Picayune Watershed. About half the present elevation of these terraces results from the Wisconsinan loess cover. Late-Sangamon paleosols are developed in the alluvium beneath the loess in these terraces. Late-Sangamon alluvium in the small valleys is the upper drainage network equivalent of the Late-Sangamon Boyer River floodplain alluvium beneath the loess-mantled terraces.

Fifteen holes were drilled in the Mill-Picayune study area. All holes terminated in pre-Holocene deposits, usually Pre-Illinoian till or Late-Sangamon alluvium. Core MP-3 was collected for laboratory analysis. Samples for radiocarbon

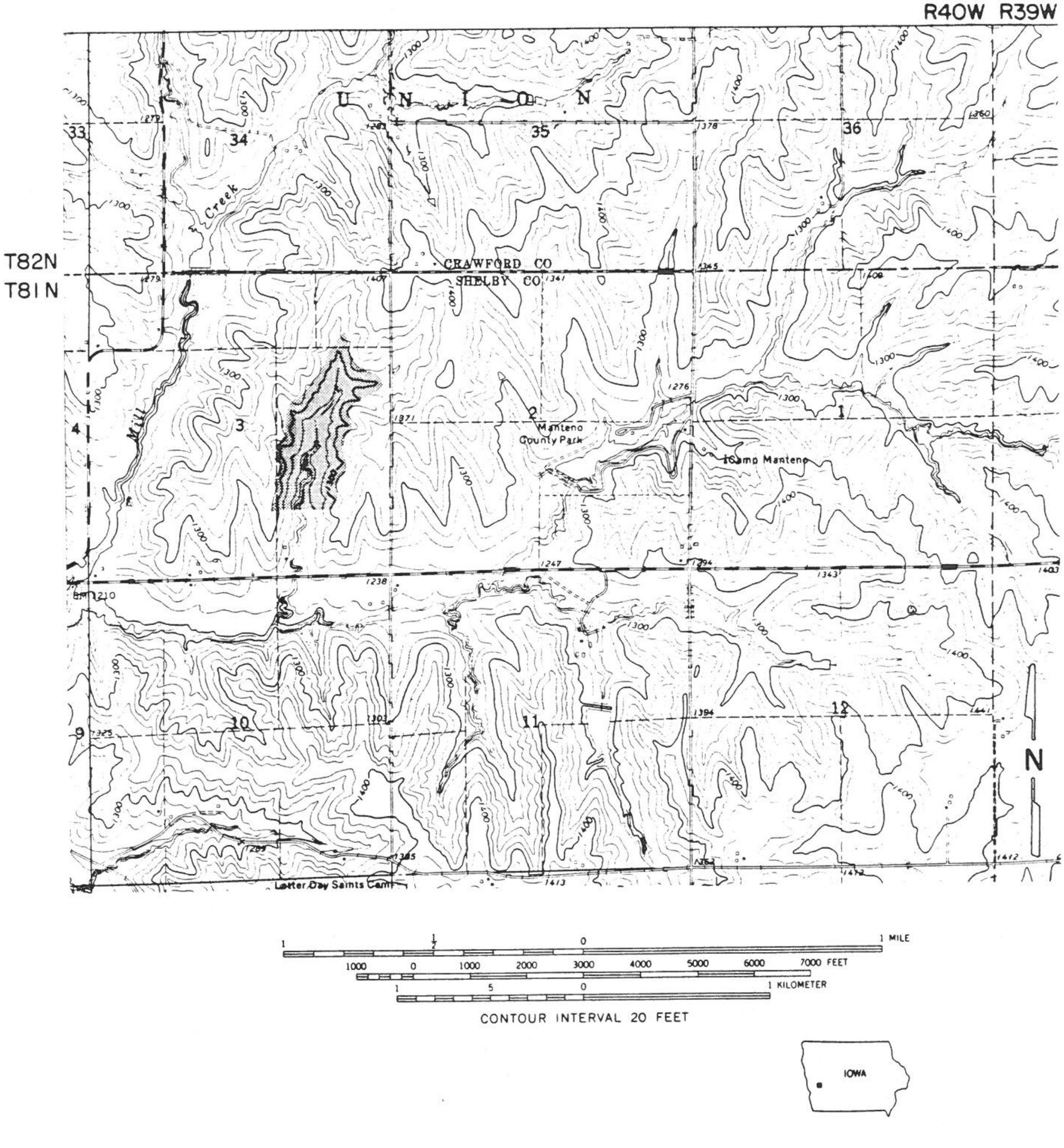


Figure 33. Topographic map showing the location of the Mill-Picayune Watershed study area in southern Crawford, northeastern Harrison, and northwestern Shelby counties. Base taken from U.S.G.S. 7.5 minute Earling, Iowa quadrangle.

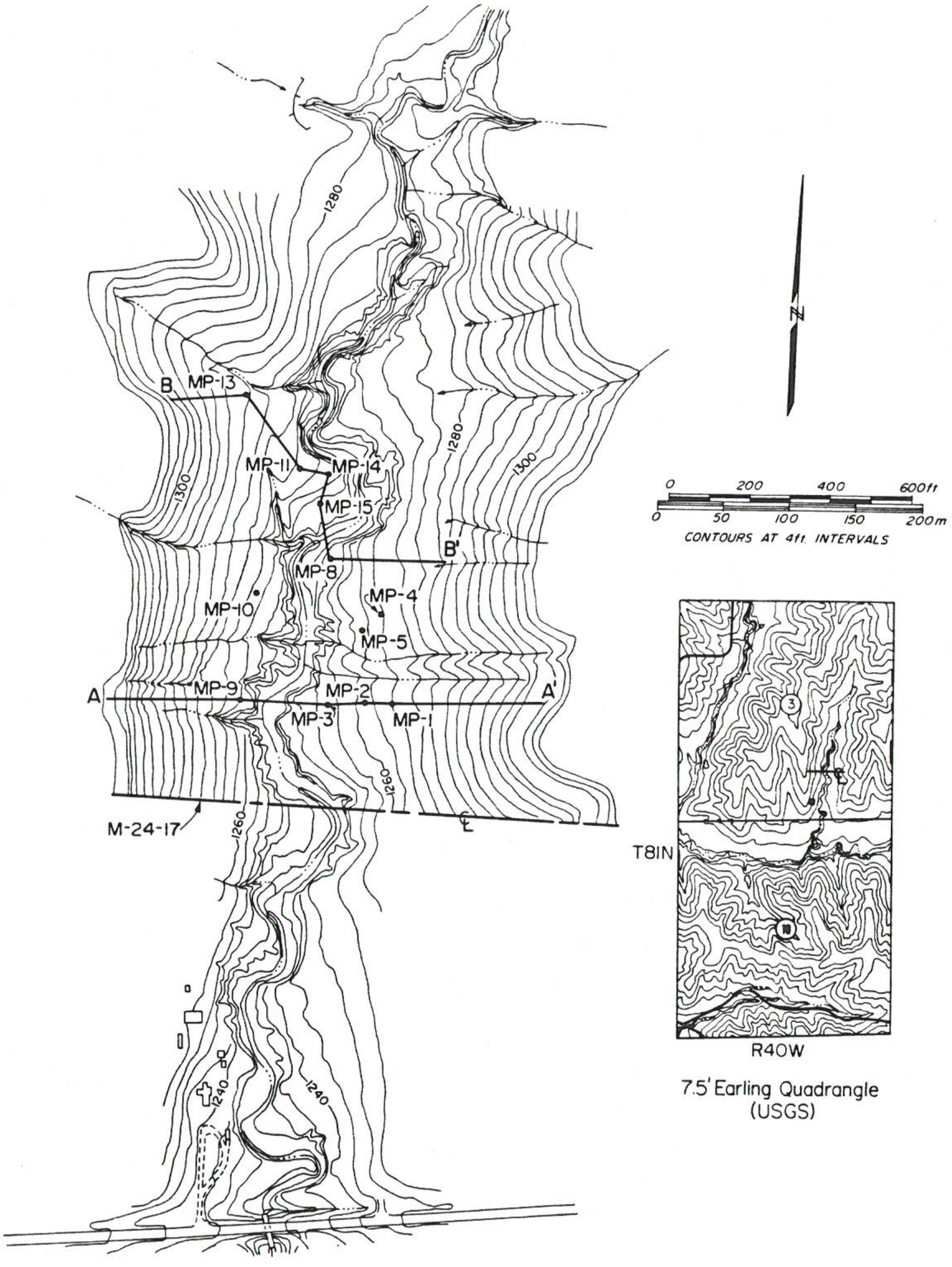


Figure 34. Topographic map of site 24-17 in Mill-Picayune Watershed showing the locations of drill holes and cross-sections discussed in the text. Contour interval is four feet (1.2 m).

analysis were not collected during the investigation.

Late Wisconsinan alluvium was encountered beneath the Holocene alluvium along the southernmost (downstream) cross-section in the mainstem area (Fig. 35). This alluvium is dark gray to greenish gray (5Y 4/1 -5GY5/1) stratified silt loam and sand and gravel. Effervescence ranges from none to moderate in this deposit. Macrofossils (needles, twigs) of coniferous trees are common in this alluvium. The upper contact of this unit with overlying Holocene alluvium is an erosional unconformity marked by abrupt textural and color changes.

The Watkins Bed of the Gunder Member was encountered in borings along the mainstem. This unit is a dark grayish brown to dark yellowish brown (l0YR4/2-4/4) noneffervescent, stratified silt loam, loam, and sand and gravel. Watkins Bed is the coarsest-textured unit of the formation in this study area. Erosion (gullying) preceding deposition of the Hatcher Bed truncated upper portions of the Watkins Bed and, in some areas, completely removed the unit.

Small, relatively steep alluvial fans are located at the junction of first-order tributaries with the main valley in the study area. Deposits making up the fans bury Pre-Illinoian till, with an erosion surface separating the fan and till (Fig. 35). Lower portions of the fans consist of stratified sand, loam and gravel. This grades upward into very dark grayish brown to brown (l0YR 3/2-4/3) noneffervescent loam to silty clay loam which comprises the bulk of the fan deposit. Thick mollisols with argillic horizons are the surface soils developed into the upper part of the fan deposits. Buried soils were not encountered within the fans. Deposits making up these fans fall within the range of characteristics of the Hatcher Bed with the exception of the lower, coarse, stratified portions of the fans which are outside the range of typical Hatcher Bed deposits in western Iowa.

Alluvial fan deposits in the small valleys of Mill-Picayune Watershed grade into the Hatcher Bed along the mainstem. The top of the Hatcher Bed merges with the valley slopes in a smooth concave profile. This unit is present beneath a distinct 1-2 meter high terrace standing above the floodplain along the modern gully. The Hatcher Bed is a very dark grayish brown (within the mollic epipedon of the surface soil) to yellowish brown (l0YR 3/2-5/4) noneffervescent, silt loam to heavy silt loam. Two distinct gully fills make up the bed in this area. The most voluminous is only stratified at its base where it often contains interbeds of sand and gravel. Another, less abundant Hatcher fill cuts into the former and is weakly stratified throughout. The later also truncates the previously discussed alluvial fans. Both of these fills occur along the mainstem and together occupy the greatest volume of the Holocene fill in the project area.

Relatively thick mollisols, some with minimally expressed argillic horizons, are the surface soils developed into the Hatcher Bed in the project area. Surface soils developed on the younger, stratified variant of the Hatcher Bed are usually slightly thinner and morphologically less well expressed than those on the older typical Hatcher fill. No buried soils were encountered within the Hatcher Bed in Mill-Picayune Watershed.

Surface soils in the project area are mapped as Ida Silt Loam in the Soil Survey of Shelby County (Jury et al., 1961). Obviously, the soils developed in Holocene alluvium in this valley are not Ida Series soils, which are developed in silty loess. Surface soils developed on the small Hatcher Bed alluvial fans and other alluvial fan areas probably would fall near the range of the Judson Series (Cumulic Hapludoll) but are slightly coarser-textured than is typical for the series.

DeForest Formation units younger than the Hatcher Bed have a patchy distribution because of extensive Historic gullying in the study area. The Mullenix Bed of the Roberts Creek Member was encountered intermittently along the mainstem (Fig. 35). This unit is inset into the Hatcher Bed as a gully fill. Mullenix Bed is a very dark gray to dark brown (l0YR3/1-3/3) noneffervescent silt loam to silty clay loam. Stratification was not evident in the holes drilled into the unit, probably as a result of a relatively slow accumulation rate and pedogenic alteration of the deposit during its accumulation. Thick, dark-colored Mollisols with Bw horizons are the surface soils developed in this unit.

Turton Bed of the Roberts Creek Member was only encountered in one hole (MP-8) in this study area. The unit is restricted to a narrow band on the east side of the mainstem along cross-section C-C' (Fig. 35). It is inset into the Hatcher Bed at this location. Turton Bed is a very dark gray to dark grayish brown (l0YR3/1-4/2) noneffervescent, stratified silt loam to silty clay loam. The surface soil developed at this location is a mollisol with a dark Bw horizon. Soils developed into the Mullenix

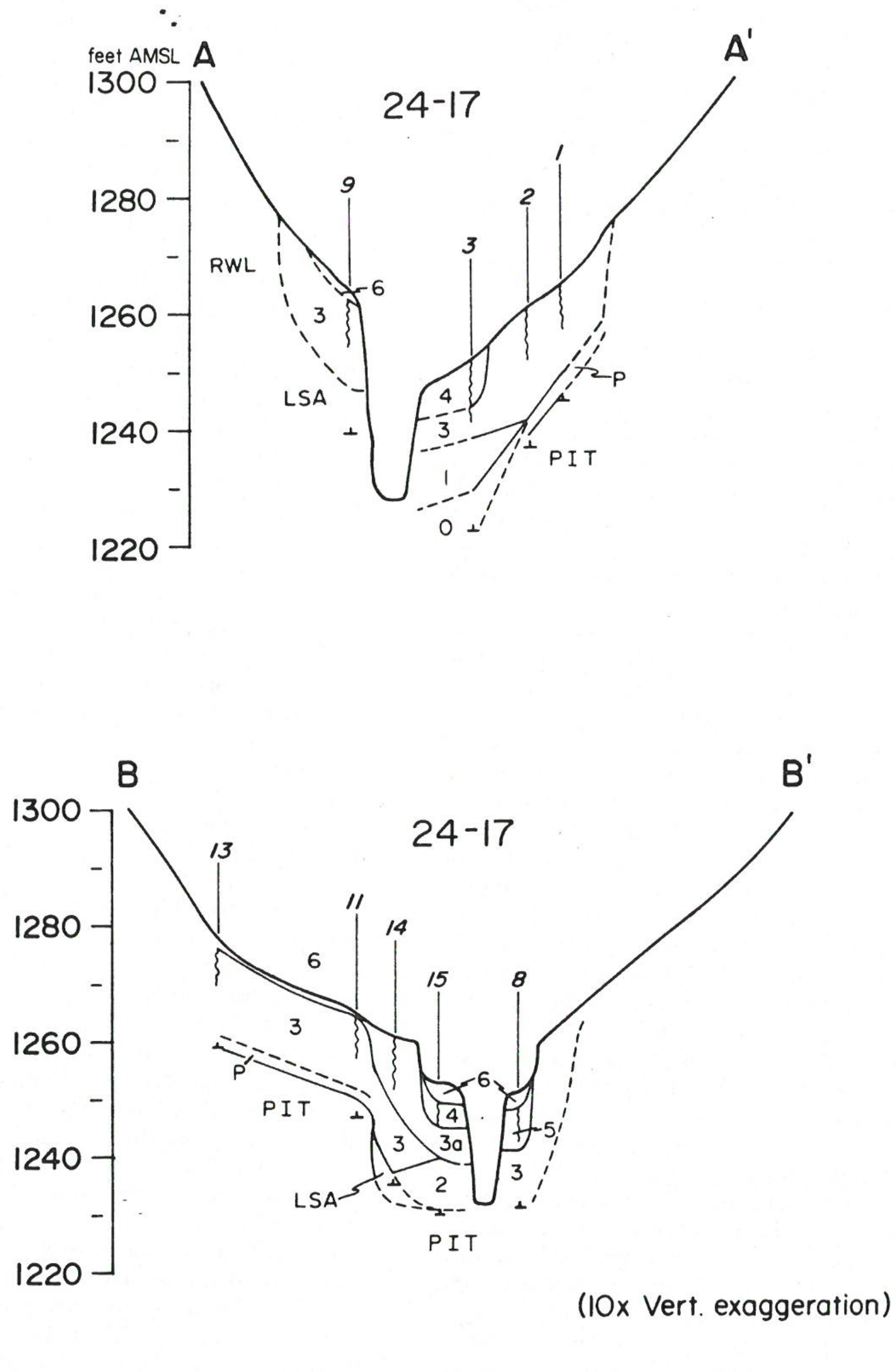


Figure 35. Cross-sections across the 24-17 valley in Mill-Picayune Watershed.

and Turton beds are probably within the range of the Napier and/or Kennebec soil series (Cumulic Hapludoll).

Camp Creek Member was encountered along fence lines and across the floodplain along the mainstem (Fig. 35). This unit is a dark brown to yellowish brown (l0YR3/3-5/4) noneffervescent silt loam to loam throughout the area. Where it is greater than about 50 cm in thickness, lower parts of the Camp Creek Member are stratified. Soils have not developed in this unit.

West Aldrich Creek Subwatershed

West Aldrich Creek Subwatershed is located in eastern Woodbury and western Ida counties within the Southern Iowa Drift Plain (Fig. 1). The study area in this subwatershed is located along Aldrich Creek in western Ida County about 7 km (4.4 mi) upstream of the creek's confluence with the Maple River (SE 1/4 NW 1/4 sec. 8 T87N R4lW) (Fig. 36). At this location West Aldrich Creek occupies a fourth-order valley with a drainage area of 988 ha (2,440 ac).

A southwest-trending third-order tributary joins the mainstem in the study area (Fig. 37). An intermittent stream flows in a narrow entrenched channel through the 0.4 km (2.5 mi) wide main valley. A prominent loess-mantled terrace stands 6 meters above Holocene-age valley surfaces along the eastern side of the valley (Fig. 37). The Wisconsinan alluvium beneath the loess in this terrace consists of oxidized, calcareous sand and gravel. A paleosol is not developed in the upper part of the alluvium, but a thin mixing zone separates the alluvium from the overlying loess. Wisconsinan alluvium beneath the terrace is inset into Pre-Illinoian till.

Valley slopes in the watershed are noticeably asymmetrical with west-facing slopes longer and gentler than east-facing slopes. Local relief is approximately 67 meters (220 ft). Peoria Loess is the dominant surficial deposit on uplands and valley slopes in West Aldrich Subwatershed. Loess thickness averages about 9 meters (30 ft) on the uplands. Sandy and gravelly, oxidized Late-Sangamon alluvium is buried beneath the Holocene and Wisconsinan alluvium along the western margin of the valley.

Ten holes were drilled in this project area along an east-west transect across the valley (Fig. 37). Samples for laboratory analysis were collected from all holes except numbers 3 and 6. All sampled holes penetrated the sequence of Holocene and late Wisconsinan deposits.

Late Wisconsinan alluvium (formerly the Soetmelk member; Bettis and Thompson, 1982) truncates the sandy alluvium of the loess-mantled terrace. The late Wisconsinan alluvium consists of grayish-green, and very dark gray (5G5/2 and 2.5Y3/0) calcareous, stratified silt loam and loam. Organic remains are abundant in this deposit. Wood collected from this unit at a depth of 7.1 to 7.3 meters (23.5t0 24.1 ft) yielded a radiocarbon date of 11,130±120 B.P. (Fig. 38) (Beta-2380).

Watkins Bed of the Gunder Member is present as two trough-shaped channel fills in this valley cross-section. Deposits making up these channel fills are greenish gray, gray, and very dark gray (5GY6/1, 5Y 5/1, and 2.5Y3/0) noncalcareous to calcareous, stratified loam and medium sand with occasional gravel lenses. Post-Watkins stream migration appears to have removed large parts of the original Watkins Bed from this area. Only the deepest channel fills of the original deposit are preserved in the stratigraphic record.

A fluvial erosion surface (the DeForest Gap) separates younger units of the DeForest Formation from the Watkins Bed and Wisconsinan-age deposits. Abrupt changes in color and texture across this boundary allow for its recognition.

Hatcher Bed is present on both sides of the valley along the cross-section. On the west side of the valley the Hatcher Bed underlies a terrace that stands approximately two meters (6.5 ft) above younger Holocene alluvium in the floodplain area. In this study area the Hatcher Bed consists of very dark grayish brown (in the mollic epipedon of the surface soil) to brown (l0YR3/2 -4/3) or grayish brown to olive gray (2.5Y5/2 - 5Y5/2) weakly to moderately effervescent, massive silt loam. On the west side of the valley the Hatcher Bed consists of two alluvial fills separated by a buried paleosol with an A-Bw-C soil profile. Lithologically the two fills are very similar with the younger being slightly lighter-colored (l0YR5/3). The younger increment is inset into older parts of the Hatcher Bed and a short, steep scarp separating the two is evident in the field. Two distinct alluvial fills in the Hatcher Bed have been observed elsewhere in western Iowa, such as in Mill-Picayune Watershed discussed in the previous section.

Surface soils developed into the Hatcher Bed are thick well-drained mollisols much like those

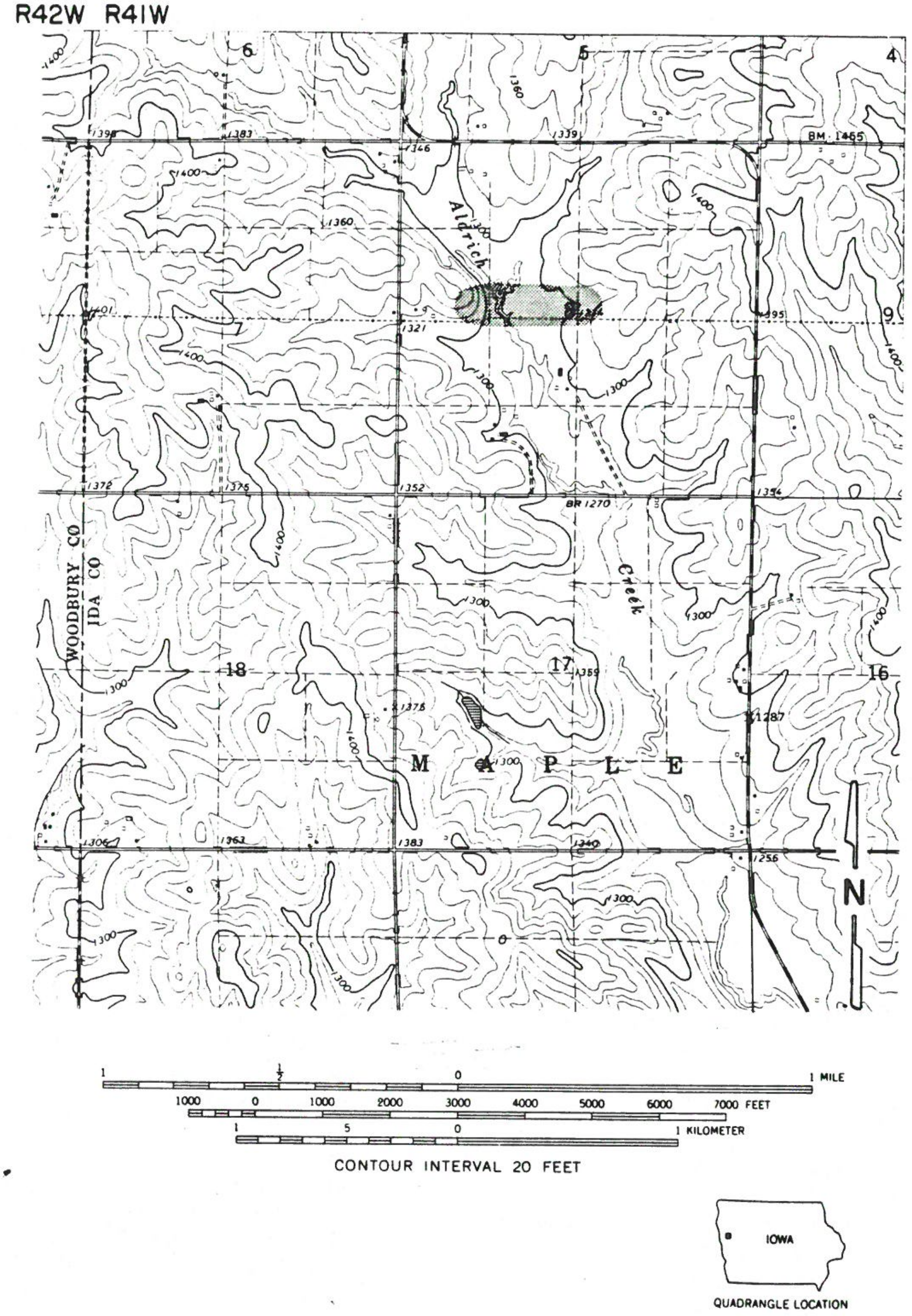


Figure 36. Topographic map showing the location of the West Aldrich Creek study area in western Ida County. Base taken from U.S.G.S. 7.5 minute Holstein, Iowa quadrangle.

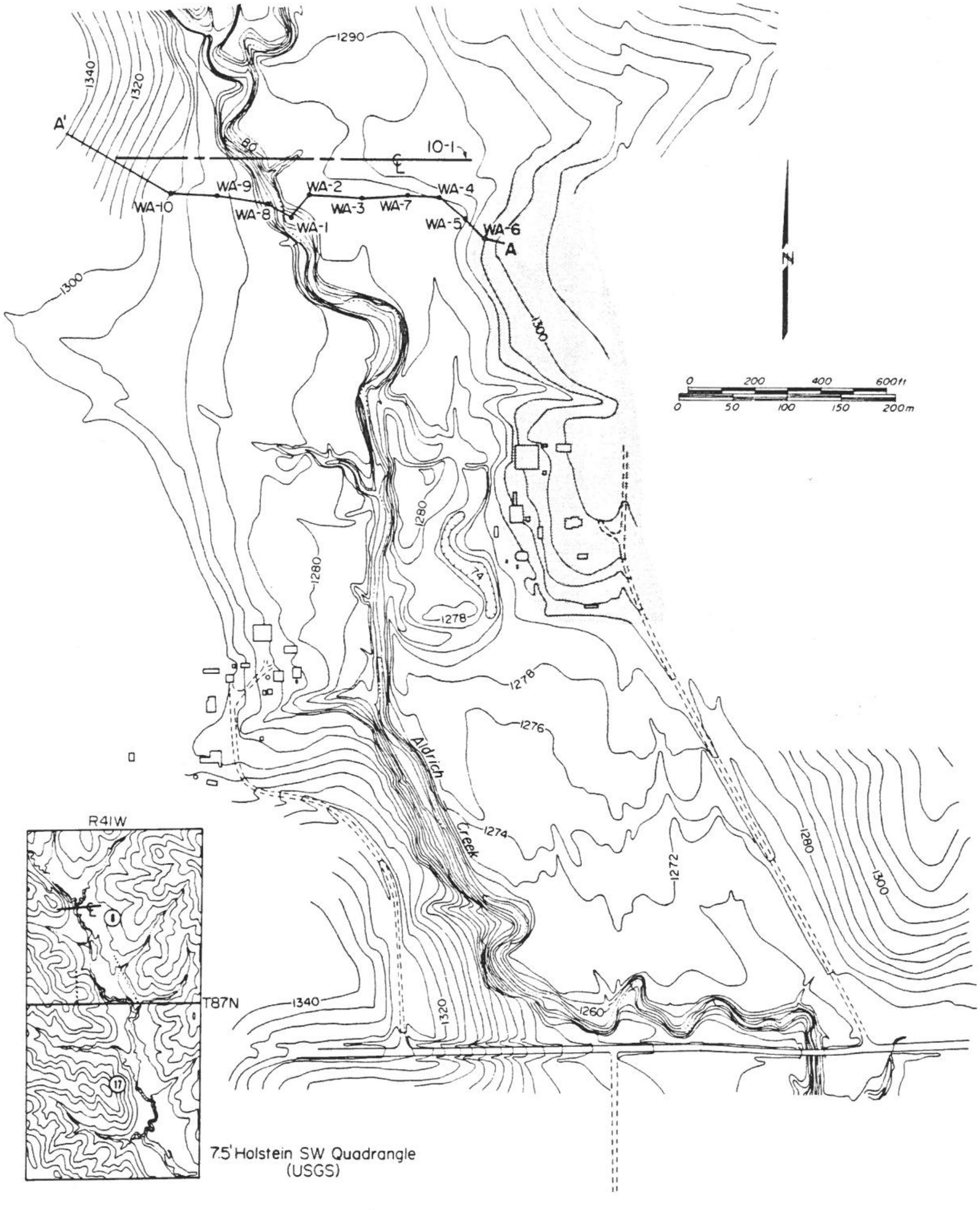


Figure 37. Topographic map of the West Aldrich Creek study area showing the locations of drill holes and the cross-section discussed in the text. Stippling denotes loess-mantled terrace along the east side of the valley. Contour interval is four feet (1.2 m)

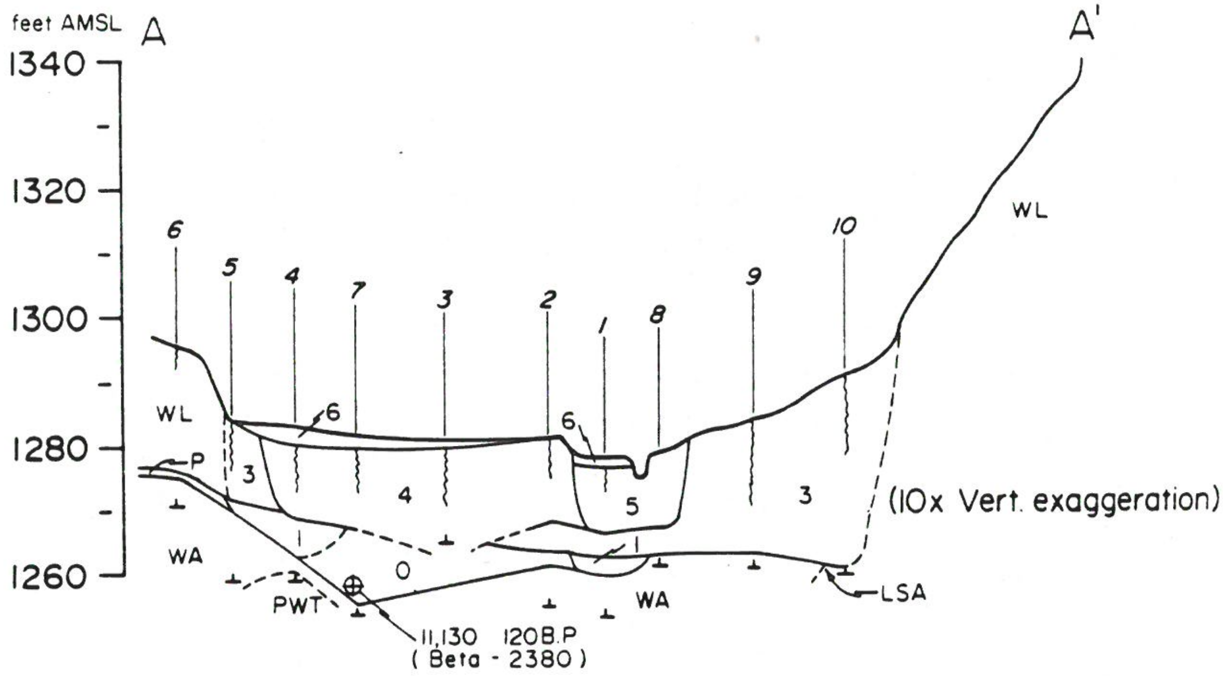


Figure 38. Cross-section A-A' across West Aldrich Creek valley showing stratigraphic relationships among DeForest Formation units and older deposits.

developed into this unit elsewhere in western Iowa. The surface soil developed in the younger of the Hatcher alluvial fills is morphologically indistinguishable from those developed on the adjacent older Hatcher terrace.

The Mullenix Bed of the Roberts Creek Member is present beneath the floodplain on the eastern side of the valley (Fig. 38). This unit consists of very dark gray to dark grayish brown (l0YR3/1-4/2) noneffervescent loam to silty clay loam. Upper portions of the unit have been pedogenically altered. Lower portions of the Mullenix Bed are stratified and often contain gravelly and sandy channel fills.

Surface soils developed into the Mullenix Bed in this area are very dark colored, thick, somewhat poorly drained mollisols. The thickness of these soils is probably a result of pedogenesis with concomitant alluviation.

The Turton Bed is present in a relatively narrow channel belt on both sides of the modern stream (Fig. 38). This unit consists of very dark gray to very dark grayish brown (l0YR3/1-3/2) noneffervescent massive to stratified loam. A gravel lag is present in the lower part of the Turton Bed in this area. Dark, somewhat poorly-drained Entisols with A-C soil profiles are the surface soils developed in the Turton Bed.

Camp Creek Member buries older Holocene alluvium and soils along the eastern portion of this valley cross-section. It is thickest adjacent to the present channel and at the base of the steep slope which ascends to the loess-mantled terrace. Throughout the area it is a very dark grayish brown to brown (10YR3/2-3/3) noneffervescent silt loam. Soils are not developed into this unit.

The morphology of the DeForest Formation units along West Aldrich Creek is similar to that in moderate-sized valleys elsewhere in western Iowa. Most of the units are slightly coarser-textured in the West Aldrich Creek study area than elsewhere because the stream cuts into older sandy and gravelly alluvium along West Aldrich Creek, whereas farther to the west the streams are often cut into loess and/or silty alluvium. Texturally, the various units overlap considerably, much more so than in the other study areas (Fig. 39).

West Aldrich Creek does not occupy a deeply entrenched channel. Most streams in the Northwest Iowa Plains and Southern Drift Plain landform regions follow this pattern. DeForest Formation units younger than the Watkins Bed in these areas typically are present as a series of successive fills progressing across the valley floor. We have referred to this type of geometry as a lateral sequence in contrast to a vertical sequence, in which younger fills successively bury older fills. Vertical sequences are typical in the Western Loess Hills area (Bettis and Thompson, 1982). Vertical sequence geometry is promoted by the presence of easily eroded, dominantly fine-grained loess and loess-derived alluvium coupled with relatively low groundwater levels. These materials do not form a barrier to downcutting and hence gullies develop and extend vertically to, or near the groundwater table. In contrast, in areas where the valley is developed in glacial till and/or coarse-grained alluvium with thinner loess in the watershed, gravel lags develop and inhibit further downcutting. The groundwater level also tends to be higher in these areas, further inhibiting downcutting. Streams in these areas adjust their gradient by migrating laterally across the floodplain, creating a lateral sequence. In lateral sequences a chronosequence of soils and surfaces is present across the valley floor. Chronosequences are not as well developed in areas where vertical sequences dominate.

DISCUSSION

The stratigraphic record in small western Iowa drainages indicates that gully cutting and filling occurred throughout the late Wisconsinan and Holocene. This record is one of episodic gully growth, gully filling, and renewed gully incision. During the Holocene a sequence of alluvial fills (the DeForest Formation) traceable from valley to valley has evolved. In western Iowa the DeForest Formation consists of four members encompassing at least six individual aggradation episodes. These members have distinct lithologic properties which permit differentiation of the members in the field or in disturbed samples. In western Iowa two of the members, the Gunder and Roberts Creek, each contain two lithologically distinct beds. Stratigraphic position of the various units and the nature of soil development in the alluvial fills further aid in their recognition and differentiation. The DeForest Formation and its western Iowa units are mappable rock bodies. Thus, the alluvial fills described in the previous pages are lithostratigraphic units (North American Commission on Stratigraphic Nomenclature, 1983).

Over 100 radiocarbon dates on wood and

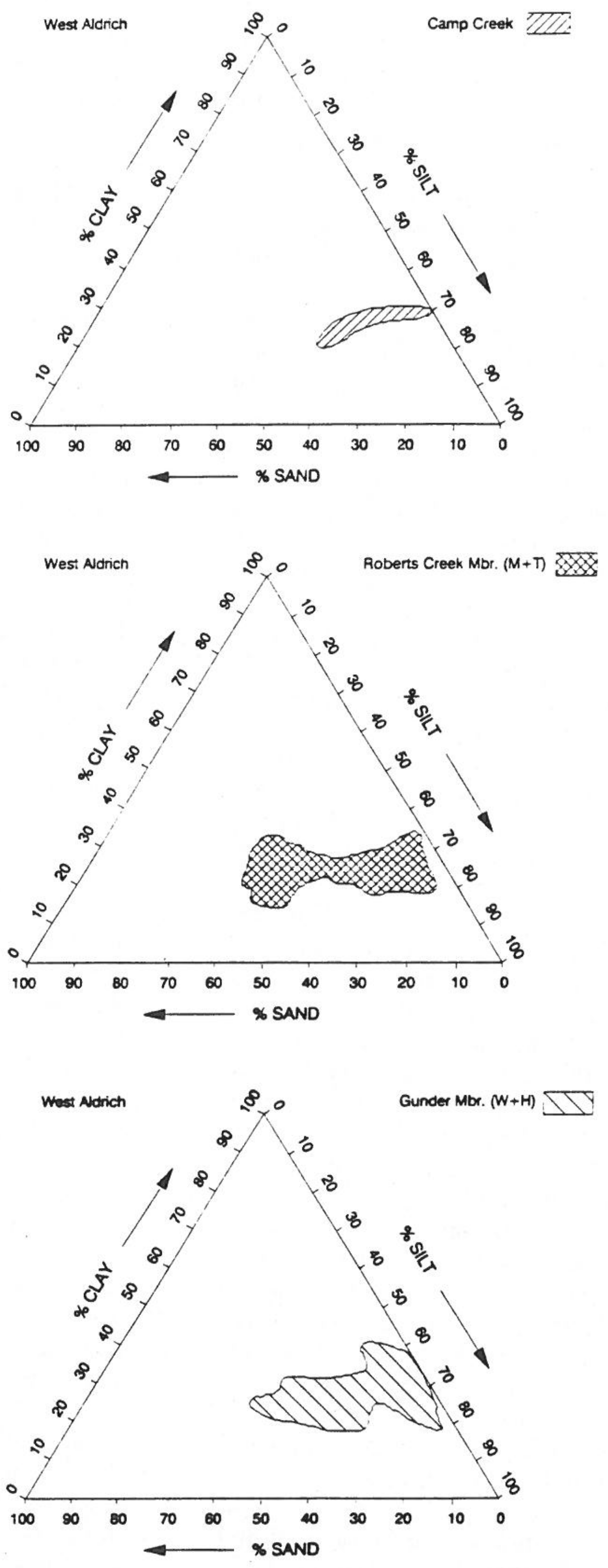


Figure 39. Textural triangle plots of DeForest Formation textures from the West Aldrich Creek study area. Note considerable overlap of the range of all units.

charcoal collected from the DeForest Formation in western Iowa, in conjunction with numerous archaeological associations, allow us to speak with some certainty about the timing of the four aggradation episodes represented by the Watkins, Hatcher, Mullenix, and Turton beds. In a given portion of the drainage network (second- through third-order for example) the timing of an individual gully filling episode was synchronous throughout the region (Fig. 40). Proceeding down a drainage, however, the basal age of an alluvial fill increases. For example, in second- and third-order drainageways the Mullenix Bed of the Roberts Creek Member began accumulating at about 1800 RCYBP. In fourth-order and larger drainageways, however, the Mullenix Bed was accumulating by about 3500 RCYBP (Fig. 40).

These age relationships indicate that gully incision began in lower parts of the drainage network, then extended into upper parts of the system. This suggests that the progression of gully extension documented on short time scales (Piest et al., 1975; Heede, 1974; Spomer and Mahurin, 1984) also occurs on a Holocene time scale. By the time gullies were active in second-order valleys, those in fourth-order valleys were more or less stable and filling with sediment. Concurrent erosion and deposition in different parts of the same drainage network has also been observed in modern arroyos in the western United States (Thornwaite et al., 1942; Patton and Schumm, 1981).

Experimental work and field studies suggest that arroyo or gully cutting and filling is a natural sequence of events by which sediment is episodically transported through the drainage system in areas where sediment yield and the resulting ratio of sediment discharge to water discharge are high (Schumm, 1973, 1977, 1980; Begin and Schumm, 1984). These studies also point to the existence of geomorphic thresholds. A geomorphic threshold is a threshold of landform stability that is exceeded either by intrinsic change of the landform itself, or by progressive change of an external variable (Schumm, 1980). Change in landforms themselves are of paramount importance, because until they have evolved to a critical situation, adjustment or failure will not occur.

Experiments and field studies by Schumm and co-workers have also shown that the ideas of progressive erosion and progressive response to altered conditions are not supported. Their studies show that instead, the fluvial system searches for a new equilibrium (complex response) and when the change is major, the system is overwhelmed by the quantity of sediment requiring movement. The result is several episodes of erosion and deposition all related to a single major change. Another interesting feature of the complex response phenomena is that the intensity of the response, be it alluviation, sediment yield, or entrenchment, usually decreases through time (see Parker, 1977; Womack and Schumm, 1977).

The DeForest Formation in western Iowa seems to have accumulated during complex response of the western Iowa fluvial system to increases in local relief and sediment availability resulting from Peoria Loess deposition. Superimposed on this response were adjustments to two or three major climatic/ hydrologic changes (Bettis, 1982). The first of these climatic/hydrologic changes occurred just prior to and during the shift from the late glacial to the pre-Boreal climatic episode, between about 12,000 and 10,500 B.P. in western Iowa (Van Zant, 1979; Gruger, 1973; Wendland and Bryson, 1974). During this interval meltwater discharge to the major streams in the area ceased, local base level was dramatically lowered by entrenchment in major valleys, and regional loess deposition came to an end. These changes triggered entrenchment (gullying) throughout the western Iowa drainage network. By 10,500 Y.B.P. entrenched channel belts in large and moderate-size valleys had stabilized and began to fill with alluvium being transported from upper parts of the network. Shortly after that date the rest of the drainage network stabilized and the Watkins Bed began to accumulate. Subsequent episodes of entrenchment and deep burial of the preserved Watkins Bed hinder a detailed understanding of the exact nature of the aggradation episode(s) producing this unit.

The second major hydrologic change in the western Iowa fluvial system resulted from a shift to drier conditions from about 9,200 to 7,000 Y.B.P. This resulted from increased zonal (west-east) circulation in the upper atmosphere which caused a greater incidence of dry Pacific air and a decrease in the penetration of moist Gulf air into the Upper Midwest (Wendland, 1980). The net effect of this shift in the upper air circulation pattern was a decrease in effective precipitation and an increase in the frequency of both drought and of relatively small, intense (cyclonic) thunderstorms (Knox et al., 1981). Maximum dryness and warmth was

DeForest Formation Chronogram, WESTERN IOWA

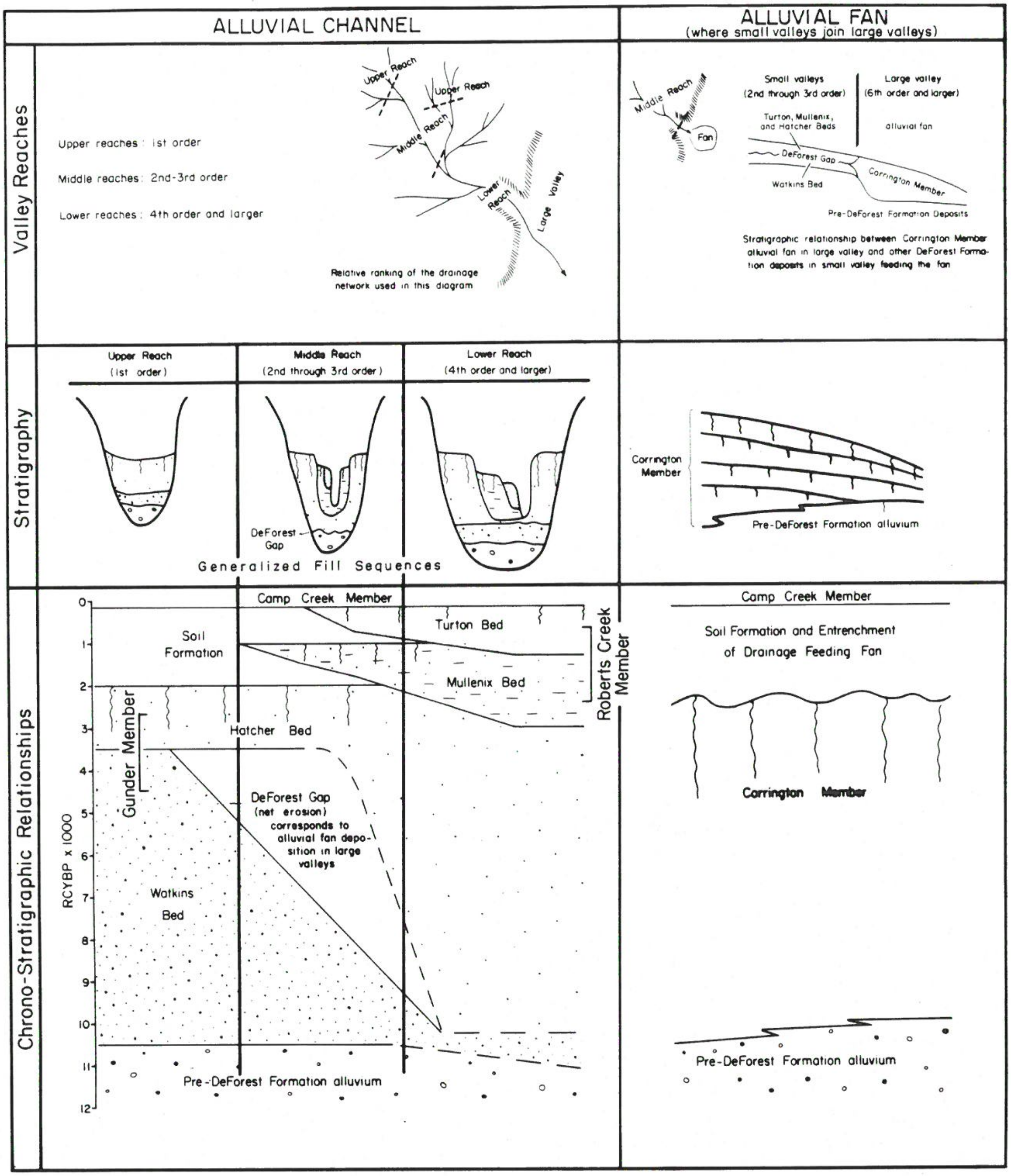


Figure 40. Chronogram for DeForest Formation alluvium in western Iowa showing temporal, stratigraphic, and geographic relationships of the units in the drainage system.

reached between about 7,000 and 6,200 Y.B.P. (Wendland, 1980).

After that time there was a progressive shift toward a more meridonal (north to south) circulation pattern of the upper atmosphere. This allowed moist Gulf air to penetrate into the Upper Midwest and produced increased precipitation in the form of frontal storms. Frontal storms produce less intense but broader-scale precipitation events. Precipitation coming in this form is more effective (for plant growth) than that associated with cyclonic storms characteristic during periods of zonal upper air circulation. Initially, this change may have promoted increased runoff resulting in greater sediment delivery to valleys, and increases in flood frequency and magnitude. Soon, however, vegetation density increased and water tables rose in response to the increase in effective precipitation. This acted to suppress runoff, sediment delivery to valleys, and flooding (Langbein and Schumm, 1958; Knox, 1972).

These climatic, hydrologic, and vegetative changes triggered various responses in the western Iowa drainage network that continued into the Historic period. The response took the form of several cut and fill episodes. The word "triggered" is more appropriate here than "caused" because we feel that prior to each episode of entrenchment, the system was at a threshold of instability in the larger-scale complex response to Peoria Loess deposition, and the extrinsic changes provided the impetus for geomorphic change at that time. Factors contributing to the inherent instability of the western Iowa fluvial system included steep valley gradients, easily eroded materials, and a relatively deep water table. Initially the system responded by entrenchment, then, when the gradient was sufficiently reduced or the water table was encountered, headward extension of the gully. After the gully headwall had progressed farther up the drainage, all the sediment derived from upvalley entrenchment and widening could no longer be transported through the lower gradient channel in the older portion of the gully and aggradation ensued. Aggradation continued until, once again, the valley gradient was over steepened and the water table was deep, setting the stage for the next gully cutting episode.

Episodes which occurred prior to about 3,500 Y.B.P. are not represented by alluvial fills in second- and third-order valleys and all but the extreme upper portions of first-order valleys (Fig. 40). Extreme upper portions of the drainage system (first-order valleys) were usually not affected by gully extension during the pre-Historic Holocene. Today these areas contain a complete, but relatively thin Holocene depositional record.

The period between about 8,000 and 3,500 Y.B.P. was characterized by net transport of sediment out of the upper portions of the drainage network. The DeForest Gap erosion surface developed during this interval. Alluvium transported out of the upper parts of the drainage network during this period accumulated in alluvial fans where small valleys entered major valleys or, where the small valleys drained to progressively larger valleys, accumulated as lower portions of the Hatcher Bed in fourth-order and larger valleys. The presence of several distinct fining-upward sequences, with a paleosol developed in the upper part of each, demonstrates that the fans accumulated episodically. Each depositional episode on the fan was produced by a gullying and sediment transport episode in the contributory basin. Periods of stability and soil formation on the fan correspond to gully stability and aggradation in the drainage feeding the fan.

After about 3,500 Y.B.P. episodes of gully growth decreased in intensity and extent to the point where some of the alluvium which accumulated during periods of aggradation was not remobilized and transported out of small and moderate-size valleys during a subsequent episode of gully growth. Gully filling episodes began in downstream portions of the drainage network before 6,000 Y.B.P. (Hatcher Bed) around 3,500 Y.B.P. (Mullenix Bed), and about 1,200 Y.B.P. (Turton Bed). Correlative periods of gully filling occurred in second- and third-order valleys beginning around 3,500 Y.B.P. (Hatcher), 1,800 Y.B.P. (Mullenix), and 750 Y.B.P. (Turton). The isopachs of these DeForest Formation fills from Smokey Hollow demonstrate that the intensity of the gullying preceding deposition of these units decreased through time. Since the size of the gullies decreased through time it is also safe to assume that the sediment yield from these areas probably also decreased through time. The decrease in intensity of the response (gullying, alluviation, and sediment yield) through time are what is expected during complex response of the fluvial system.

What is probably the most important aspect of our understanding of the DeForest Formation deposits in western Iowa is that the entire drainage network was not in synchrony with regard to downcutting and alluviation. In very few studies have episodes of erosion and alluviation been dated throughout the drainage network. If only the sequence in second- and third-order valleys had been dated, a sequence coinciding with the major alluvial discontinuities proposed by Knox (1975, 1983) would be recognized. The sequence in the lower part of the drainage network, however, does not provide as good a fit to Knox's generalized sequence. If, as it has been argued in this report, gullying and alluviation in upper parts of the system was in response to entrenchment farther down the drainage network the timing of episodes in western Iowa do not correspond with those proposed by Knox (ibid.). The point that we would like to stress is that episodes of fluvial activity in western Iowa are not uniformly distributed in time and space. In comparable order drainages the episodes were synchronous and of approximately the same magnitude. This is not the case when different order drainages are compared. In fact, the "episodes" were time transgressive through the drainage network and those in upper parts of the network were in response to the progression of gully extension from lower in the network. This realization should inject an air of caution into the fitting of local alluvial chronologies into a broad climatic model without having the benefit of detailed stratigraphic investigations and dating throughout the drainage network.

We argued in previous pages that climatic change appears to have forced the western Iowa fluvial system across thresholds of landform stability during the terminal Wisconsinan/early Holocene and the middle Holocene period of increased acidity. A combination of climate and responding vegetative cover also appears to have significantly affected lithologic characteristics of some of the DeForest Formation units.

Accumulation of the Corrington Member seems to have been significantly influenced by two factors: 1) a complex response to increased local relief resulting from loess accumulation on the landscape, and 2) decreased vegetative cover in the contributory basins resulting from a climatic shift toward increased aridity. These two factors acted together to foster episodic erosion of the contributory basins and the resultant accumulation of alluvial fans at the junction of those basins with large valleys. Decreasing vegetative cover during this period of time, combined with intense localized thunderstorms characteristic during periods of zonal upper air circulation pattern, produced intense episodic erosion of slopes and high sediment delivery to the small streams in these basins. Limited work on Corrington Member fans in western Iowa indicates that episodes of fan sedimentation and soil development may have been roughly synchronous throughout western Iowa (Hoyer, 1980a; Bettis, 1981). Several of these episodes correspond closely with climatically induced fluvial discontinuities outlined by Knox (1983). This suggests that climatic shifts during the early and middle Holocene may have promoted the crossing of geomorphic thresholds during a larger scale complex response in small basins draining to the fans (Hoyer, 1980a).

The absence of deposits from the period of approximately 8,000 to 3,500 Y.B.P. in second- and third-order valleys is related to geomorphic, climatic, and hydrologic conditions acting in unison to promote net transfer of sediment out of the upper part of the drainage system. We interpret the absence of these deposits as indicating subsequent erosion of alluvium deposited in these valleys during this interval rather than nondeposition from 8,000 to 3,500 Y.B.P. It seems likely that the same climatic and geomorphic parameters which fostered erosion of the alluvial fills and slopes in small basins draining to alluvial fans were also operative in second- and third-order valleys draining to progressively larger valleys.

By about 3,500 Y.B.P. geomorphic and climatic conditions had changed to the point where alluvium that accumulated in the small valleys was stored there rather than being remobilized and transported to downstream portions of the drainage network. The first major alluvial fill to accumulate after 3,500 Y.B.P. in the valleys was the Hatcher Bed of the Gunder Member. Multiple radiocarbon dates from several Hatcher sections indicate that this unit accumulated quite rapidly in these areas (0.57-0.64 cm/yr; Bettis and Thompson, 1982, Table 6.1). Descriptions of the Hatcher Bed in previous sections of this report indicate that this unit is usually oxidized. Major portions of the Hatcher Bed were derived from erosion of adjacent loess-mantled valley slopes. This erosion may have been enhanced by increased runoff resulting from greater penetration of moist Gulf air masses into the Upper Midwest beginning around 4,000 Y.B.P. (Wendland, 1980; Knox et al., 1981). It seems likely that the extensive slope erosion occurred because vegetation had not yet completely responded to the more effective precipitation.

A climatic signal is preserved in the lithology of the Mullenix and Turton beds of the Roberts Creek Member. These units are dark-colored as a result of a relatively high organic carbon (OC) content, and exhibit more pronounced bedding than the Hatcher Bed of the Gunder Member. We feel that their high OC content results from the fact that these fills accumulated during a period of increased vegetation cover resulting from more effective precipitation. The greater vegetation density combined with a higher water table resulted in the accumulation of alluvium high in OC content. Relatively high water tables subsequent to accumulation of the Roberts Creek Member have fostered preservation of the OC.

Roberts Creek Member alluvium was not derived primarily from erosion of valley slopes, as was the case with the lighter-colored, lower OC content Hatcher Bed of the Gunder Member. Instead, the Roberts Creek Member alluvium was derived primarily from reworking of the Hatcher Bed. This reworking, in combination with greater baseflow produced by higher watertables, resulted in greater sorting and development of more pronounced bedding in the Roberts Creek Member relative to that in the Hatcher Bed of the Gunder Member.

Results of our investigations into the lithologic properties, distribution, and age of the DeForest Formation in western Iowa have significant implications for scientists and engineers concerned with landuse, natural history, and prediction of the future behavior of western Iowa's fluvial system. We now know that gullying is part of the normal progression in the development of the western Iowa fluvial system. Gully and entrenched stream development has occurred several times during the Holocene followed by bed and bank stabilization and aggradation. Both instability and stability begin in high-order parts of the system (larger valleys) and progress into low-order drainages through time. This suggests that special attention should be focused on evaluating the effects that landuse practices, including channel modifications, will have on channels in lower parts of the fluvial system. Likewise, it seems that grade stabilization measures will be most effective when emplaced in high-order drainages provided that the drainages are in an unstable condition. Planners should recognize the fact that the western Iowa fluvial system is very dynamic. Channels in parts of it have been in entrenched and nonentrenched conditions during the Historic period as well as several times during the Holocene. All indications are that the system will continue to be dynamic in the future.

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APPENDIX A

DETAILED DESCRIPTIONS OF TYPE AND REFERENCE SECTIONS FOR THE DEFOREST FORMATION IN WESTERN IOWA

Reference section of the Watkins Bed of the Gunder Member exposed in the west bank of McPherron Creek, Mills County, Iowa.

Location: SE 1/4 SW 1/4 sec. 30, T7lN, R42W
Landscape position: terrace
Parent material: alluvium
Slope: 2-5%
Vegetation: shrubs
Date described: 9/15/82
Described by: E. A. Bettis III and D. M. Thompson
Remarks: Upper 2.24 meters beyond reach, section description begins in C horizon of surface soil. Surface soil developed in upper 2.24 meters of the Gunder Member, Hatcher Bed. Watkins Bed in this exposure is a channel fill.

Depth (m)	Soil Horizon (weathering zone)	Description
		DEFOREST FORMATION GUNDER MEMBER HATCHER BED
2.24-2.64	C (MOL)	dark grayish brown to brown (10YR4/2-4/3) silt loam, weak medium subangular blocky soil structure, friable, pH 6.4, abrupt smooth lower boundary, few fine horizontal and vertical tubules, common medium black and dark reddish brown (lOYR2/l and 5YR2/2) accumulations, abundant fine yellowish red (5YR5/6) iron concretions, common fine to medium yellowish brown (10YR5/6) mottles.
2.64-2.79	2Ab	dark grayish brown (10YR4/2) silt loam, weak medium subangular blocky, friable, pH 6.5, clear smooth boundary, horizontal and vertical tubules more abundant and larger than above, common fine olive brown (2.5Y4/4) mottles, abundant medium to fine dark reddish brown (5YR3/2) accumulations.
2.79-3.0	2ACb	dark grayish brown (10YR4/2) silt loam, very weak medium subangular blocky, friable, pH 6.5, gradual wavy boundary, tubules have very thin discontinuous coatings and are more abundant than above, abundant fine to medium dark yellowish brown (10YR3/4-4/4) mottles, common medium black (lOYR2/l) accumulations.
3.0-3.51	2C (MOL)	dark grayish brown to grayish brown and olive brown olive brown (2.5Y4/2-5/2 and 4/4) silt loam, very weak medium subangular blocky to massive, friable, pH 6.6, abrupt smooth boundary, common vertical and few horizontal tubules, occasional hard medium pipestems, common medium brown (7.5YR4/4) mottles, common dark gray (2.5Y4/0) mottles surrounding vertical tubules.
3.51-3.71	3ABb	dark grayish brown to olive brown (2.5Y4/2-44) silt loam,

		weak medium subangular blocky, friable, pH 7.1, clear smooth boundary, few vertical tubules, abundant fine to medium dark yellowish brown (10YR4/4) mottles, common fine very dark brown (10YR2/2) accumulations.
3.71-3.89	3C1 (OU)	grayish brown and brown (2.5Y5/2 and 10YR5/3) silt loam, very weak medium subangular blocky, friable, pH 7.8, clear smooth boundary, common vertical tubules, common fine brown (7.5YR4/4) iron concretions, few fine very dark grayish brown (10YR3/2) accumulations.
3.89-4.09	3C2 (MOU)	olive brown to light olive brown (2.5Y4/4-5/4) silt loam, very weak medium subangular blocky to massive, pH 7.8, clear smooth boundary, common medium pipestems (black 5YR2/1 exterior, grayish brown 7.5Y5/2 interior), few fine brown (7.5YR4/4) iron concretions, abundant medium grayish brown (2.5Y5/2) mottles.
4.09-4.32	3C3 (MOU2)	olive brown to light olive brown (2.5Y4/4-5/4) silt loam, very weak medium subangular blocky to massive, friable, pH 7.8, abrupt smooth boundary, few medium reddish brown (5YR4/4) pipestems, common medium dark yellowish brown and grayish brown (10YR4/6 and 2.5Y5/2) and abundant medium dark reddish brown (5YR3/2) mottles, common fine soft secondary carbonate concretions.
4.32-4.83	3C4 (MOU2)	olive brown (2.5Y4/4) silt loam, massive, friable, pH 7.8, clear smooth boundary, common vertical and few horizontal tubules, few thin discontinuous coatings in vertical tubules, few medium soft yellowish brown (10YR5/6) pipestems, abundant medium to coarse grayish brown (2.5Y5/2) mottles, common fine soft secondary carbonate concretions.
4.83-4.95	3C5 (MOU2)	dark grayish brown to olive brown (2.5Y4/2-4/4) silt loam, massive, friable, pH 7.8, abrupt smooth boundary, very few tubules, pipestems and mottles as above, common fine to medium soft and hard secondary carbonate concretions.
4.95-5.18	4Alb	dark grayish brown (2.5Y4/2) silt loam, very weak medium subangular blocky, friable, pH 7.9, abrupt smooth boundary, few vertical and abundant horizontal tubules, common krotovina, common light olive brown (2.5Y5/6) soft pipestems, common medium and fine light olive brown (2.5Y5/4) mottles, common medium and fine hard secondary carbonate concretions.
5.18-5.38	4A2b	very dark grayish brown (2.5Y3/2) silt loam, weak medium subangular blocky, friable, pH 7.9, clear smooth boundary, common vertical tubules, common medium brown (7.5YR4/4) soft pipestems, few medium olive (5Y5/4) mottles, abundant fine and medium hard secondary carbonate concretions.

5.38-5.54	4ACb	dark grayish brown to grayish brown (2.5Y4/2-5/2) silt loam, very weak medium subangular blocky to massive, friable, pH 7.8, clear smooth boundary, common medium brown (7.5YR4/4) soft pipestems, common fine very dark grayish brown (2.5Y3/2) mottles, common medium and fine hard secondary carbonate concretions.
5.54-5.99	4C1 (MOU2)	light olive brown (2.5Y5/4) silt loam, massive, friable, pH 7.8, clear smooth boundary, common medium hard pipestems (brown 7.5YR4/4 exterior, dark reddish brown 5YR2/2 interior), few fine brown (7.5YR4/4) iron concretions, common medium grayish brown (2.5Y5/2) mottles, common fine soft secondary carbonate concretions.
5.99-7.29	4C2 (MOU2 and MDU2)	olive brown and grayish brown (2.5Y4/4 and 5/2) stratified silt loam (planar bedded, beds are 1-2 cm thick), massive, friable, pH 7.9, abrupt wavy boundary, cmmon medium gray (2.5Y5/0) and few medium light olive brown (2.5Y5/6) (2.5Y5/6) (2.5Y5/6) mottles, very few fine soft secondary carbonate concretions segregated in thin horizontal zones.
7.29-7.37	4C3 (MDU)	grayish brown (2.5Y5/2) silt loam, massive, friable, pH 7.9, abrupt wavy boundary, boundary, abundant medium brown (7.5YR4/4) iron concretions.
7.37-7.44	4C4 (MDU)	dark grayish brown (2.5Y4/2) silt loam, massive, friable, pH 7.9, gradual irregular boundary, abundant fine brown (7.5YR4/4) mottles, abundant fine charcoal flecks, radiocarbon date on charcoal 6870±210 B.P. (Beta-5354).
7.44-8.05	4C5 (OU)	olive brown and grayish brown (2.5Y4/4 and 5/2) weakly stratified silt loam, massive, friable, pH 7.9, clear smooth boundary, abundant brown (7.5YR5/4) soft pipestems.
8.05-8.71	4C6 (MDU)	grayish brown (2.5Y5/2) stratified silt loam, occasional dark grayish brown (2.5Y4/2) zones at base, massive, friable, pH 7.8, abrupt wavy boundary, common fine to medium brown (7.5YR4/4) soft pipestems, few fine dark gray (2.5Y4/0) accumulations, common fine reddish brown (5YR4/4) mottles.
8.71-9.78	4C7 (MOU and MDU)	olive brown and grayish brown (2.5Y4/4 and 5/2) stratified silt loam and heavy silt loam, massive, and and friable, pH 7.7, abrupt wavy boundary, abundant medium o coarse brown and dark reddish brown (7.5YR4/4 and 5YR3/3) hard pipestems.
		WATKINS BED
9.78-9.88	5C1 (MDU)	dark grayish brown (2.5Y4/2) silt loam, massive, friable, pH 7.7, abrupt wavy boundary, few fine brown (7.5YR4/4) mottles, abundant wood.

9.88-9.98	5C2 (UU)	dark greenish gray (5GY4/1) silt loam, massive, friable, pH 7.9, abrupt smooth boundary.
9.98-10.19	5C3 (OU)	dark grayish brown to olive brown (2.5Y4/2-4/4) silt loam, massive, friable, pH 7.7, abrupt smooth boundary, common medium reddish brown (5YR4/4) soft pipestems.
10.19-11.0	5C4 (DJU)	dark greenish gray (5GY4/2) silt loam, massive, friable, pH 7.9, abrupt smooth boundary, common brown (7.5YR4/4) coarse pipestems, thin continuous brown (7.5YR4/4) stains along vertical joints, common organics.
11.0-11.15	5C5 (UU)	black (5Y2/1) silt loam, massive, friable, pH 7.2, clear wavy boundary, abundant fibric organics and wood, this horizon is within a channel fill sequence and the organics are detrital, C-14 date on wood (<u>Ulmus rubra</u>-red elm) 8,180 + 110 B.P. (Beta-2425).
11.15-11.28	5C6 (MUU)	dark greenishgray (5GY4/1) silt loam, massive, firable, pH 7.5, abrupt irregular boundary, common medium brown (7.5YR4/4) iron concretions, few medium brown (7.5YR4/2) mottles.
11.28-12.01	5C7 (MDU)	olive gray (5Y4/2-5/2) silt loam, weak medium subangular blocky, friable, pH 7.2, abrupt smooth boundary, few medium olive (5Y5/3) and occasional coarse brown (7.5YR4/4) mottles.
		SUB-DEFOREST FORMATION ALLUVIUM
12.01-base of exposure (12.7)	6C (MOU)	grayish brown to brown (10YR5/2-5/3) silt loam, weak medium loam, weak medium subangular blocky, friable, pH 7.5, occasional brown (7.5YR4/4) lenses of fine to medium sand, few fine brown (7.5YR4/4) soft pipestems, few medium yellowish brown (10YR5/4) mottles.

Reference section of the Hatcher Bed of the Gunder Member along the southeast side of Beaulieu Valley in Plymouth County, Iowa.

97RW43
Location: SW 1/4 NE 1/4 sec. 24 T90N R48W
Landscape position: valley floor at sidevalley mouth, next to pipe
Parent material: alluvium
Slope: 5%
Vegetation: pasture with trees along gully margin
Described: 9/10/81
Described by: E. A. Bettis III

Depth (m)	Soil Horizon (weathering zone)	Description
		DEFOREST FORMATION CAMP CREEK MEMBER
0-0.12	A	very dark grayish brown (10YR3/2) silt loam, weak fine granular soil structure, friable, pH 7.6, clear boundary, abundant roots.
0.12-0.53	AC	very dark grayish brown to dark grayish brown (10YR3/2-3/3) silt loam, weak medium subangular blocky, friable, pH 8.0, abrupt boundary, common roots.
		GUNDER MEMBER HATCHER BED
0.53-0.69	2Alb	very dark gray to very dark grayish brown (lOYR3/l-3/2) silt loam, moderate medium to coarse granular, friable, pH 7.5, gradual boundary, abundant root channels.
0.69-0.94	2A2b	very dark grayish brown (10YR3/2) silt loam, moderate to fine subangular blocky, friable, pH 8.0, clear boundary, common root channels.
0.94-1.63	2Bwlb	dark brown (10YR3/3) silt loam, moderate medium subangular blocky, friable, pH 7.8, gradual boundary, few roots.
1.63-2.03	2Bw2b	dark brown (10YR3/3) silt loam, moderate medium subangular blocky, friable, pH 7.9 gradual boundary, few thick discontinuous secondary carbonate accumulations in root channels.

2.03-3.17	2Bwk3b	dark brown (10YR3/3) silt loam, moderate medium to coarse subangular blocky, friable, pH 8-8.2, gradual boundary, abundant thick almost continuous and continuous secondary secondary carbonate coatings in root channels, some root channels are completely plugged with carbonate accumulations.
3.17-4.19	2Bwk4b	dark brown (10YR 4/3) silt loam, weak coarse subangular blocky, friable, pH 8-8.2, gradual boundary, abundant thin continuous secondary carbonate coatings in root channels.
4.19-4.93	2C1 (OU2)	yellowish brown (10YR5/4) silt loam, massive, friable, pH 8.0, gradual boundary, very few fine secondary carbonate concretions, common charcoal and burned earth C-14 date on charcoal--2,600±80 B.P. (Beta-2382).
4.93-5.77	2C2 (MOU2)	yellowish brown (10YR5/4) silt loam, massive, friable, pH 8-8.1, clear boundary, common medium grayish brown (10YR5/2) mottles, secondary carbonate concretions as above, occasional gastropod shells, occasional charcoal and burned earth.
5.77-6.6	2C3 (MOU2)	pale brown and light yellowish brown (10YR6/3 and 6/4) stratified silt loam, planar bedded, massive breaks along 2 to 7 cm thick bedding planes, friable, pH 7.9-8.0, clear boundary, common medium gray (10YR5/0) and few fine dark yellowish brown (10YR4/4) mottles, few fine secondary carbonate concretions.
6.6-8.03	2C4 (MOU)	dark grayish brown and brown (2.5Y4/2 and 10YR5/3) stratified loam, planar bedded, massive breaks along 5 to 7 cm thick bedding planes, friable, pH 7.6-7.9, abrupt boundary, common medium brown (10YR4/3) mottles, few fine iron accumulations, common eroded carbonate concretions and pipestems 7.32-7.92.
8.03-9.19	2C5 (UU)	dark greenish gray (5GY4/1) stratified loam, planar bedded, massive breaks along bedding planes, friable, pH 7.8-8.0, abrupt boundary, few dark gray (5Y4/1) organic zones with wood.
9.19-9.88	2C6 (UU)	dark greenish gray (5GY4/1) stratified gravel and silt loam (gravel is primarily limestone with some shale), planar bedded, massive and single grain breaks along bedding planes, friable, pH 7.6-7.9, abrupt boundary, rare wood.
9.88-10.69	2C7 (MRU)	dark greenish gray (5GY4/1) stratified silt loam with few gravel lenses, planar bedded, massive breaks along bedding planes, friable, pH 7.9-8.1, abrupt boundary, few medium olive (5Y4/4) mottles, gravel lens at base.

10.69-11.28	2C8 (MOU)	olive gray (5Y4/2) stratified silt loam, planar bedded, massive breaks along bedding planes, friable, pH 8.1, gradual boundary, abundant fine gray and light olive brown (2.5Y5/0 and 5/6) mottles, common wood, C-14 date on wood--2,770±90 B.P. (Beta-2383).
11.28-13.06	2C9 (MOU)	olive gray (5Y4/2) silt loam, massive, friable pH 7.3-8.0, abrupt boundary, common medium dark grayish brown (2.5Y4/2) streaks, few medium olive brown (2.5Y4/4) mottles.
13.06-base	2C10	dark gray (2.5Y4/0) stratified silt loam and gravel (gravel is predominately limestone with a few metamorphics), massive, friable, pH 8.2.

Type Section of the Corrington Member at the Corrington alluvial fan along the west valley wall of the Little Sioux Valley in Cherokee County, Iowa.

Location: W 1/2 SW 1/4 SE 1/4 sec. 4, T91N R40W
Landscape position: alluvial fan; midfan
Parent material: alluvium
Slope: 5-9%
Vegetation: row crops
Date described: 8/13-14/73
Described by: B. E. Hoyer and G. R. Hallberg

Depth (m)	Soil Horizon (weathering zone)	Description
		DEFOREST FORMATION CORRINGTON MEMBER
0-0.22	A1	black (10YR2/1) silt loam, strong medium to fine platy at top grading to weak medium platy and into very fine crumb soil structure, hard, slightly sticky and slightly plastic.
0.22-0.42	A2	black to very dark gray (10YR2-3/1) silty clay loam, moderate coarse subangular blocky, firm, slightly sticky and slightly plastic, pebbles mainly resistant types quartz primarily.
0.42-0.68	BA	very dark gray (10YR3/1) heavy silty clay loam, strong fine prismatic breaking to moderate fine subangular blocky, thin continuous cutans (clay films) on prisms discontinuous on blocks, hard, slightly sticky and plastic, pebbles other than resistant silicious types appear -dark basic types, limonite, etc.
0.68-0.87	Bt1	very dark grayish brown to very dark gray (10YR3/2-1) on ped surfaces to dark brown (10YR3/3) in the interior and when crushed silty clay loam, strong medium prismatic breaking to strong fine prisms and to mod-erate fine subangular blocky, continuous fine and discontinuous (common) moderately thick cutans on prisms common thin and few moderatly thick cutans on fine blocks, very firm, sticky and plastic, weakly calcareous at base (secondary carbonate).
0.87-1.13	Bt2	dark brown (10YR3/3) heavy silty clay loam strong medium prismatic breaking to strong fine prisms (stronger than unit above) and to moderate fine subangular blocky, continuous moderately thick and common thick cutans on prisms with many thin cutans on fine blocks, very firm, sticky and plastic, secondary carbonate present throughout and strong at the base locally, with concretions up to 2cm in diameter.

1.13-1.46	Bt3	the character of this unit changes from the top to the bottom of the peds, and is unusual in this respect. Very dark grayish brown to dark brown (10YR3/2-3) on the upper portions of peds, dark grayish brown to dark brown (10YR4/2-3) on the lower faces, and dark yellowish brown (10YR4/4) on the interior, silty clay loam, strong coarse prismatic breaking to strong medium prisms, continuous moderately thick and few thick cutans on the top horizontal surface of the prisms, continuous moderately thick cutans on vertical face grading to discontinuous cutans at the bottom of the coarse prisms, very firm, sticky and plastic, some secondary carbonate present.
1.46-1.9	2Ab(Bt)	very dark grayish brown (10YR3-4/2) on peds to dark brown (10YR3/3) crushed silty clay, some resistant pebbles, strong coarse angular blocky (moderate coarse prismatic structure, possibly superimposed on this horizon), continuous moderately thick and few thick cutans, firm, slightly sticky and plastic, weakly calcareous, readily distinguished from above unit on a dry, weathered exposure.
1.9-2.21	2Bt1b	very dark grayish brown to dark grayish brown (10YR 3-4/2) on peds to dark brown (10YR3/3) crushed silty clay, some resistant pebbles, strong coarse subanular blocky breaking to moderate medium subangular blocks, continuous thin common to many moderately thick cutans, some thick cutans around root tubules, numerous root tubules--tubular, inped and exped, open and random, very firm, sticky and plastic.
2.21-2.54	2Bt2b	dark yellowish brown (10YR4/4) on peds, some yellowish brown (10YR5/4) colors in interior silty clay loam, strong coarse angular blocky to weak coarse prismatic, continuous thin and few moderately thick cutans, few thick cutans around tubular root channels, sticky and plastic, more pebbles than unit above and more variety in pebble lithologies.
2.54-2.73	2Cb (OU2)	yellowish brown (10YR5/4) to dark yellowish brown (10YR4/4) texture variable -patchy gravel at the top of the unit, some sandy zones, some silty, in general it is a (pebbly) silt loam, weak medium subangular blocky -strength of structure varies with texture, cutans vary with texture, also common thin on finer textured blocks, silans along horizontal faces but not on vertical faces, variable amounts of secondary carbonate present, stronger concentration with coarser materials, generally coating pebbles, some concretions and carbonate lines the numerous root tubules.
2.73-2.78	2Ckb (OU2)	pebbly loam, as above, secondary calcium carbonate continuous in this horizon.

2.78-2.93	3Alb	very dark brown (10YR2/2) with 0.5 cm thick dark brown (lOYR 3/3) bands in lower 7 cm heavy silty clay loam with coarser bands in lower 7cm, moderate coarse angular blocky, leached to very weakly calcareous at base.
2.93-3.13	4A2kb	very dark brown (10YR2/2) on ped exterior, to very dark grayish brown (10YR3/2) crushed silty clay to silty clay loam, strong medium prismatic breaking to strong fine prisms, continuous thin and moderately thick cutans, patchy thick cutans around root tubules, firm, sticky and plastic, abundant charcoal, some bones present, secondary carbonate coating pebbles and lining fine random root tubules.
3.13-3.33	4Btlb	dark brown to brown (10YR3/3-4/3) pebbly silty clay loam, strong medium prismatic breaking to moderate medium prismatic and then to moderate fine subangular blocky, firm, thin to moderately thick cutans on larger peds with few thick cutans around medium vertical tubules, sticky and plastic, abundant root tubules, random inped and exped (larger tubes exped and vertical); lined with cutans and secondary carbonate.
3.33-3.58	4Bt2b	brown (10YR4/3) to dark brown (10YR3/3) pebbly silty clay loam, weak medium prismatic, firm, slightly sticky and plastic, discontinuous thin and moderately thick cutans on vertical faces, discontinuous thin cutans elsewhere, abundant root tubules with secondary carbonate linings, moderately thick cutans around large tubules.
3.58-4.53	5Cb (OU2)	brown to dark brown (l0YR5-4/3) variable sediments of alluvial and colluvial origin, ranging from thin lenses and wedges of sand and gravel and coarse sand to sandy loam, massive silt loam and silty clay loam, variable hoizontally and vertically, abundant secondary carbonate with concentrations in gravelly layers, some poorly sorted colluvial (?) deposits --massive pebbly silt loam or pebbly silty clay loam, one channel was noticed that was filled with sand and gravel, and indicated stream flow from the adjoining hillslopes toward the Little Sioux River; one bedded silt deposit which wedges out toward the valley wall and thickens toward the river.
4.53-4.62	6Ab	very dark grayish brown (10YR3/2) silt loam, strong medium subangular blocky, very firm, few moderately thick cutans on peds, moderate effervescence, clear boundary; abundant hackberry seeds and gastropods with much burned bone, common calcium carbonate concretions.
4.62-4.74	6Btb	dark brown (10YR3/3) silty clay loam, moderate medium subangular blocky, firm, few moderately thick cutans on peds, moderate effervescence; abrupt boundary, band of secondary calcium carbonate concretions at base.

4.74-4.88	7Ab	dark brown (10YR3/3) silty clay loam, moderate coarse and medium subangular blocky, firm, sticky and plastic, few moderately thick cutans on peds, weak effervescence, clear boundary, many gastropods, secondary calcium carbonate concretions especially at base.
4.88-4.98	7Btlb	brown (10YR5/3) clay loam, moderate coarse and medium subangular blocky, firm, sticky and plastic, few moderately thick cutans on peds, weak effervescence, gradual boundary, common secondary calcium carbonate concretions.
4.98-5.12	7Bt2b	brown (10YR4/3) clay loam, weak to moderate medium subangular blocky, firm, many moderately thick cutans on peds, weak to moderate effervescence, gradual boundary, includes pebbles up to 32 cm in diameter and small sand lenses, common secondary calcium carbonate concretions.
5.12-5.29	7Bt3b (Ab)	brown (10YR4/3) silty clay loam, weak to moderate medium subangular blocky, firm, common thick cutans on peds, weak to moderate effervescence, gradual boundary, contains gastropods and secondary calcium carbonate concretions.
5.29-5.49	7Bt4b	brown (10YR5/3) silt loam, weak medium subangular blocky, friable, few thin cutans on peds, moderate effervescence, clear boundary, common limonite concretions.
5.49-5.77	7Clb (OU)	brown (10YR5/3) clay loam, massive, friable to firm, few moderately thick cutans; moderate effervesecence; clear boundary, coarse to medium stratified sands, hearth-like features with burned earth and hackberry seeds.
5.77-5.93	7C2b (OU2)	brown (10YR5/3) stratified silt loam, with a banded appearance, moderate effervescence, common charcoal flecks, abundant gastropods, secondary calcium carbonate concretions, bands of coarse sand, clear boundary.
5.93-6.0	8Ab	dark grayish brown (10YR4/2) silty clay loam, moderate medium subangular blocky, firm, many moderately thick cutans on peds, very weak to weakly effervescence, secondary calcium carbonate concretions, gastropods, charcoal; clear boundary.
6.0-6.04	8Btb	brown (10YR4/3) silty clay loam, moderate medium subangular blocky, firm, common moderately thick cutans, weak to moderate effervescence, clear boundary, sand lenses.
6.04-6.12	9Ab	dark grayish brown (10YR4/2) silty clay loam, moderate medium subangular blocky, firm, common moderately thick cutans, clear boundary, gastropods very abundant, charcoal, secondary calcium carbonate concretions.

6.12-6.2	9Btb	grayish brown (10YR5/2) silty clay loam, moderate medium subangular blocky, firm, common moderately thick cutans, clear boundary, many gastropods and secondary calcium carbonate concretions, charcoal flecks.
6.2-6.32	10Ab	dark grayish brown (10YR4/2) silty clay loam (same as 6.04-6.12).
6.32-6.36	10Bwb	(same as 6.12-6.2).
6.32-6.46	11Ab	dark grayish brown (10YR4/2) silty clay loam (same as 5.93-6.0).
6.46-6.84	11Bwb	brown (10YR5/3) clay loam, weak medium subangular blocky, friable, few thin cutans, weak to moderate effervescence, abrupt boundary, contains channel filled with stratified sand and silt, especially at base, secondary calcium carbonate concretions
		SUB DEFOREST FORMATION
6.84-6.96	12Ab	very dark grayish brown (10YR 3/2) silty clay loam, moderate medium subangular blocky, firm, continuous thick cutans on peds, weak effervescence, clear boundary, few calcium carbonate concretions, many gastropods, bone, Little Sioux River alluvium

Reference section of the Roberts Creek Member (Mullenix and Turton Beds) along the west side of Smokey Hollow Valley in Woodbury County, Iowa.

97SHB-2
Landscape position: floodplain
Parent material: alluvium
Location: SE1/4, NW1/4, sec. 22, T86N, R44W
Slope: 0-2%
Vegetation: pasture
Date described: 11/11/81
Described by: E.A. Bettis III

Depth (m)	Soil Horizon (weathering zone)	Description
		DEFOREST FORMATION ROBERTS CREEK MEMBER TURTON BED
0-0.15	A	very dark gray to dark grayish brown (10YR3/1-3/2) silt loam, weak medium to fine granular soil structure, friable, pH 7.6, abrupt boundary, abundant roots, secondary carbonate accumulation at base.
0.15-0.23	BA	black (10YR2/1) silt loam, weak medium subangular blocky, very friable, pH 7.7, abrupt boundary, abundant roots.
0.23-0.36	Bw	very dark gray to dark gray (10YR3/1-4/1) loam, very weak medium columnar, very friable, pH 7.7, gradual boundary, common roots.
0.36-0.61	BC	very dark gray (10YR3/1) heavy loam, very weak medium to fine subangular blocky, very friable, pH 7.7, abrupt boundary, abundant fine light gray (10YR7/2) soft secondary carbonate accumulations, common roots, abundant broken gastropod shells.
0.61-0.84	C1 (UU)*	very dark gray (2.5Y3/0) heavy loam, massive, friable, pH 7.7, clear boundary, few roots.
0.84-1.3	C2 (UU)*	dark gray (10YR4/1) light clay loam, very weak medium subangular blocky to massive, friable, pH 7.8, gradual boundary, few thin grayish brown (10YR5/2) lenses, abundant insect burrows.
1.3-1.47	C3 (UU)*	dark gray (10YR4/1) silty clay loam, very weak medium columnar to massive, friable, pH 7.9, abrupt boundary, occasional thin discontinuous brown (7.5YR5/4) coatings on ped surfaces, common insect burrows.

1.47-1.85	C4 (UU)*	very dark gray and light brownish gray (10YR3/1 and 6/2) stratified light clay loam and silt loam, planar bedded massive separates along 2 to 5 cm thick bedding planes, friable, pH 7.8, abrupt boundary, common broken gastropod shells in light colored beds.
		MULLENIX BED
1.85-2.03	2C1 (uu2)*	very dark gray (10YR3/1) clay loam, massive, friable, pH 7.8, clear boundary, few fine secondary carbonate concretions, occasional burned earth and charcoal.
2.03-2.44	2C2	very dark gray to dark gray (10YR3/1-4/1) light clay loam, massive, friable, pH 7.7, abrupt boundary, very few fine secondary carbonate concretions, common burned earth and charcoal, clam shell fragment at 2.24 meters.
2.44-2.57	2C3 (UU)*	very dark gray (10YR3/1) light clay loam, very weak medium columnar, friable, pH 7.8, gradual boundary, thick continuous grayish brown (10YR5/2) coatings on ped surfaces, these columns appear to be formed by intersecting dessication cracks and the coatings on them may have resulted from flooding of the dessicated surface.
2.57-2.97	2C4 (UU)*	very dark gray (10YR3/1) light clay loam, massive, friable, pH 7.7, clear boundary, abundant medium dark grayish brown (10YR4/2) blotches.
2.97-3.35	2C5 (UL)*	very dark gray (10YR3/1) silty clay loam, very weak medium subangular blocky to massive, friable, pH 6.7, clear boundary, very few medium dark grayish brown (10YR4/2) blotches.
		GUNDER MEMBER HATCHER BED
3.35-3.76	3C1 (DU)	dark grayish brown (2.5Y4/2) loam, massive, friable, pH 7.4, clear boundary.
3.76-4.34	3C2 (DU2)	very dark grayish brown to dark grayish brown (2.5Y3/2-4/2) loam, massive, slightly sticky, slightly plastic, pH 8.0, gradual boundary, common to abundant medium secondary carbonate concretions, many of these concretions appear to be weathered and abraded.
4.34-base (4.7)	3C3 (DU)	dark grayish brown (10YR4/2) loam, massive, slightly sticky, slightly plastic, pH 8.0, few medium weathered and abraded carbonate concretions.

*Weathering zone terminology is problematical in deposits with a high content of finely disseminated organic material. It is assumed that these deposits are in an "unoxidized" state.

Type Section of the Camp Creek Member along the northwest side of Camp Creek valley in Woodbury County, Iowa.

97CC-24
Location: NW1/4, SW1/4, sec. 1, T87N, R45W
Landscape position: west bank of Camp Creek, level inset into Hatcher Bed fan
Parent material: alluvium
Slope: 2-5%
Vegetation: shrubs
Date described: 7/29/80
Described by: E. A. Bettis III

Depth (m)	Soil Horizon (weathering zone)	Description
		DEFOREST FORMATION CAMP CREEK MEMBER
0-1.17	C1 (OU & OL)	dark brown and brown (10YR 3/3 and 4/3) stratified silt loam; breaks along 2 cm thick bedding planes, planar bedded, weak medium subangular blocky within beds, friable, moderate effervescence to noneffervescent, clear boundary; common roots.
1.17-1.52	C2 (OU)	dark brown (10YR 3/3) silt loam, weak medium subangular blocky, friable, weak effervescence; clear boundary, common roots.
1.52-1.80	C3 (OU)	very dark grayish brown to dark brown (10YR3/2-3/3) stratified silt loam, massive breaks along 2 to 5 cm thick bedding planes, planar bedded, friable, moderate effervescence, abrupt boundary, common roots.
		ROBERTS CREEK MEMBER TURTON BED
1.80-2.03	ACb	very dark brown (10YR 2/2) silt loam, moderate medium platy, friable, weak to moderate effervescence, clear boundary, common roots.
2.03-2.74	Ab	very dark brown (10YR 2/2) silt loam, weak medium subangular blocky, friable, moderate effervescence, clear boundary.
2.74-3.38	C (OU)	very dark grayish brown (10YR 3/2) silt loam, weak medium subangular blocky to massive, slightly sticky slightly plastic, moderate effervescence, abrupt boundary, water table at top of horizon.

		GUNDER MEMBER HATCHER BED
3.38 -base (3.71)	2C (MDU)	dark grayish brown (2.5Y4/2) heavy silt loam, massive, slightly sticky slightly plastic, weak effervenscence, common medium brown (7.5YR 4/4) mottles, hole collapsed.