AN ABSTRACT OF THE THESIS OF

Dustin White for the degree of Master of Arts in Interdisciplinary Studies in Anthropology, Geology, and Anthropology presented on May 27, 1998. Title: Late-Quaternary Stratigraphy, Pedology and Paleoclimatic Reconstruction of the Cremer Site (24SW264), South-Central Montana: A Geoarchaeological Case Study.

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Robson Bonnichsen

This study utilizes a multidisciplinary research approach integrating the sciences of archaeology, geology, pedology and paleoclimatology. Deeply stratified and radiocarbon dated sedimentary sequences spanning the last 10,000 yr B.P. are reported for the Cremer site (24SW264), south-central Montana. Previous investigations at the site revealed an archaeological assemblage with Early Plains Archaic through Late Prehistoric period affiliations. Expanded testing of the site integrates the existing cultural record with new data pertaining to Holocene environmental changes at this northwestern Great Plains locality.

Detailed pedological descriptions were made along three trenches excavated at the site. The combined soil-stratigraphic record indicates that distinct intervals of relative landscape stability and soil development occurred at the site at ca. 10,000 yr B.P., 7,500 yr B.P. and intermittently throughout the last ca. 6,000 yr B.P. Periods of significant landscape instability (upland erosion and valley deposition) occurred immediately

following each of the early Holocene soil forming intervals identified above, and episodically throughout the middle to late Holocene. The impetus for early Holocene environmental instability is attributed to generally increased aridity on the northwestern Great Plains. Comparative analyses of site data with both regional environmental proxy records and numerical models of past climates (General Circulation and Archaeoclimatic models) are made to test the findings from the Cremer site.

The collective paleoenvironmental evidence indicates that the period of maximum post-glacial warming and aridity occurred at the Cremer site during the early Holocene period (prior to ca. 6,000 yr B.P.). These data also indicate that the existing archaeological assemblage from the site is younger than ca. 6,000 yr B.P., although future excavations may reveal cultural sequences associated with the earliest dated soils at the site. This geoarchaeological study of the Cremer site should contribute to a much needed research base in this sparsely studied region.

Late-Quaternary Stratigraphy, Pedology and Paleoclimatic Reconstruction of the Cremer Site (24SW264), South-Central Montana: A Geoarchaeological Case Study

by

Dustin White

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Chapter 1

Introduction

Problem Statement

Archaeologists have long recognized the importance of applying principles and methods from the earth and atmospheric sciences to specific cultural problems. The close ties between these disciplines are not surprising given the fact that changes in climatic and environmental conditions often initiate shifts in human adaptive strategies. The result has been the emergence of a unique multidisciplinary approach to understanding the interactions between environmental and cultural systems in both North American and world prehistory.

Researchers investigating the processes involved in the peopling of the Americas disagree as to the origins and timing of the first colonizers of the New World (Adovasio 1993; Bonnichsen and Turnmire 1991; Carlisle 1988; Dillehay and Meltzer 1991; Frison 1991). This debate involves a number of cultural issues, but also centers on the rate and timing of climatic and environmental changes both preceding and following the last glacial period. The transition from a late-glacial to post-glacial climate following the late-Wisconsin glacial maximum was accompanied by one of the most dynamic periods of late-Quaternary climatic and floral changes in North America (Barnosky et al. 1987a; Thompson et al. 1993; Webb et al. 1987). One unresolved issue is the timing and effects early-middle Holocene warming and aridity had on landscape conditions and on the human and animal populations dependent on them. This issue is further complicated by the apparent diachronic nature of maximum Holocene warmth and aridity throughout western North America (Baker 1983; Baker et al. 1992; Barnosky 1989; Barnosky et al. 1987a, 1987b; Holliday 1989; Markgraf and Lennon 1986; Mack et al. 1983; Mehringer et al. 1977; Mock and Bartlein 1995; Thompson et al. 1993; Whitlock 1993; Whitlock and Bartlein 1993).

For the region of the northwestern Great Plains (Figures 2.1 and 2.10), few studies concerning late-glacial/post-glacial environmental transitions have been reported (Barnosky 1989; Barnosky et al. 1987b). This area is particularly important considering its geographic proximity to the "ice-free corridor" and the convergence of a variety of ecological zones. The Cremer site is located within this topographically complex and marginally studied region, and serves as an important research site for investigating the nature of post-glacial climatic and environmental changes and responses in human adaptive strategies (see Appendices A and B).

Previous Work at the Cremer Site

The long presence of aboriginal North Americans in central Montana is well established (Davis 1993; Frison 1991; Lahren 1976; Lahren and Bonnichsen 1974; Mulloy 1958). Mulloy's (1958) study was one of the first comprehensive investigations of prehistoric cultural sequences on the northwestern Great Plains. With the reporting of a number of additional sites, Frison (1991) developed a slightly revised cultural chronology for this region that today many Plains archaeologists utilize. Frison's cultural chronology for the northwestern Great Plains is shown in Figure 1.1.

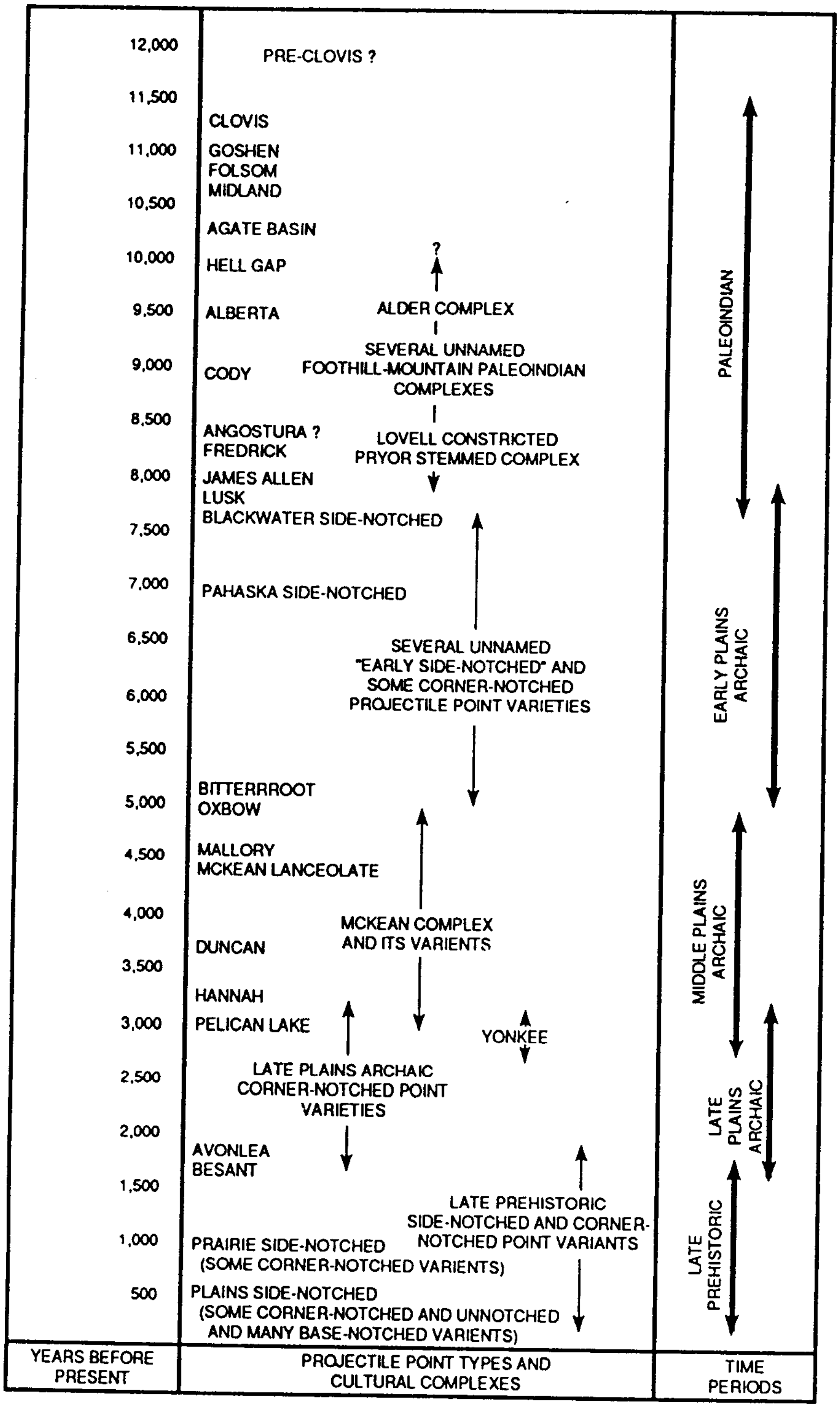

Figure 1.1. Northwestern Plains chronological chart (Frison 1991).

Excavations at the Cremer site have revealed a distinct series of human occupation levels that have been compared to the Plains cultural chronology reported by Frison (1991). Stone artifacts were first found at the site in the 1950's by landowner George Cremer. Recognizing the significance of these findings, G. Cremer contacted Dr. Larry Lahren who arranged for German graduate student Gabriele Nowatzyk to initiate her Master's research project at the site in 1979 and 1980. Results from these earliest investigations at the Cremer site are summarized below.

The Cremer site has been interpreted as a stratified, multi-component open-air campsite dating to the middle-Holocene period (Nowatzyk 1983; White et al. 1997). During the 1979/1980 field seasons, 14 contiguous square meters of the site were exposed along a stream cutbank (see Figure 4.1) to a mean depth of 150 centimeters. These excavations unearthed a rich archaeological assemblage consisting of flaked stone tools, hearths and fire-cracked rocks, rock features and posthole depressions (indicating the construction of temporary dwellings at the site). Additionally, a variety of faunal remains were recovered, including bison (*Bison bison*), antelope (*Antliocarpa american*), white-tailed deer (*Odeocolieus americanus*), as well as canids. The fragmentary nature of many of the remains suggests that bone was routinely processed at the site for marrow extraction and bone grease. The collective artifact assemblage from the Cremer site was reported by Nowatzyk (1983) to represent at least five occupation sequences with Early Plains Archaic through Late Prehistoric period affiliations (Figure 1.2).

The five cultural bearing levels are embedded in a series of fossil soils (buried A horizons) separated by overbank deposition of alluvium during periods of flooding and/or accelerated streamflow. Nowatzyk's interpretation of the natural and cultural record

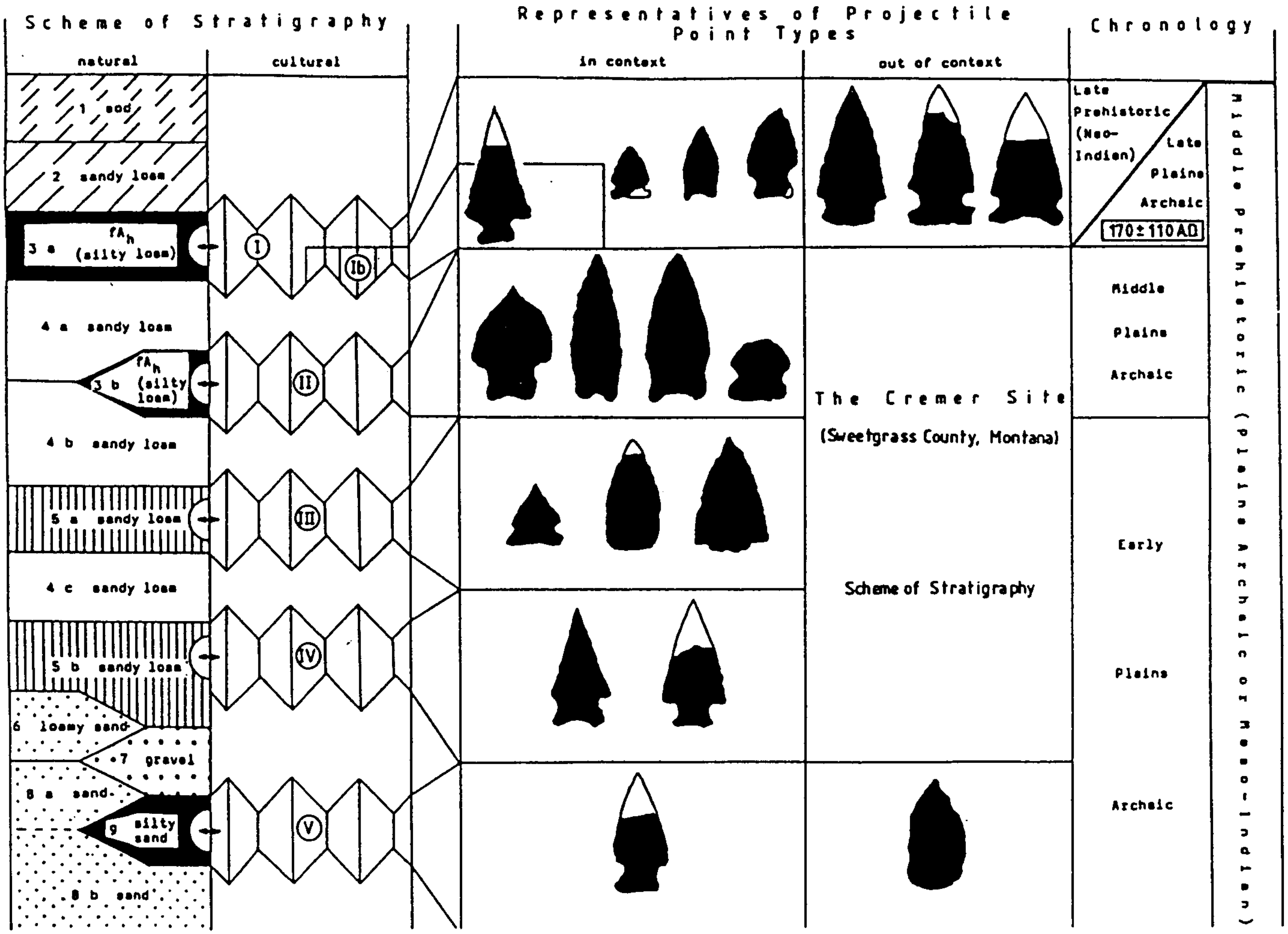

Figure 1.2. Summary of the natural and cultural stratigraphy of the Cremer site identified in 1979/1980 (Nowatzyk 1983).

suggests that human groups inhabited the Cremer site during distinct intervals of relative climatic and environmental stability (which fostered soil development), and likely abandoned it during episodes of increased upland erosion and valley deposition (landscape instability).

In total, Nowatzyk (1983) identified 13 "natural layers" represented in the site stratigraphy (Figure 1.2). The oldest cultural level (i.e., Cultural Layer V) occurs within a very thin (maximum 5 centimeters) and discontinuous "silty sand layer of dark brown shade" (Natural Layer 9). Forty-two artifacts were recovered from Cultural Layer V, including two side-notched projectile points. A distinct "sand layer" (Natural Layer 8) and "gravel layer" (Natural Layer 7) directly overlie the earliest cultural bearing stratum. The unmistakable character of the gravelly deposit serves as an important geologic marker in correlating stratigraphic observations made in 1979/1980 with those of the present study. A single leaf-shaped projectile point was found within the redeposited materials of Natural Layer 7.

Soil development (Natural Layer 5b) overlying the gravel layer designates Cultural Layer IV. In some locations, a "loamy sand" (Natural Layer 6) separates the underlying gravel deposit from Layer 5b. Of the 460 artifacts recovered from Cultural Layer IV, 15 are projectile points, including six corner-notched and eight side-notched points. A thin lens of alluvium (Natural Layer 4c) derived from overbank flood deposition separates Cultural Layer IV from overlying Cultural Layer III. This latter cultural bearing stratum occurs within the soil horizon identified as Natural Layer 5a. Seven of the 164 artifacts recovered from Cultural Layer III are projectile points. The similarity in pedologic and cultural attributes of Layers IV and III indicates a close temporal relationship between these occupation sequences (Nowatzyk 1983).

Following this extended period of occupation at the Cremer site, inhabitants likely relocated as renewed alluvial deposition (Natural Layer 4b) buried Cultural Layer III (Natural Layer 5a). Overlying this alluvial deposit is another fossil soil horizon, identified as Natural Layer 3b and Cultural Layer II. Of the 735 artifacts recovered from this level, eight were projectile points, including two "McKean" points and three "Duncan" points. These projectile point typologies have traditionally been viewed as diagnostic indicators of the Middle Plains Archaic period (Frison 1991; Todd and Kornfeld 1985; see Figure 1.1).

Renewed alluvial deposition (Natural Layer 4a) during a period of flooding at the site separates Natural Layer 3b from Layer 3a, another identified fossil soil (buried A horizon). Overlying Layer 3a is a "heavily rooted sandy loam" (Natural Layer 2) which is capped by the "sod layer" (Natural Layer 1). Natural Layers 3a, 2 and 1 have all been designated as Cultural Layer I, as artifacts were present in all of these highly bioturbated horizons. Of the 457 artifacts recovered from Cultural Layer I, nine were projectile points, including several with Pelican Lake, Avonlea and post-Avonlea affiliations. According to Nowatzyk (1983: 67), the possibility that more than one occupation sequence is represented in Cultural Layer I appears reasonable.

The cultural chronology reported by Nowatzyk (1983) is primarily based on relative dating techniques, including the typological comparison of diagnostic projectile points from the Cremer site with those recovered from other sites that have more precise chronological controls. However, during a pre-excavation survey of the site conducted by Dr. L. Lahren in 1978, a charcoal sample collected from a sub-surface feature yielded a radiocarbon age (in calendar years) of A.D. 170 $\pm$ 100 years (RL-1296) (Nowatzyk 1983: 68). Unfortunately, the provenience of the associated feature lacks precise correlation with the site's reported stratigraphy (which was not adequately described and mapped until a year later). Although this radiocarbon age has been assigned to Natural Layer 3a (Cultural Layer I), there remains some uncertainty as to the true provenience of this charcoal sample. As will be discussed later, new radiocarbon determinations from the Cremer site (i.e., from Trench 1) call into question the temporal accuracy of the identified cultural levels and the overall antiquity of the existing archaeological assemblage from the Cremer site.

One of the principal conclusions drawn from the 1979/1980 excavations at the Cremer site is the possibility that the site represents an "altithermal" occupation of the western Plains of Montana (Nowatzyk 1983: 89). As will be discussed later, the term "Altithermal" (or the "Atlantic" climatic period of the Blytt-Sernander system) has been used to describe a prolonged period of warmth and aridity in western North America spanning the early-middle Holocene periods. A number of researchers have suggested that during this interval of intensified drought conditions, the Plains were at times either entirely abandoned by human and game populations or reduced to a few small hunter-gatherer bands occupying foothill and mountain regions peripheral to the Plains landscape (Frison 1975; Hurt 1966; Mulloy 1958; Wedel 1961). This idea of a climatically induced cultural hiatus in northern Plains prehistory is not without its detractors. For example, Reeves (1973) argues that the paucity of evidence for human occupation on the Plains during the "altithermal" period is a result of sampling biases, geological factors and problems relating to the recognition of artifact typologies. However, only through continued interdisciplinary research efforts will a more complete understanding of past environmental and cultural relationships on the northwestern Plains be revealed. The present study is designed to contribute toward this end.

Objectives of Study

There is a growing body of literature which illustrates the important role soils can play in archaeological investigations (Birkeland 1984; Holliday 1990, 1992; Rapp and Hill 1998; Reider 1990; Schiffer 1987; Waters 1992; to name only a few). While the uses of soil data depend on specific research questions, some of the more common archaeological applications include their use as stratigraphic markers, as a means of numerical dating, and as inputs to climatic and environmental reconstructions of a site or region. Such information can be highly valuable to researchers who seek to understand the relationships between natural and cultural landscapes.

The objective of this study is to understand the processes involved in the evolution of the Cremer site locality and to recognize the influence that these processes have had on soil formation and sedimentation patterns. In this context, soil-stratigraphic data is used to provide a paleoclimatic and paleoenvironmental framework for the archaeological record from the Cremer site. Specific research objectives include the following:

(1) presentation of a detailed description of site geomorphology, stratigraphy and pedology;

(2) identify soil-stratigraphic indicators of climate and environmental change;

(3) reconstruct a chronological model of the post-glacial evolution of the Cremer site locality;

(4) compare inferred paleoclimatic evidence from the Cremer site to both regional environmental proxy records and numerical models (General Circulation and Archaeoclimatic models) of past climates; and

(5) relate the collective geoarchaeological evidence from the Cremer site to general ecological and cultural sequences on the northwestern Great Plains following the last glacial period.

Organization of Study

This thesis is organized into a series of chapters designed to address the research objectives outlined above. Following this introductory chapter, which has discussed the research problem at hand and provided a brief background to previous work conducted at the Cremer site, Chapter 2 reviews the physical setting of the study area. This section describes the geologic and topographic character of the Cremer site, including the drainage network unique to this locality. Additionally, special attention is given to the modern climate of the study area through the review of climate records from weather stations located near the Cremer site. This analysis of modern climatic conditions in central and south-central Montana is important in understanding how past climatic patterns differed from those of the present. Chapter 2 concludes with a summary of the soil and plant taxonomic classes occurring at the Cremer site.

In Chapter 3, a review of research methods is presented. This section summarizes the field techniques utilized during the 1995/1996 site investigations, including trench excavations and soil-stratigraphic profile descriptions. Additionally, laboratory techniques used for data analyses are discussed. These include particle size and organic carbon testing of collected soil samples, species identification of charcoal samples as well as procedural considerations and results from submitted radiocarbon samples. Finally, a brief introduction to paleoclimate modeling techniques concludes Chapter 3.

Chapter 4 presents a detailed description of the geomorphic and sedimentological character of the Cremer site. This chapter is organized into three main sections, one for each of the three trenches excavated at the site (i.e., Trench 1, Trench 2 and Trench 3). For each trench, the associated landform morphology is evaluated, followed by a detailed review of the major stratigraphic and pedologic attributes observed along the trench walls. At the end of each of these sections is a synthesis of the inferred paleoclimatic conditions reflected in the observed profiles and a general reconstruction of the post-glacial evolution of the landform. "Plates" of each trench are provided in the sleeve of this thesis to illustrate the major stratigraphic units comprising each landform. The conclusion of Chapter 4 includes a general assessment of the significance of site stratigraphy to paleoclimatic reconstructions of central Montana.

In Chapter 5, a review of regional climate research in areas surrounding the Cremer site is presented to provide a broader context of the paleoenvironmental setting of the northwestern Great Plains. Additionally, results from both General Circulation Modeling (GCM) and Archaeoclimatic (site-specific) modeling techniques applicable to the site and its setting are discussed and compared to the inferred paleoclimatic conditions derived from the Cremer site soil-stratigraphic record. An evaluation is made as to which model output best supports the field data.

In the concluding chapter (Chapter 6), a summary of the general paleoenvironmental setting of the Cremer site is presented. Results from this new research are then compared to the site's archaeological record to better understand past environmental and cultural relationships, and the chronological boundaries of the defined cultural sequences. The thesis concludes by providing suggestions as to how future research efforts might contribute to a broader understanding of post-glacial climate changes and cultural sequences at the Cremer site, and for the northwestern Great Plains in general.

Chapter 2

Physical Setting of the Study Area

Site Location

The Cremer site is located in the northeast corner of Sweetgrass County, Montana (Township 4 North, Range 16 East, Section 4; lat. 46° 07' N., long. 109° 40' W.). This part of south-central Montana occupies a transitional position between the northwestern Great Plains and the eastern edge of the Rocky Mountain Front (Figure 2.1). The general character of the topography in the immediate vicinity surrounding the site area is rolling to hilly, dissected high plains, with elevations ranging from 4,800 to 5,300 feet (1,463 to 1,615 meters) above sea level (asl). The elevation of the Cremer site itself is approximately 4,885 feet (1,489 meters) (see Figures 2.5 and 4.1).

Geologic Structure and Bedrock

Interbedded sandstones and shales of the Tertiary (Paleocene) Fort Union Formation form the bedrock of the Cremer site locality. The development of Fort Union strata is closely tied to mountain building activity in the late Cretaceous and early Tertiary periods. During this time, tectonic compressional forces known as the Laramide Orogeny were creating the Rocky Mountains to the west. This orogenesis resulted in many of the prominent topographic and structural features that exist today in Montana. As the mountains rose, the Cretaceous Interior Seaway of North America began to retreat, and the rivers and streams extending from the newly formed mountains deposited vast amounts of sediment on the gently sloping plain to the east. Many of the large structural

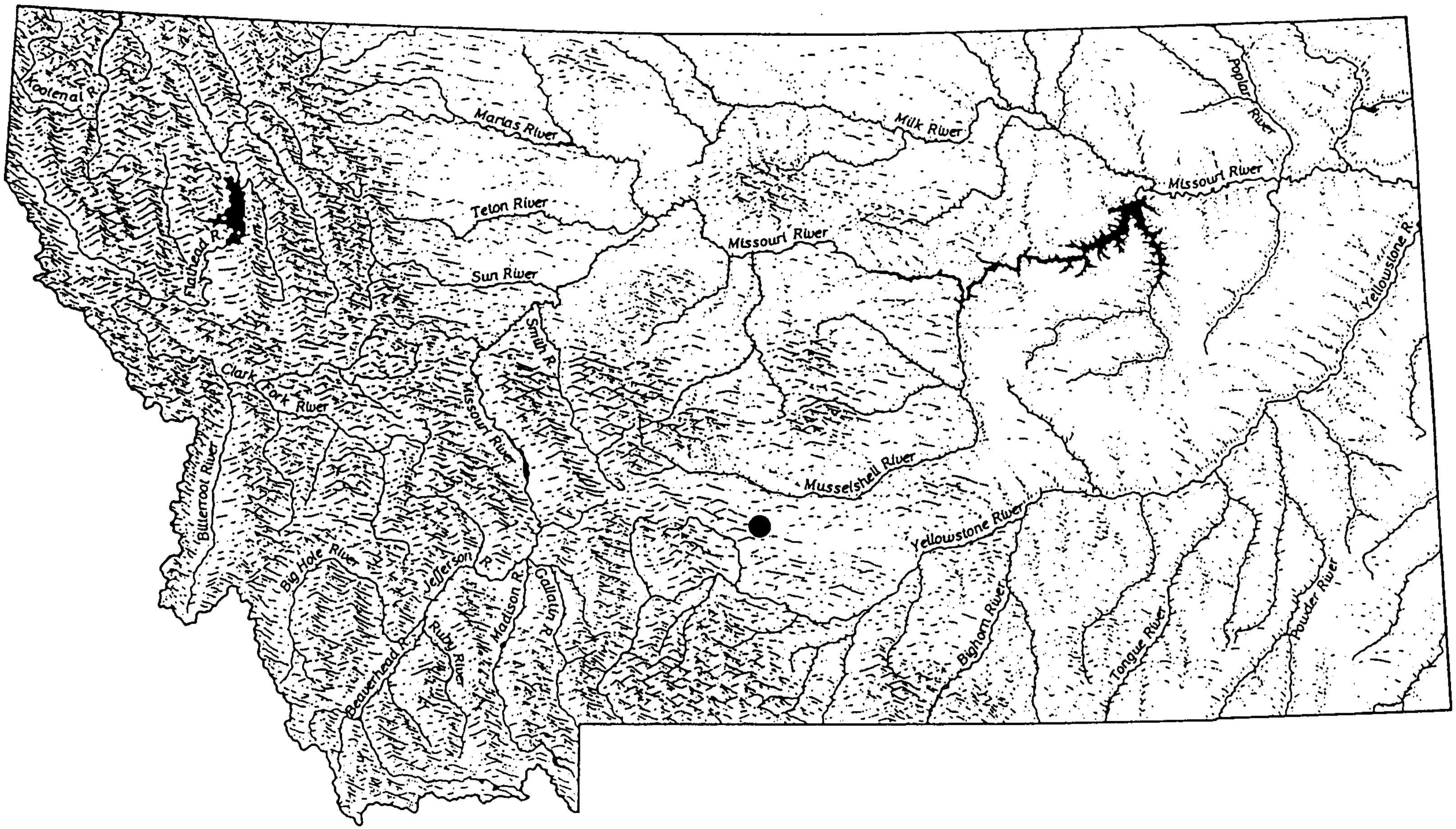

Figure 2.1. Physiographic map of Montana (Malone et al. 1991).

basins in central and eastern Montana became sediment traps as the eroding mountains supplied an abundant source for basin infilling.

The topographic and structural setting of central Montana is very complex. Three major physiographic provinces intersect in this general region, including the Northern Rocky Mountain Province; the Middle Rocky Mountain Province; and the Unglaciated Missouri Plateau of the Great Plains Province (Figure 2.2). Additionally, to the east of the Rocky Mountain Divide, a number of isolated mountain ranges rise abruptly above the Plains landscape. The contrasting topography throughout central Montana allows for unique combinations of geologic materials, climate, flora and fauna to exist within relatively closely spaced areas.

The structural component of the Cremer site is part of the northeastern marginal area of the Crazy Mountains Basin (Figure 2.3). The Crazy Mountains Basin is both a physiographic depression and a structural basin, bounded on the north by the Castle Mountains and the Shawmut anticlinal trend, and on the northeast by the Huntley-Lake Basin Fault Zone (Garrett 1972: 113). Smith (1965: 1401) describes the 200 kilometer long Huntley-Lake Basin Fault Zone as a classic example of *en echelon* tensional fractures resulting from transcurrent movements at depth. This fault zone strikes in a west-northwesterly direction with the multitude of *en echelon* normal faults striking in a northeastward direction (Smith 1965).

The complex genesis of the Crazy Mountains Basin has resulted in the formation of a number of diverse geologic structures. The northeastern rim of the Crazy Mountains Basin is situated near the juncture between the southeast margin of the Shawmut anticlinal trend and the northwestern terminus of the Huntley-Lake Basin fault zone.

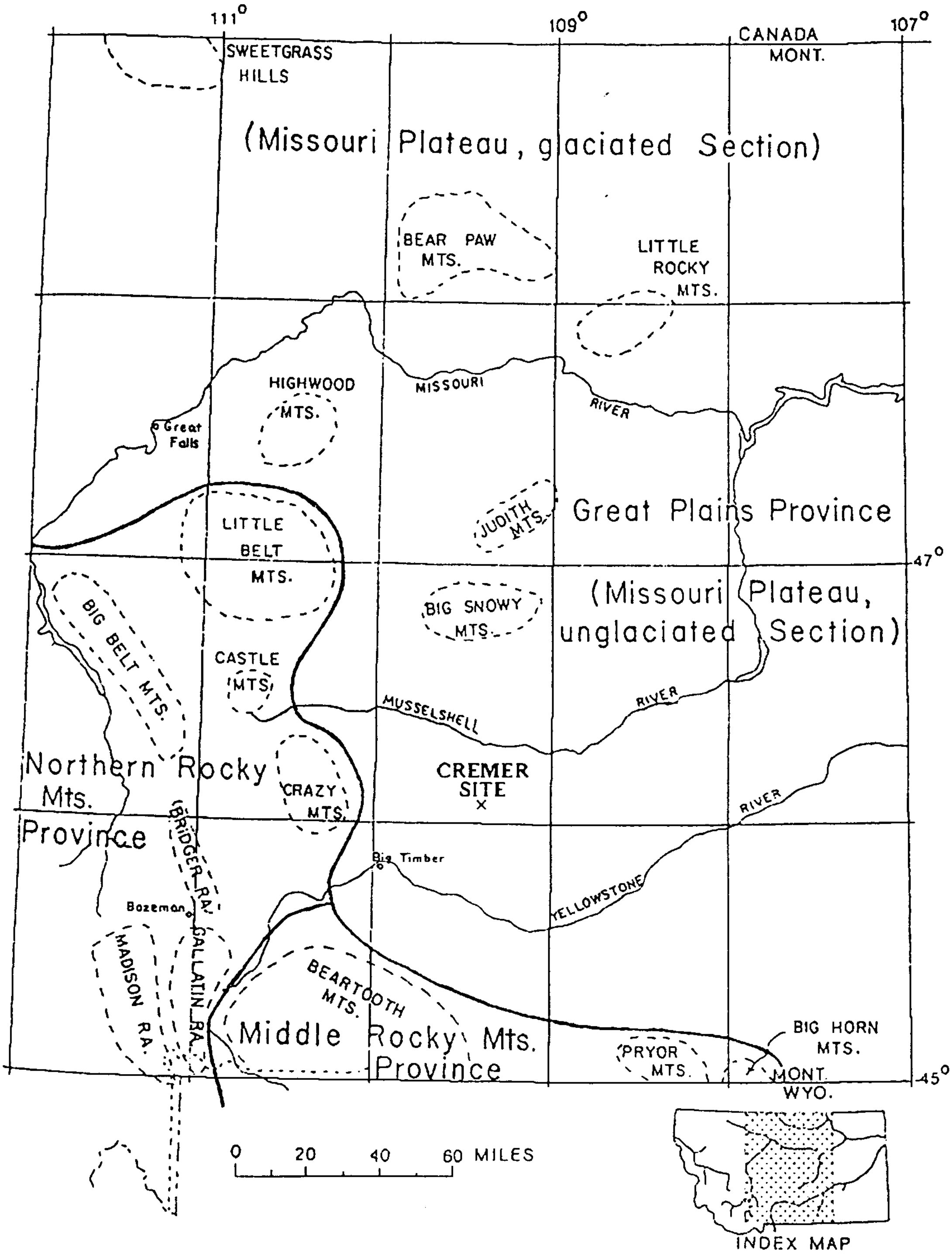

Figure 2.2. Physiographic divisions of central Montana (modified from Aten 1974).

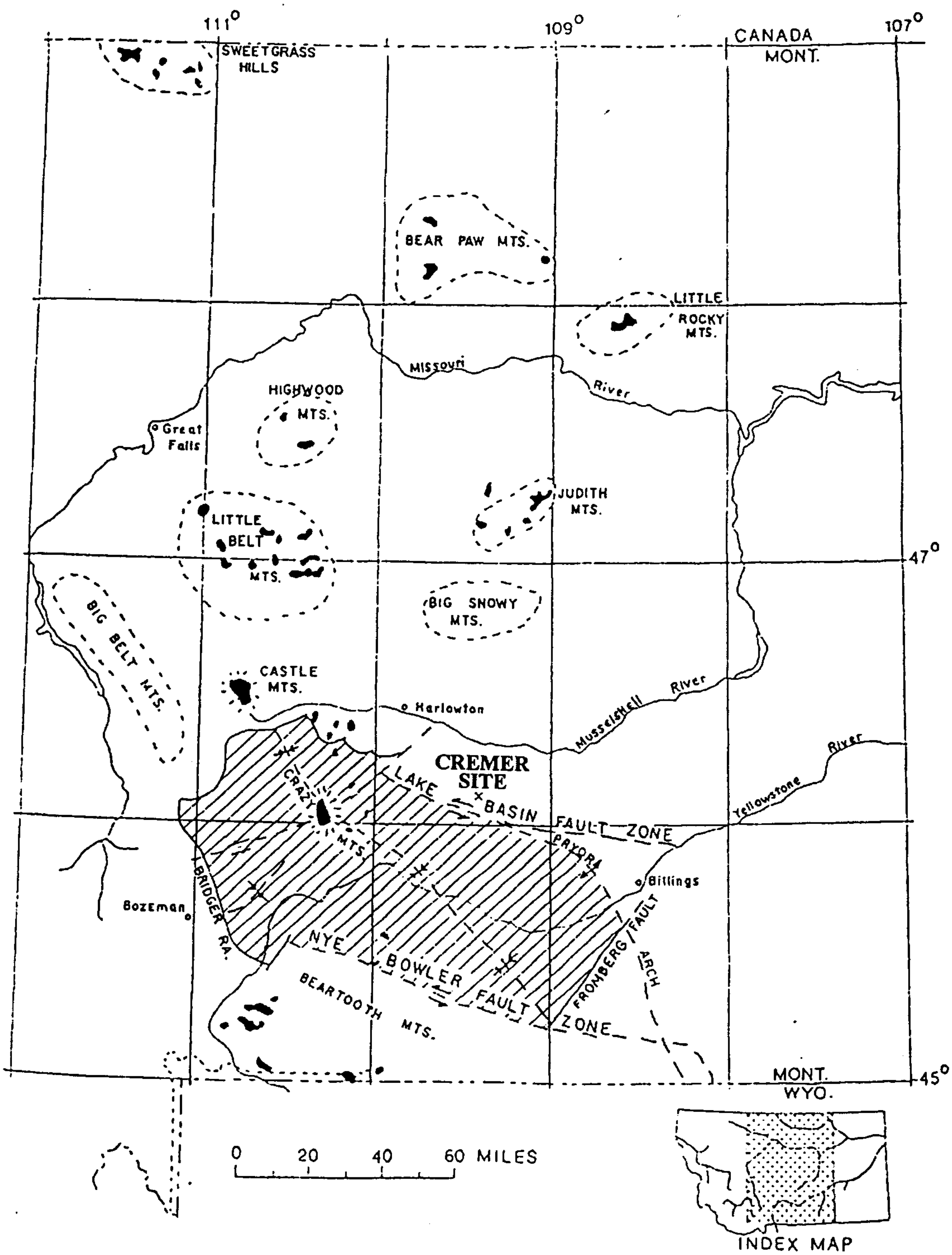

Figure 2.3. Crazy Mountains Basin and Tertiary intrusives east of the Rocky Mountain Front (modified from Aten 1974).

In this general region of south-central Montana, geologic strata have been folded mainly due to stresses associated with strike-slip movements along the Lake Basin Fault Zone (David Lopez, personal communication, 1997). However, more detailed geologic mapping will be required to fully delineate specific structural features present in the Cremer site area.

The northern Crazy Mountains Basin is extraordinarily rich in both fossil mammals and non-marine mollusks. Much of the geological work undertaken in this part of south-central Montana has focused on establishing a biostratigraphic reference section of late Cretaceous and early Tertiary aged strata for the northern Great Plains (Hartman 1989: 170). Discoveries of fossil mammals and mollusks in the Crazy Mountains Basin have been reported since the beginning of this century (Simpson 1937; Fields 1956). Since then, a number of important new quarry sites have been investigated that provide an overall framework for Paleocene biostratigraphic and biochronologic correlation in the northern Great Plains (Hartman 1989; Hartman et al. 1989; Hartman and Krause 1993). The collective mammalian and molluscan fossil assemblage from the northern Crazy Mountains Basin makes this region only the second depositional basin in North America where quarry assemblages of early, middle, and late Paleocene age are present in demonstrable superposition (Hartman and Krause 1993: 79).

Investigations of these fossil-bearing quarries are closely related to lithostratigraphic studies of central Montana. The sequence of sedimentary rocks exposed along the ridges and hillslopes surrounding the Cremer site are all part of the Paleocene Fort Union Formation. According to Veseth and Montagne (1980: 74), the Fort Union Formation consists of variable floodplain sediments deposited on a topography of low relief with numerous ponds and swamps. This non-marine formation is generally divided into three members, in ascending order, the Tullock (sandstone), Lebo (shale), and Tongue River (sandstone), respectively. It is believed that the shaley member was deposited in a low-energy ponded environment and the sandy members were deposited along river and stream channels in a broad fluvial and floodplain environment.

The terminology used to identify members of the Fort Union Formation in south-central Montana is still debated (Hartman 1989; Hartman et al. 1989). The traditional approach, following the USGS, is to describe the Paleocene units of the Fort Union Formation as the Tullock, Lebo and Tongue River members (Hartman 1989: 163). However, strata that are chrono-stratigraphically equivalent to the Tullock and Tongue River members found in the northeastern part of the Crazy Mountains Basin are lithologically distinct from the original type sections described in eastern Montana and northeastern Wyoming. This distinctiveness in lithologies has led geologists working in the Crazy Mountains Basin to use the terms Bear and Melville for strata equivalent in age to the Tullock and Tongue River members, respectively. Hartman (1989: 163) cautions, however, that these terms are used knowing that additional study of their sedimentology and provenience is necessary to substantiate their continued use.

Of the three units that comprise the Fort Union Formation, only the Lebo member and overlying Melville (Tongue River) member were identified in exposures and outcrops surrounding the immediate area of the Cremer site (Figure 2.4). The basal unit of the Fort Union Formation, the Bear (Tullock) member, was identified from geologic maps published by Hartman (1989) as occurring approximately 2 miles to the east of the Cremer site locality. Investigations at Simpson Quarry (Hartman et al. 1989), several

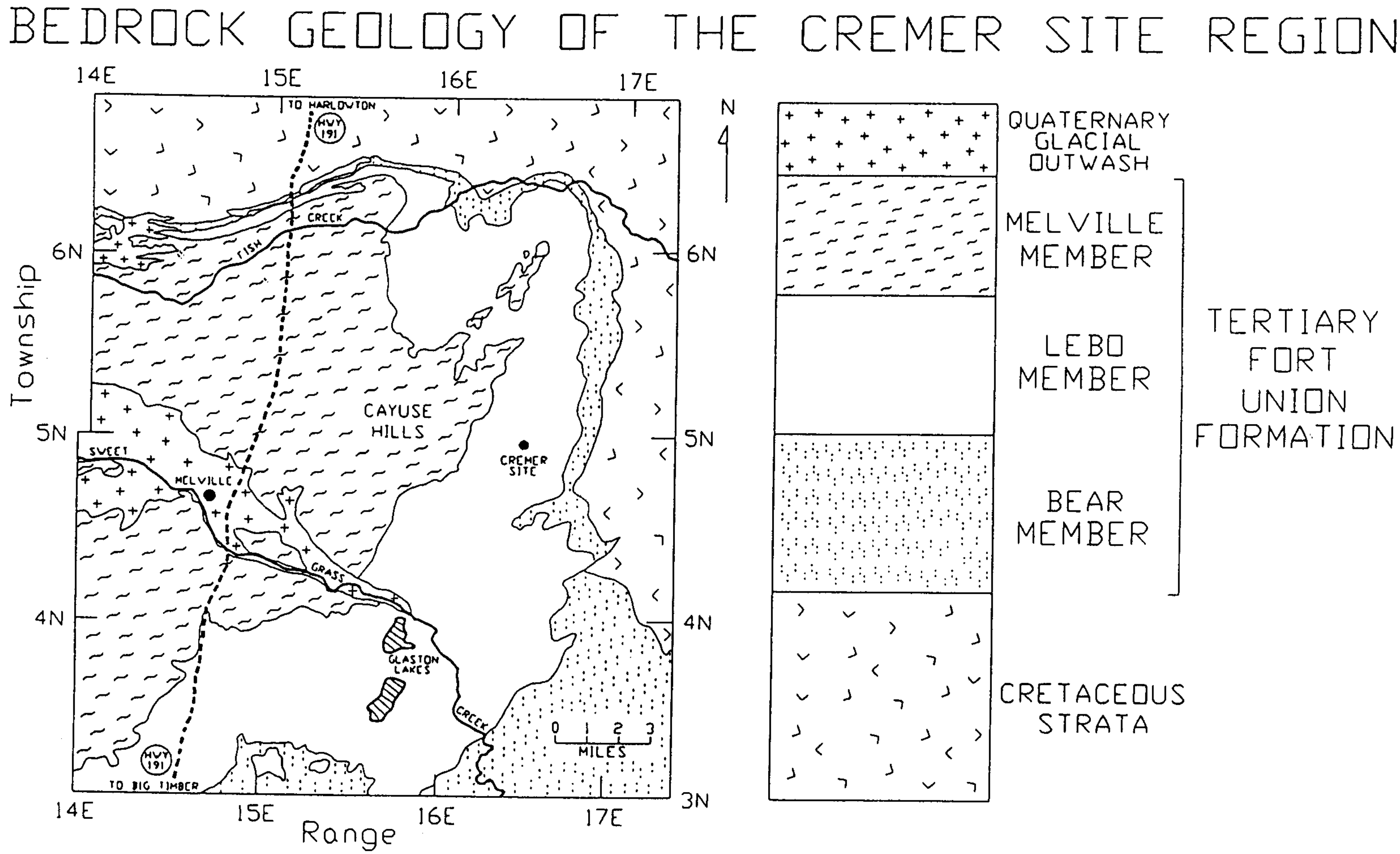

Figure 2.4. Bedrock geology of the Cremer site region (modified from Hartman and Krause 1993).

miles to the northwest of the Cremer site, revealed the Bear (Tullock) member to consist predominantly of buff to gray, fine-grained calcareous sandstones and siltstones, gray calcareous shales, and dark-green to brown organic-rich shales. Although it is the least studied of the Fort Union members in south-central Montana, the assemblage of mammal fossils recovered from Simpson Quarry is among the largest and most diverse of currently described Puercan Land-Mammal Age assemblages from the Western Interior of North America, which represents an important period in the early evolutionary history of placental mammals (Hartman et al. 1989: 179).

Overlying the Bear (Tullock) member is the Lebo Shale member. The Lebo member is a fine textured, dark gray to olive-green clayey alkaline shale, with thin fine-grained sandstone and sandy shale lenses (Veseth and Montagne 1980: 76). In south-central Montana, this formation commonly weathers to form a series of variously inclined hogbacks and blow-out riddled grassed valleys (Hartman et al. 1989: 76). The Cremer site locality, including the grass covered hills and buttes that immediately surround the site, are all part of the Lebo Shale member (see Figure 2.4 and Appendices A and B).

Strata of the overlying Melville (Tongue River) member are identified as the steep sandstone escarpments that cap the upland areas approximately 2 miles to the west-northwest of the Cremer site (see Appendix A). Hartman and Krause (1993: 76) describe the Melville (Tongue River) member as consisting primarily of a basal, yellow to off-white sandstone overlain by olive-green shales and sandstones. Veseth and Montagne (1980: 76) describe the Tongue River member in general as being composed of soft

interbedded light yellow to yellowish gray, lenticular sandstones, yellowish gray siltstone, gray claystone and shale, thin dark carbonaceous shale, coal seams and clinker.

The strata of the upper Lebo and lower Melville (Tongue River) members span the transition from the middle Paleocene (Torrejonian Land-Mammal Age) to the late Paleocene (Tiffanian Land-Mammal Age) (Hartman and Krause 1993: 71). The lithostratigraphic contact between these two members is often identified by the grass-coniferous tree line along the surface exposures of sandstone ridges (see Appendix A). The resistant sandstone of the Melville (Tongue River) member makes distinct bouldery outcrops, and the pore spaces between the clastic particles can often hold enough water to support healthy stands of coniferous trees.

Topography and Drainage

The topography of central Montana includes both rolling to hilly grasslands and isolated mountain ranges that project distinctly above the Plains landscape (Figure 2.2). Many of these mountain summits rise between 2,000 and 5,000 feet (610 and 1,524 meters) above the surrounding Plains topography, with the Crazy Mountains having the closest proximity to the Cremer site. These isolated mountain ranges would have provided prehistoric human groups with a number of important resources that were not available on the Plains to the east, and may have served as important "refuge areas" during times of climatic stress (Hurt 1966).

The Cremer site lies approximately 30 miles (48 kilometers) northeast of the Crazy Mountains, within the rugged and dissected uplands of the Cayuse Hills. The Cayuse Hills consist of a distinctive series of buttes and ridges which were formed primarily as a result of folding and differential stream erosion of the sandstone and shaley members of the Fort Union Formation. This region lies at the northeast margin of the

Crazy Mountains Basin and forms the divide between the Yellowstone River and Musselshell River drainage basins. The higher part of this divide to the north and east of the town of Melville (near the Cremer site) is eroded into steep hills and buttes, and to the southeast these hills and buttes grade into an undulated divide several miles wide in places (Anonymous 1956).

The Cremer site is located at the outlet of a very poorly drained basin (the Anderson Haymeadow) near the headwaters of Antelope Creek, a tributary of the Musselshell River (see Figure 2.5 and Appendix B). The north-south oriented basin is fed by an active springhead(s) in the upper watershed above the Anderson Haymeadow. The small basin appears to have been formed by water and wind erosion of the softer shales and siltstones that occur between more resistant sandstone units. No evidence for former elevated shorelines was found along the margins of the basin (the Anderson Haymeadow) while ground surveying the area. Their presence would have indicated that the basin supported a small pond during the late-Pleistocene or at some other time in the past. The absence of shoreline features is consistent with the concept that Antelope Creek has maintained its position during the late-Quaternary period, downcutting faster than any regional uplifting. Any damming of the basin's outlet stream (Antelope Creek) due to landslides or slumping would have likely been short-lived. However, the presence of active springs in the upper watershed of Antelope Creek, and the basin's persistent high water table, suggest that marshy conditions could have existed in the basin during wetter periods, making this an attractive location for both human and animal populations during the past.

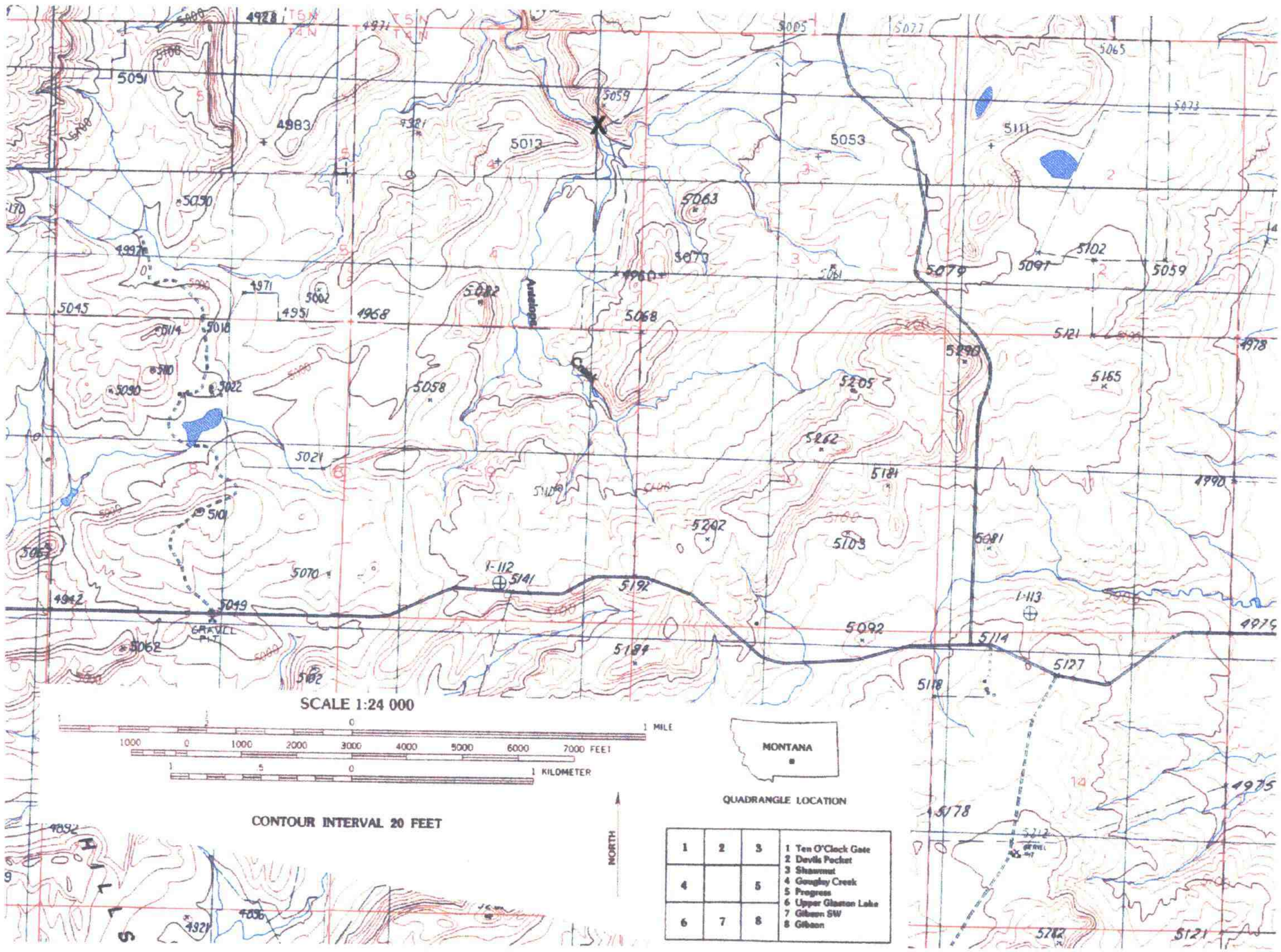

Figure 2.5. Topographic map of the Cremer site (20 feet contour interval) (USGS Jim Creek quadrangle 1985).

The hillslopes, terrace benches and colluvial-alluvial floodplain deposits that comprise the Cremer site are all substantially influenced by three small streams that converge within the site locality (see Figures 2.5 and 4.1 and Appendix B). Immediately upstream from the site, approximately two square miles of watershed or total catchment area is drained by Antelope Creek and its tributaries. The main stem of Antelope Creek enters the site area at the north end of the poorly drained basin. This section of Antelope Creek has a distinctive meandering pattern along its course through the basin, which reflects the generally high water table and low stream gradient. The morphology and stream character of the basin indicates that colluvial-alluvial derived sediments in the Anderson Haymeadow have generally been aggrading throughout the Holocene, unable to be adequately transported out of the basin by the low gradient stream.

The two tributary streams that converge with Antelope Creek within the site locality are more intermittent in character. Stream flow along these tributaries occurs primarily during the spring and early summer seasons, when precipitation is at a maximum and the rising water table comes into contact with the streambed (or as surface runoff during periods of unusually high precipitation). These tributaries often run dry by late summer as the water table falls below the bed of the channel, and thus remove the stream from baseflow. However, due to their steeper gradient and capacity to accommodate accelerated streamflow, these tributary streams have contributed a substantial portion of the alluvial deposits that are found at the Cremer site, as well as to repeated episodes of landform scouring in the past.

The tributary streams enter the main stem of Antelope Creek from the northeast only a short distance from one another (see Figure 4.1). The micro-interfluves that separate these streams were the locations selected for 2 of the 3 backhoe trenches which form the basis of this study. The stratigraphy exposed along the trench walls provides clear evidence of periods of high stream flow during the past. The sequence of alluvial-colluvial deposits at the Cremer site reflect episodes of tributary stream headcutting (erosion) with subsequent deposition downstream.

Approximately 1/2 mile downstream from where these intermittent tributaries meet the principal stream, the valley of Antelope Creek is strongly constricted by thick beds of sandstone that are considerably harder and more resistant to erosion than the other bedrock in the area (see Figure 2.5). Very steep hills of interbedded sandstone and shale (including some prominent sandstone cliffs) lie immediately to the west and to the northeast of the stream in this vicinity. The contact between the upper sandstone (Melville/Tongue River) and underlying shale (Lebo) members of the Fort Union Formation can be identified along the steep slopes to the northwest across the valley of Antelope Creek from this location as well. The resistant sandstone, being underlain by softer shales, creates a series of landforms with abrupt vertical bluff tops with steep scree slopes beneath. From this location, Antelope Creek and its tributaries flow to the north into Tony Creek, which in turn flows in a northeasterly direction into Fish Creek before intersecting the east-flowing Musselshell River near the town of Ryegate, Montana.

Springs

During the 1995 field season, it was determined that at least one spring emerges from the base of a sandstone terrace escarpment along the northernmost tributary stream, just a short distance from its confluence with Antelope Creek. This gravity spring, or seep, is under no confining pressure, and water slowly drains from the underground source to the surface through fissures in the porous sandstone bedrock. Abundant precipitation in 1995 and consequent summer flow in a normally intermittent stream made it difficult to determine exactly how many springs occur along the terrace escarpment (Beatty 1996).

During the 1996 field season, drier conditions and reduced summer flow (lowered water table) revealed that only a very small spring was presently active along the sandstone escarpment. The spring's reduced flow in 1996 suggests that its groundwater source is not distinctly perennial and that it could remain inactive during very dry years or during periods of prolonged drought. Nonetheless, during years of abundant or adequate precipitation, the springs occurring near the Cremer site would have been a reliable water source for both humans and other animals.

Climate

Climate of the North American Plains

The shortgrass Plains of Montana have one of the most variable climates in North America. The climate of this region is classified as semiarid continental, exhibiting wide seasonal and annual variations in temperature and precipitation, with strong winds common year-round. These general climatic trends are largely the result of the modifying influences surrounding topography has on prevailing atmospheric circulation patterns.

The synoptic climatology of the northwestern Great Plains, and of the continental interior in general, is affected by the trajectories of three prevailing air masses: the Mild

Pacific, the Arctic, and the Tropical Maritime. The high mountains of the Continental Divide to the west of the Plains intercept moisture from air masses originating over the Pacific Ocean. Although the Great Plains are in the path of this prevailing westerly circulation, most precipitation is dropped as rain and snow on the higher mountains and very little reaches the Plains to the east, creating a strong "rainshadow effect". The dry continental air that flows down the eastern slopes of the Rocky Mountains continues across the Plains to the east, significantly modifying the influences of neighboring air masses. Generally, the overall low precipitation of the shortgrass Plains region is the result of dominating dry Mild Pacific air circulation.

During the winter season, cool and dry Pacific air circulation typically dominates on the Plains, resulting in strong westerly flows and low precipitation. Periodic "blasts" of cold arctic air moving down from Canada can inundate much of the Great Plains during this season. These frigid invasions, however, are fairly infrequent and generally short-lived. Intrusions of cold arctic air are often followed by periods of warm "chinook" winds that move down the eastern slope of the Rocky Mountain Front and onto the Plains to the east.

The spring and early summer seasons bring a precipitation maximum to the region surrounding the Cremer site (Figure 2.6). This general pattern results when Mild Pacific air circulation weakens and allows for intrusions of moist Arctic air from Canada and Tropical Maritime air originating from easterly monsoonal flows out of the Gulf of Mexico. The spring-early summer precipitation maximum of the Great Plains region typically drops off sharply by mid-summer as dry Pacific air returns to the shortgrass Plains. The steep rainfall gradient associated with the summer mean frontal position of

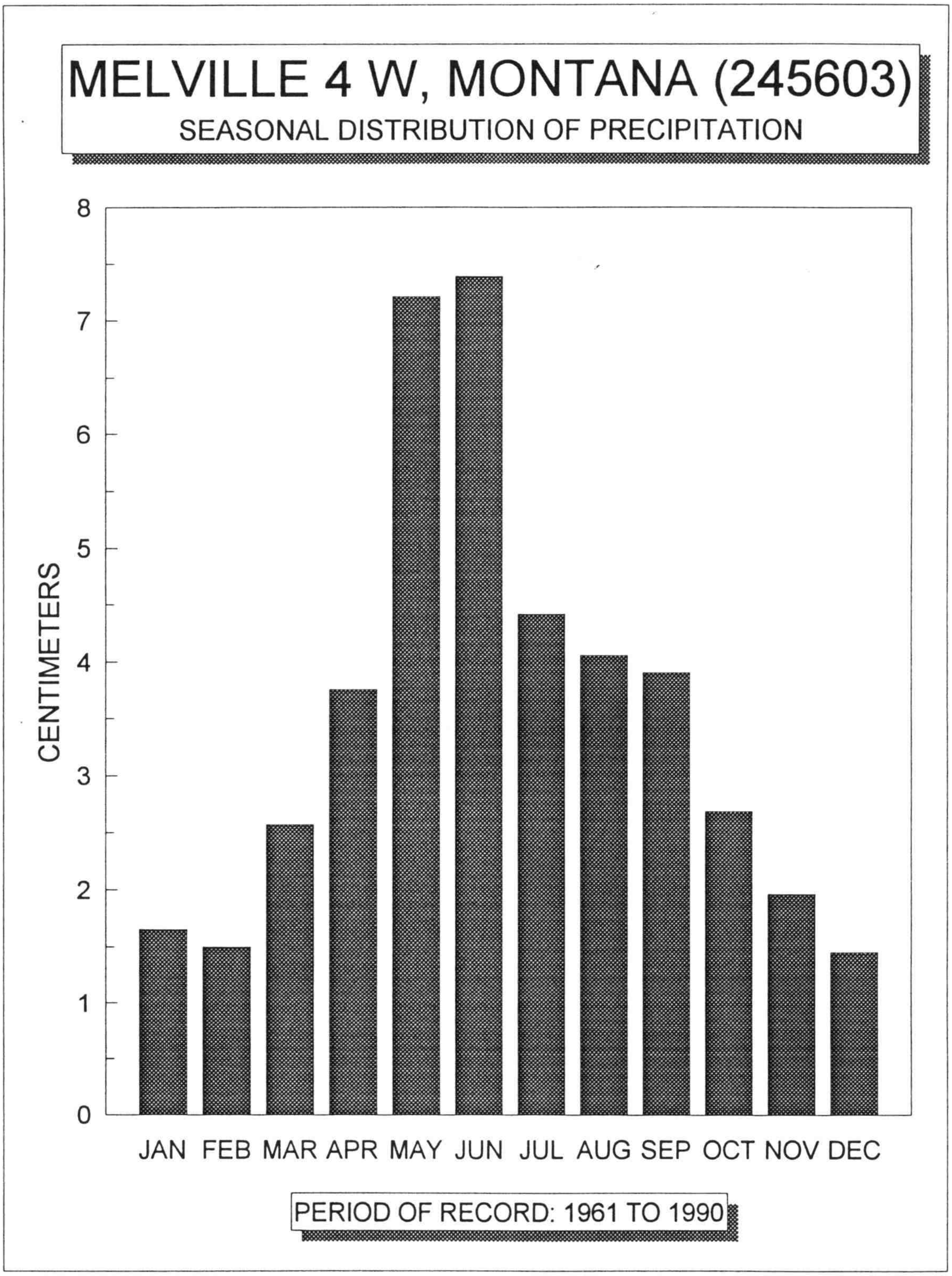

Figure 2.6. Melville, Montana seasonal distribution of precipitation.

dry Mild Pacific air delineates the boundary between the shortgrass region and the taller grasses of the eastern Prairies. Total precipitation values are lower in the shortgrass Plains in comparison to eastern Prairies, as the Tropical Maritime air mass intrusions are less frequent (Reeves 1973: 1224). Borchert (1950: 6) states that mean summer rainfall decreases very sharply westward from the 100th meridian across the Plains, with the greatest decrease in May and June across the southern Plains, and in July and August across the northern Plains.

Modern Climate of the Study Area

In order to better understand modern weather patterns and the overall climate of the Cremer site region, data from a number of weather stations scattered across central and south-central Montana were reviewed (Caprio and Nielsen 1992; Western Regional Climate Center 1997). By accounting for proximity, elevation, and topography, it was determined that climate data recorded near the town of Melville would provide the most accurate means of approximating modern climatic conditions of the Cremer site. Additionally, climate data recorded near the towns of Rapelje and Harlowton were reviewed and compared to the Melville record to assess the strength of the precipitation gradient controlled by the Cordilleran "rainshadow". Climatic data from these weather stations are presented below, followed by a summary of the modern climatic conditions at the Cremer site locality.

Climate records from the Melville 4 W (245603) weather station (lat. 46° 06' N, long. 110° 03' W) are presented in Table 2.1a. Melville is located approximately 12 miles (19.3 kilometers) to the west of the Cremer site. The elevation at Melville (5,365 feet/1,635 meters asl) is approximately 480 feet higher than the Cremer site locality (4,885 feet/1,489 meters asl), and the town sits within mountain foothills and upon late-Wisconsin age glacial outwash deposits derived from the eastern flanks of the Crazy Mountains (Aten 1974). Average annual precipitation at Melville, recorded between 1961 and 1990, is 16.75 inches (42.55 centimeters) (Table 2.1a). On average, Melville receives over 34 percent of the total annual precipitation during the months of May and June (spring-summer maximum). In the five-month period from April 1 to August 31, the Melville area averages over 63 percent of the total annual precipitation. Average mean maximum and minimum monthly temperatures at Melville range from 76.2 °F in July, the warmest month, to 10.3 °F in January, the coldest month, with 40.9 °F being the average mean annual temperature.

In order to assess the strength of precipitation gradients along the Rocky Mountain Front-Plains transition zone, climate data from weather stations adjacent to Melville were reviewed. The Rapelje 4 S (246862) weather station (lat. 45° 55' N, long. 109° 15' W) is located approximately 24 miles (38.6 kilometers) to the east-southeast of the Cremer site. The elevation of Rapelje is 4,125 feet (1,257.3 meters) asl, approximately 760 feet lower than the Cremer site locality. Average annual precipitation recorded between 1961 and 1990 at Rapelje is 15.46 inches (39.27 centimeters) with a spring-early summer maximum (Table 2.1b). Nearly 33 percent of the total annual precipitation is received during the months of May and June. In the five-month period from April 1 to August 31, the Rapelje area averages almost 60 percent of the mean total annual precipitation. Average mean maximum and minimum monthly temperatures at

TABLE 2.1

Table 2.1a. Summary of "average" climate recorded between 1961 to 1990 for Melville, Montana.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
max temp °F	33.5	37.2	41.9	50.9	59.8	68.4	76.2	75.0	65.4	55.8	42.9	34.9	53.5
min temp °F	10.3	13.7	18.5	26.2	34.8	42.3	47.3	46.2	38.5	30.3	19.6	11.8	28.3
total precip (in.)	0.65	0.59	1.01	1.48	2.84	2.91	1.74	1.60	1.54	1.06	0.77	0.57	16.75
total precip (cm.)	1.65	1.50	2.57	3.76	7.21	7.39	4.42	4.06	3.91	2.69	1.96	1.45	42.55

Table 2.1b. Summary of "average" climate recorded between 1961 to 1990 for Rapelje, Montana.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
max temp °F	34.9	40.2	47.6	57.6	67.0	77.2	86.4	85.1	73.1	61.7	45.8	36.3	59.5
min temp °F	11.5	15.6	21.8	29.6	38.1	46.2	51.5	50.2	41.1	32.4	21.8	13.2	31.1
total precip (in.)	0.69	0.67	0.95	1.37	2.77	2.29	1.33	1.42	1.45	1.13	0.78	0.60	15.46
total precip (cm.)	1.75	1.70	2.41	3.48	7.04	5.82	3.38	3.61	3.68	2.87	1.98	1.52	39.27

Table 2.1c. Summary of "average" climate recorded between 1961 to 1990 for Harlowton, Montana.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
max temp °F	34.8	40.1	46.8	56.6	65.9	75.3	83.0	81.6	70.8	60.2	45.2	35.7	58.1
min temp °F	12.4	16.0	20.9	28.5	37.2	45.2	49.6	47.8	39.3	31.5	21.7	14.2	30.4
total precip (in.)	0.50	0.48	0.63	1.02	2.34	2.70	1.61	1.44	1.26	0.85	0.53	0.47	13.83
total precip (cm.)	1.27	1.22	1.60	2.59	5.94	6.86	4.09	3.66	3.20	2.16	1.35	1.19	35.13

Rapelje range from 86.4°F in July, the warmest month, to 11.5 °F in January, the coldest month, with 45.3 °F being the average mean annual temperature.

The Harlowton (243939) weather station (lat. 45° 55' N, long. 109° 15' W) is located approximately 22 miles (35.4 kilometers) to the northwest of the Cremer site. The elevation of Harlowton is 4,140 feet (1,261.9 meters) asl, approximately 745 feet lower than the Cremer site locality, and approximately 15 feet higher than Rapelje. Average annual precipitation recorded between 1961 and 1990 at Harlowton is 13.83 inches (35.13 centimeters) with a spring-early summer maximum (Table 2.1c). Over 36 percent of the average total annual precipitation is received during the months of May and June. In the five-month period from April 1 to August 31, the Harlowton area averages nearly 66 percent of the mean total annual precipitation. Average mean maximum and minimum monthly temperatures at Harlowton range from 83.0 °F in July, the warmest month, to 12.4 °F in January, the coldest month, with 44.3 °F being the average mean annual temperature.

The observed differences in recorded climate data between weather stations in central and south-central Montana reflect a modest contrast in temperature and precipitation patterns. On average, mean monthly temperatures are warmer at Rapelje and Harlowton than at Melville, particularly during the summer months (Figure 2.7). Based on 1961 to 1990 averages for Melville, and assuming a normal lapse rate of 3.5 °F per 1,000 feet of elevation, the Cremer site should have an average mean annual temperature of about 42.6 °F, with annual high temperatures averaging 55.2 °F and annual low temperatures averaging about 30.0 °F.

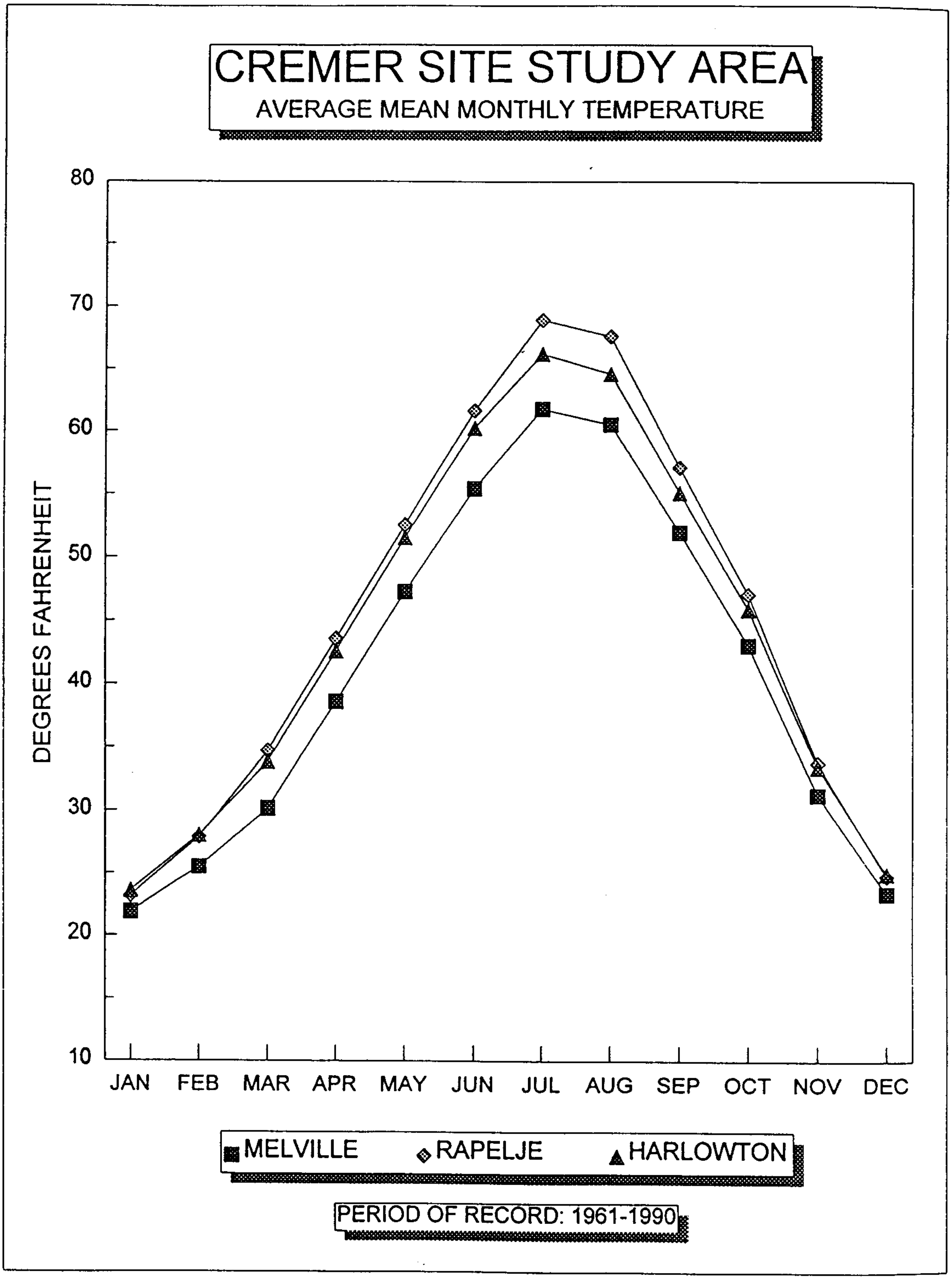

Figure 2.7. Cremer site study area average monthly temperature.

In view of the factors of elevation and the closer proximity of Melville to the Crazy Mountains, average mean annual precipitation recorded at the Melville weather station reflects slightly wetter conditions than those occurring at Rapelje and Harlowton, as well as an important variance in the distribution of early summer rainfall (Figure 2.8). Precipitation trends occurring at the beginning of summer (June) show that rainfall values modestly decrease at Rapelje, whereas average rainfall totals slightly increase at both Melville and Harlowton. This summer precipitation gradient is important in that increased and extended rainfall during the month of June allows for a wetter landscape to exist further into the summer months, contributing to a longer growing season for the grasslands. Considering the above factors, average precipitation totals at the Cremer site are likely to be higher than those recorded at Rapelje and Harlowton and generally more typical of the Melville area.

Site Conditions During the 1995 and 1996 Field Seasons

In order to better understand how the average modern climate of the site area varies from conditions occurring during the 1995 and 1996 field seasons, a comparison is made between the "average" annual climate and "observed" site micro-climate. One primary goal of this comparison is to reveal how yearly weather patterns affected landscape characteristics (stream runoff, groundwater flow, grassland productivity, density of basal cover, etc.) observed at the site during the two summers of fieldwork. Temperature and precipitation summaries for Melville of the 1961-1990 average mean, and for the individual years of 1995 and 1996 are presented in Tables 2.2a, 2.2b and 2.2c, respectively.

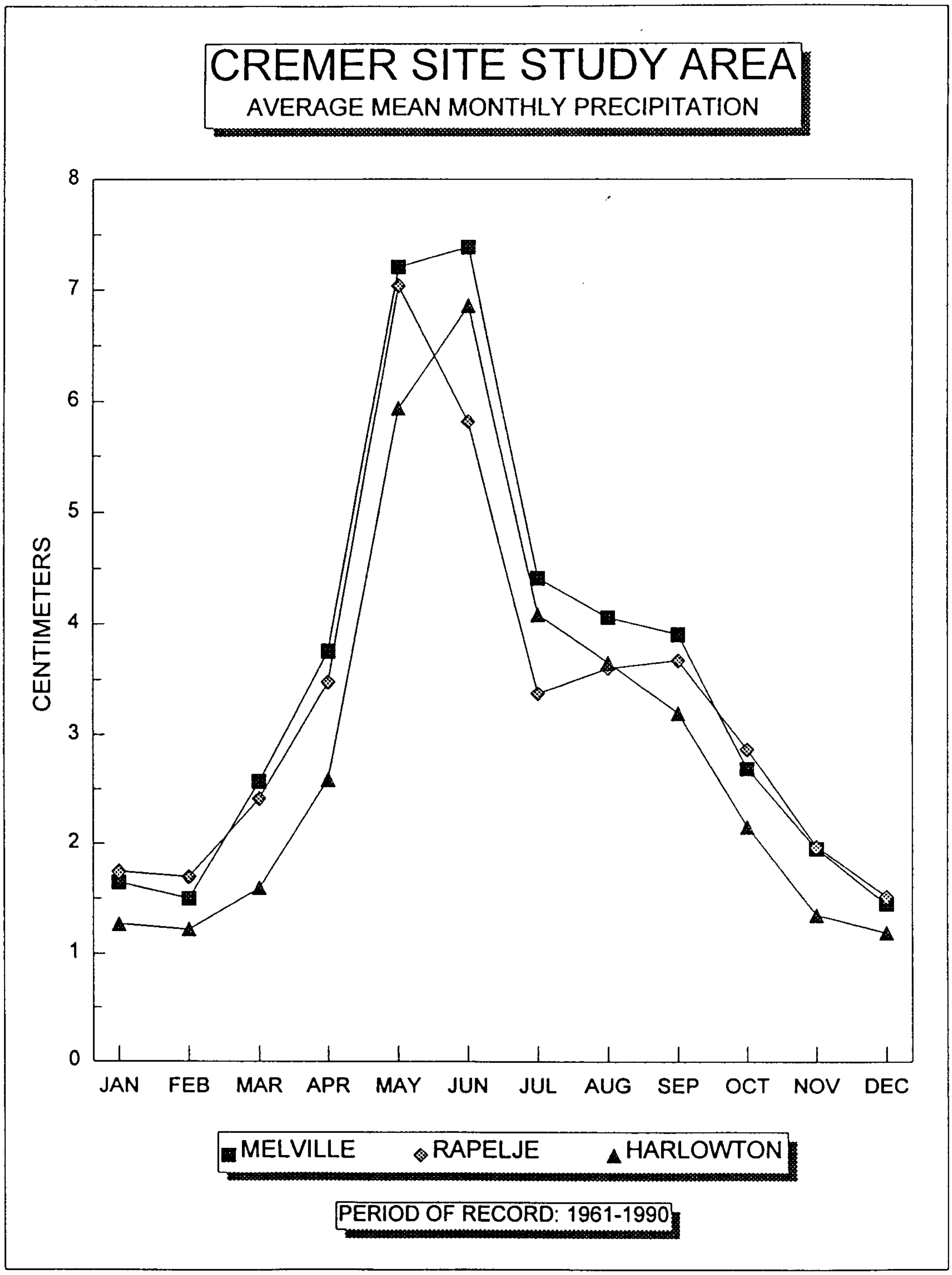

Figure 2.8. Cremer site study area average monthly precipitation.

TABLE 2.2

Table 2.2a. 1961-1990, 1995 and 1996 temperature (in °F) summaries for Melville, Montana.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1961-90 mean max temp	33.5	37.2	41.9	50.9	59.8	68.4	76.2	75.0	65.4	55.8	42.9	34.9	53.5
1961-90 mean min temp	10.3	13.7	18.5	26.2	34.8	42.3	47.3	46.2	38.5	30.3	19.6	11.8	28.3
1995 mean max temp	38.5	40.6	40.5	48.4	55.6	65.2	73.2	77.4	63.4	50.8	44.4	36.9	52.9
1995 mean min temp	13.3	17.3	15.9	23.5	31.1	39.4	45.6	42.4	36.0	26.3	20.5	12.0	26.9
1996 mean max temp	28.6	36.4	34.7	51.7	52.9	71.8	76.1	78.5	65.0	53.5	34.1	29.9	51.1
1996 mean min temp	2.2	10.8	13.4	27.5	31.6	42.9	46.2	45.7	34.3	25.5	12.6	6.0	24.9

Table 2.2b. 1961-1990, 1995 and 1996 precipitation (in inches) summaries for Melville, Montana.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1960-90 total mean precip	0.65	0.59	1.01	1.48	2.84	2.91	1.74	1.60	1.54	1.06	0.77	0.57	16.75
1995 total mean precip	0.58	0.17	0.65	3.07	3.23	4.86	3.72	0.99	1.41	1.20	0.69	0.24	20.81
1996 total mean precip	1.12	1.31	1.63	1.06	5.35	1.01	1.02	0.23	1.06	1.47	1.51	1.32	18.09

Table 2.2c. 1961-1990, 1995 and 1996 precipitation (in centimeters) summaries for Melville, Montana.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1960-90 total mean precip	1.65	1.50	2.57	3.76	7.21	7.39	4.42	4.06	3.91	2.69	1.96	1.45	42.55
1995 total mean precip	1.47	0.43	1.65	7.80	8.20	12.34	9.45	2.51	3.58	3.05	1.75	0.61	52.86
1996 total mean precip	2.84	3.33	4.14	2.69	13.59	2.57	2.59	0.58	2.69	3.73	3.84	3.35	45.95

Thesis field research took place during June, July and August in 1995, and in August in 1996. Although above average precipitation occurred in both 1995 and 1996, Figure 2.9 reveals that the distribution of rainfall at Melville during these two years are distinctly in contrast. In 1995, a "typical" spring-early summer precipitation maximum occurred at Melville, with significantly increased rainfall totals in early spring (March) and early summer (June and July) accounting for the above average annual precipitation. This "wet" year of 1995 was reflected at the Cremer site in landscape features such as sustained stream runoff, high groundwater levels, and productive grasslands with high densities of basal cover that persisted well into the late summer.

In contrast, precipitation in 1996 was much more evenly distributed throughout the year, punctuated only by above average rainfall during the month of May (Figure 2.9). Of particular relevance to observed site conditions is the extremely low precipitation totals occurring during the months of June, July and August. Low rainfall during these summer months accounted for the dry conditions observed at the Cremer site during the August 1996 field season. The landscape character of the site during this second field season revealed reduced flow along Antelope Creek, dry creek beds along the two intermittent streams that converge with the main stem of Antelope Creek, and overall lower water table levels. This latter condition had several important advantages for conducting fieldwork during the 1996 season. Abundant precipitation in 1995 made descriptions of the basal stratigraphy along trench excavations difficult at best, as the high groundwater levels prevented careful and detailed mapping and sampling. The drier conditions and reduced water table in 1996 made lower stratigraphic units more

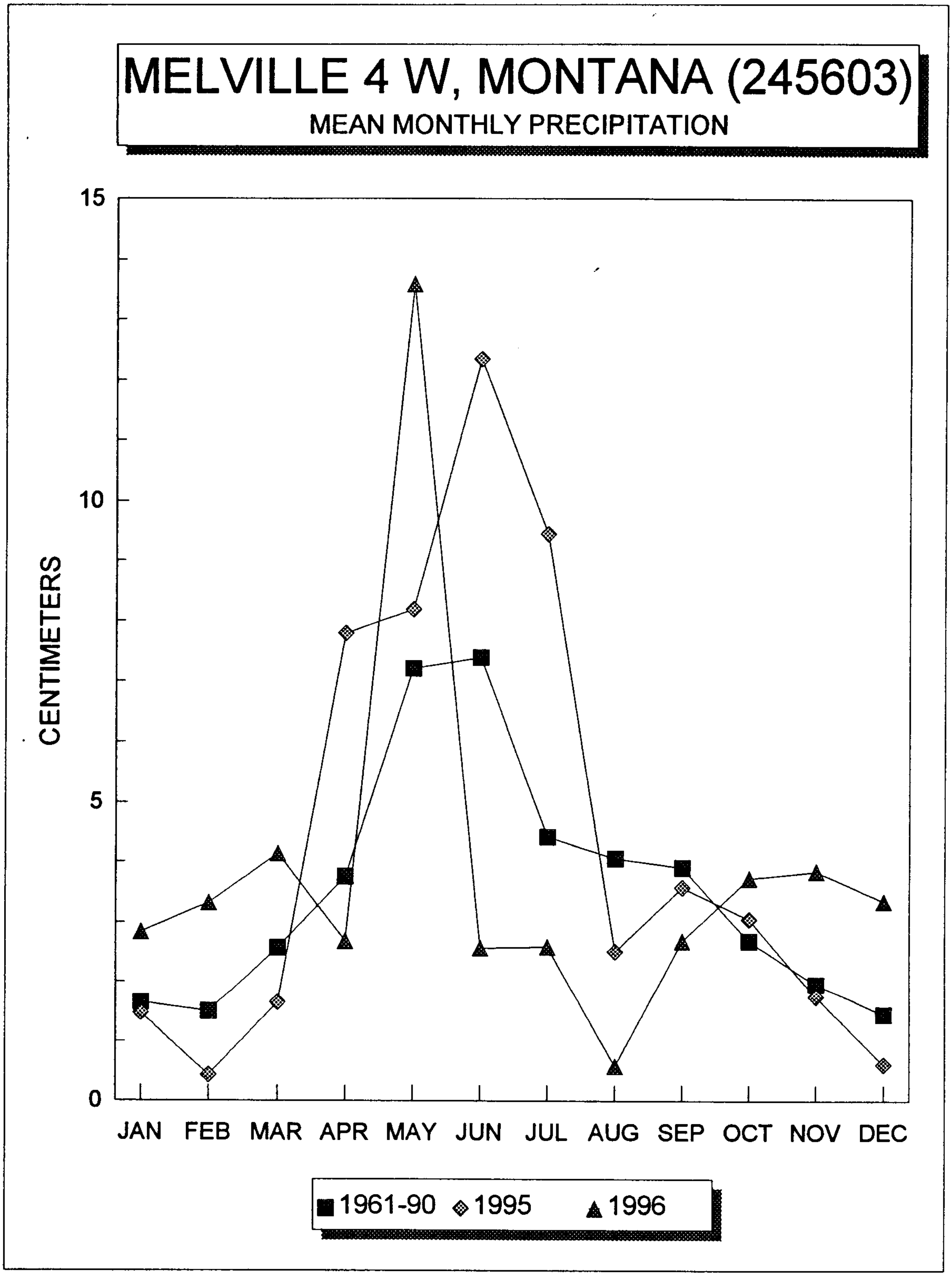

Figure 2.9. Melville, Montana mean precipitation: 1961-1990, 1995 and 1996.

"accessible", and thus contributed to a more complete description of the site's soil-stratigraphic record.

Soils

One common definition for soils describes them as "natural bodies" that result from the effects of climate and living organisms acting on geologic parent material, with topography or relief exerting a modifying influence, and time required for soil-forming processes to act (modified from Soil Survey Staff 1993: 8). These processes have long been identified as the five factors of soil formation (Jenny 1941). In general, the physical attributes and morphologies of soils reflect the environmental conditions that have contributed to their formation.

The unconsolidated sedimentary deposits that give topography to the Cremer site are derived from the weathering of the soft sandstone, mudstone, siltstone and shale of the Fort Union Formation. This erosion has removed and redeposited massive amounts of material from the uplands and sideslopes to the drainageways and stream terraces that border them. The transport of these sediments has been accomplished by the combined forces of gravity, water and wind, resulting in the mixed colluvial-alluvial deposits found at the site locality. This removal and redeposition has been an intermittent process, with intervals during which soils have formed on terrace surfaces, only to be buried during periods of renewed erosion and sedimentation (Beatty 1996). The complex patterns of sedimentation (landscape instability) and soil development (landscape stability) at the Cremer site will be discussed in detail in Chapter 4 of this thesis.

Soil scientists from the Natural Resource Conservation Service, USDA, are currently compiling data and preparing for the publication of the Soil Survey of Sweetgrass County, Montana. The scheduled release date is set for sometime in 1999. However, fieldwork and mapping have been nearly completed, and these results are summarized below.

The scale at which county soil mapping has been conducted allows for a number of soil series to exist in a single mapping unit. Mapping units represent unique natural landscapes that have distinct patterns of soils, relief and drainage features. At the Cremer site, soils that occur along the drainageways and on the fan deposits and stream terraces that border them have been generally grouped as an Ustic Torriorthent-Typic Fluvaquent complex, with 0 to 25 percent slopes (Soil Survey Staff 1994). These soils are classified as Mollisols, an order of soils commonly formed under grassland vegetation.

A higher order map unit for the Cremer site has been tentatively identified as a Straw-Clunton-Fairway Variant complex, with 2 to 15 percent slopes (Sweetgrass County Soil Survey staff, personal communication, 1995). The Straw series consists of very deep, well drained soils located on higher fans and stream terraces at the site. This series is classified as a fine-loamy, mixed, frigid Cumulic Haploboroll, with approximately 4 percent slopes. The Fairway series consists of very deep, somewhat poorly drained soils located on lower fans (toeslopes) and stream terraces along Antelope Creek. The term Variant is used if the soil profile is non-calcareous throughout. The taxonomic class of this series is a fine-loamy, mixed, frigid Fluvaquentic Haploboroll, with approximately 4 percent slopes. And finally, the Clunton series consists of deep, very poorly drained soils located along the streamcourse and modern floodplain of Antelope Creek. This series is classified as a fine-loamy, mixed, frigid Fluvaquentic Endoaquoll, with 2 percent slopes.

Soils occurring on the uplands and sideslopes in the vicinity surrounding the Cremer site consist primarily of Reedpoint very channery loam, with slopes delineated into two groups: 2 to 15 percent, and 15 to 60 percent. The Reedpoint series consists of very shallow (generally less than 10 inches), well drained soils that formed in residuum or colluvium weathered from sandstone. The taxonomic class of this series is a loamy-skeletal, mixed frigid Lithic Haploboroll. These soils are found on bedrock-floored plains, hills and mountains throughout many parts of south-central Montana (Anonymous 1956). Veseth and Montagne (1980: 76) report that the clay mineralogy of the Fort Union strata is generally mixed, with a predominance of illite and kaolinite. This mineral assemblage would be expected to occur in the clay size fraction of the soils formed from Fort Union bedrock.

Flora

The Cremer site is located within the western shortgrass Plains (Figure 2.10). Flora of the shortgrass Plains are distinguished from the grasslands of the eastern Plains and Prairies by their representative community members, densities and species growth heights. The presence and relative abundance of these types of grasses and forbs depends on soil character and available soil moisture, with the tall grasses dominant where precipitation is more abundant and the short grasses dominant where precipitation is less abundant (Bamforth 1988: 32). However, much of the grassland character throughout the Great Plains has been substantially influenced by the effects of modern agriculture and

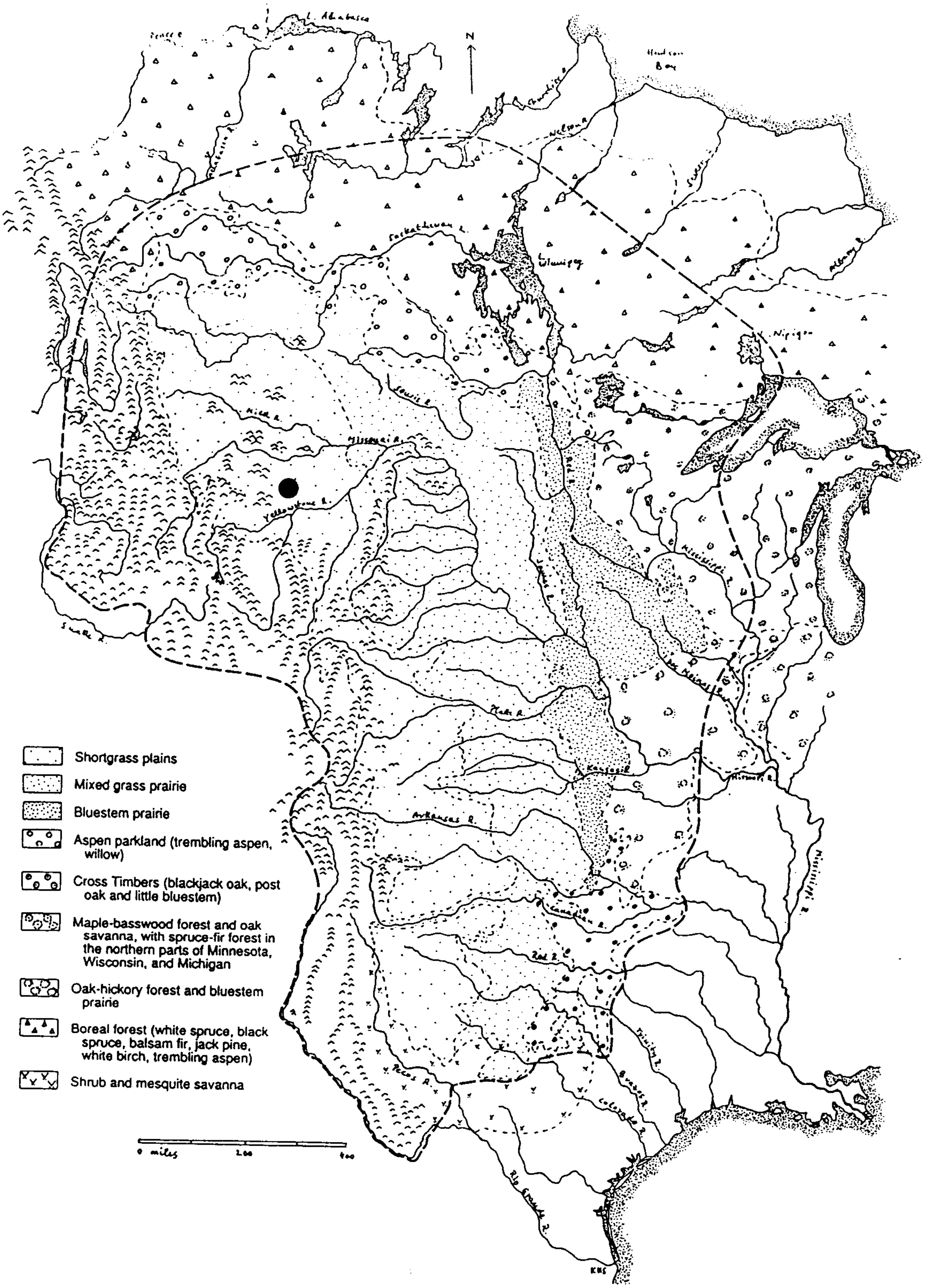

Figure 2.10. Vegetation map of the central North American grasslands and adjacent areas (Schlesier 1994).

cattle ranching, thus altering climax (natural) conditions of the grassland biome where it has not been replaced altogether by cultivation.

The contrasting topography and soil character found at the Cremer site influence the distribution of species within the grassland community. Dominant vegetation in the potential plant communities on the uplands and stream terraces consists primarily of bluebunch wheatgrass (*Agropyron spicatum*), western wheatgrass (*Agropyron smithii*), thickspike wheatgrass (*Agropyron dasystachyum*), needleandthread grass (*Stipa comata*), and blue grama (*Bouteloua gracilis*), plus a variety of forbs. Lowland areas along drainages are vegetated by green needlegrass (*Stipa viridula*), western wheatgrass, thickspike wheatgrass, basin wildrye (*Elymus cinereus*), and bluebunch wheatgrass, plus an array of other grasses and forbs, as well as occasional brush (Sweetgrass County Soil Survey Staff, personal communication, 1995).

Approximately 1/2 mile downstream from the Cremer site, isolated ponderosa pine (*Pinus ponderosa*) and occasional Rocky Mountain juniper trees (*Juniperus scopularum*) can be found along protected sandstone ridges. Plains cottonwood (*Populus sargentii*) begin to grow along Antelope Creek near this locality as well. During past climatic intervals favorable to each species expansion, it is quite reasonable to assume that these trees also occupied sheltered areas at the Cremer site.

Chapter 3

Research Methodology

Introduction

Methods used for the acquisition of data from the Cremer site were selected for their appropriateness to the research objectives of the study, effectiveness, and economy. The author's research objectives were just one component of a larger, multidisciplinary research project organized by Dr. Robson Bonnichsen. Funding for the collective field project was made available through Earthwatch, the Center for the Study of the First Americans (C.S.F.A.), and the landowner, George Cremer. Laboratory support and funding for the analyses of collected soil samples were made available through the Soil and Plant Analysis Laboratory of the University of Wisconsin-Extension, and through the Soil Physics Laboratory and the Central Analytical Laboratory, Department of Crop and Soil Science, Oregon State University.

Field Methods

The joint Earthwatch/C.S.F.A. Cremer Site Project was conducted during the summer field seasons of 1995 and 1996. The 1995 season involved three 2-week field sessions in which a number of Earthwatch volunteers participated with C.S.F.A. staff. This first field season began in mid-June and lasted until early August, 1995. The C.S.F.A. research team and Earthwatch participants returned to the site in August 1996 for a single 2-week session.

Interdisciplinary Research Objectives of the 1995-1996 Cremer Site Project

In addition to the research objectives outlined in the introduction of this report, several other objectives were sought by the project's principal investigator, the most important of which included expanding the archaeological excavation originally conducted by G. Nowatzyk (1979-1980) into lower stratigraphic levels, and to further develop a systematic excavation strategy and recovery procedure for small-scale organic material, including human and animal hair. Bonnichsen and Beatty (1992) report that naturally shed human and animal hair can be routinely recovered from many archaeological deposits. This exciting new field of "molecular archaeology" has the potential to greatly expand our abilities to determine the biological and cultural identities of people who occupied prehistoric sites, and may play a significant role in the next generation of models that seek to explain the peopling of the Americas.

During the 1995 and 1996 field seasons, hundreds of 2-liter soil samples were carefully excavated from a number of locations at the Cremer site. These samples were subsequently screen-washed and dried, and the contents separated by categories (i.e., hair, bone, teeth, insect, seed, plant fiber, charcoal, lithic flakes, etc.). Sample contents now await further analyses.

Trench Excavations

The goal of the author's fieldwork and research is to understand the geomorphic character, stratigraphy and pedology of the Cremer site, and to link these data to climatic and environmental trends that characterized the Montana Plains during the late-Pleistocene and Holocene periods. In accomplishing these objectives, three backhoe trenches totaling nearly 125 meters in length and between 1 and 4 meters in depth were excavated at the site by landowner George Cremer (see Figure 4.1). The locations selected for trench excavations were based on: (1) prominence of micro-landforms within the site vicinity; (2) locations likely to yield the most complete stratigraphic and pedologic records; and (3) locations potentially associated with archaeological deposits.

Trench exposures revealed a unique cross-section of the Cremer site that had never been seen before. To assist in meeting the objectives of the study, a variety of field techniques were utilized, including: (1) general observations of site geomorphic character influencing landform and soil development; (2) delineation and mapping of major soil-stratigraphic units along the entire lengths of excavated trenches; (3) detailed pedological profile descriptions at selected locations along the trenches; (4) collection of soil samples from each of the soil horizons identified during pedological descriptions; (5) collection and documentation of faunal remains and other organic materials exposed along the trench walls; and (6) collection and documentation of archaeological features and materials.

Initial excavation of Trench 1 began during the 1995 field season, when three short segments of the trench were exposed by backhoe. Profile observations from segments A, B and C of Trench 1 revealed complex stratigraphic and pedologic sequences. At the end of the 1995 field season (after both preliminary profile descriptions and soil-stratigraphic mapping), it was determined that a complete delineation of the mixed colluvial-alluvial sequences that comprise the footslope/terrace and floodplain landforms would require additional excavation and study. A more complete delineation of the pedologic and stratigraphic relationships occurring along

Trench 1 and the Northeast Streamface was accomplished during the 1996 field season following the re-excavation of the original trench segments and the further trenching of the unexcavated portions of Trench 1 (Figure 4.1). At the end of the 1996 field season, Trench 1 extended from the terrace escarpment of Antelope Creek (i.e., the Northeast Streamface) to more than 33 meters into the footslope/terrace landform to the northeast, with unconsolidated sedimentary materials reaching depths greater than 3.5 meters below the modern surface (see Plate 1 and Appendix C).

Excavation of Trench 2 involved a two-part strategy that spanned both the 1995 and 1996 field seasons. In 1995, Trench 2 was excavated from the modern floodplain of Antelope Creek into the stable colluvial fan/terrace landform to the southeast for a distance of approximately 36.0 meters. Detailed stratigraphic and pedologic descriptions were made at a number of locations along this trench exposure. During the 1996 field season, a 10 meter extension was added to Trench 2 (between 0.0 m to 10.0 m, leaving an unexcavated section of the landform between 10.0 m to 14.0 m). The primary purpose of this extension was to reveal a deeper and more continuous pedologic sequence and to determine the depth of bedrock below the modern surface. At the end of the 1996 field season, Trench 2 extended from the terrace escarpment of Antelope Creek into the fan/terrace landform to the southeast for a distance of approximately 48.0 meters, with unconsolidated sedimentary materials reaching a maximum depth of 4.10 meters below the modern surface (see Plate 2 and Appendix D).

Finally, Trench 3 was excavated during the 1996 field season. In total, Trench 3 extended from the modern floodplain of Antelope Creek into the predominantly alluvial derived landform to the east for a distance of approximately 40.0 meters, with unconsolidated deposits exceeding depths greater than 1.5 to 2.5 meters below the modern surface (see Plate 3).

Site Stratigraphy and Soil Profile Descriptions

Mapping of trench stratigraphy was undertaken to delineate the major soil and depositional units observed in the exposed profiles. Representative profile sections along the trench walls were described and sampled according to standard pedological methods of the National Cooperative Soil Survey (Soil Survey Staff 1993). Within each of the stratigraphic units, pedological horizons and other sedimentary layers were assessed in terms of thickness, horizonization, color, structure, consistency, texture, reaction to dilute HCl acid, and boundary characteristics. Additional comments were noted as appropriate (i.e. gravel content, redox features, etc.). This systematic approach to describing site pedology has widespread recognition, and the results can be easily understood and compared with systematic pedological studies conducted at other localities throughout the world. A detailed description of site stratigraphy and pedology is presented in Chapter 4 of this thesis

Laboratory Methods

Particle Size Analysis

During the fall of 1996, soil samples collected from the three trenches (at Profiles # 2, # 3, # 4, # 7 and # 8) at the Cremer site were analyzed to determine particle size distribution (texture). This new data set complimented the preliminary particle size results from Profiles # 1, # 5 and # 6 obtained from the Soil and Plant Analysis

Laboratory of the University of Wisconsin-Extension following the 1995 field season. Each sample was first passed through a number 10 sieve to separate the fine earth fraction (< 2 millimeters in diameter) from the larger particles (coarse fragments). After drying, the percentage of each sample's coarse fragments greater than 2 millimeters in diameter was then recorded. All subsequent analyses were performed only on the remaining fine earth fractions.

For each sample, particle size distribution without removal of organic matter was determined using the hydrometer method (Tan 1992; Horneck et al. 1989). Hydrometer readings were taken at 4 minutes, 6 minutes, 8 hours and 24 hours after initial aggregate dispersal. After the final readings, the fine-earth fraction of each sample from Trench 1 (Profiles # 2 and # 3) and Trench 2 (Profile # 4) were carefully poured into a number 270 sieve to separate the sand fraction from the silt and clay particles. After drying, the sand fraction was weighed and then mechanically agitated in a series of sieves to separate the very coarse (2.0-1.0 mm), coarse (1.0-0.5 mm), medium (0.5-0.25 mm), fine (0.25-0.10 mm), very fine (0.10-0.05 mm), and residual silt (<0.05 mm) components (Soil Survey Staff 1993). These individual components were then weighed and percentages of each recorded.

Organic Carbon Analyses and Soil pH

Several different techniques were utilized to determine the percentages of both total organic carbon and total organic matter present in the sediment and soil samples. Total organic carbon (TOC) results for samples from Profiles # 2, # 3, # 4, # 7 and # 8 (collected during the 1996 field season) were obtained by the Walkley-Black method

(Tan 1992; Horneck et al. 1989). Total organic matter (TOM) percentages for samples from Profiles # 1, # 5 and # 6 (collected during the 1995 field season) were obtained by loss on ignition. Staff at the Soil and Plant Analysis Laboratory of the University of Wisconsin-Extension administered both of these carbon testing procedures.

Soil pH was determined for all samples collected from Profiles # 2, # 3, # 4, # 7 and # 8 by using an ATI Orion PerpHecT model 350 electronic pH meter with a 1 to 2 soil:water solution. Staff at the Soil and Plant Analysis Laboratory of the University of Wisconsin-Extension conducted pH tests for samples from Profiles # 1, # 5 and # 6.

Charcoal Identification

During the spring of 1997, a number of charcoal samples collected from the Cremer site during the 1996 field season were sent to Dr. Lucinda McWeeney at the Yale University Herbarium to be identified to the most recognizable level of plant taxonomy. Dr. McWeeney participated in excavations at the Cremer site in 1995 as an Earthwatch volunteer. The results from these analyses are presented in Table 3.1.

Wood and charcoal identifications are made using a collection of known specimens, reference slides and photomicrographs. Each charcoal sample from the Cremer site was examined under a Zeiss binocular microscope with magnification between 7 and 50X for initial specimen orientation and cross-section analysis. Additionally, an incident light microscope with magnification up to 400X was needed for viewing the tangential and radial sections of each sample (McWeeney 1997). Taxonomic classifications follow Fernald (1970).

Table 3.1. Summary of identified wood charcoal from the Cremer site (McWeeney 1997).

Locality	Location/Depth (cm)	Horizon	Species	Comments
Trench 2	Unit VIII 3.0 m along trench 312-320 cm dbs	10Ab	*Cercocarpus* spp. (mountain mahogany/ curlleaf cercocarpus)	ID # 099 Associated ^{14}C age 10,090 $\pm$ 130 yr B.P. Identification remains tentative.
Trench 3	Unit III 22.0 m along trench 65-80 cm dbs	3Abk	*Salix* spp. (willow)	ID # 017
Trench 3	Unit III 21.1 m along trench 110 cm dbs	3Abk	*Salix* spp. (willow)	ID # 037
Trench 3	Unit VI 23.9 m along trench 98 cm dbs	4C	*Salix* spp. (willow)	ID # 038
Trench 3	Unit VI 24.4 m along trench 100 cm dbs	4C	*Salix* spp. (willow)	ID # 042
Trench 3	Unit VIII 28.0 m along trench 168 cm dbs	6C	*Salix* spp. (Willow)	ID # 043

Radiocarbon Samples

Six samples were selected for radiocarbon determinations to assist in establishing a chronology of landscape evolution and prehistoric cultural patterns at the Cremer site (Table 3.2). The samples submitted for ^{14}C dating were selected in an attempt to determine the approximate ages of the buried soils exposed in the trench walls. Three samples were collected from Trench 1, where a standard radiometric analysis obtained an age for a bison mandible {5,920 ± 80 yr B.P. (Beta-88601)}, and two accelerator mass spectrometry (AMS) analyses obtained ages for charred organic material {5,100 ± 70 yr B.P. (Beta-88602)} and a long bone section of a large herbivore (unidentified) {3,730 ± 110 yr B.P. (Beta-100154)}.

Three samples were submitted from Trench 2, but only two of the three were determined to have reliable ages. These come from an AMS dated bone fragment (unidentified) {7,490 ± 100 yr B.P. (Beta-100155)} and an AMS determination obtained from charcoal found in an organic-rich soil layer {10,090 ± 130 yr B.P. (Beta-100153)}. A standard radiometric analysis from a bison rib bone {8,200 ± 80 yr B.P. (Beta-103886)} is questioned given the sample's association with redeposited slopewash.

Submitted ^{14}C samples underwent a series of pretreatment procedures at the Beta Analytic Laboratories to eliminate secondary carbon components. The bone specimens were first washed in de-ionized water and gently crushed. Dilute, cold HCl acid was then repeatedly applied and replenished until the mineral fraction (bone apatite) was eliminated. The collagen component was then inspected to ensure the absence of rootlets. Alkali (NaOH) was applied to remove all secondary organic acids. Two of the bone

Table 3.2. Summary of radiocarbon analyses from the Cremer Site.

Trench	Material	Age (^{14}C years BP)	Laboratory Number	Location/ Depth (cm)	Unit/ Horizon	Comments
Trench 1	Bone	3,730 ± 110	Beta-100154 AMS	17.2 m along trench 182 cm dbs	V/ 6Akb	Sample recovered near base of Unit V.
Trench 1	Charcoal	5,100 ± 70	Beta-88602 AMS	27.2 m along trench 236 cm dbs	VIII/ 12Akb	Unit consists of several weakly developed Ab horizons separated by thin lenses of colluvium.
Trench 1	Bone	5,920 ± 80	Beta-88601	31.5 m along trench 254 cm dbs	VIII/ 12Akb	Unit consists of several weakly developed Ab horizons separated by thin lenses of colluvium.
Trench 2	Bone	8,200 ± 80	Beta-103886	Unit IV 43.4 m along trench 187 cm dbs	IV/ 5Bkb3	Sample associated with redeposited slopewash, rendering the assigned age to horizon 5Bkb3 unreliable.
Trench 2	Bone	7,490 ± 100	Beta-100155 AMS	Unit V 46.6 m along trench 215 cm dbs	V/ 6Ab	Sample recovered near base of Unit IV.
Trench 2	Charcoal	10,090 ± 130	Beta-100153 AMS	Unit IX 49.0 m along trench 320 cm dbs	IX/ 10Ab	Sample recovered in lab from bulk sample of Unit IX (horizon 10Ab).

specimens were analized by AMS and the other two by standard radiometric analysis (Beta Analytic Inc., personal communication, 1997).

The two samples of "charred material" (charcoal) were both analyzed by AMS. The pretreatment of each sample involved gently crushing and dispersing them in de-ionized water. Each sample was then given hot HCl acid washes to eliminate carbonates, and alkali washes (NaOH) to remove secondary organic acids. Each chemical solution was neutralized prior to the application of the next and prior to drying. During this series of rinses, mechanical contaminants such as those associated with sediments and rootlets were eliminated from each sample (Beta Analytic Inc., personal communication, 1997).

Paleoclimate Modeling

Recent advancements in understanding the mechanisms behind global climate change have resulted in a number of unique approaches of modeling past climates. To facilitate the reconstruction of paleoenvironmental trends on the northwestern Great Plains, I obtained climate data from two different modeling techniques. In cooperation with the Center for Climatic Research at the University of Wisconsin-Madison, paleoclimate data from four cells of the Community Climate Model were reviewed for the general region surrounding the study area (Pat Behling, personal communication, 1996). Additionally, site-specific paleoclimate data for the study area was kindly provided by R.A. Bryson and R.U. Bryson (personal communication 1996). The results from these modeling techniques are presented in Chapter 5 of this thesis.

Chapter 4

Site Stratigraphy and Pedology

Introduction

This chapter reviews aspects of geomorphology, stratigraphy and pedology of the Cremer site. These topics are of fundamental importance in understanding site formation processes and the complex development of the micro-landforms present in the area under investigation. Landform evolution at the Cremer site has periodically fluctuated between intervals of accelerated colluviation and alluviation (landscape instability) and intervals of pedogenesis (landscape stability). Recognizing these distinct patterns of sedimentation and soil development along trench exposures helps determine the nature of the environment at *specific* times of site occupation and/or between occupations. This approach to landscape reconstruction is also important in assessing how the site has changed *through* time, and how these changes affected patterns of human occupation at the site. An understanding of the episodic nature of landscape evolution is critical in reconstructing both the paleoenvironmental setting and prehistoric cultural patterns at the Cremer site.

This chapter presents the stratigraphic and pedologic results from each of the three trenches excavated during the 1995/1996 field seasons at the Cremer site. Additionally, soil-stratigraphic observations were made along the terrace escarpment (Northeast Streamface) of Antelope Creek (Figure 4.1), as this cutbank exposure was the only available means of making direct correlations with the natural and cultural stratigraphy

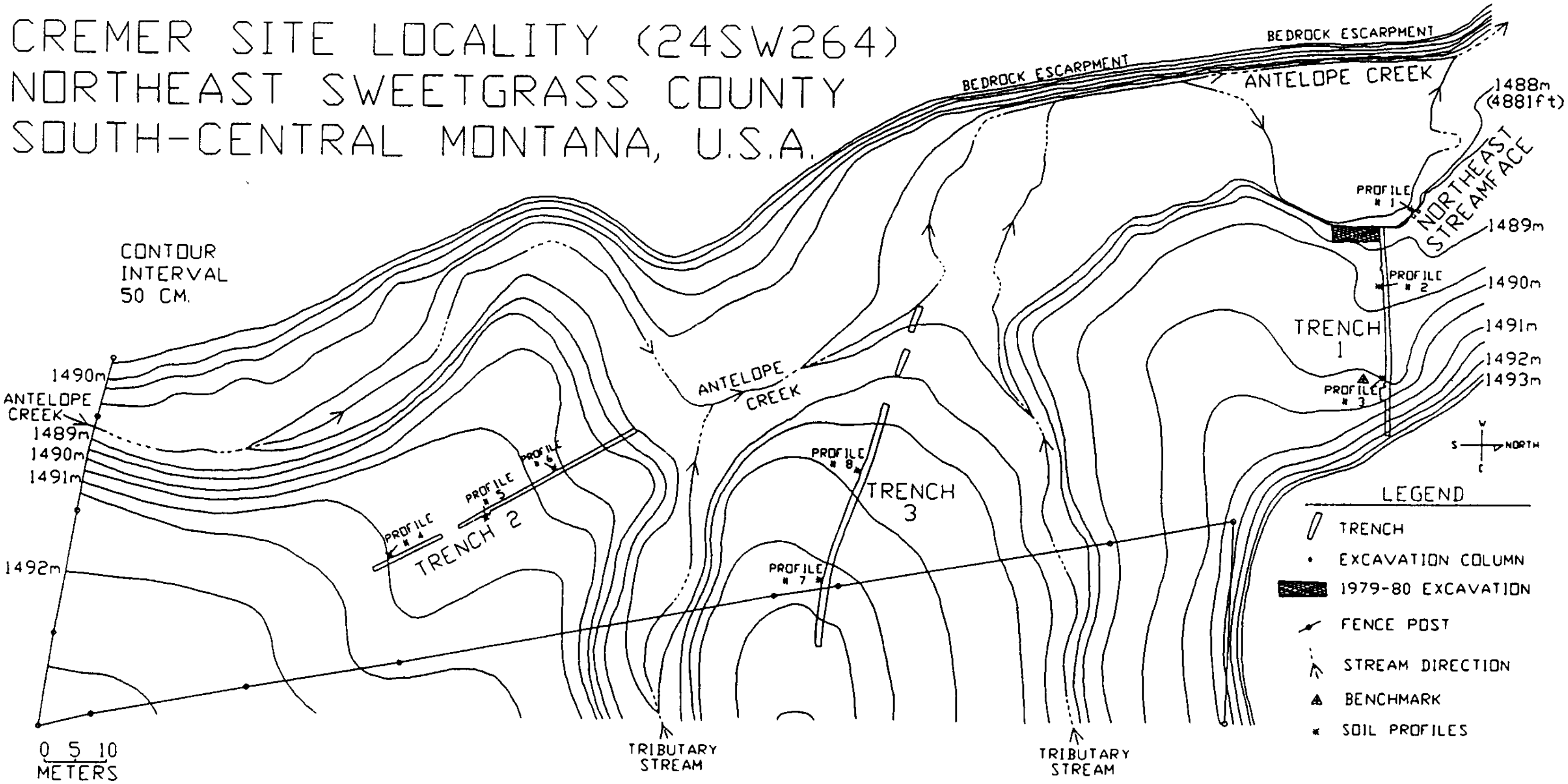

Figure 4.1. Plan view and topographic map of the Cremer site (50 centimeter contour interval).

reported by Nowatzyk (1983). Results from these observations and from each of the three trenches are presented below.

Site Stratigraphy and Pedology: An Overview

Strata of the Fort Union Formation are overlain by unconsolidated sediments of late-Quaternary age. Stratigraphic units and pedologic horizons identified along the excavated trenches and terrace escarpment of Antelope Creek were systematically described and sampled according to procedures outlined by the Soil Survey Staff (1993). These sedimentary units reflect the various materials that comprise the Antelope Creek terrace stratigraphy and were identified and mapped based on each stratum's similarity and/or dissimilarity to adjacent strata. The stratigraphic groups indicate relative internal homogeneity in terms of depositional history and/or pedologic development. Diagnostic properties used to differentiate stratigraphic units and pedologic horizons for all profile sections included observations of abrupt textural discontinuities, distinct color changes, degree of structural development, and other associated attributes. For all trenches, the numerical delineations of each stratigraphic group have generally been assigned in reverse order of their chronology of deposition.

The following description of the geomorphic character, stratigraphy and pedology of the Cremer site reveals a complex sequence of post-glacial landscape evolution. Deposits from each of the three trenches excavated at the site exhibit significant differences in age, stratigraphic association and horizonizaton. These differences reflect the distinct geomorphic positions of the landforms studied, particularly with respect to landform slope and the varying degrees in which the principal and tributary streams have shaped the modern topography (see Appendix B). Based of the collective radiocarbon and sedimentological evidence from the Cremer site, a series of models can be reconstructed which provides a chronology for the evolution of the landforms studied and the site locality in general. These evolutionary reconstructions will be presented as summary sections following the description of results from each of the three trenches.

Trench 1 and the Northeast Streamface

Landform Morphology

The footslope-terrace components of the landform associated with Trench 1 and the Northeast Streamface are composed of both colluvial and alluvial sediments. Trench 1 is approximately 33.5 meters in length and occupies a transitional position between the footslope of the steep residual uplands to the east and the more gently sloping landform (stream terrace and floodplain) to the west (see Figure 4.1 and Appendix C). The upper (east) terminus of the trench lies within the landform's sideslope-footslope transition zone, where slope gradient averages approximately 21° (34%). Deposits revealed along this section of the trench are predominantly colluvial in origin, having originated from the steeper upland areas to the east. The steeper uplands are convex in shape and subject to frequent erosion. The hillslope here receives less infiltration of precipitation and more surface runoff. Consequently, these upland slopes are poorly vegetated and have only a thin (< 20 cm.) soil overlying colluvial sandstone fragments.

The character of the trench deposits changes substantially as slope topography transitions from convex (sideslope) to concave (footslope-terrace) in shape. Slope gradient along the landform's transition zone and the trench itself is approximately 5°

(9%) (see Appendix C). This reduced slope gradient allows for the deposition and accumulation of colluvial materials from the uplands, resulting in the increased thicknesses of deposits and soils revealed along the trench walls. Additionally, the slope gradient change allows for more moisture to exist in the soil profile through increased infiltration rates and less surface runoff. Deeper soils here also allow greater total water holding capacity to support vegetation. This increase in soil moisture enables more vegetation to occupy the ground surface and thus facilitates the accumulation of soil organic matter. Stable surfaces where organic matter accumulated prior to burial by renewed sedimentation are identified as paleosols (buried A and/or B horizons) in the described soil profiles.

With closer proximity to Antelope Creek (to the west), exposed stratigraphy along the middle and lower sections of Trench 1 (between 19.0 m to 33.5 m) become increasingly alluvial in character. Deposits here record episodes of lateral stream channel migration and periods of high stream flow. These are reflected along the trench profile as channel fill and overbank flood deposits, stone lines, and a distinct erosional sequence triggered by overland flooding with subsequent repositioning of the stream channel.

The lower (west) terminus of Trench 1 intersects the terrace escarpment (Northeast Streamface) and modern floodplain of Antelope Creek at a 45° angle, where disturbed deposits from the archaeological excavations conducted by G. Nowatzyk in 1979 and 1980 were encountered (see Figure 4). Surface disturbances and backfill from these previous excavations precluded any mapping and description of the stratigraphic units and pedologic horizons occurring along the lower terminus of Trench 1, and required that extrapolation be made from observations along the Northeast Streamface.

The Northeast Streamface lies along the outer edge of a small meander bend of Antelope Creek, and both soil development and overbank deposition of flood deposits are evident along the cutbank. Stream entrenchment within the valley of Antelope Creek has occurred in the middle to late-Holocene, isolating former floodplains and creating the terrace escarpment (Northeast Streamface). This escarpment has no counterpart along the opposite side of Antelope Creek (an unpaired terrace), and no older terrace surfaces were identified upslope from the cutbank.

Slope aspect also plays an important role in landform development at the Cremer site. The steep upland component of the landform associated with Trench 1 is generally oriented in a southerly direction. This more direct orientation to the sun results in increased solar radiation that reaches the surface, and thus higher soil temperatures. The effects of slope aspect will vary according to prevailing climatic conditions and degree of slope gradient, but one result for south facing slopes is reduced soil moisture. During periods of drought, loss of soil moisture can have a debilitating consequence for vegetative cover, leading to accelerated erosional and depositional patterns, and general landscape instability. As will be discussed shortly, the stratigraphy exposed along Trench 1 clearly records alternating patterns of colluviation-alluviation and soil development, reflecting patterns of general landscape instability and stability, respectively.

Stratigraphy and Pedology: Trench 1 and the Northeast Streamface

Terrace stratigraphy exposed along the Northeast Streamface and Trench 1 has had a complex origin, being derived from intervals of both accelerated alluviation and colluviation, separated by periods in which soils have had sufficient time to develop.

Alluvial deposition from Antelope Creek has played a significant role in the development of terrace stratigraphy along the Northeast Streamface and the lower (west) terminus of Trench 1. Deposition of colluvium derived from the steep upland slopes to the east has been the principal sedimentation process occurring along the upper section of the trench. Soils have formed in both of these colluvial and alluvial parent materials.

Trench 1 is approximately 33.5 meters in length and was excavated to depths ranging between 2.0 to 4.0 meters (see Plate 1). The numerous soil horizons and sedimentary layers that comprise the footslope/terrace landform of Trench 1 and the Northeast Streamface have been grouped into 10 major stratigraphic units (Plate 1). Within each of these stratigraphic units exists a distinct sequence of pedologic horizons. Figures 4.2, 4.3 and 4.7 and Tables 4.1, 4.2a, 4.2b, 4.3a and 4.3b show the existing associations between stratigraphic units and soil horizons occurring along the Northeast Streamface and Trench 1.

Detailed stratigraphic and pedologic descriptions were undertaken at three separate locations along the Northeast Streamface and Trench 1 to: a) correlate new descriptions of the Northeast Streamface with the previously identified natural and cultural stratigraphy of the archaeological site (Profile # 1); and b) reveal the distinct alluvial (Profile # 2) and colluvial (Profile # 3) depositional components occurring along Trench 1. The following stratigraphic and pedologic summary of the Northeast Streamface and Trench 1 assesses the origin and character of each stratigraphic unit and associated soil horizon(s) in an attempt to reconstruct the events responsible for the late-Quaternary evolution of the associated footslope/terrace landform.

Soil-Stratigraphic Profile # 1 (Northeast Streamface)

Pedologic descriptions along the Northeast Streamface were made during the 1995 field season to facilitate stratigraphic correlation between Nowatzyk's "Natural and Cultural Layers" (Figure 1.2), the terrace escarpment (Northeast Streamface), and Trench 1. Stratigraphic mapping and field descriptions of pedologic properties for Profile # 1, plus laboratory analyses of selected soil attributes, are presented in Figure 4.2 and Table 4.1. In total, seven distinct stratigraphic units representing 10 pedologic horizons were identified along the Northeast Streamface during the 1995 field season. Results from Profile # 1 are presented below.

Stratigraphic Unit IX

Stratigraphic and pedologic descriptions at Profile # 1 along the Northeast Streamface are generally in agreement with the "natural stratigraphy" reported by Nowatzyk (1983). However, there are some notable exceptions. The lowest stratigraphic unit (Unit IX) was encountered just over 145 centimeters below the modern surface of the terrace escarpment. This unit is designated as horizon 8Cg along the cutbank exposure and is distinguished from the overlying deposits by a distinct clay loam texture, "reduced" color and general anaerobic character, and by a relatively low percentage of sandstone gravel, cobbles and channers. This deposit was not identified in the report published by Nowatzyk (1983). Stratigraphic Unit IX will be discussed more completely when reviewing soil profiles along Trench 1 (Profiles # 2 and # 3), as these materials occur as the basal unit along part of this trench as well.

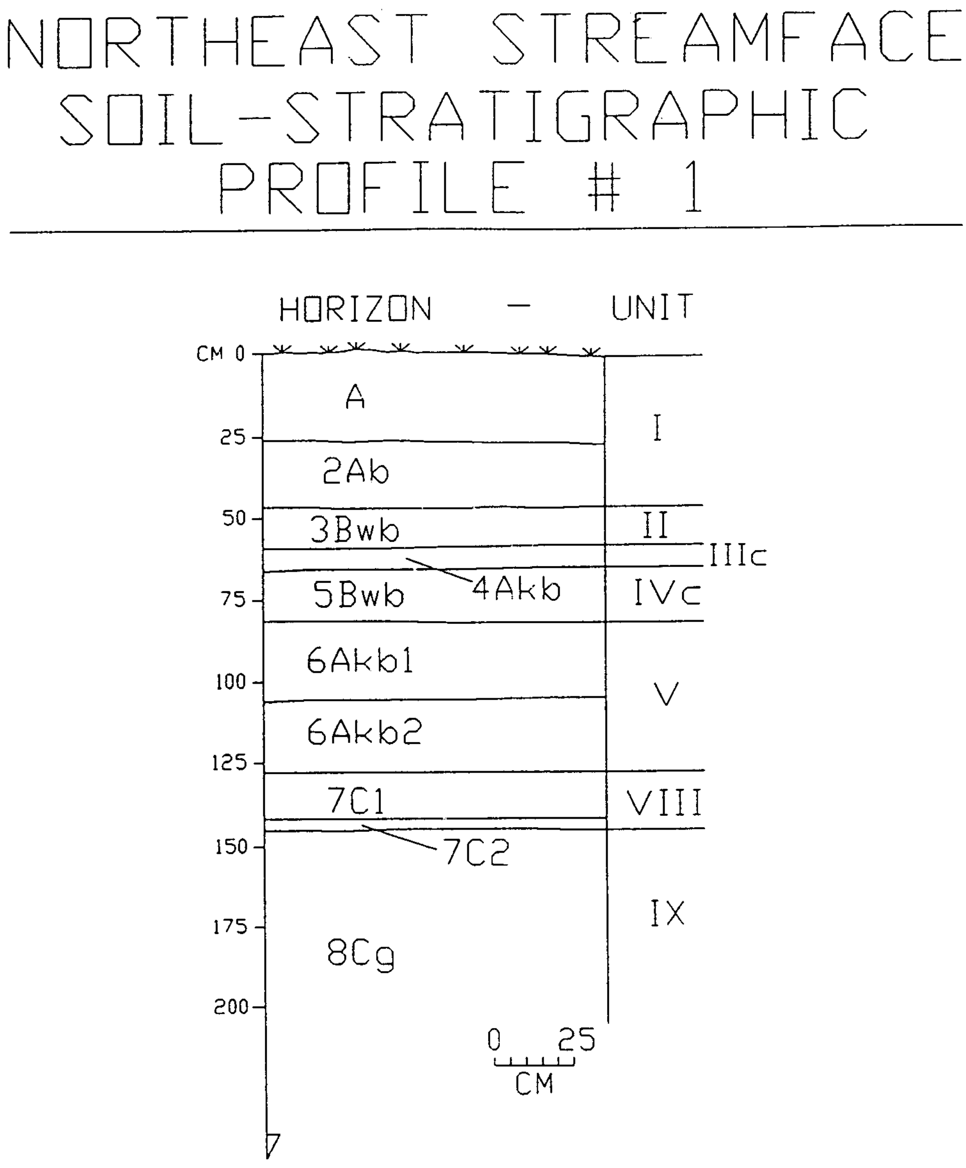

Figure 4.2. Soil-Stratigraphic Profile # 1 (Northeast Streamface).

Table 4.1. Soil-Stratigraphic description and laboratory results for Profile # 1 (Northeast Streamface).

Unit	Horizon	Nowatzyk Layers	Depth (cm.)	Color (moist)	Color (dry)	Texture	Structure	Consistence	Boun-dary	pH	TOM %	Sand %	Silt %	Clay %
I	A	1 and 2	0-26	10YR 3/2	10YR 5/3	sl	3 f sbk	wss,mvfr,dh	as	6.8	3.7	60	27	13
I	2Ab	3a	26-47	10YR 2/1	10YR 3/2	l	3 f abk	wss,mvfr,dh	as	7.4	4.7	46	39	15
II	3Bwb	4a	47-60	10YR 3/2	10YR 5/2	l	3 m abk	wss,mfr,dh	gs	7.9	3.2	48	33	19
IIIc	4Akb	3b	60-66	10YR 2/2	10YR 4/2	l	2/1 m abk	wss,mvfr,dh	gi/db	-	-	-	-	-
IVc	5Bwb	4b	66-81	10YR 4/3	10YR 5/2	l/scl	1 m abk	wss,mfr,dh	gs	8.3	1.8	52	27	21
V	6Akb1	5a and 4c	81-107	10YR 2/1	10YR 3/1	sl/scl	m	ws,mvfr,dh	as	8.3	2.2	58	22	20
V	6Akb2	5b	107-128	10YR 3/2	10YR 4/2	sl/scl	m	wss,mvfr,dh	as	8.3	1.4	64	17	19
VIII	7C1	7	128-140	10YR 5/2	10YR 6/2	vgrsl	m	wso,mlo,dlo	gs	-	-	-	-	-
VIII	7C2	8	140-145	10YR 5/2	10YR 6/2	grsl	m	wso,mlo,dlo	aw	-	-	-	-	-
IX	8Cg	-	145+	2.5Y 4/0 2.5Y 5/4	2.5Y 6/0 2.5Y 6/4	grcl/l	m	ws,mvfr,dh	-	-	-	-	-	-

Stratigraphic Unit VIII

Overlying Unit IX is a sequence of alluvial sands and gravels that comprise Stratigraphic Unit VIII. This unit has an abrupt/wavy boundary with underlying Unit IX and consists of a thin (ca. 5 centimeters thick) deposit of gravelly sandy loam in its lower component (horizon 7C2). Horizon 7C2 has a grayish brown (10YR 5/2) moist matrix color and likely corresponds with Natural Layer 8 identified during archaeological excavations in 1979 and 1980. The upper component of Stratigraphic Unit VIII is designated as horizon 7C1 and consists of a distinct layer (ca. 15 centimeters in thickness) of medium angular and subangular gravels (about 50% of the total volume) and angular channers (about 20% of the total volume) in a matrix of sandy loam. Horizon 7C1 has a gradual and smooth lower horizon boundary and correlates well with the gravel layer (Natural Layer 7) identified by Nowatzyk (1983). This layer of angular and subangular gravels and channers extends into the terrace landform to the northeast of the cutbank for a lateral distance of at least 15 meters. Stratigraphic Unit VIII represents the former streambed of a migrating Antelope Creek and serves as an important marker bed in correlating alluvial stratigraphy along the Northeast Streamface and the lower section of Trench 1.

Stratigraphic Unit V

Unconformably overlying Stratigraphic Unit VIII is a weakly developed sandy loam and sandy clay loam paleosol (Unit V). Stratigraphic Unit V is distinguished from underlying Unit VIII by the presence of soil development (darker color and higher organic content) and relative absence of sandstone gravels and channers. Unit V is approximately 50 centimeters thick and consists of two soil horizons that are separated by a thin lens of stream deposited sands and gravels.

The lower component of Unit V is designated as horizon 6Akb2. This horizon is approximately 20 centimeters thick and has an abrupt and smooth boundary with underlying Unit VIII. Horizon 6Akb2 is a buried A horizon and contains the maximum concentration of calcium carbonate from the overlying sequum (pH 8.3). This horizon is a massive sandy loam/sandy clay loam with a very dark grayish brown (10YR 3/2) moist matrix color. Horizon 6Akb2 also shows evidence of common fine mottling, a condition reflecting alternating patterns of oxidation and reduction from a fluctuating water table. Horizon 6Akb2 is interpreted as corresponding with Natural Layer 5b and Cultural Layer IV as defined by Nowatzyk (1983).

The upper component of Stratigraphic Unit V includes another buried A horizon designated as horizon 6Akb1. This horizon is darker (10YR 2/1 m) than underlying horizon 6Akb2, but otherwise shares similar pedologic attributes. Horizon 6Akb1 is approximately 20 centimeters thick and is interpreted as being equivalent to Natural Layer 5a and Cultural Layer III as identified by Nowatzyk (1983).

Also included in Stratigraphic Unit V is a discontinuous lens of alluvial sands and gravels that interrupted pedogenesis between horizons 6Akb2 and 6Akb1. This distinct alluvial deposit is generally about 10 centimeters in thickness and is interpreted as being derived from overbank deposition during a period of accelerated alluviation (flooding). This alluvial deposit was probably emplaced during a relatively brief interval and suggests that soil horizons 6Akb1 and 6Akb2 are closely related in time, thus supporting the existing interpretation of close association between Cultural Layers III and IV. This lens of alluvial sands and gravels comprises the lower section of horizon 6Akb1, and is interpreted as correlating with Natural Layer 4c as described by Nowatzyk (1983).

Stratigraphic Unit IVc

Overlying the paleosol sequence of Stratigraphic Unit V is Unit IVc (horizon 5Bwb). Stratigraphic Unit IVc/horizon 5Bwb is approximately 15 centimeters thick and consists of a massive loam/sandy clay loam, interpreted as corresponding with Natural Layer 4b as identified by Nowatzyk (1983). This unit/horizon is derived from overbank deposition along Antelope Creek and is distinguished from underlying Unit V by being lighter in color (10YR 4/3 m) and having a weak, medium angular blocky structure. The boundary between horizon 5Bwb and underlying Unit V is gradual and smooth.

Stratigraphic Unit IIIc

Overlying Stratigraphic Unit IVc is another buried A horizon, designated as Unit IIIc and horizon 4Akb. This unit/horizon is between 5 to 10 centimeters thick and is distinguished from underlying Unit IVc/horizon 5Bwb by its darker color (10YR 2/2 m) and loam texture. This horizon effervesces with HCl and has a pH of 7.9. Horizon 4Akb has a weak to moderate medium angular blocky structure with a generally gradual irregular boundary with underlying horizon 5Bwb. Horizon 4Akb is interpreted as being equivalent to Natural Layer 3b and Cultural Layer II as defined by Nowatzyk (1983).

Stratigraphic Unit II

Stratigraphic Unit II overlies Unit IIIc and is designated as horizon 3Bwb. This thin unit/horizon (about 10 centimeters in thickness) is distinguished from underlying

Unit IIIc by being lighter in color (10YR 3/2 m) and having a considerably stronger (strong medium angular blocky) structure. Horizon 3Bwb has a loamy texture and effervesces slightly with HCl (pH 7.9). This unit/horizon is derived from overbank deposition of fine alluvium during an episode(s) of flooding, interrupting pedogenic activity of underlying horizon 4Akb. Horizon 3Bwb is interpreted as correlating with Natural Layer 4a as described by Nowatzyk (1983).

Stratigraphic Unit I

Overlying Unit II is a relatively thick (about 50 centimeters) sequence of A horizons that comprise Stratigraphic Unit I. Unit I consists of two components, each being approximately equal in thickness. The lower section of Unit I is designated as horizon 2Ab and is distinguished from underlying Unit II primarily by being darker in color (10YR 2/1 m) and having a higher total organic matter content. Horizon 2Ab has a loam texture with a strong fine angular blocky structure. This horizon lacks effervescence to HCl and has a pH of 7.4. Horizon 2Ab is a buried A horizon and is interpreted as corresponding with Natural Layer 3a and the lower component of Cultural Layer I as identified by Nowatzyk (1983).

The upper section of Unit I is a surface A horizon and is distinguished from underlying horizon 2Ab by being lighter in color (10YR 3/2 m), having a reduced total organic matter content, and having a sandier texture. This youthful A horizon is heavily rooted, has a strong fine subangular blocky structure, and is interpreted as correlating with Natural Layers 2 and 1 and the upper component of Cultural Layer I as defined by Nowatzyk (1983).

Soil-Stratigraphic Profile # 2 (Trench 1 at 24.0 m)

Stratigraphic and pedologic descriptions were made along Trench 1 to substantiate the developmental sequence of terrace stratigraphy as revealed along the Northeast Streamface. The full length of Trench 1 extended from the cutbank of Antelope Creek for more than 33 meters into the terrace-footslope landform to the east (see Appendix C). A complex array of both alluvial and colluvial deposits was observed along the trench walls, and detailed mapping and description of these materials were made to document these contrasting sedimentation patterns (see Plate 1).

The axis of Trench 1 was oriented perpendicular to the modern channel of Antelope Creek in an attempt to reveal the diverse stratigraphic materials present, and to locate geomorphic evidence of former migrating alluvial channels. High water table levels and the close proximity of the trench to Antelope Creek made it both unpractical and ineffective to excavate to a depth greatly below the water table. Therefore, between 3.0 m to 31.0 m along the trench, the floor was excavated to a depth equal to or just below the existing level of the water table (see Plate 1). Only a short section (between 10.0 m to 14.0 m) of the trench floor was left slightly raised to serve as a dry "island" in facilitating trench access.

In order to determine the full vertical extent of unconsolidated materials occurring along Trench 1, backhoe excavations were undertaken at both ends of the trench in an attempt to reach bedrock. After removing more than 1.5 meters of deposits below the water table, the bedrock contact was encountered at both the east and west termini of

Trench 1. The estimated bedrock contact and basal stratigraphic associations illustrated in Plate 1 are likely much more irregular than projected.

Profile # 2 is located approximately 10 meters to the east of Antelope Creek, in a distinctly alluvial section of Trench 1 (see Plate 1). This location was selected for pedologic description and sampling because it illustrated the major stratigraphic units present along the lower section of Trench 1, and was sufficiently close to the Northeast Streamface that correlation could be made with these deposits (Profile # 1). Stratigraphic and pedologic descriptions at Profile # 2 are generally consistent with observations made along the Northeast Streamface. Seven distinct stratigraphic units containing at least 14 pedologic horizons were identified along the lower (west) section of Trench 1 (Figure 4.3). Summaries of Profile # 2 field descriptions and laboratory analyses are presented in Tables 4.2a and 4.2b, and Figures 4.4, 4.5, and 4.6. Results from Profile # 2 are discussed below.

Stratigraphic Unit IX

Backhoe excavations were undertaken between approximately 30.0 m and 33.0 m along Trench 1 to determine the complete depth of unconsolidated deposits overlying bedrock. After removing nearly 1.5 meters of deposits occurring beneath the water table, the bedrock contact was encountered by backhoe at approximately 2.65 meters below the present surface (as measured from 32.0 m along Trench 1). However, this depth measurement is misleading due to modern surface disturbances at this location. It is estimated that the total thickness of unconsolidated deposits near Profile #2 was approximately 3.40 meters prior to surface disturbances.

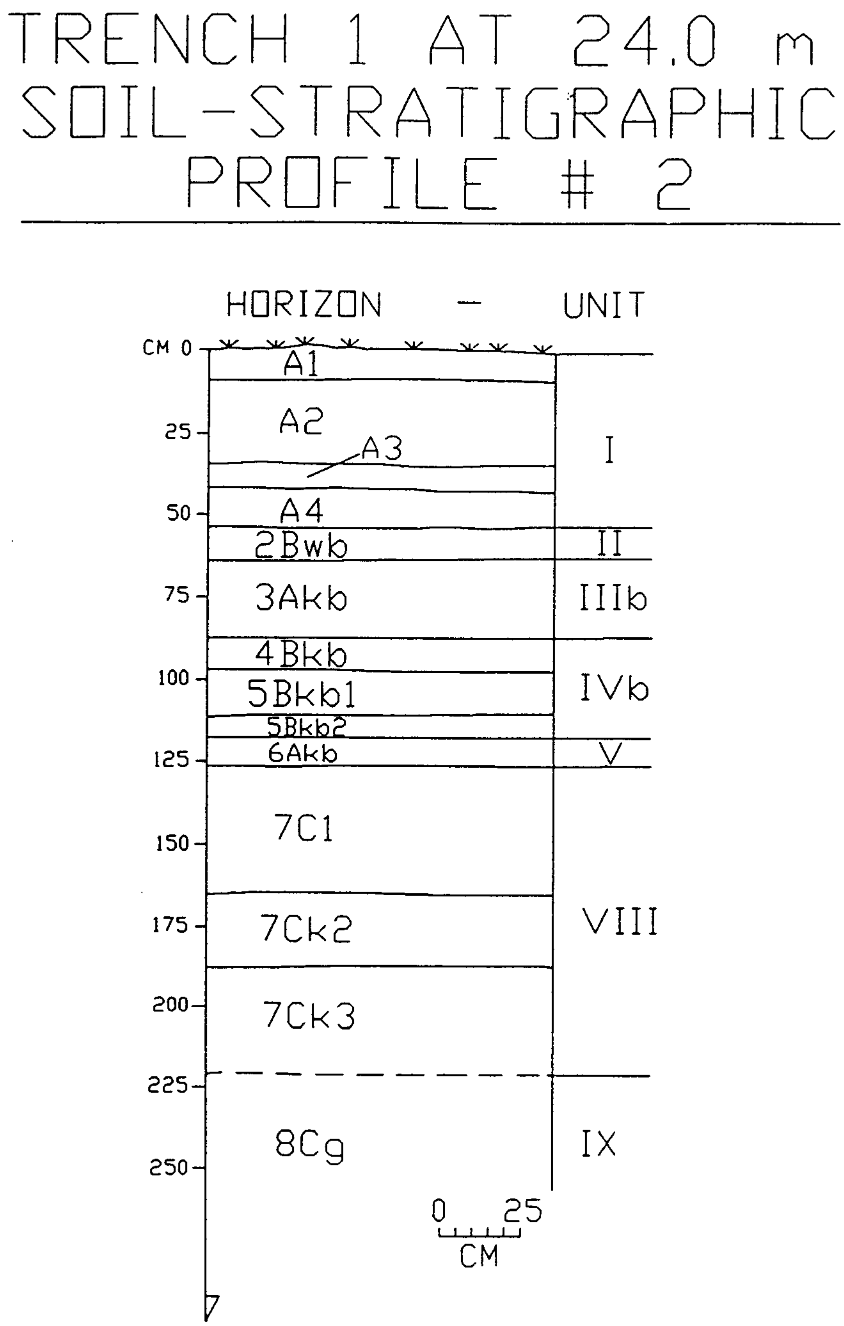

Figure 4.3. Soil-Stratigraphic Profile # 2 (Trench 1 at 24.0 m).

Table 4.2a. Soil-Stratigraphic description of Profile # 2 (Trench 1 at 24.0 m).

Unit	Horizon	Depth (cm.)	Color (moist)	Color (dry)	Texture	Structure	Consistence	Boundary	pH	TOC %
I	A1	0-10	10YR 3/2	10YR 4/2	l	2 f sbk	wss,mfi,dh	as	6.7	3.4
I	A2	10-35	10YR 2/2	10YR 4/2	l	2 m abk	ws,mfr,dh	aw	7.2	3.4
I	A3	35-42	10YR 3/2-2/2	10YR 4/2	l	1 f abk	wss,mfr,dh	as	7.6	3.4
I	A4	42-54	10YR 3/2-2/2	10YR 5/2-4/2	scl/sl	1 f sbk	wss,mfr,dh	aw	7.8	2.6
II	2Bwb	54-64	10YR 4/3	10YR 6/3-6/2	vgrl/scl	2 m abk/pr	wso,mfr,dvh	as	8.3	0.8
IIIb	3Akb	64-88	10YR 2/2	10YR 4/2	l/scl	2 m/c abk	ws,mfr/fi,dh	aw	8.3	1.7
IVb	4Bkb	88-96	10YR 3/2	10YR 4/2	scl/l	1 m abk	ws,mfr,dvh	as	8.5	1.2
IVb	5Bkb1	96-111	10YR 3/2	10YR 4/2-5/2	l	1 c abk	ws,mfr,dvh	aw	8.4	1.1
IVb	5Bkb2	111-118	10YR 3/2-3/3	10YR 4/2	l/scl	1 c abk	ws,mfr,dh	as	8.6	0.8
V	6Akb	118-127	10YR 2/1	10YR 3/1	scl	m	ws,mvfr,dh	as	8.6	1.4
VIII	7C1	127-165	10YR 5/2	10YR 6/3	grsl	m	wso,mlo,dlo	aw	8.7	0.3
VIII	7Ck2	165-187	10YR 5/2	10YR 6/3	exgrsl	m	wso,mlo,dlo	gw	8.3	0.4
VIII	7Ck3	187-220	10YR 6/2	10YR 6/2-6/1	grsl/scl	m	wss,mfr,dh	as	8.2	0.3
IX	8Cg	220+	2.5Y 4/0-5/4	2.5Y 6/0-6/4	grcl/l	m	ws,mvfr,dh	-	8.0	0.7

Table 4.2b. Particle size distribution of soil samples collected at Profile # 2 (Trench 1 at 24.0 m).

Horizon	Depth (cm.)	Coarse Frag. %	**Total Sand %**	V Coarse Sand %	Coarse Sand %	Medium Sand %	Fine Sand %	V Fine Sand %	**Total Silt %**	Coarse Silt %	Med/F Silt %	**Total Clay %**
A1	0-10	10.2	**42.5**	3.1	3.7	5.2	18.1	12.4	**34.5**	16.1	18.4	**23.0**
A2	10-35	3.9	**36.9**	1.6	2.6	3.9	15.5	13.2	**37.6**	17.0	20.6	**25.5**
A3	35-42	1.6	**35.3**	1.0	2.5	3.9	14.8	13.2	**40.1**	18.3	21.8	**24.6**
A4	42-54	4.2	**38.4**	0.9	2.9	4.4	16.2	14.1	**37.0**	16.7	20.3	**24.6**
2Bwb	54-64	25-50	**54.9**	7.2	7.7	7.4	20.4	12.3	**23.6**	12.5	11.1	**21.5**
3Akb	64-88	0.5	**49.1**	0.9	3.2	5.0	21.7	18.3	**28.7**	15.7	13.0	**22.2**
4Bkb	88-96	1.6	**52.3**	1.1	4.9	6.8	22.6	17.1	**25.7**	14.3	11.4	**22.0**
5Bkb1	96-111	1.7	**45.9**	1.4	4.6	6.2	18.6	15.1	**30.6**	16.8	13.8	**23.5**
5Bkb2	111-118	1.6	**46.3**	0.9	4.3	7.2	20.5	13.4	**29.1**	14.9	14.2	**24.6**
6Akb	118-127	4.9	**51.7**	4.7	11.4	9.6	16.0	10.0	**24.4**	12.9	11.5	**23.9**
7C1	127-165	20-25	**75.2**	12.8	21.3	14.5	19.7	7.0	**11.9**	5.5	6.4	**12.9**
7Ck2	165-187	60-70	**66.8**	9.3	14.6	12.8	21.7	8.5	**16.4**	8.4	8.0	**16.8**
7Ck3	187-220	5-10+	**56.8**	0.1	3.4	10.5	28.9	13.8	**24.0**	11.4	12.6	**19.2**
8Cg	220+	15-25	**33.6**	1.2	5.7	5.2	11.8	9.7	**38.2**	12.5	25.7	**28.2**

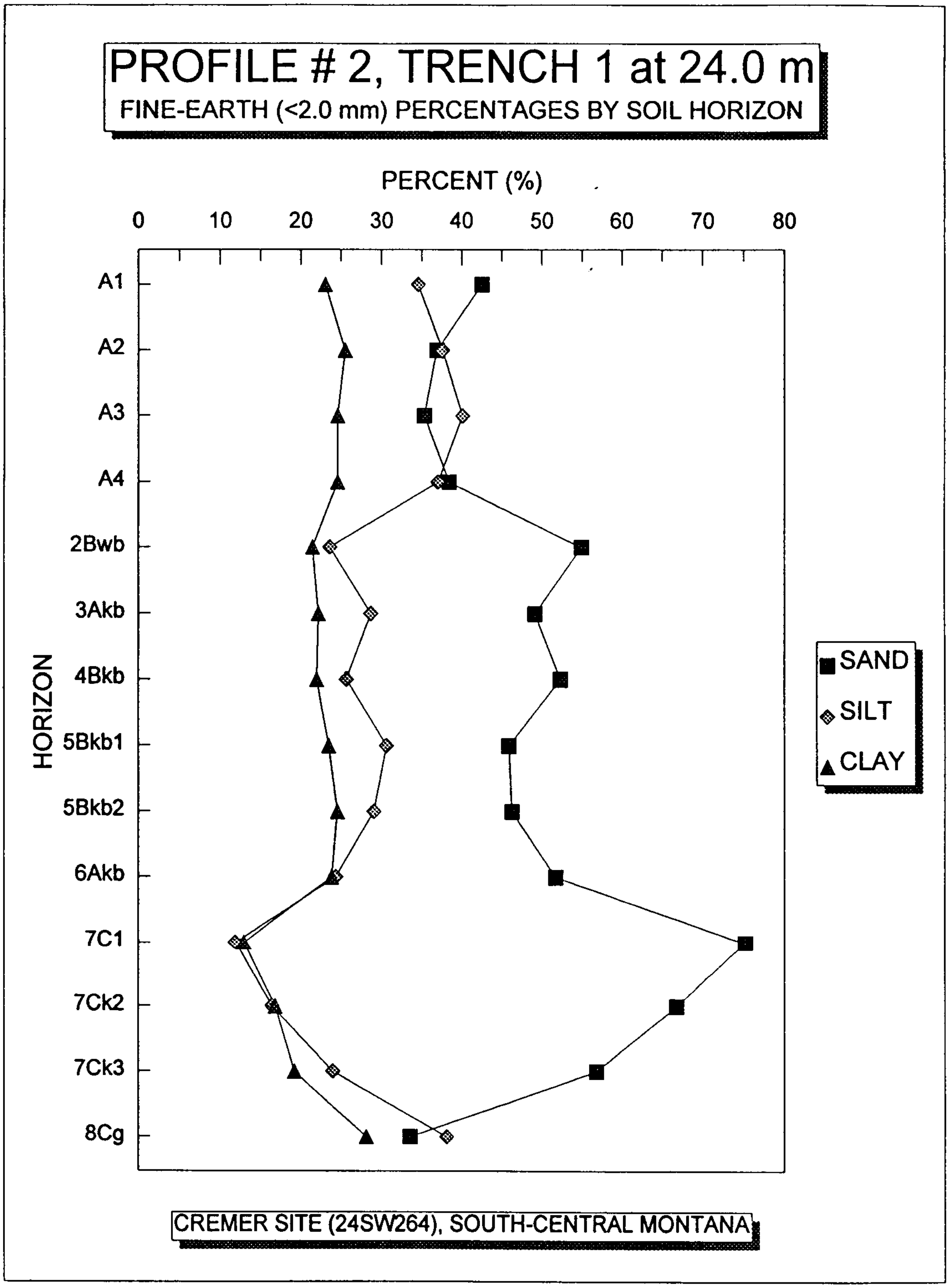

Figure 4.4. Fine-earth (< 2.0 mm in diameter) percentages by soil horizon at Profile # 2 (Trench 1 at 24.0 m).

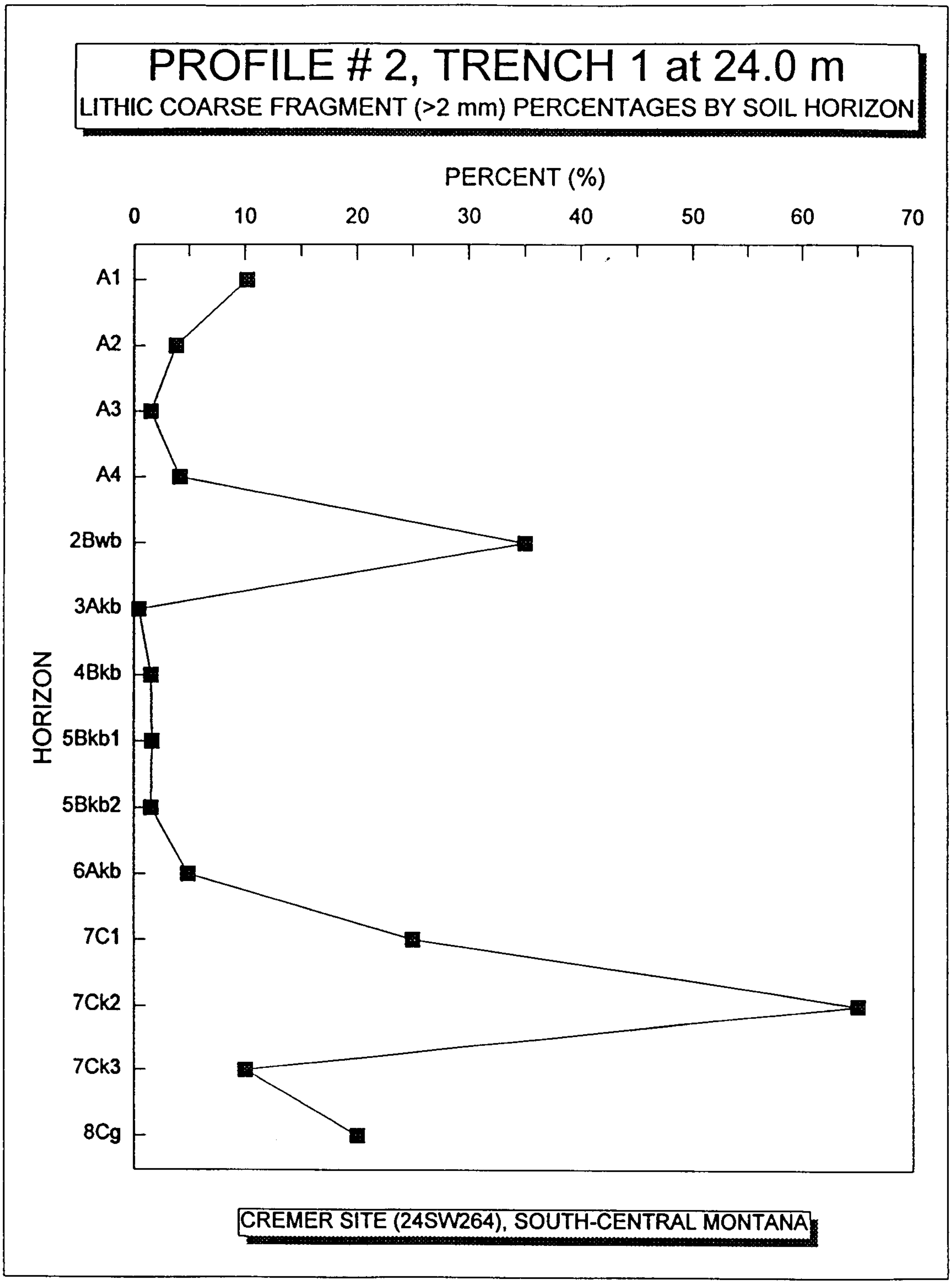

Figure 4.5. Lithic coarse fragment (> 2.0 mm in diameter) percentages by soil horizon at Profile # 2 (Trench 1 at 24.0 m).

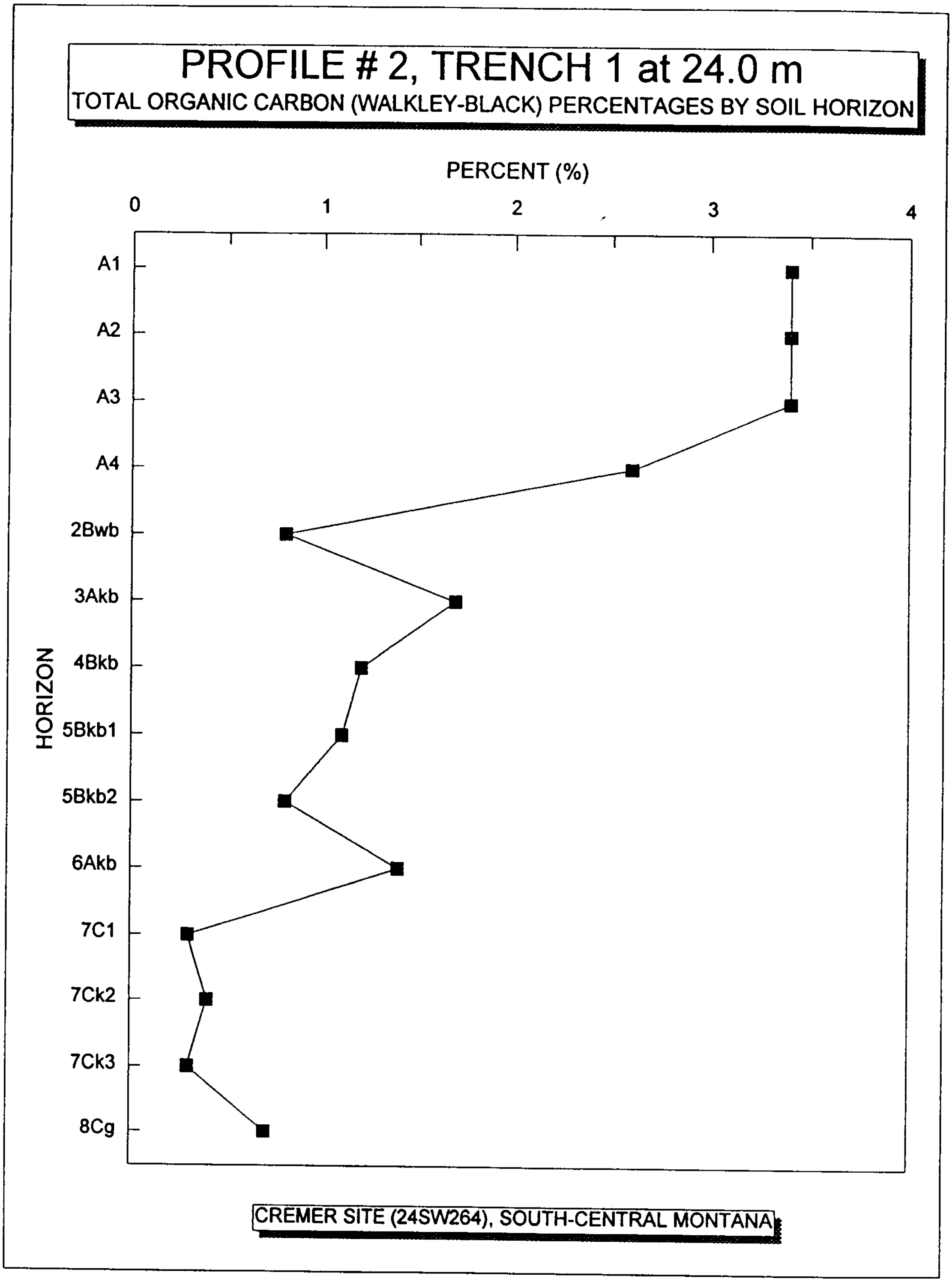

Figure 4.6. Total organic carbon (Walkley-Black) percentages by soil horizon at Profile # 2 (Trench 1 at 24.0 m).

At the lower (west) terminus of Trench 1, Stratigraphic Unit IX directly overlies Fort Union bedrock. This unit was previously identified as the basal unit along the Northeast Streamface and is distinguished by its generally low percentage of coarse fragments, distinct clay loam texture, and overall "reduced" character. The estimated thickness of Unit IX is between 1 and 1.5 meters, and is known to occur beneath the modern floodplain of Antelope Creek and was observed extending from the floodplain into the terrace landform to the northeast for a lateral distance of at least six meters.

A number of pedologic attributes distinguish Stratigraphic Unit IX (horizon 8Cg) from all other units identified along Trench 1 and the Northeast Streamface. Results from particle size analyses revealed that deposits from Unit IX have both the lowest percentage of sand and highest percentage of clay when compared to all other samples (horizons) collected along Trench 1. This textural distinction is important in that all other soil samples from Profiles # 1, # 2 and # 3 generally have a much greater sand:clay ratio. As a result, deposits comprising Stratigraphic Unit IX are the only group along Trench 1 and the Northeast Streamface to have a distinctly clay loam texture. Other important particle size characteristics from Unit IX include the predominance of medium to fine components of sand and silt fractions and a general increase in coarse fragments with depth (coarse fragments comprise 15 to 25 % of the total volume).

Its overall gray color and general anaerobic character also distinguish Stratigraphic Unit IX. These attributes reflect the very poorly drained conditions along Antelope Creek and the deposit's stratigraphic position below the existing water table level. Color designations from this unit are 2.5Y 4/0 (moist), with occasional lenses of 2.5Y 5/4 (moist). The upper component of Unit IX has a soil pH of 8.0 and total organic carbon content of 0.7%, while the lower section of this unit has both a higher pH (8.5) and a slightly lower total organic carbon percentage (0.5%). Material from this unit does not effervesce with HCl. Stratigraphic Unit IX is interpreted as a low-energy swale deposit consisting of highly weathered residuum from a late-Pleistocene/early-Holocene environment (see discussion of Profile # 3 for additional description).

Stratigraphic Unit VIII

The unconsolidated sedimentary deposits that overlie Unit IX record a complex sequence of depositional and soil forming events. Along the lower (west) section of Trench 1, a mixed sequence of alluvial sands, gravels and channers unconformably overlie Unit IX. This coarse textured sandstone alluvium is identified as Stratigraphic Unit VIII at Profile # 2. Unit VIII has an abrupt smooth boundary with underlying Unit IX and consists of poor to moderately well sorted angular to subangular coarse fragments in a matrix of sandy loam. Within this gravelly sandy loam unit, silt and clay fractions increase slightly with depth. The thickness range of this unit varies between 70 to more than 100 centimeters. Unit VIII contains the lowest concentration of total organic carbon (0.3 to 0.4 %) in the described section at Profile # 2. Diagnostic properties that distinguish Unit VIII from underlying Unit IX include stratigraphic position and distinct textural and color changes.

Stratigraphic Unit VIII is divided into three separate pedologic horizons. The lowest horizon, 7Ck3, is a gravelly sandy loam/sandy clay loam exhibiting a relatively low percentage of coarse fragments (5-10 %) when compared to both underlying and overlying horizons. Horizon 7Ck3 is slightly lighter in color (10YR 6/2 m) than overlying horizons from this unit, with common distinct, brownish yellow (10YR 6/6 m) mottles. The thickness range of this horizon varies between 30 and 40 centimeters. Horizon 7Ck3 effervesces slightly with HCl and registered a pH of 8.2. This horizon has a gradual wavy boundary with overlying horizon 7Ck2.

Overlying horizon 7Ck3 is an extremely gravelly sandy loam designated as horizon 7Ck2. This horizon is composed of large angular and subangular cobbles and channers in a matrix of coarse gravels and sands (coarse fragments comprise 60 to 70 % of the total volume). Horizon 7Ck2 ranges in thickness between 20 and 25 centimeters with inclusions of stone (channer and flagstone) lines extending over three meters in length in some places. This horizon has a grayish brown (10YR 5/2) moist matrix color, with common medium prominent brownish yellow (10YR 6/6 m) mottles. Horizon 7Ck2 exhibited slight effervescence with HCl and has a pH of 8.3. This horizon is interpreted as representing a former stream channel of Antelope Creek. It correlates to horizon 7C1 from Profile # 1 along the Northeast Streamface and Natural Layer 7 as identified by Nowatzyk (1983).

The upper component of Stratigraphic Unit VIII is comprised of horizon 7C1. This horizon is a gravelly sandy loam exhibiting a substantial reduction in coarse fragments (20 to 25 % of the total volume) in comparison to underlying horizon 7Ck2. Horizon 7C1 ranges up to 40 centimeters in thickness and has color and mottling properties similar to those identified in underlying horizon 7Ck2. Although horizon 7C1 did not effervesce with HCl, it recorded a pH of 8.7, making it among the most alkaline deposits found at the Cremer site.

Stratigraphic Unit V

Overlying the alluvial horizons that comprise Unit VIII is a distinct buried A horizon (paleosol) that extends the entire length of Trench 1. This paleosol is designated as Stratigraphic Unit V and horizon 6Akb at Profile # 2. This unit is distinguished from underlying Unit VIII by its darker color (10YR 2/1 m) and higher total organic carbon content (1.4 %), reduced occurrence of coarse fragments (5 % of the total volume), and both higher clay and lower sand percentages.

Horizon 6Akb is a massive sandy clay loam and has an abrupt smooth boundary with underlying Unit VIII. This horizon measures approximately 10 centimeters in thickness and exhibits slight effervescence with HCl and registers a pH of 8.6. Unit V/horizon 6Akb is interpreted as corresponding to horizons 6Akb1 and 6Akb2 (Unit V) from Profile # 1 along the Northeast Streamface, and to Natural Layers 5a, 4c and 5b (Cultural Layers III and IV) as defined by Nowatzyk (1983). A section of long bone from an unidentified herbivore found within horizon 6Akb was dated by AMS at 3,730 $\pm$ 110 yr B.P. (Beta-100154).

Stratigraphic Unit IVb

Unconformably overlying Unit V is Stratigraphic Unit IVb. This unit is approximately 30 centimeters in thickness and is comprised of several carbonate-rich (Bk) soil horizons. Unit IVb is distinguished from underlying Unit V by its lighter color, discernible structure, and slight textural change from a sandy clay loam to a predominantly loamy matrix. Sediments comprising Unit IVb are interpreted as having primarily an alluvial origin.

Stratigraphic Unit IVb is separated into three subdivisions. Horizons 5Bkb1 and 5Bkb2 comprise the lower section of the unit. These two horizons measure approximately 20 centimeters in thickness and share similar pedologic attributes, including a weakly developed coarse angular blocky structure, loamy texture and a relative absence of coarse fragments (1.7 % of the total volume). These two horizons have a very dark grayish brown (10YR 3/2) to dark brown (10YR 3/3) moist matrix color. Both effervesced with HCl and had pH values between 8.6 and 8.4. Total organic carbon contents range between 0.8 % and 1.1 %.

The upper section of Unit IVb contains horizon 4Bkb. Horizon 4Bkb is a sandy clay loam/loam containing few coarse fragments (1.6 % of the total volume) with a weakly developed medium angular blocky structure. This horizon has a very dark grayish brown (10YR 3/2) moist matrix color, effervesces with HCl, and has a total organic carbon percentage of 1.2 %. Horizon 4Bkb is between 8 and 10 centimeters thick and has an abrupt smooth boundary with underlying horizon 5Bkb1.

Stratigraphic Unit IVb is interpreted as being alluvial in origin, having truncated a sequence of colluvial deposits that occur along the upper section of Trench 1 (Units IVa and IIIa). This erosional process was likely not characteristic of rapid and high intensity flooding as Unit IVb contains very few coarse fragments. The collective horizons of Stratigraphic Unit IVb at Profile # 2 are interpreted as corresponding to horizon 5Bwb (Unit IVc) at Profile # 1 along the Northeast Streamface, and to Natural Layer 4b as identified by Nowatzyk (1983).

Stratigraphic Unit IIIb

Overlying Unit IVb is Stratigraphic Unit IIIb. Unit IIIb consists of a prominent buried soil designated as horizon 3Akb. This unit/horizon has a loam/sandy clay loam texture, with a moderately well developed, medium to coarse angular blocky structure. Horizon 3Akb is darker (10YR 2/2 m) than the underlying horizons included within Unit IVb, and has a relatively high (1.7 %) total organic carbon content. This buried A horizon generally is between 20 to 25 centimeters thick, contains very few coarse fragments (0.5 % of the total volume), and effervesces slightly with HCl (pH 8.3). Horizon 3Akb has an abrupt wavy boundary with underlying 4Bkb and is interpreted as correlating to horizon 4Akb (Unit IIIc) at Profile # 1 along the Northeast Streamface and to Natural Layer 3b (Cultural Layer II) as described by Nowatzyk (1983).

Stratigraphic Unit II

Unconformably overlying Unit IIIb is Unit II (horizon 2Bwb), another distinctly alluvial deposit. This unit/horizon is distinguished from underlying Unit IIIb by being lighter in color (10YR 4/3 m), having a substantially higher percentage of coarse fragments (25 to 50 % of the total volume), and exhibiting no effervescence when HCl is applied (pH 8.3).

Horizon 2Bwb is a very gravelly loam/sandy clay loam having a moderately well developed medium prismatic to angular blocky structure. Within this loamy matrix is an abundance of sandstone gravels and cobbles (no channers were observed). Along the lower section of Trench 1, Unit II ranges in thickness from 10 centimeters at Profile # 2 to over 45 centimeters between 20.0 m and 23.0 m along the trench. The expanded thickness of this unit reflects the former presence of a secondary stream channel and subsequent channel fill deposits. Unit II is interpreted as being emplaced during a distinct interval of overland flooding and accelerated erosion and alluviation along Antelope Creek. Between 18.0 m and 20.0 m along Trench 1, a facies change was observed where the alluvial deposits of Unit II interfinger with the colluvial deposits that comprise Stratigraphic Unit II along the upper section of the trench (described at Profile # 3). At Profile # 2 along Trench 1, horizon 2Bwb is interpreted as corresponding to horizon 3Bwb (Unit II) at Profile # 1 along the Northeast Streamface, and to Natural Layer 4a as described by Nowatzyk (1983).

Stratigraphic Unit I

Overlying Unit II is a sequence of surface A horizons (Unit I) approximately 50 centimeters thick. Unit I is composed of four pedologic horizons (A1-A4) and is distinguished from underlying Unit II by darker colors (10YR 2/2-3/2 m), distinctly higher total organic carbon contents (2.6 to 3.4 %), and lower percentages of coarse fragments (2 to 10 % of the total volume). Values of pH for Unit I range from 7.8 for the lower section to 6.7 near the surface. None of these horizons effervesce in HCl.

Pedologic horizons A4 and A3 total approximately 20 centimeters in thickness and comprise the lower section on Unit I. Both exhibit weak to moderately well developed fine subangular to angular blocky structure. Horizon A4 is a sandy clay loam/sandy loam while horizon A3 has a loamy texture. These horizons are interpreted as corresponding to horizon 2Ab at Profile # 1 along the Northeast Streamface and to Natural Layer 3a as identified by Nowatzyk (1983).

The upper section of Unit I totals approximately 35 centimeters in thickness and consists of horizons A2 and A1 (sod layer). Horizon A2 has a loamy texture with moderately well developed medium angular blocky structure. Horizon A1 is also a loam with moderately well developed fine subangular blocky structure. These horizons are interpreted as corresponding to the surface A horizon at Profile # 1 and to Natural Layers 2 and 1 as identified by Nowatzyk (1983).

Soil-Stratigraphic Profile # 3 (Trench 1 at 8.0 m)

Profile # 3 is located approximately 26 meters to the east of Antelope Creek, in a distinctly colluvial section of Trench 1 (see Plate 1). This location was selected for pedologic description and sampling because it illustrated the general colluvial stratigraphic sequence present along the footslope-terrace landform component, and was conveniently adjacent to a small excavation unit opened during the 1995 field season in which soil samples were systematically collected and processed for recovery of small-scale organic materials.

Stratigraphic and pedologic descriptions at Profile # 3 are generally consistent with observations made at Profiles #1 and # 2. However, a number of new units/horizons were identified along this predominantly colluvial profile. Nine Major Stratigraphic Units representing at least 20 pedologic horizons were identified along the upper section of Trench 1 (Figure 4.7). Results from Profile # 3 field descriptions and laboratory analyses are presented in Tables 4.3a and 4.3b, and Figures 4.8, 4.9, and 4.10. A complete summary of Profile # 3 is presented below.

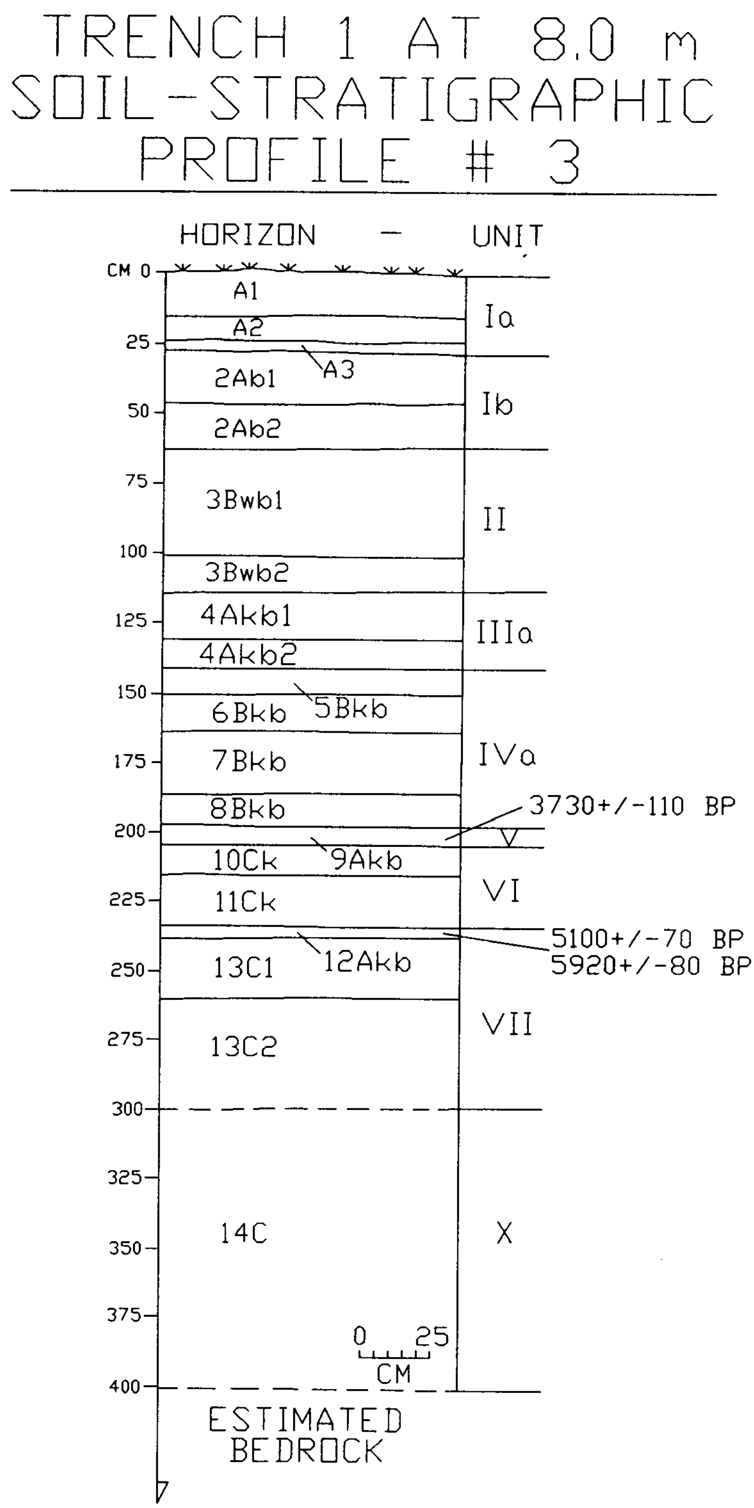

Figure 4.7. Soil-Stratigraphic Profile # 3 (Trench 1 at 8.0 m).

Table 4.3a. Soil-Stratigraphic description of Profile # 3 (Trench 1 at 8.0 m).

Unit	Horizon	Depth (cm.)	Color (moist)	Color (dry)	Texture	Structure	Consistence	Boundary	pH	TOC %
Ia	A1	0-16	10YR 3/2	10YR 4/2	l	2 vf abk	wss,mfr,dvh	as	5.8	4.7
Ia	A2	16-24	10YR 2/2-2/1	10YR 4/2-3/2	l/scl	2 c abk	wss,mfr,dh	as	6.0	3.0
Ia	A3	24-28	10YR 3/2	10YR 4/2	l/scl	1 f abk	wss,mvfr,dh	as	6.2	2.8
Ib	2Ab1	28-46	10YR 2/2-2/1	10YR 3/2-4/2	l	2 f abk	ws,mvfr,dh	as	6.2	2.8
Ib	2Ab2	46-62	10YR 2/2-2/1	10YR 4/2	l/cl	2 f abk	ws,mvfr,dh	as	7.0	2.2
II	3Bwb1	62-101	10YR 4/3	10YR 5/3	grscl/sl	1 f abk	wss,mvfr,dh	as	7.4	0.7
II	3Bwb2	101-114	10YR 4/3-3/2	10YR 5/3-4/2	grscl/sl	2 f abk	wss,mvfr,dh	as	7.8	0.7
IIIa	4Akb1	114-130	10YR 2/1	10YR 3/2	grl/scl	2 m abk	wss,mvfr,dh	cs	8.0	2.5
IIIa	4Akb2	130-141	10YR 2/2	10YR 4/2	grscl/sl	2 m abk	wss,mvfr,dh	as	8.3	1.7
IVa	5Bkb	141-151	10YR 3/2	10YR 5/3	grsl/scl	m	wss,mvfr,dh	as	8.3	0.7
IVa	6Bkb	151-162	10YR 3/3	10YR 4/3	sl/scl	m	ws,mvfr,dh	as	8.4	0.4
IVa	7Bkb	162-185	10YR 4/3-3/3	10YR 6/2	scl/l	m	wss,mvfr,dh	as	8.5	0.6
IVa	8Bkb	185-197	10YR 4/3-3/2	10YR 5/2-6/2	grsl/scl	m	ws,mfr,dh	as	8.3	0.2
V	9Akb	197-203	10YR 2/1-2/2	10YR 3/1	l/scl	m	ws,mvfr,dh	as	8.1	1.0
VI	10Ck	203-214	10YR 3/3-4/3	10YR 5/3	sl/scl	m	wss,mfr,dh	as	8.4	0.4
VI	11Ck	214-233	10YR 4/2	10YR 5/3	scl/sl	m	wss,mfr,dh	as/gw	8.4	0.6
VII1	12Akb	233-237	10YR 3/1	10YR 4/1	grsl	m	wss,mvfr,dh	as/gw	8.4	0.5
VII2	13C1	237-260	10YR 4/2-5/2	10YR 6/2	grsl	m	wso,mvfr,dh	as/gw	8.3	0.3
VII3	13C2	260-300	10YR 4/2-5/2	10YR 6/2	vgrsl	m	wss,mvfr,dh	as	-	-
X	14C	300-400	-	-	exgrsl	m	wso,mlo,dlo	-	-	-

Table 4.3b. Particle size distribution of soil samples collected at Profile # 3 (Trench 1 at 8.0 m).

Horizon	Depth (cm.)	Coarse Frag. %	**Total Sand %**	V Coarse Sand %	Coarse Sand %	Medium Sand %	Fine Sand %	V Fine Sand %	**Total Silt %**	Coarse Silt %	Med/F Silt %	**Total Clay %**	Texture
A1	0-16	13.0	**46.0**	6.2	6.0	6.1	16.1	11.5	**31.7**	16.1	15.4	**22.3**	l
A2	16-24	14.4	**46.2**	5.3	6.1	6.3	16.9	11.5	**28.9**	14.8	14.1	**24.9**	l/scl
A3	24-28	8.5	**47.8**	5.1	6.1	6.2	17.9	12.6	**28.8**	16.4	12.4	**23.4**	l/scl
2Abl	28-46	8.2	**45.2**	4.2	6.2	6.0	16.5	12.3	**30.4**	16.5	13.9	**24.4**	l
2Ab2	46-62	4.2	**40.5**	4.7	5.9	5.0	13.3	11.6	**34.2**	18.4	15.8	**25.3**	l/cl
3Bwb1	62-101	24.0	**55.0**	7.0	8.4	7.6	18.9	13.1	**24.1**	15.1	9.0	**20.9**	grscl/sl
3Bwb2	101-114	19.4	**55.8**	8.0	9.8	7.7	18.3	12.0	**22.4**	15.1	7.3	**21.8**	grscl/sl
4Akb1	114-130	29.5	**49.1**	9.9	8.4	6.6	15.5	8.8	**28.8**	16.6	12.2	**22.1**	grl/scl
4Akb2	130-141	29.6	**53.0**	7.8	9.1	7.4	17.2	11.5	**26.0**	15.9	10.1	**21.0**	grscl/sl
5Bkb	141-151	15-20	**56.0**	6.4	8.5	7.7	20.2	13.2	**25.6**	15.5	10.1	**18.4**	grsl/scl
6Bkb	151-162	9.8	**59.0**	7.1	8.6	8.1	21.8	13.4	**21.6**	13.6	8.0	**19.4**	sl/scl
7Bkb	162-185	7.2	**48.6**	3.3	5.9	6.1	19.4	13.8	**27.3**	14.9	12.4	**24.1**	scl/l
8Bkb	185-197	10-15	**64.2**	1.6	4.9	11.1	34.6	11.9	**16.3**	8.5	7.8	**19.5**	grsl/scl
9Akb	197-203	1.5	**44.8**	1.1	3.6	5.5	20.5	14.3	**29.8**	15.3	14.5	**25.4**	l/scl
10Ck	203-214	9.3	**65.5**	6.3	11.5	9.8	25.5	12.4	**16.3**	10.3	6.0	**18.2**	sl/scl
11Ck	214-233	13.0	**54.5**	4.6	6.8	7.6	21.8	13.7	**24.4**	14.0	10.4	**21.1**	scl/sl
12Abk	233-237	28.8	**70.9**	14.2	12.4	9.6	23.5	11.2	**15.9**	11.6	4.3	**13.2**	grsl
13C1	237-260	16.1	**68.7**	3.6	10.5	13.3	30.5	10.9	**15.4**	7.9	7.5	**15.9**	grsl
13C2	260-300	20-40	-	-	-	-	-	-	-	-	-	-	vgrsl
14C	300-400	50-75	-	-	-	-	-	-	-	-	-	-	exgrsl

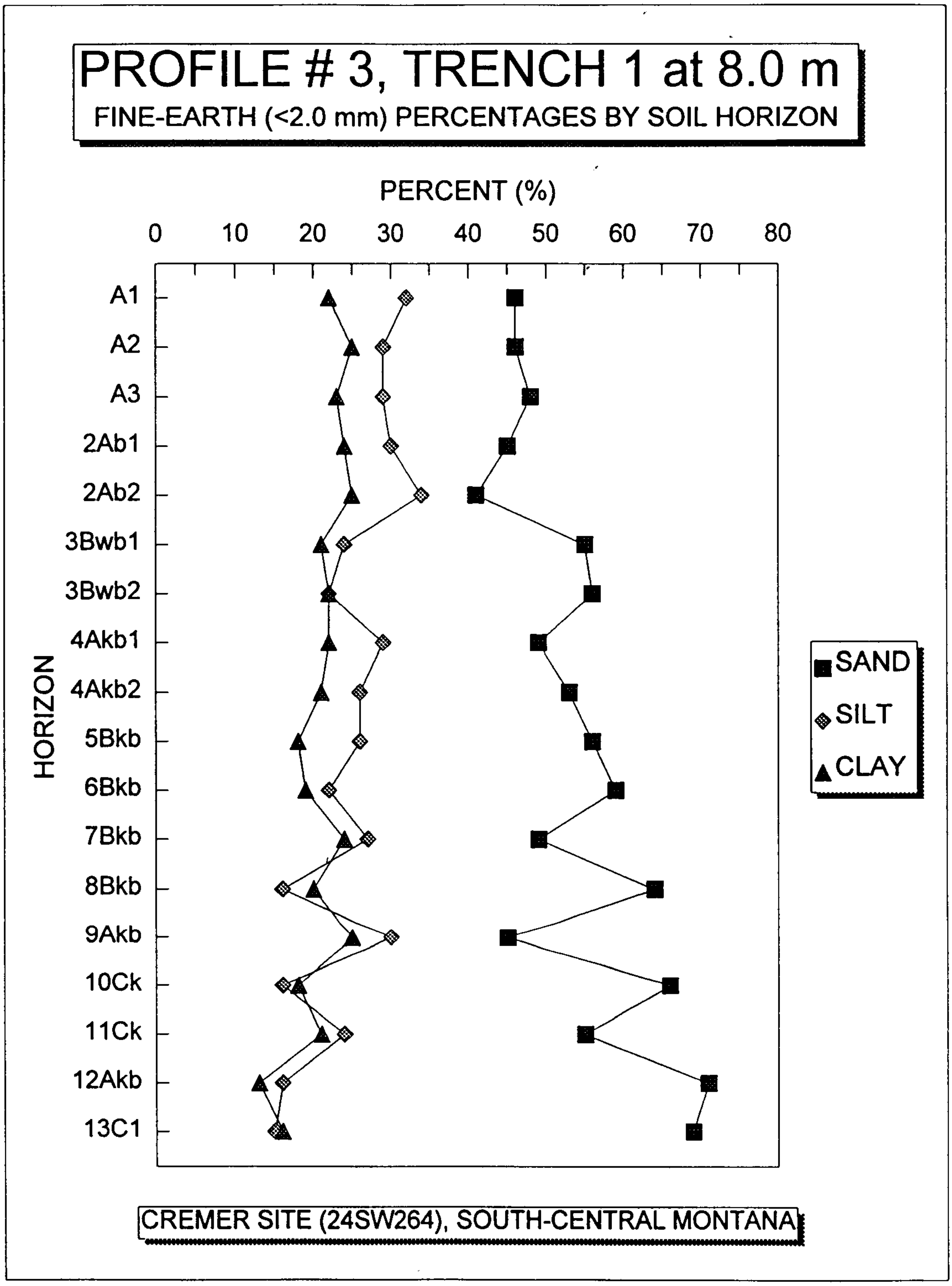

Figure 4.8. Fine-earth (< 2.0 mm in diameter) percentages by soil horizon at Profile # 3 (Trench 1 at 8.0 m).

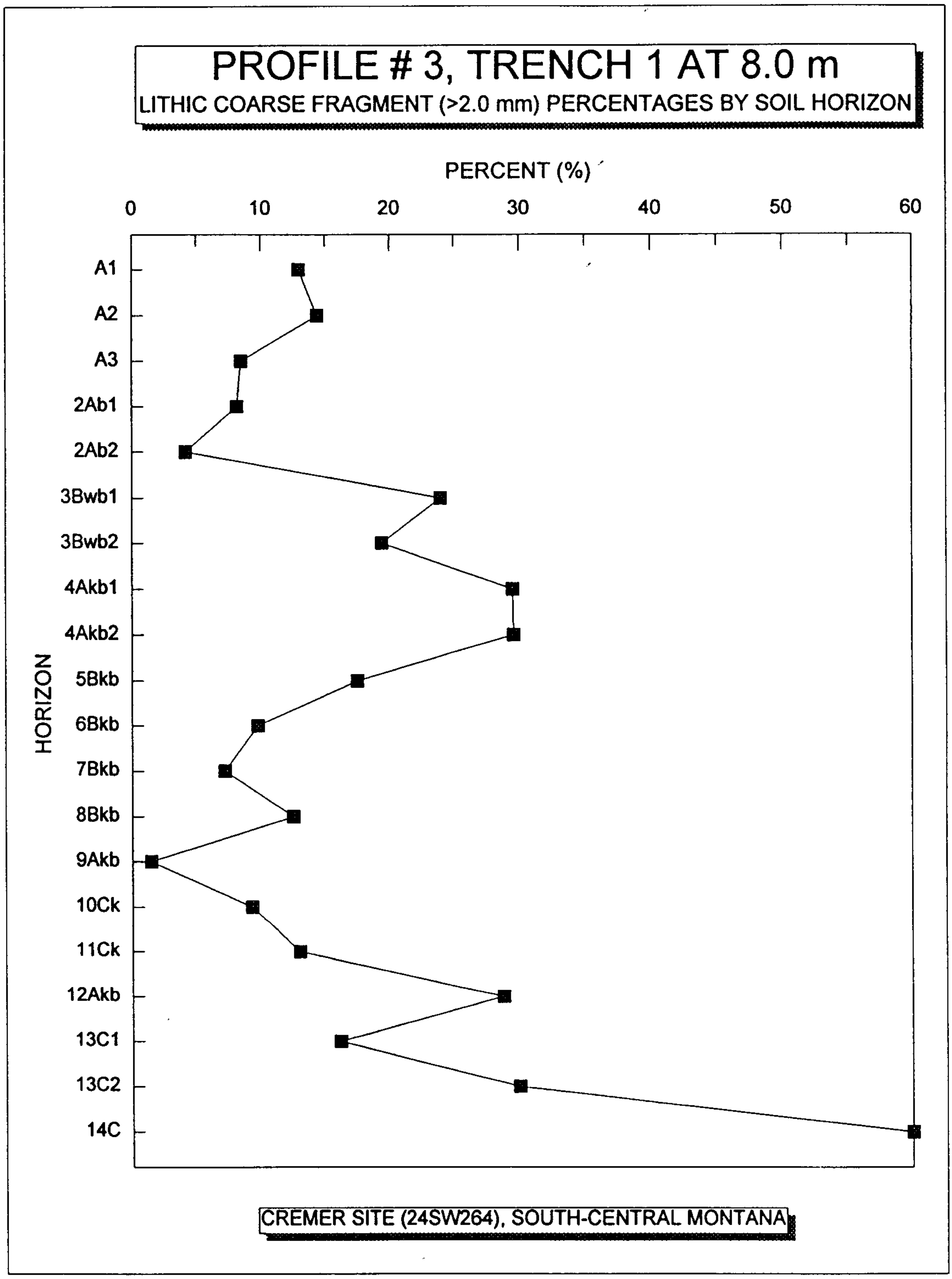

Figure 4.9. Lithic coarse fragment (> 2.0 mm in diameter) percentages by soil horizon at Profile # 3 (Trench 1 at 8.0 m).

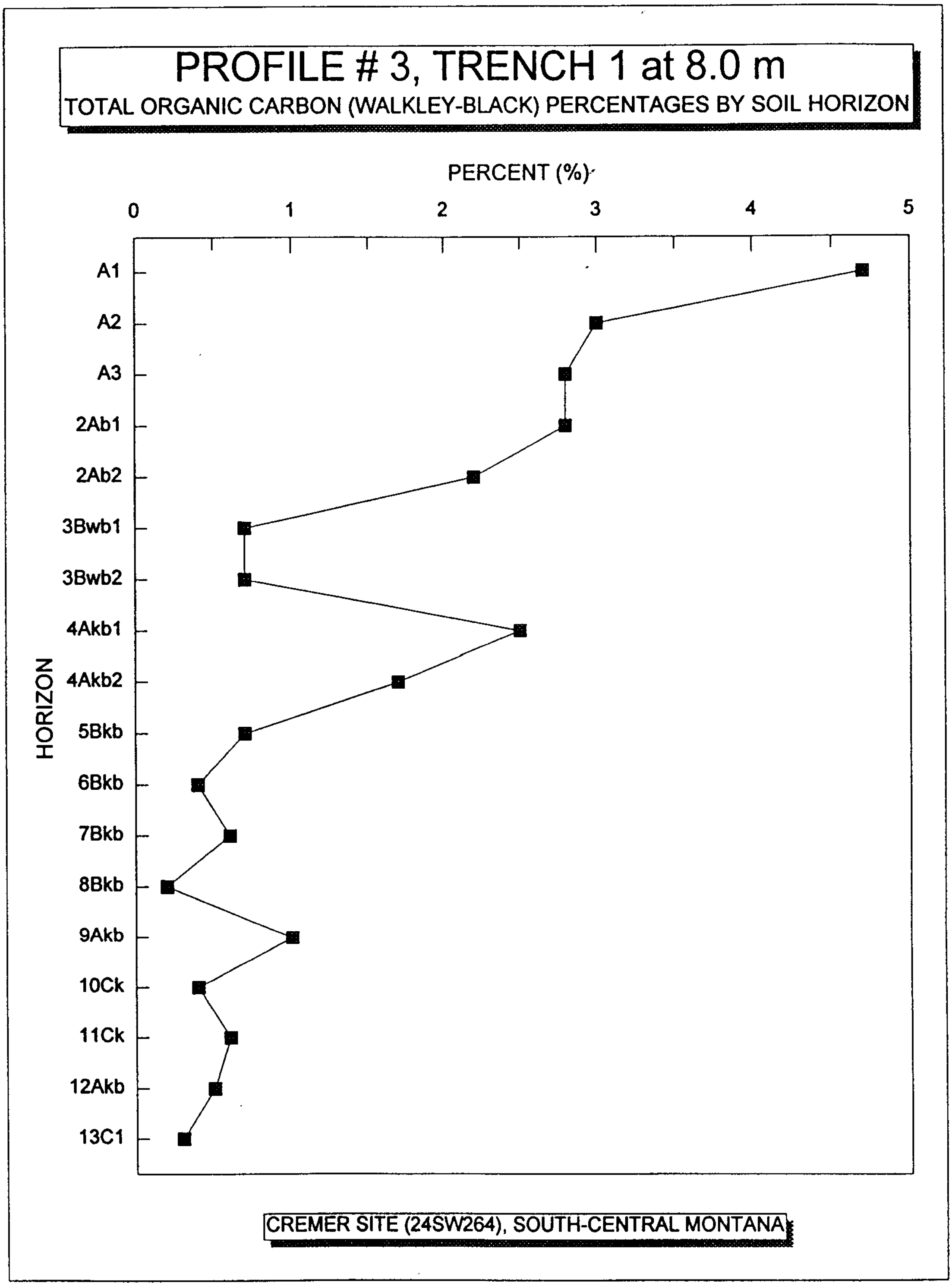

Figure 4.10. Total organic carbon (Walkley-Black) percentages by soil horizon at Profile # 3 (Trench 1 at 8.0 m).

Stratigraphic Unit X

In order to determine the full vertical extent of unconsolidated colluvial materials occurring near the upper (east) terminus of Trench 1, deep trenching by backhoe was undertaken between 0.0 m to 3.0 m along the trench (see Plate 1). Bedrock was encountered at approximately 4.0 meters below the modern surface. This lithic contact was well below the water table and a spring vent was ruptured as a section of bedrock was displaced by the backhoe bucket. Given these obstacles, Rob Bonnichsen was lowered by backhoe into this section of the trench to measure the profile's vertical depth and to recover and provenience a bison mandible exposed along the trench wall. Additional observations of the basal stratigraphy were made prior to partial infilling of the lower depths of the trench segment in an attempt to stabilize the rising water table and to prevent the collapse of trench walls.

The lowest and presumably oldest deposits found along the upper section of Trench 1 were mapped as an undifferentiated group of coarse fragments (Unit X) directly overlying sandstone bedrock. This unit is approximately 1 meter thick and, due to limited exposure, could be observed for a lateral distance of only three to four meters (between 0.0 m to 4.0 m along the trench). Stratigraphic Unit X (designated as horizon 14C) consists of poorly sorted and weakly stratified angular to subangular flagstones, channers, cobbles and gravels in a matrix of sandy loam. The volumetric percentage of coarse fragments from this unit exceeded 75 percent in some places. This unit likely represents the former stream channel(s) of Antelope Creek.

Due to the difficulties encountered in excavating below the water table (unstable trench walls, lack of space for adequate stratigraphic/pedologic observations and profiling, etc.), the interface between Stratigraphic Unit X (Profile # 3) and Stratigraphic Unit IX (Profiles # 2 and # 1) was not directly observed. This lateral boundary undoubtedly occurs somewhere along the middle section of the trench, delineating the contact between the alluvial bottoms recorded in Unit X and the low-energy deposits of Unit IX. Using the depth to bedrock determinations made at both ends of the trench, an approximated bedrock depth along the entire length of Trench 1 is shown in Plate 1. The estimated bedrock contact and basal stratigraphic relationships illustrated in Plate 1 are likely much more irregular and complex than projected.

Stratigraphic Unit VII

Overlying Unit X is a complex sequence of colluvial materials and weakly developed soil lenses comprising Stratigraphic Unit VII. Within this major stratigraphic unit, sub-Units VII3 and VII2 record the increased accumulation of fine earth colluvium directly above the coarse, undifferentiated residual deposits of Unit X. During the 1995 and 1996 field seasons, the water table was in and immediately below sub-Unit VII2. As a result, observations of sub-Units VII3 and VII2 were made primarily during trenching efforts to reach bedrock near the upper (east) terminus of Trench 1. The basal section of this unit (designated as horizon 13C2) was identified as a sandy loam deposit with many gravels, cobbles and channers present (as much as 50 % of the total volume). Due to the conditions imposed by a fluctuating water table level, an abundance of redoximorphic features (mottles) were observed throughout horizon 13C2. Deposits comprising sub-Unit VII3/horizon13C2 were not systematically described in the field and underwent no laboratory analyses.

Sub-Unit VII2 was the lowest depth in which detailed pedological descriptions could be made at Profile # 3. This unit is designated as horizon 13C1. Horizon 13C1 is similar to underlying horizon 13C2 with one notable exception, the presence of several thin (ca. 2 to 3 centimeters in thickness) dark lenses and discontinuous organic-rich horizons. This very gravelly sandy loam horizon has a predominantly dark grayish brown (10YR 4/2) to grayish brown (10YR 5/2) moist matrix color, with very dark grayish brown (10YR 3/2 m) organic lens inclusions and yellowish red (5YR 5/6 m) mottles. Horizon 13C1 is approximately 20 centimeters thick at Profile # 3 and contained an abundant accumulation of coarse fragments (channers, cobbles and gravels comprised between 15 and 50 % of the total volume). This horizon did not effervesce with HCl and registered a pH of 8.3. The thin and discontinuous organic-rich lenses within horizon 13C1 are interpreted as micro-Ab horizons, indicating the incipient formation of soil horizons on a landscape adjusting to changing climatic conditions.

Overlying sub-Unit VII2 is sub-Unit VII1, which consists of a more continuous buried soil horizon (designated as horizon 12Akb at Profile # 3). The surface exposure of this paleosol may have been for a longer duration than related organic lenses (micro- Ab horizons) occurring below, indicating a longer period of relative landscape stability. This weakly developed soil could be identified along the trench wall for a lateral distance of nearly 10 meters (between 0.0 m and 9.0 m). Horizon 12Akb has a gravelly sandy loam texture and a very dark gray (10YR 3/1) moist matrix color. This horizon ranged in thickness between three and eight centimeters and contains numerous coarse fragments (29 % of the total volume). Horizon 12Akb effervesced slightly with HCl (pH 8.4) and has a total organic carbon content of 0.5 %. Both the upper and lower boundaries of horizon 12Akb were generally abrupt and smooth. Charcoal and bone samples submitted from horizon 12Akb were determined to have radiocarbon ages of 5,100 ± 70 yr B.P. (Beta-88602) and 5,920 ± 80 yr B.P. (Beta-88601), respectively.

Stratigraphic Unit VI

Overlying Stratigraphic Unit VII is Unit VI, another sequence of complex colluvial deposits with several weakly developed and discontinuous organic-rich lenses. Unit VI is designated as horizons 11Ck and 10Ck in its lower and upper components, respectively. Horizon 11Ck is a massive sandy clay loam/sandy loam approximately 20 centimeters in thickness at Profile # 3. Horizon 10Ck is a massive sandy loam/sandy clay loam ranging between 10 and 15 centimeters in thickness. Upslope from Profile # 3, deposits comprising Unit VI range up to 80 centimeters in thickness. In general, an upward fining in coarse fragments was discernible in this unit, as angular channers and cobbles (10 % of volume) and angular to subangular gravels (30 % of volume) gave way to smaller and reduced percentages of coarse fragments near the upper section of Unit VI.

Horizons 11Ck and 10Ck have dark grayish brown (10YR 4/2) to brown (10YR 3/3) moist matrix colors with inclusions of few fine faint light gray (10YR 7/2 m) mottles. These two horizons both effervesced with HCl and registered pH values of 8.4. Total organic carbon contents ranged from 0.6 % for horizon 11Ck and 0.4 % for horizon 10Ck.

As was the case with sub-Unit VII2, Unit VI contains at least two discontinuous organic-rich lenses ranging between two and four centimeters in thickness. These micro-Ab horizons contain relatively few coarse fragments and have a very dark grayish brown

(10YR 3/2) moist matrix color. Their occurrence provides further evidence for discrete intervals of organic matter accumulation, and thus surface stability, interrupted by cycles of colluviation. The sequence of colluvial sedimentation and brief pedogenesis recorded in the micro-Ab horizons within Stratigraphic Units VII and VI provides evidence for a distinct climatic/environmental shift which provided the necessary conditions for a series of weakly developed soils to form. The weakly developed micro-Ab horizons and horizon 12Akb are likely closely related temporally, and point to significant climatic changes occurring in south-central Montana beginning approximately 6,000 yr B.P. This lowest sequence of Ab-C horizonization was not found along soil profiles described at Profiles # 1 and # 2.

Stratigraphic Unit V

The cyclic pattern of colluviation and pedogenesis revealed in Stratigraphic Units VII2, VII1 and VI came to an end with the formation of a prominent paleosol (Unit V) that extends the entire length of Trench 1. This weak to moderately well developed buried A horizon (horizon 9Akb at Profile # 3) records an interval of general landscape stability and serves as a principal stratigraphic marker in correlating the colluvial and alluvial profiles along Trench 1, as well as the archaeological stratigraphy associated with the Northeast Streamface. Unit V/horizon 9Akb has an abrupt smooth boundary with underlying Unit VI at Profile # 3.

Horizon 9Akb ranges between 5 and 20 centimeters in thickness and contains very few coarse fragments (1.5% of the total volume). This interval of non-deposition and soil formation was distinguished in the field by its dark color (10YR 2/1 m) and loam/sandy loam texture. Subsequent laboratory analyses confirmed the horizon's comparatively high total organic carbon content (1.0 %) with respect to adjacent horizons. Horizon 9Akb effervesced slightly with HCl and has a soil pH of 8.1.

Horizon 9Akb is interpreted as correlating with horizon 6Akb (Unit V) identified at Profile # 2 along Trench 1, to horizons 6Akb1 and 6Akb2 at Profile # 1 along the Northeast Streamface (Unit V), and to Natural Layers 5a and 5b as described by Nowatzyk (1983). Throughout its exposure along Trench 1, Stratigraphic Unit V contained numerous bone fragments in various states of preservation. One well preserved section of long bone from an unidentified herbivore found within Unit V was dated by AMS at 3,730 $\pm$ 110 yr B.P. (Beta-100154). As will be discussed later, this age determination and interpreted stratigraphic correlation between Trench 1 and the Northeast Streamface supports a more recent antiquity of the archaeological component of the Cremer site.

Between 8.0 m and 11.5 m along Trench 1, angular to subangular sandstone gravels (50 to 60 % of the total volume) and channers (10 % of the total volume) directly overly Stratigraphic Unit V. This discrete deposit is distinguished from both underlying and overlying materials by its abundant percentage of coarse fragments, lighter color (10YR 5/3 m), and sandy loam texture. This deposit is approximately 3 meters in length and ranges between 3 and 10 centimeters in thickness. It is interpreted as a secondary stream channel formed during a particularly wet period when Antelope Creek flooded its banks.

Stratigraphic Unit IVa

Overlying Unit V is a thick series of deposits that comprise Stratigraphic Unit IVa. This sequence of carbonate-rich (Bk) horizons ranges between 40 and 60 centimeters in thickness and contains the maximum concentration of CaCO3 in the soil profile. Unit IVa is distinguished from underlying Unit V by being lighter in color (10YR 4/3-3/2 m), having increased concentrations of coarse fragments, and lower percentages of total organic carbon. All horizons within this unit have abrupt smooth lower boundaries. Unit IVa extends along the upper section of Trench 1 until approximately 20.0 m (see Plate 1) where it is truncated by Unit IVa (see discussion from Profile # 2).

Stratigraphic Unit IVa is separated into four subdivisions. The lowest horizon, designated as 8Bkb, is a massive gravely sandy loam/sandy clay loam approximately 15 centimeters thick. Although coarse fragment screening in the laboratory revealed only a small percentage of particles greater than 2 mm in diameter (2.6 % of the total volume), a slightly higher percentage was observed along the trench wall (10 to 15 % of the total volume). Horizon 8Bkb has a strong reaction (effervescence) to HCl (pH 8.3) and a total organic carbon content of 0.2 %. The moist matrix color of this horizon ranged from brown (10YR 4/3) to very dark grayish brown (10YR 3/2), with dry carbonate colors of very pale brown (10YR 8/2) to light gray (10YR 7/1).

Overlying horizon 8Bkb is horizon 7Bkb, a massive sandy clay loam/loam 20 to 25 centimeters thick. This horizon is distinguished from underlying horizon 8Bkb by having a more clayey texture, higher total organic carbon content (0.6 %), reduced concentration of coarse fragments (7.2 % of the total volume), and strong to violent reaction (effervescence) to HCl (pH 8.5). Of the four pedologic horizons that comprise Stratigraphic Unit IVa, horizon 7Bkb has the least amount of sand and highest percentages of silt and clay. This horizon also contains the greatest concentration of CaCO3 from the overlying sequum.

Horizons 6Bkb and 5Bkb overlie horizon 7Bkb, each being approximately 10 centimeters thick. These massive sandy loam/sandy clay loam horizons are distinguished from underlying horizon 7Bkb by a slight textural change (more sandy), darker color (10YR 3/2-3/3 m), and slightly reduced effervescence to HCl. Horizon 6Bkb registered a pH of 8.4 and total organic carbon value of 0.4 %, with nearly 10 % of its volume comprised of small angular gravels. Horizon 5Bkb recorded a pH of 8.3 and total organic carbon content of 0.7 %. Although laboratory analyses determined this horizon to have a total coarse fragment percentage of just over 8 % of its total volume, field observations indicate this value should be considerably higher (between 15 to 20 % of the total volume). Pedologic horizons comprising Stratigraphic Unit IVa are interpreted as corresponding to horizons 4Bkb, 5Bkb1 and 5Bkb2 at Profile # 2 along Trench 1, horizon 5Bwb at Profile # 1 along the Northeast Streamface, and to Natural Layer 4b as described by Nowatzyk (1983).

Stratigraphic Unit IIIa

A prominent paleosol (Unit IIIa) directly overlies the series of Bk horizons that comprise Unit IVa. Stratigraphic Unit IIIa is distinguished from deposits comprising underlying Unit IVa by being darker in color (10YR 2/1-2/2 m), having a distinctly higher total organic carbon content (1.7-2.5 %), and having a substantially increased amount of angular to subangular coarse fragments (30 % of the total volume). Unit IIIa extends along the upper section of Trench 1 until it is abruptly truncated near 19.0 m by Unit IIIb (see discussion from Profile # 2).

Stratigraphic Unit IIIa is designated as horizons 4Akb1 and 4Akb2 and ranges in thickness between 20 and 35 centimeters in thickness. Horizon 4Akb2 is a gravelly sandy clay loam/sandy loam, while horizon 4Akb1 is a gravelly loam/sandy clay loam. Both of these horizons have a moderately well developed medium angular blocky structure. Both effervesce with HCl, and have pH values ranging between 8.3 and 8.0. Unit IIIa is interpreted as corresponding to horizon 3Akb at Profile # 2 along Trench 1, horizon 4Ab at Profile # 1 along the Northeast Streamface, and to Natural Layer 3b as identified by Nowatzyk (1983).

Stratigraphic Unit II

Unconformably overlying Unit IIIa is a prominent series of Bw (cambic) horizons (Unit II) that can be traced along the entire length of Trench 1. Between 19.0 m and 34.0 m (see Plate 1), this unit has a distinctly alluvial character, reflecting the former position of the stream channel and subsequent channel fill deposits (angular to subangular gravels) (see discussion of Profile # 2). A facies change is evident upslope from 19.0 m along the trench, as deposits reflect deposition by colluvial processes.

At Profile # 3, Stratigraphic Unit II is divided into two pedologic horizons, 3Bwb2 and 3Bwb1. These horizons total approximately 50 centimeters in thickness and are distinguished from underlying Unit IIIa by being lighter in color (10YR 3/2-4/3 m), having a distinctly reduced percentage of total organic carbon (0.7 %), and exhibiting no effervescence with HCl (pH ranges from 7.8 to 7.4). Horizons 3Bwb2 and 3Bwb1 have a gravelly sandy clay loam/sandy loam texture with weak to moderately well developed fine angular blocky structure. These horizons contain a moderately high percentage of coarse fragments (20 to 25 % of the total volume) and have abrupt smooth lower boundaries. Unit II is interpreted as corresponding with horizon 2Bwb (Unit II) at Profile # 2 along Trench 1, horizon 3Bwb (Unit II) along the Northeast Streamface, and to Natural Layer 4a as identified by Nowatzyk (1983).

Stratigraphic Unit Ib

Overlying Unit II is a sequence of buried A horizons that comprise Stratigraphic Unit Ib. Unit Ib consists of horizons 2Ab2 and 2Ab1 and is distinguished from underlying Unit II by its darker color (10YR 2/1-2/2 m), higher total organic carbon content (2.2 to 2.8 %), and lower percentage of coarse fragments (4 to 8 % of the total matrix volume). Horizon 2Ab2 is a loam/clay loam while horizon 2Ab1 is a loam. Both horizons have a moderately well developed, fine angular blocky structure. Unit Ib is between 30 and 40 centimeters thick and has an abrupt smooth boundary with both underlying and overlying horizons. pH values for these horizons vary from 7.0 to 6.2. Unit Ib is interpreted as correlating to horizons A4, A3, A2 and A1 at Profile # 2 along Trench 1, horizons 2Ab and A at Profile # 1 along the Northeast Streamface, and to Natural Layers 3a, 2 and 1 as described by Nowatzyk (1983).

Included within Unit Ib is a distinct lens (5 to 12 centimeters in thickness) of angular to subangular gravels and cobbles (25 to 30 % of the total volume) that occur between 9.5 m and 13.5 m along Trench 1 (see Plate 1). These coarse fragments occur within a very dark grayish brown (10YR 3/2 m) sandy loam matrix. This four meter long deposit has abrupt smooth boundaries with adjacent soil horizons and was likely emplaced during an interval of intense and/or extended precipitation when Antelope Creek flooded its banks and created a secondary stream channel on the eastern side of the valley.

Stratigraphic Unit Ia

Overlying Unit Ib is a youthful series of surface A horizons (Unit Ia) that extend from upslope to near 22.0 m along the trench before thinning out (see Plate 1). Unit Ia is between 45 and 15 centimeters thick and is distinguished from underlying Unit Ib by being generally lighter in color (10YR 3/2-2/2 m), having slight increases in both total organic carbon content (2.8 to 4.7 %) and total coarse fragments (10 to 15 % of the total volume), and by its lack of continuity along the lower section of Trench 1.

The horizons that comprise Unit Ia (A3, A2, A1) at Profile # 3 have a loam/sandy clay loam texture with weak to moderately well developed angular blocky structure. pH values vary between 6.2 to 5.8 for this unit. Unit Ia reflects recent colluvial slopewash derived from the uplands to the east of Trench 1 and is not represented by related deposits at Profiles # 2 and # 1.

Evolutionary History of the Trench 1/Northeast Streamface Landform

Materials revealed in Trench 1 and along the cutbank exposure (Northeast Streamface) adjacent to the trench's lower (west) terminus record a complex sequence of valley fill deposition (landscape aggradation) and episodes of pedogenesis (Figure 4.11).

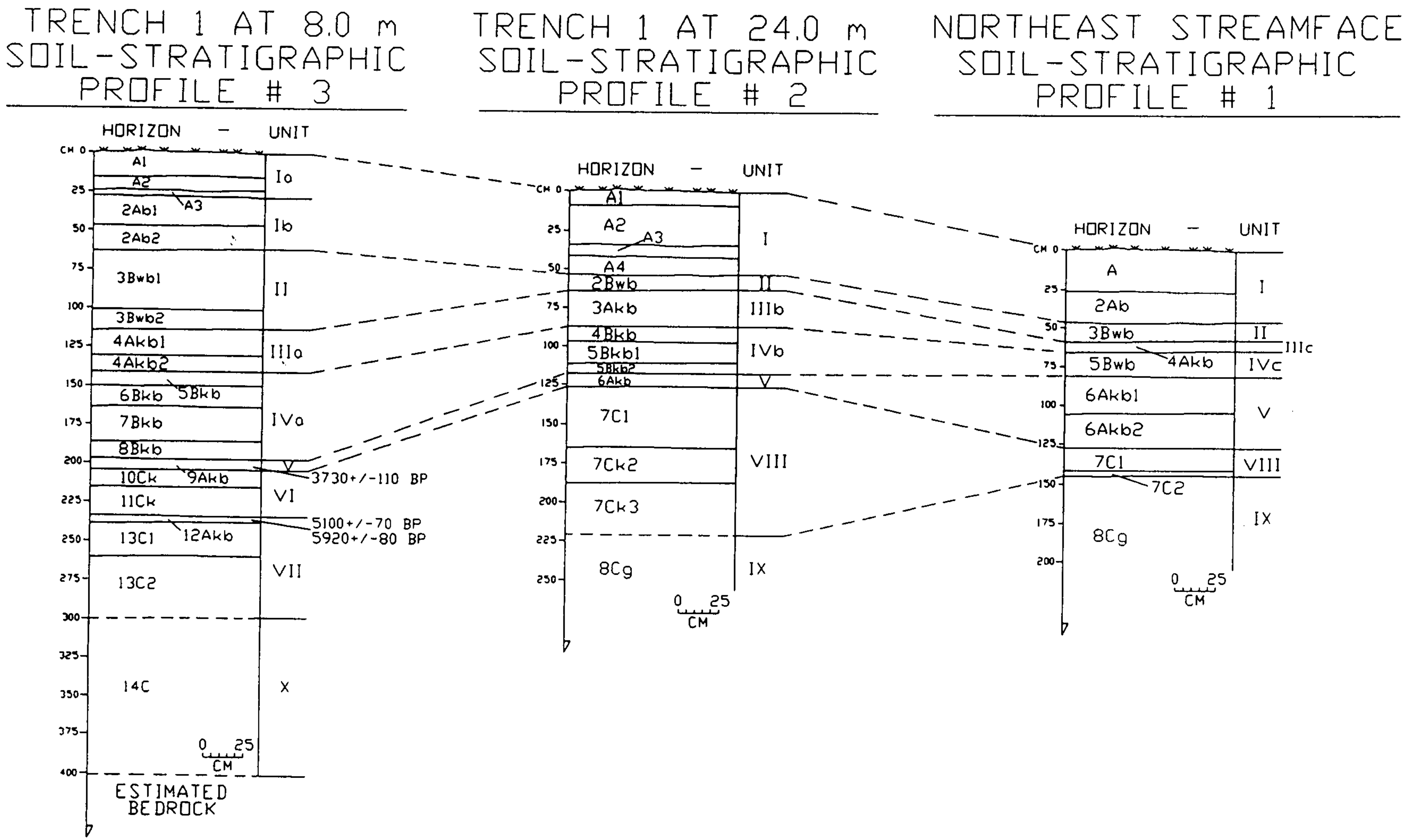

Figure 4.11. Trench 1 and the Northeast Streamface soil-stratigraphic profile composite.

Depositional sequences have resulted from the combination of colluvial materials washed down from the steep upland areas immediately to the east of the trench and from alluviation along a meandering Antelope Creek. These factors of pedogenesis, multiple depositional sources, steep slopes and the close proximity of a continuously changing stream course have all contributed to the very dynamic soil-stratigraphic record revealed along Trench 1 and the Northeast Streamface.

The lowest and presumably oldest deposits described along Trench 1 and the Northeast Streamface consist of two stratigraphic units (X and IX) with distinctly contrasting characteristics. Stratigraphic Unit X was identified along the upper (east) section of the trench and consists of a thick (> 1 meter) sequence of coarse fragments directly overlying sandstone bedrock (see Plate 1). This undifferentiated group of gravels, cobbles, channers and flagstones represents a series of former stream channels when an ancestral Antelope Creek was positioned on the opposite (east) side of the narrow valley. Intervals of rejuvenated streamflow during wetter periods of the past likely eroded away any previous evidence of soil formation and/or fine-earth accumulation. Stratigraphic Unit X is interpreted as a major erosional unconformity created by repeated episodes of stream scouring during the late-Pleistocene and early Holocene periods.

Near the lower (west) terminus of Trench 1, Unit IX was identified as occurring in a position stratigraphically equivalent to Unit X. Stratigraphic Unit IX directly overlies bedrock and consists of a thick deposit distinguished by its reduced character and generally low percentage of coarse fragments (see Plate 1). Deposits representing Unit IX are interpreted as highly weathered residuum from a late-Pleistocene/early Holocene environment that were not completely "flushed out" of the upper Antelope Creek watershed during the interval(s) of landform scouring associated with Stratigraphic Unit X. Limited exposure of these two units along Trench 1 make definitive conclusions regarding depositional/erosional chronologies difficult. What is known is that repeated erosional cycles along the upper (east) section of Trench 1 have greatly contributed to the landform's relatively youthful age.

The pattern of channel migration (from east to west) and erosion across the entire width of the narrow stream valley has removed all evidence of previous episodes of soil development and depositional sequences at this part of the site. Following this interval of early Holocene landform scouring, a shift in climatic and environmental conditions is indicated by the accumulation of fine-earth colluvium (Stratigraphic sub-Unit VII3) along the upper (east) section of Trench 1 and the abandonment of Antelope Creek from the east side of the valley toward the western side. This climatic signal may reflect increased precipitation on a fairly unstable landscape. Overall low precipitation during the early part of the Holocene may have significantly reduced vegetation and ground cover, making the steep slope immediately to the east of Trench 1 very susceptible to accelerated colluviation during the initial stages of landscape adjustment to wetter conditions. Following this period of adjustment, increased landscape stability is indicated by the presence of micro-Ab horizons in Stratigraphic sub-Unit VII2 and by the formation of soil horizon 12Akb (sub-Unit VII1) along the upper (east) section of Trench 1. Results from radiocarbon determinations from a bison mandible and charcoal found within horizon 12Akb produced ages of 5,920 $\pm$ 80 yr B.P. (Beta-88601) and 5,100 $\pm$ 70 yr B.P. (Beta-88602), respectively (Table 3.2). These results suggest that by ca. 6,000 yr

B.P., climatic conditions on the High Plains of south-central Montana became significantly wetter and more conducive to organic matter accumulation.

Following this earliest period of soil formation and relative landscape stability along the upper (east) section of Trench 1 (which likely ended sometime around ca. 5,000 yr B.P.), Stratigraphic Unit VI records an interval of accelerated colluviation which was again punctuated at times by the development of micro-Ab horizons. These slopewash deposits and paleosol stringers suggest oscillating conditions between drier and wetter climates. During a period of increased dryness immediately post-dating the soil forming interval which lasted between ca. 6-5,000 yr B.P., depleted soil moisture could have denuded the upland slopes of vegetation, thus facilitating colluvial deposition during strong but perhaps infrequent rainfall events. A shift to generally wetter conditions may have ultimately produced sufficient moisture for vegetation and ground cover growth, thus stabilizing the surface for pedogenic activity (formation of micro-Ab horizons) prior to burial by renewed colluviation. Radiocarbon dates bracket Stratigraphic Unit VI and indicate that this interval of generally increased colluviation with brief episodes of pedogenesis occurred between ca. 5-4,000 yr B.P. During this period of repeated soil development, an ancestral Antelope Creek continued to migrate toward the west side of the narrow valley, as recorded by the thick alluvial sequences comprising Stratigraphic Unit VIII along the lower (west) section of Trench 1 (see Plate 1).

Evidence for a prolonged period of landscape stability is indicated by the formation of a prominent paleosol (Stratigraphic Unit V) which extends the entire length of Trench 1. This buried soil directly overlies the alluvial bottoms of Unit VIII along the lower (west) section of the trench which implies a further westward migration of an ancestral Antelope Creek at this time. AMS dating of a well preserved long bone section found within Stratigraphic Unit V determined a radiocarbon age of 3,730 $\pm$ 110 yr B.P. (Beta-100154) for this specimen. This age assignment and interpreted stratigraphic correlation between Trench 1 and the Northeast Streamface suggests that Cultural Levels III and IV identified by G. Nowatzyk (1983) do not date to the Early Plains Archaic period, but rather the Middle Plains Archaic period. This evidence of a more recent age for the archaeological assemblage contradicts Nowatzyk's (1983) interpretation that Cultural Levels III and IV represent an "altithermal" period occupation of the Cremer site. The geoarchaeological implications of these findings will be discussed in more detail in the conclusion of this report (Chapter 6).

Following this period of soil formation (Unit V) and site occupation about 3,730 yr B.P., environmental conditions began to deteriorate and inhabitants apparently abandoned the site. Support for this proposed scenario is indicated by the incision of a secondary stream channel (directly overlying Unit V between 8.0 m to 11.5 m along Trench 1) when Antelope Creek flooded its banks during a particular wet period. This was followed by an interval of general landscape instability recorded by the deposition of colluvium and alluvium comprising Stratigraphic Unit IV (a, b, and c) (Plate 1).

Climatic amelioration and increased landscape stability is indicated by the formation of Stratigraphic Unit III (a, b and c). This buried soil extends the entire length of Trench 1 and suggests that an interval of warmer and more moist climatic conditions prevailed at the Cremer site. This period of non-deposition and pedogenesis (surface stability) also witnessed the reoccupation of the site by prehistoric cultural groups. Nowatzyk (1983) identifies this sequence of site occupation as Cultural Level II.

A significant period of climatic and environmental change immediately post-dating the formation of Stratigraphic Unit III is recorded along Trench 1 by the deposition of Stratigraphic Unit II. Stratigraphic Unit II consists of a thick (> 50 cm) series of colluvial deposits along the upper (east) section of the trench and a relatively thin lens of alluvium along most of the lower (west) section. Additionally, the presence of a secondary stream channel between 20.0 m to 23.5 m along Trench 1 indicates an episode of rechannelization along Antelope Creek due to accelerated stream flow and alluviation. However, given the amount of colluvial deposition along the upper (east) section of the trench, it is likely that destabilization of the upland slopes immediately to the east was facilitated by a loss of ground cover (vegetation), perhaps a result of increased aridity. This may suggest that Stratigraphic Unit II developed during a generally drier period that was episodically influenced by significant rainfall events. It is difficult to determine this pattern of climatic oscillation or how long these conditions lasted. The archaeological record indicates that the site was at least temporarily abandoned.

Overlying Stratigraphic Unit II is a thick organic rich unit that includes the modern surface soil (Unit I). The development of Stratigraphic Unit I has resulted from the most recent period of landscape stability associated with modern climatic conditions. This period of pedogenesis witnessed heavy runoff at times, as indicated by the formation of a secondary stream channel between 10.0 m and 13.0 m along Trench 1 (see Plate 1). Along the upper (east) section of the trench, Unit I is divided into sub-Units Ib and Ia. Sub-Unit Ia comprises the surface soil along this section of the trench and was at least partly influenced by increased deposition (colluviation) due to local livestock grazing during the initial settlement of this region by European pioneers. The soil sequence comprising Stratigraphic Unit I is identified as Cultural Level I by Nowatzyk (1983).

In summary, the fan/terrace landform revealed along Trench 1 and the Northeast Streamface displays a repeated pattern of soil development (landform stability) and subsequent surface burial by renewed sedimentation (landform instability) spanning the last 6,000 yr B.P. Earlier evidence of this cyclic process has been largely eroded by the migration of an ancestral Antelope Creek from the east side of the narrow valley to the western edge. Any archaeological assemblage(s) associated with this earliest period of landform development would have been eroded and redeposited downstream along with the surrounding matrices. The collective geoarchaeological evidence from Trench 1 and the Northeast Streamface suggests that the earliest existing evidence for human occupation at the Cremer site (Cultural Level V) is no older than approximately 6,000 yr B.P., and perhaps even more recent than this.

Trench 2

Landform Morphology

Trench 2 was excavated into a stable colluvial landform approximately 150 meters to the south of Trench 1, near the outlet of the low gradient basin (the Anderson Haymeadow) in which the main stem of Antelope Creek traverses (see Figure 4.1 and Appendices B and D). This landform is bound by two streams along its margins, resulting in its characteristic micro-interfluve topography. The principal stream of Antelope Creek enters the site area from the south (through the basin) in a series of sharp meander bends. This upper section of Antelope Creek is unable to adequately transport incoming deposits out of the low gradient basin (which acts as a "sediment sump" for materials washed in from the surrounding hillslopes), and thus inhibits significant alluviation and/or erosion of the landform located at the basin's outlet. The intermittent tributary stream emerges into the low lying site area from its upland sources to the east. The trench was excavated through the center of the landform (most stable position), approximately equi-distance from the associated streams. In total, Trench 2 extended from the modern floodplain of Antelope Creek into the fan/terrace landform to the south-east for a distance of approximately 48.0 meters (see Plate 2).

The sedimentary materials that comprise the Trench 2 fan/terrace are derived from upland sources just a short distance (150 to 250 m) to the east and southeast of the trench. Unlike the steep slopes adjacent to Trench 1 (where slope gradient averages nearly 35 %), Trench 2 is associated with a much more gently sloping landform. Immediately upslope from the upper terminus of Trench 2, slope gradient averages approximately 5 % (3°). Along the upper section of Trench 2 slope gradient averages approximately 4 % (2°), and near the lower section of the trench the slope reaches a maximum gradient of approximately 12 % (7°) where the terrace landform intersects the modern floodplain of Antelope Creek. The Trench 2 landform has thus formed from periods of soil formation and the slow accumulation of colluvium from gently sloping upland sources. These factors of low slope gradient and slow stream flow along the main stem of Antelope Creek (which singularly has little erosive or depositional potential) account for the landform's relative stability and older age.

Stratigraphy and Pedology: Trench 2

During excavations of Trench 2, a principal objective was to determine the thickness and character of unconsolidated materials overlying Fort Union bedrock. Between the modern stream channel of Antelope Creek and 32.0 m along the trench, bedrock was encountered at depths ranging from 1.5 to 2.0 meters (see Plate 2). Near 30.0 m, bedrock began to dip sharply and could not be traced beyond 28.0 m. This ridge or nose of sandstone bedrock is considered to represent an ancestral channel margin of Antelope Creek, and upon repositioning of the stream to its present location, exhibited a substantial influence on deposits that accumulated upslope from this projection.

Further attempts to reach bedrock by direct backhoe trenching proved to be unsuccessful beyond 28.0 m. Therefore, during profile descriptions at 3.0 m (Profile # 4) and 20.0 m (Profile # 5) along Trench 2, a hand auger was used for continued subsurface soil description and attempts to reach bedrock. At both of these locations, sandstone bedrock was contacted at an approximate depth of 4.10 meters below the modern surface.

Trench 2 fan/terrace stratigraphy was mapped and described in detail at three separate locations along the trench (Profiles # 4, # 5, and # 6). In total, 10 major stratigraphic units were identified along the trench walls (see Plate 2), each of which are associated with a distinct pedological sequence. Figures 4.12 and 4.16 show the existing associations between stratigraphic units and soil horizons exposed along Trench 2. Additionally, results from field descriptions and laboratory analyses of selected soil properties are presented in Tables 4.4a, 4.4b, 4.5 and 4.6, and Figures 4.13, 4.14, and 4.15. The following stratigraphic and pedologic summary of the Trench 2 fan/terrace landform evaluates the origin and character of each stratigraphic unit and associated soil horizons to illustrate the sequence of events leading to landform evolution and development.

Soil-Stratigraphic Profile # 4 (Trench 2 at 3.0 m)

Profile # 4 is located near the upper terminus of Trench 2, approximately 47 meters to the southeast of the main stem of Antelope Creek (see Plate 2). This section of the trench was part of the 1996 extension of Trench 2 (between 0.0 to 10.0 m) which exposed nearly 10 additional meters of the landform's soil-stratigraphic record. This location was selected for pedologic description and sampling because it represented the deepest and most continuous soil/depositional sequence thus far found at the Cremer site. In total, 10 major stratigraphic units representing at least 16 pedologic horizons were identified along the upper (southeast) section of Trench 2. The relationships between stratigraphic units and pedologic horizons described at Profile # 4 are presented in Figure 4.12 and Tables 4.4a and 4.4b. Results of laboratory analyses of selected soil properties are illustrated in Figures 4.13, 4.14, and 4.15. A complete description of Profile # 4 is presented below.

Stratigraphic Unit X

The lowest materials described at Profile # 4 consist of a thick sequence of clay loam colluvial deposits (Unit X). Unit X is just under 1 meter thick at Profile # 4, with the lower component occurring within the level of the 1996 water table. This unit is distinguished by a relative absence of coarse fragments, the presence of many medium distinct mottles, and low total organic carbon content. Unit X directly overlies sandstone bedrock and was identified and mapped between 0.0 m to 23.0 m along Trench 2.

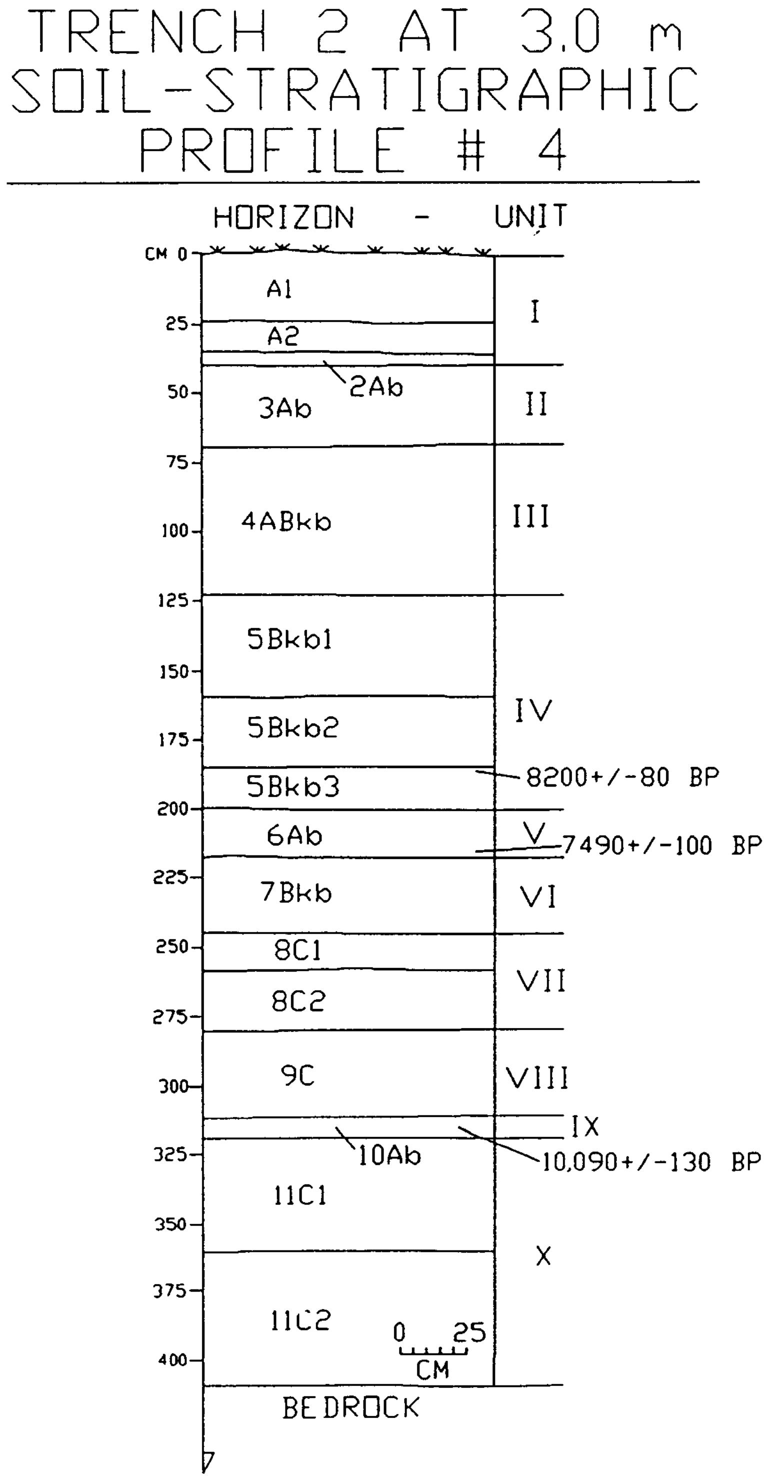

Figure 4.12. Soil-Stratigraphic Profile # 4 (Trench 2 at 3.0 m).

Table 4.4a. Soil-Stratigraphic description of Profile # 4 (Trench 2 at 3.0 m).

Unit	Horizon	Depth (cm.)	Color (moist)	Color (dry)	Texture	Structure	Consistence	Boundary	pH	TOC %
I	A1	0-24	10YR 3/2	10YR 4/2	cl	1 m pr	ws,mfi,dvh	as	6.8	2.0
I	A2	24-34	10YR 3/2	10YR 5/3	l/cl	2 m pr	ws,mfi,dh	gs	7.0	1.6
I	2Ab	34-40	10YR 3/2	10YR 4/2	l/cl	2 m pr	ws,mfi,dh	as	7.4	2.0
II	3Ab	40-70	10YR 3/2	10YR 5/2-4/2	l/cl	2 m pr	ws,mfi,dh	cs	7.7	1.6
III	4ABkb	70-123	10YR 4/2-3/2	10YR 5/2	cl	2 m pr/abk	ws,mfi,dh	gw	8.2	1.1
IV	5Bkb1	123-159	10YR 5/2-4/2	10YR 6/2-7/2	scl/l	2 m pr	ws,mfi,dvh	gw	8.1	0.6
IV	5Bkb2	159-186	10YR 4/3	10YR 5/3-7/2	scl/l	m	ws,mfi,dvh	gw	8.0	0.4
IV	5Bkb3	186-200	10YR 4/3	10YR 5/3-5/4	grscl/cl	m	ws,mfi,dvh	gw	7.8	0.4
V	6Ab	200-218	10YR 3/2-2/2	10YR 4/2	cl	m	ws,mfr,dvh	aw	7.9	0.8
VI	7Bkb	218-245	10YR 4/3-4/2	10YR 5/3-5/4	cl	m	wss,mfr,dvh	as	7.9	0.7
VII	8C1	245-258	10YR 4/3	10YR 5/3	vgrscl	m	wso,mfr,dh	as	7.7	0.3
VII	8C2	258-280	10YR 4/3-5/3	10YR 6/3	scl	m	wso,mvfr,dsh	gw	8.0	0.3
VIII	9C	280-312	10YR 5/3-4/3	10YR 6/3	cl	m	wso,mfr,dh	gw	8.0	0.5
IX	10Ab	312-320	10YR 3/2-4/2	10YR 4/2-5/2	cl	m	wss,mvfr,dsh	aw	7.9	0.9
X	11C1	320-360	10YR 5/2-5/3	10YR 6/2	cl	m	wss,mfr,dvh	-	8.0	0.4
X	11C2	360-410	10YR 5/2	-	cl	m	-	-	-	-

Table 4.4b. Particle size distribution of soil samples collected at Profile # 4 (Trench 2 at 3.0 m).

Horizon	Depth (cm.)	Coarse Frag. %	**Total Sand %**	V Coarse Sand %	Coarse Sand %	Medium Sand %	Fine Sand %	V Fine Sand %	**Total Silt %**	Coarse Silt %	Med/F Silt %	**Total Clay %**	Texture
A1	0-24	1.0	**35.6**	0.2	1.1	3.6	16.6	14.0	**35.6**	18.6	17.0	**28.8**	cl
A2	24-34	0.4	**36.8**	0.1	0.9	3.0	17.7	15.1	**36.2**	17.4	18.8	**27.0**	cl/l
2Ab	34-40	0.2	**32.4**	0.5	1.6	2.9	14.0	13.4	**40.5**	17.5	23.0	**27.1**	cl/l
3Ab	40-70	1.5	**40.0**	0.8	3.5	4.4	16.6	14.8	**33.1**	15.4	17.7	**26.9**	cl/l
4ABkb	70-123	1.8	**35.6**	0.1	3.4	4.5	14.7	13.0	**35.3**	16.4	18.9	**29.1**	cl
5Bkb1	123-159	12.4	**49.5**	0.1	4.3	7.3	23.6	14.2	**26.8**	12.1	14.7	**23.7**	scl/l
5Bkb2	159-186	6.7	**50.9**	3.7	8.7	6.7	19.3	12.6	**25.5**	10.7	14.8	**23.6**	scl/l
5Bkb3	186-200	15.0	**54.4**	2.5	7.3	6.4	23.4	14.7	**25.5**	13.0	12.5	**20.1**	grscl/sl
6Ab	200-218	0.9	**38.0**	1.5	3.5	4.1	16.2	12.6	**33.0**	15.3	17.7	**29.0**	cl
7Bkb	218-245	0.7	**32.4**	0.1	2.1	4.0	14.8	11.3	**36.5**	14.4	22.1	**31.1**	cl
8C1	245-258	20-25	**53.7**	3.5	10.4	8.1	20.6	11.2	**23.2**	8.9	14.3	**23.1**	grscl
8C2	258-280	7.2	**53.5**	2.4	7.0	7.7	24.0	12.4	**23.9**	10.5	13.4	**22.6**	scl
9C	280-312	1.1	**36.6**	0.6	4.1	4.4	15.0	12.4	**32.9**	12.4	20.5	**30.5**	cl
10Ab	312-320	0.3	**33.1**	0.1	1.7	3.2	16.0	12.1	**34.4**	14.3	20.1	**32.5**	cl
11C1	320-360	0.8	**33.8**	0.2	1.6	3.1	15.2	13.7	**34.5**	14.3	20.2	**31.7**	cl
11C2	360-410	-	-	-	-	-	-	-	-	-	-	-	-

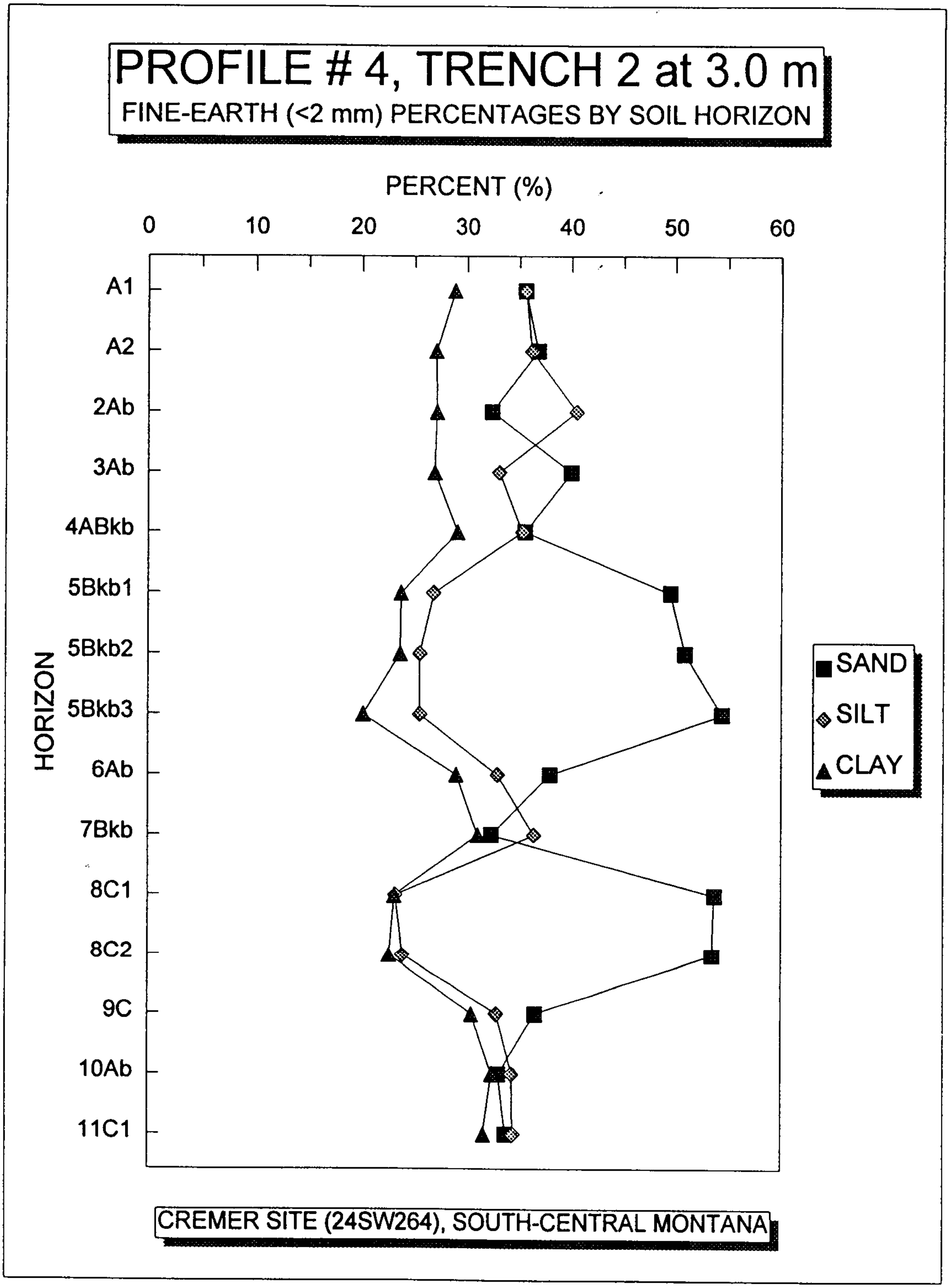

Figure 4.13. Fine-earth (< 2.0 mm in diameter) percentages by soil horizon at Profile # 4 (Trench 2 at 3.0 m).

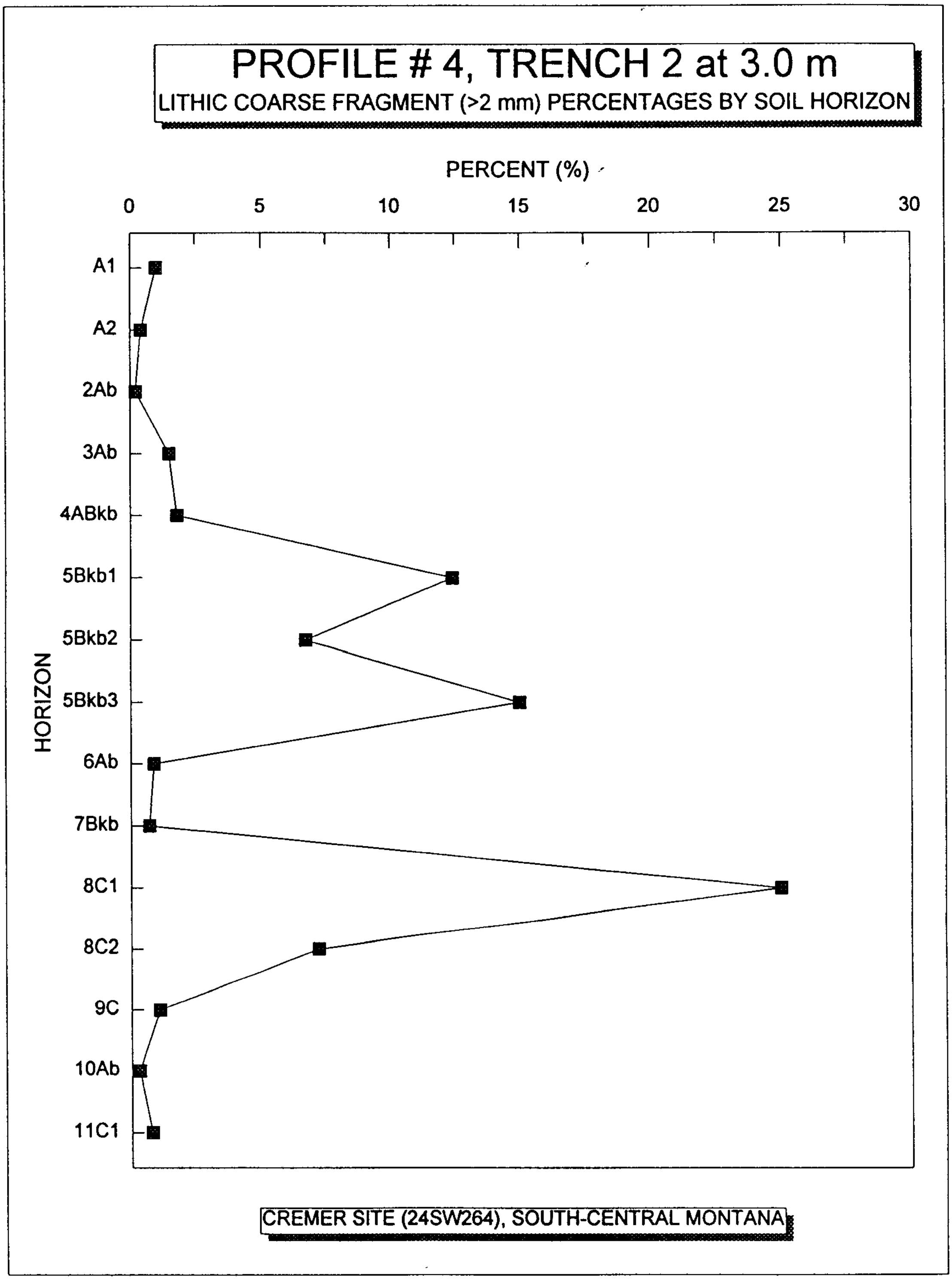

Figure 4.14. Lithic coarse fragment (> 2.0 mm in diameter) percentages by soil horizon at Profile # 4 (Trench 2 at 3.0 m).

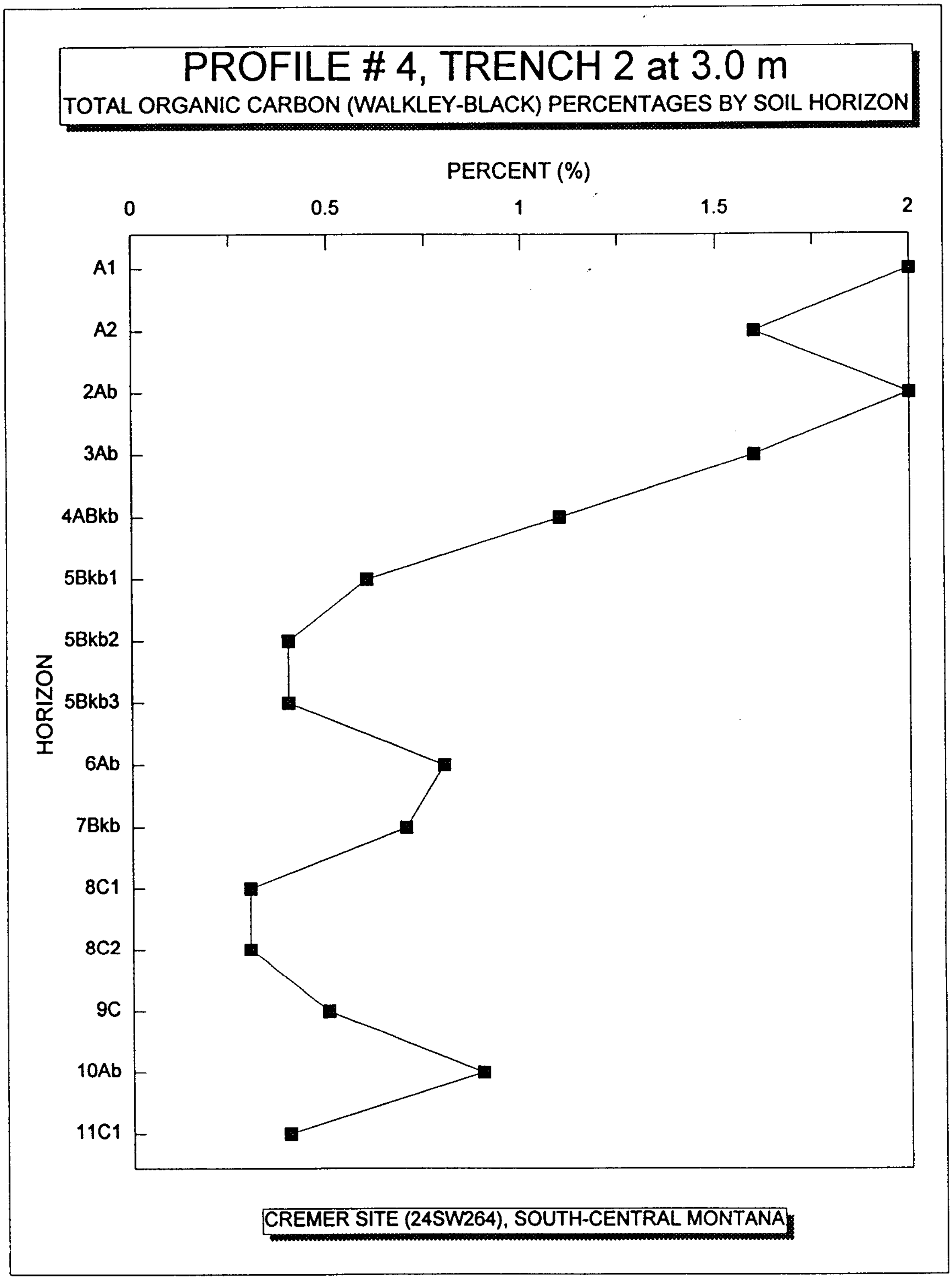

Figure 4.15. Total organic carbon (Walkley-Black) percentages by soil horizon at Profile # 4 (Trench 2 at 3.0 m).

Limited exposure near the middle of the trench prevented adequate observation and description of this unit beyond 23.0 m (see Plate 2).

Horizons 11C2 and 11C1 comprise Stratigraphic Unit X at Profile # 4. These massive clay loam deposits primarily have a grayish brown (10YR 5/2) moist matrix color with strong evidence of mottling (increases with depth). Although generally lacking coarse fragments (< 1.0 %), small gravels and sandstone pieces do tend to increase with depth. Horizons 11C2 and 11C1 both have total organic carbon contents of 0.4 % and lack effervescence to HCl (pH 8.0).

Stratigraphic Unit IX

Overlying Unit X is a weakly developed soil identified as Stratigraphic Unit IX (horizon 10Ab). This buried A horizon is the lowest and oldest soil thus far found at the Cremer site. It ranges between 3 to 10 centimeters in thickness and was observed along Trench 2 between 0.0 m to 22.5 m. Horizon 10Ab has a massive clay loam texture and extremely low occurrence of coarse fragments (0.3 % of the total volume). This horizon is distinguished from underlying horizons 11C1 and 11C2 by being darker in color (10YR 3/2-4/2 m) and having a distinctly increased total organic carbon content (0.9 %). Horizon 10Ab lacks effervescence with HCl and has a pH of 7.9.

Charcoal samples found within this deeply buried A horizon were submitted for both radiocarbon dating and species identification. AMS dating determined an age of 10,090 $\pm$ 130 yr B.P. (Beta-100153) for this soil horizon (Table 3.2). Microscopic analysis of wood charcoal from horizon 10Ab resulted in a tentative identification of

Cercocarpus spp., possibly *C. montanus* Raf. (mountain mahogany) or *C. ledifolius* Nutt. (curlleaf cercocarpus) (Table 3.1) (McWeeney 1997).

Stratigraphic Unit VIII

Overlying Unit IX is a distinctive clay loam layer (Unit VIII) that was identified and mapped along the entire length of Trench 2. The thickness range of Unit VIII varies between 30 and 45 centimeters along most of the trench exposure, except between 23.0 m and 29.0 m where the stratum's width increases substantially. This increase in thickness is partly the result of a ridge of sandstone bedrock that acted as a barrier to further sediment movement, and thus facilitated sediment accumulation.

Unit VIII consists of a colluvial deposit designated as horizon 9C at Profile # 4. This unit/horizon is a massive clay loam that is distinguished from the underlying paleosol by a lighter color (10YR 5/3-4/3 m), coarser texture, and reduced total organic carbon content (0.5 %) .

Stratigraphic Unit VII

Overlying Unit VIII is a discontinuous stratum of sandy and gravelly colluvial slopewash (Stratigraphic Unit VII). Unit VII reaches its maximum thickness (ca. 35 cm.) near 3.0 m along the trench, before thinning out near 10.0 m. The matrix of this stratum consists of a sandy clay loam with a relatively low percentage of coarse fragments in its lower component (horizon 8C2), and an abundant accumulation of coarse fragments throughout most of the upper section (horizon 8C1). Materials comprising Unit VII reveal characteristics indicating deposition during an interval of intense precipitation and were likely emplaced during relatively short periods of time.

Stratigraphic Unit VII is composed of two horizons at Profile # 4. Horizon 8C2 is a sandy layer with a distinct increase in coarse fragments (7.2 % of the total volume) when compared to underlying horizons 9C and 10Ab. Horizon 8C1 records an even greater concentration of coarse fragments (20 to 25 % of the total volume). These horizons have a brown (10YR 4/3) moist matrix color and low total organic carbon contents (0.3 %). Horizons 8C2 and 8C1 are likely closely related temporally, having been derived from upland colluvial sources during episodes of landscape instability.

Stratigraphic Unit VI

Overlying the slopewash deposits of Stratigraphic Unit VII is a carbonate-rich stratum comprising Unit VI. Stratigraphic Unit VI is distinguished from underlying Unit VII by a distinctive clay loam texture, abrupt reductions in both coarse fragments and sandy matrix, and higher total organic carbon content. Unit VI is approximately 25 to 30 centimeters thick and occurs along the upper section of Trench 2 before becoming discontinuous near 22.0 m.

Stratigraphic Unit VI consists of horizon 7Bkb at Profile # 4. Horizon 7Bkb is a massive clay loam that revealed slight effervescence with HCl. This unit/horizon is just over 25 centimeters thick and has a brown (10YR 4/3) to dark grayish brown (10YR 4/2) moist matrix color. Horizon 7Bkb is distinguished from underlying horizon 8C1 by an abrupt reduction in coarse fragments (0.7 % of the total volume), higher total organic carbon content (0.7 %), and the presence of carbonates. Horizon 7Bkb has an abrupt smooth lower boundary with Unit VII and a pH of 7.9.

Stratigraphic Unit V

A prominent buried soil (Unit V) occurs directly above Unit VI and was observed along the entire length of Trench 2 (overlying Unit VIII from 22.0 m to the terrace escarpment of Antelope Creek). Unit V has a variable thickness along Trench 2, ranging from 20 centimeters along the upper section of the trench to over 50 centimeters near the center of the trench (see Plate 2). Unit V is distinguished from underlying Unit VI by being darker in color (10YR 3/2-2/2) and lacking effervescence with HCl.

Unit V is designated as horizon 6Ab at Profile # 4. Horizon 6Ab is a moderately well developed soil approximately 18 centimeters thick at Profile # 4. This horizon has a total organic carbon content of 0.8 %, a pH of 7.9, and coarse fragment percentage of 0.9 %. A well preserved bone fragment found at 3.40 m along the south wall of Trench 2 and associated with the lower section of horizon 6Ab (215 cm dbs) was determined to have a radiocarbon age of 7,490 $\pm$ 100 yr B.P. (Beta-100155).

Another distinctive feature of Unit V/horizon 6Ab is the occurrence of prominent undulations (ca. 13-15 cm.) in the horizon's upper boundary with overlying Unit IV (identified near 20.0 m). This "wavy" appearance is interpreted as resulting from an episode of small-scale solofluction in which localized slope movement may have been triggered by super-saturated surface and/or subsurface conditions. This evidence for mass movement is most likely *not* associated with the presence of permafrost, which characteristically requires below-freezing soil temperatures to warm and act as a plane for basal sliding and sediment deformation. It is likely that the increased thickness of Unit V between 24.0 m to 27.0 m along the trench is a consequence of the deceleration of the solofluction lobe resulting from a loss of water (which served as a transporting agent).

The ridge or nose of bedrock near 30.0 m was also a likely contributor in slowing soil movement and thus increasing the thickness of Unit V/horizon 6Ab at this location.

Stratigraphic Unit IV

Unconformably overlying Unit V is a thick sequence of carbonate-rich (Bk) horizons that comprise Stratigraphic Unit IV. This unit exceeds thicknesses greater than 75 centimeters in some places along the upper section of Trench 2 before thinning out near 10.0 m. Unit IV is distinguished from underlying Unit V by a lighter color and lower total organic carbon content, increased occurrence of coarse fragments, sandy clay loam texture, and high accumulation of carbonates.

Stratigraphic Unit IV is comprised of three pedologic horizons at Profile # 4. Horizons 5Bkb3, 5Bkb2, and 5Bkb1 each range in thickness between 15-30 centimeters, having moist matrix colors predominantly brown to grayish brown (10YR 4/3-5/2). These horizons are distinguished from underlying horizon 6Ab by being lighter in color, having increased accumulations of coarse fragments (7 to 15 % of the total volume), sandy clay loam textures, and an abundant accumulation of carbonates (strong to violent effervescence). pH values for these horizons range between 7.8 and 8.1, with total organic carbon contents slightly increasing with closer proximity to the surface, from 0.4 % in horizon 5Bkb3 to 0.6 % in horizon 5Bkb1. The upper horizon of Stratigraphic Unit IV (horizon 5Bkb1) has discernible moderately well developed medium angular blocky structure. All of these Bkb horizons have gradual wavy lower boundaries.

A well preserved rib bone from an unidentified herbivore (bison?) recovered near the bottom of Unit IV (at 6.60 m along the south wall of Trench 2 at a depth of 1.87 m below the surface) was determined to have a radiocarbon age of 8,200 ± 80 yr B.P. (Beta-103886). The provenience of this sample is associated with pedologic horizon 5Bkb3. This age determination is chrono-stratigraphically inconsistent with the ^{14}C date obtained from the bone specimen recovered from underlying horizon 6Ab (7,490 ± 100 yr B.P.). The apparent anomaly in age is attributed to the fact that the contents of horizon 5Bkb3 are likely associated with redeposited older slopewash (colluvium). Evidence for this interpretation is illustrated in Figure 4.14, which shows that coarse fragment percentages significantly increase in horizon 5Bkb3. These observations suggest that the radiocarbon date assigned to pedologic horizon 5Bkb3 (8,200 ± 80 yr B.P.) is unreliable.

Stratigraphic Unit III

Overlying the series of Bkb horizons that comprise Stratigraphic Unit IV is Unit III. Unit III ranges between 40 to 50 centimeters in thickness along most of Trench 2, before thinning considerably near 35.0 m and becoming discontinuous at 45.0 m. This unit is distinguished from underlying Unit IV by a sharp decrease in coarse fragments (1.5 % of the total volume), reduced sand content, and an increased total organic carbon content.

Stratigraphic Unit III has pedologic properties identified as somewhat transitional between major pedologic horizons A and B. Thus, this unit is designated as horizon 4ABkb. Horizon 4ABkb has a clay loam texture with moderate medium prismatic to angular blocky structure. This horizon has a dark grayish brown to very dark grayish brown (10YR 4/2-3/2) moist matrix color with a moderately high total organic carbon content (1.1 %). Horizon 4ABkb has a strong reaction (effervescence) to HCl (pH 8.2) and a gradual wavy lower horizon boundary.

Stratigraphic Unit II

Overlying Unit III is another buried soil (horizon 3Ab) that comprises Stratigraphic Unit II. Unit II ranges between 30 to 60 centimeters in thickness and could be observed along the complete exposure of Trench 2. Unit II is a clay loam/loam and consists of a well to moderately well developed buried A horizon (horizon 3Ab) distinguished from underlying Unit III by a darker color (10YR 3/2 m) and higher total organic carbon content (1.6 %), and the absence of carbonates (pH 7.7). Horizon 3Ab has a moderate medium prismatic structure, low percentage of coarse fragments (1.5 % of the total volume) and a clear smooth lower horizon boundary.

Stratigraphic Unit I

Overlying Unit II is a more youthful sequence of A horizons (2Ab, A2, A1) that comprise Stratigraphic Unit I. This unit is approximately 35 to 45 centimeters thick and was identified along the entire length of Trench 2.

Horizons 2Ab, A2 and A1 all have a very dark grayish brown (10YR 3/2) moist matrix color and contain very few coarse fragments (< 1.0 % of the total volume). Textural classes for these horizons include loams and clay loams, with weak to moderately well developed medium prismatic structures. These A horizons have high total organic carbon contents (1.6 to 2.0 %), lack effervescence to HCl (pH values between 7.4 and 6.8), and have abrupt clear smooth lower horizon boundaries.

Soil-Stratigraphic Profile # 5 (Trench 2 at 20.0 m) and Profile # 6 (Trench 2 at 32.5 m)

Detailed stratigraphic and pedologic descriptions were also made at two other locations along Trench 2 (at 20.0 m and 32.5 m) (see Plate 2). These observations generally support the previously described soil profile at Profile # 4 (3.0 m). Results from soil profile descriptions and laboratory analyses at 20.0 m (Profile # 5) and 32.5 m (Profile # 6) along Trench 2 are presented in Figure 4.16 and Tables 4.5 and 4.6.

Evolutionary History of the Trench 2 Landform

The sedimentary sequences exposed along Trench 2 reveal the most complete record of post-glacial landscape response available for the Cremer site (Figure 4.16). Based on the collective radiocarbon and sedimentological data set from Trench 2, this landform began to take its modern form following a period of climatic amelioration which signaled the end of the last glacial period and the onset of the present interglacial climate. Trench 2 deposits date back to the late-Pleistocene, making them the oldest and most continuous stratigraphic sequence thus far found at the Cremer site. A buried soil (Profile # 4: Stratigraphic Unit IX/horizon 10Ab) was discovered near the bottom of this trench at a depth between 312 and 320 cm below the modern surface and approximately 90 cm above bedrock (see Figure 4.16 and Plate 2). Wood charcoal recovered from this buried soil was determined to have a radiocarbon age of 10,090 $\pm$ 130 yr B.P. (Beta-100153). This indicates that following the last glacial period and sometime prior to ca. 10,000 yr B.P., climatic conditions on the High Plains of south-central Montana were suitable for modest pedogenesis. The approximately 90 cm of colluvial deposits (Profile # 4: Stratigraphic Unit X/horizons 11C2 and 11C1) underlying this

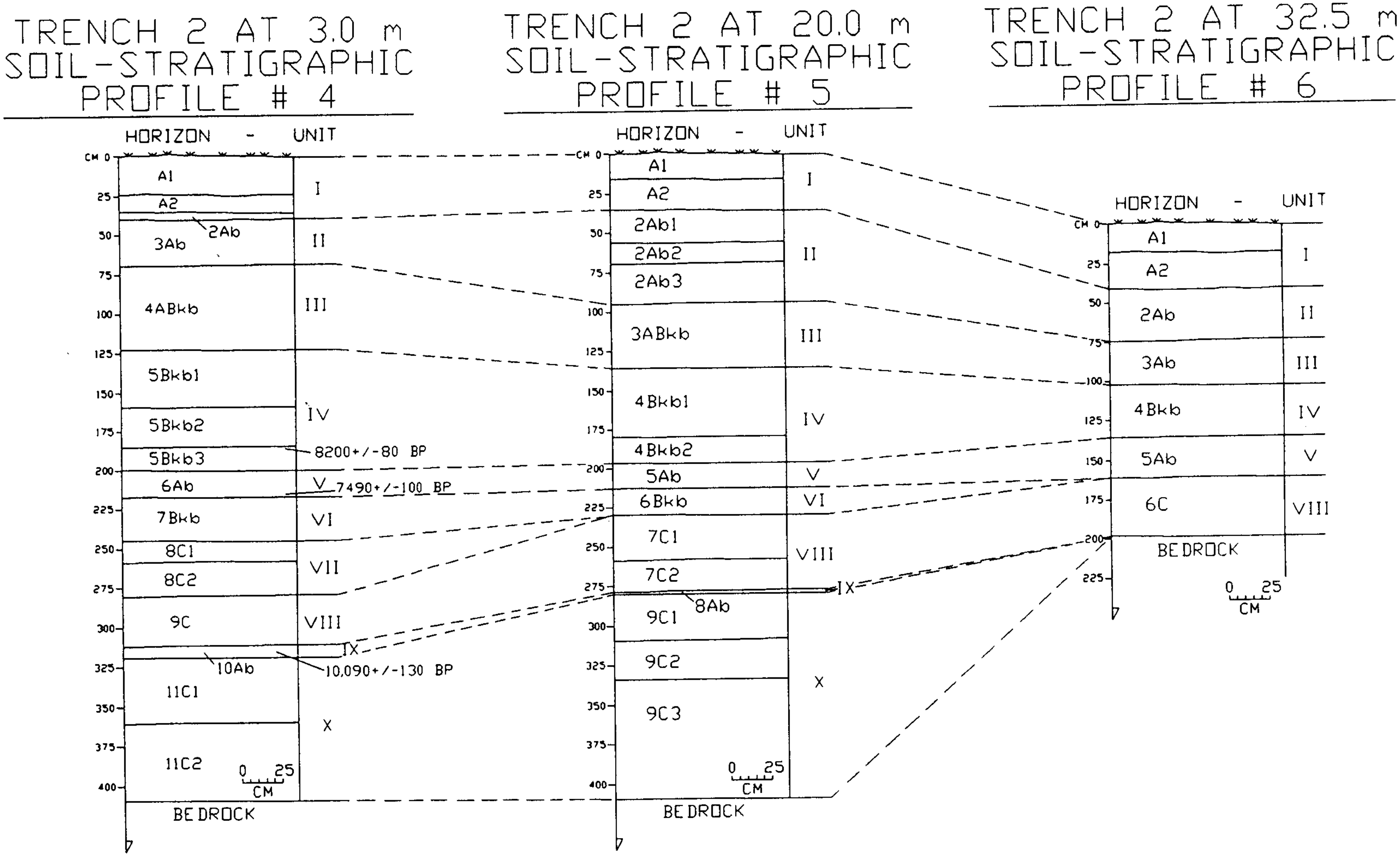

Figure 4.16. Trench 2 soil-stratigraphic profile composite.

Table 4.5. Soil-Stratigraphic description and laboratory results for Profile # 5 (Trench 2 at 20.0 m).

Unit	Horizon	Depth (cm.)	Color (moist)	Texture	Structure	Consistence	Boundary	pH	TOM %	Sand %	Silt %	Clay %
I	A1	0-15	10YR 3/2	l	2 m pr/sbk	mvfr	cs	6.7	5.1	44	33	23
I	A2	15-33	10YR 3/2	l	1 f pr/sbk	mvfr	as	7.1	3.1	44	37	19
II	2Ab1	33-57	10YR 3/3	l	1 m pr/abk	mfr	cs	7.2	3.1	48	31	21
II	2Ab2	57-70	10YR 3/2	scl/sl	1 c pr/abk	mfr	ds	7.7	2.4	54	25	21
II	2Ab3	70-94	10YR 3/2-4/2	l	1 m pr	mfr	ds	7.9	2.5	46	31	23
III	3ABkb	94-136	10YR 4/3	scl	1 c pr/abk	mfr	ds	8.1	2.0	50	24	26
IV	4Bkb1	136-179	10YR 6/3-4/3	sl	m	mfi	ds	8.3	1.5	60	19	21
IV	4Bkb2	179-197	10YR 4/2	sl	m	wss,mvfr	as	8.4	1.4	62	20	18
V	5Ab	197-213	7.5YR 5/3 10YR 3/1 10YR 4/2	cl/scl	m	ws,mfr	cs	8.3	2.0	42	29	29
VI	6Bkb	213-230	10YR 4/2-5/2	cl/scl	m	ws,mfr	cs	8.3	1.9	42	28	30
VIII	7C1	230-258	2.5Y 5/2 2.5Y 5/4	cl	m	ws,mfr	-	-	-	-	-	-
VIII	7C2	258-278	2.5Y 5/2 2.5Y 5/4	cl	m	ws,mfr	-	-	-	-	-	-
IX	8Ab	278-280	10YR 2/1-4/1	cl	m	ws,mfr	-	-	-	-	-	-
X	9C1	280-310	2.5Y 5/2	cl	m	ws,mfr	-	-	-	-	-	-
X	9C2	310-335	2.5Y 5/2	l	m	wss	-	-	-	-	-	-
X	9C3	335-410	2.5Y 5/2	-	m	-	-	-	-	-	-	-

Table 4.6. Soil-Stratigraphic description and laboratory results for Profile # 6 (Trench 2 at 32.5 m).

Unit	Horizon	Depth (cm.)	Color (moist)	Texture	Structure	Consistence	Boundary	pH	TOM %	Sand %	Silt %	Clay %
I	A1	0-17	10YR 3/2	sl	2 f/m abk/gr	mfi	cs	7.0	4.9	54	27	19
I	A2	17-39	10YR 2/2	cl/l	1 c abk	mvfr	cw	7.1	3.8	44	35	21
II	2Ab	39-74	10YR 3/2	cl/l	2 m/f abk	mfr	ds	7.6	2.4	44	28	28
III	3Ab	74-103	10YR 3/3	cl	2 m abk	mfr	ds	8.4	2.1	44	28	28
IV	4Bkb	103-136	10YR 3/3	scl/cl	m	mfr	as	8.3	1.7	54	25	21
V	5Ab	136-163	10YR 2/1	cl	m	mfr	gs	8.1	2.5	38	31	31
VI	6C	163-198	10YR 4/2-4/4	cl	m	mfr	aw	8.0	2.0	44	26	30

buried soil and occurring directly above bedrock reveals the incipient post-glacial accumulation of fine-earth materials on a relatively unstable landscape. A shift to a more climatically stable landscape (i.e., increased temperature and precipitation) by approximately 10,000 yr B.P. is supported by the formation of the soil horizon designated as Stratigraphic Unit IX/horizon 10Ab (see Plate 2).

Microscopic analyses of wood charcoal found within Stratigraphic Unit IX/horizon 10Ab resulted in a tentative identification of *Cercocarpus* spp., possibly *C. ledifolius* Nutt. (curlleaf cercocarpus) or *C. montanus* Raf. (mountain mahogany) (McWeeney 1997). The potential presence of *Cercocarpus* spp. at the Cremer site at the end of the Pleistocene would be significant if it can be further verified. The modern distribution of *C. ledifolius* Nutt. (curlleaf cercocarpus) is found in foothills and on mountain slopes throughout western and south-central Montana, including Meagher, Wheatland, Golden Valley, Musselshell, Treasure, Park, Sweetgrass, Stillwater, Yellowstone, Carbon and Big Horn counties (Dorn 1984). The modern distribution of *C. montanus* Raf. (mountain mahogany) in Montana includes only Treasure county, growing on hills, slopes and canyons (Dorn 1984). Given the "tentative" nature of the *Cercocarpus* spp. identification, additional palynological research in central and south-central Montana is needed to support the findings from the Cremer site.

Also revealed in the basal stratigraphy of Trench 2 is an ancestral stream channel of Antelope Creek which formerly existed between approximately 25.0 m and 29.0 m along the trench (see Plate 2). As noted previously, Stratigraphic Units X and IX could only be traced to about 22.5 m along Trench 2 and backhoe excavations indicated a sharp dip in the sandstone bedrock between 30.0 and 27.0 m. It appears that at the end of the last glacial period, the main stem of Antelope Creek was positioned immediately to the southeast of this bedrock projection. A change in climatic conditions (i.e., increased aridity) immediately post-dating the earliest period of pedogenesis likely contributed to the repositioning of Antelope Creek to its present course. The impetus for this channel repositioning may have resulted from increased colluvial deposition along the drainageways from upland sources. This pattern of stream migration would account for the absence of the soil dating to ca. 10,000 yr B.P. along this section of the trench (which would have been eroded) and the presence of alluvial sands and gravels directly overlying bedrock between 35.5 m and 43.0 m along Trench 2.

The 10,090 $\pm$ 130 yr B.P. age determination for the lowest buried soil from Trench 2 forms the benchmark from which a chronology can by established for the late-Quaternary evolution of the Cremer site. Following this earliest interval of site pedogenesis, climatic conditions appear to have rapidly deteriorated, initiating a period of increased colluviation and general landscape instability, possibly a result of increased aridity. Increased aridity at the Cremer site during the early Holocene would have had several important consequences for landform and site development. Stratigraphic evidence from Trench 2 indicates that significant episodes of colluviation resulted from the drier conditions immediately following the earliest period of soil formation. This increase in colluvial deposition likely resulted from a decrease in soil moisture (i.e., the combined result of increased temperatures and reduced precipitation) and subsequent loss of vegetation cover throughout the upland watershed. Infrequent but at times very intense rainfall would have transported slopewash from these denuded uplands toward the drainageways.

Stratigraphic Units VIII and VII from Trench 2 provide a record of these early Holocene events which buried the soil horizon (Stratigraphic Unit IX) dating to 10,090 yr B.P. Unit VIII (horizon 9C at Profile # 4) extends the entire length of Trench 2 (directly overlying bedrock between 30.0 to 35.5 m and 43.0 to 48.0 m) and reflects the initial landscape response to increasing aridity. Overlying this deposit is Stratigraphic Unit VII, which exhibits characteristics indicating an even greater period of landscape degradation and erosion. The lower component of Unit VII (horizon 8C2) has a sandier texture and an increase in coarse fragments relative to underlying strata (Figures 4.13 and 4.14). The upper component of Unit VII (horizon 8C1) reflects a particularly intense interval of landscape instability. The composition of this latter slopewash deposit has coarse fragment percentages exceeding 25 percent of the total matrix volume. Given the low slope gradient of the Trench 2 landform (< 5 %), generally arid conditions combined with an unusually severe period of rainfall may have been required to generate the magnitude of deposition recorded in Stratigraphic Unit VII. These deposits were likely emplaced during a relatively short interval of time and may reflect the period of greatest Holocene aridity at the Cremer site.

The colluvial deposits (Stratigraphic Unit VI) which overlie the gravelly horizon (8C1) of Unit VII record an intermediate phase of landscape adjustment. Unit VI extends from the upper (southeast) section of Trench 2 to 22.0 m and is distinguished from underlying strata by an abrupt decrease in coarse fragments and a relatively high total organic carbon content. This period of landform development likely witnessed slightly increased precipitation which supported the recolonization of grasslands in the upper watershed and more surface stability, accounting for the unit's higher percentage of organic carbon accumulation (Figure 4.15).

The brief interval of landscape adjustment recorded in Unit VI reached a prolonged period of surface stability with the formation of Stratigraphic Unit V, a prominent paleosol that extends the complete length of Trench 2. $CaCO_3$ accumulation in underlying Unit VI (horizon 7Bkb at Profile # 4) indicates that this buried soil (horizon 6Ab at Profile # 4) likely formed under conditions that allowed dissolution, leaching and reprecipitation of $CaCO_3$. A bone specimen found within Unit V at a depth of 215 cm below the modern surface was determined to have a radiocarbon age of 7,490 $\pm$ 100 yr B.P. (Beta-100155).

Additionally, a rib bone from an unidentified herbivore (bison?) recovered approximately 13 cm above Unit V (within horizon 5Bkb3 of Unit IV at Profile # 4) received a radiocarbon age of 8,200 $\pm$ 80 yr B.P. (Beta-103886). This latter bone specimen is associated with redeposited older slopewash (colluvium), and thus renders the age assignment for pedologic horizon 5Bkb3 unreliable (Figure 4.14). It is probable that this bone specimen was formerly associated with the buried soil designated as Stratigraphic Unit V, and was subsequently redeposited from upslope during renewed erosion and sedimentation. If this hypothesis is correct, the buried soil identified as Unit V would have a minimum age of ca. 8,200 yr B.P.

Following this period of early-middle Holocene pedogenesis, a shift in climatic conditions is indicated by significantly increased valley deposition recorded in Stratigraphic Unit IV. This unit is characterized by poorly sorted colluvium with distinctly sandier textures and increased percentages of coarse fragments relative to underlying strata (Figures 4.13 and 4.14). Low total organic carbon contents for this unit also implies an interval of general landscape instability (Figure 4.15). Climatic conditions during this period of colluvial deposition were likely significantly more arid than the previous period of soil development, resulting in poorly vegetated upland surfaces highly susceptible to erosion. The degree of aridity indicated by Stratigraphic Unit IV was probably of a magnitude similar to that which occurred during the deposition of Stratigraphic Units VIII and VII during the early Holocene.

The period of middle Holocene landscape instability recorded in Stratigraphic Unit IV began to lose strength during the development of Stratigraphic Unit III. Unit III is identified as having soil attributes somewhat transitional between major pedologic horizons A and B. Specific environmental indicators from this unit include increased total organic carbon content and low percentage of coarse fragments (Figures 4.14 and 4.15). CaCO3 accumulation in underlying Unit IV implies well drained conditions characteristic of a warm and generally dry climate. Unit III corresponds well with a gradual shift to a less arid climate which would have contributed to the revegetation of the upland watershed, leaching and redeposition of CaCO3, and reduced valley deposition (i.e., increased surface stability).

A series of soil horizons comprising Stratigraphic Units II and I overlie Unit III. These polygenetic A horizons reflect a generally stable landscape spanning the last several thousand years. Although there are no radiocarbon dates from this upper soil component of Trench 2, it is likely that Stratigraphic Units III, II and I span the last ca. 5-6,000 yr B.P. The absence of higher frequency indicators of climate variability during this time period (as compared to the Trench 1 fan/terrace landform) is a consequence of the stable geomorphic position of the Trench 2 landform with respect to low stream discharge at the basin's outlet and low slope gradient from the uplands. As mentioned previously, these factors account for the landform's relative stability and older age.

In summary, the landform into which Trench 2 was excavated represents a continuous sequence of both colluvial deposition and soil formation spanning more than 10,000 yr B.P. Soil-stratigraphic evidence indicates that stable surfaces (i.e., buried soils) were present at approximately 10,000 yr B.P. (Stratigraphic Unit IX), 7,500 yr B.P. (Stratigraphic Unit V), and generally throughout the last several thousand years (Stratigraphic Units III, II and I). Periods of greatest Holocene aridity (i.e., landscape instability) are indicated at approximately 9,000 yr B.P. (Stratigraphic Units VIII and VII) and sometime around 6,500 yr B.P. (Stratigraphic Unit IV). Archaeological investigations of the earliest dated soils from Trench 2 have not been systematically undertaken. Future studies of this lowest soil sequence may provide evidence of either Paleoindian and/or Early Plains Archaic period occupations at the Cremer site.

Trench 3

Landform Morphology

Trench 3 measured 40.0 meters in length, extending from the modern floodplain of Antelope Creek into the predominantly alluvial landform to the east (see Plate 3). The upper terminus of Trench 3 is located approximately 60 meters to the north of Trench 2, and approximately 95 meters to the southeast of Trench 1 (Figure 4.1). Along most of the trench and immediately upslope, slope gradient averages approximately 4 % (2°). Near the lower section of the trench (ca. 32.0 m), the slope begins to increase and reaches a maximum gradient of approximately 10 % (6°) where the terrace landform intersects the modern floodplain of Antelope Creek.

Materials that comprise the Trench 3 landform have been deposited primarily by the two intermittent streams that emerge into the low lying site area from the east (along the margins of the associated landform) (Figure 4.1). Trench deposits and surface features (i.e., stream meander scars) indicate a complex alluvial sequence is responsible for the development and evolution of the Trench 3 landform, characterized by repeated episodes of stream erosion and channel repositioning. Minor contributions from colluvium are evident along the upper section of the trench and further upslope.

Stratigraphy and Pedology: Trench 3

Trench 3 terrace stratigraphy was mapped along the entire length of the trench and described (and sampled) in detail at two locations (Profiles # 7 and # 8). In total, eight major stratigraphic units were identified along the trench walls (see Plate 3). Each of these stratigraphic groups is associated with a distinct series of pedologic horizons. Figure 4.17 shows the existing associations between stratigraphic units and soil horizons exposed along Trench 3. Field descriptions and laboratory analyses of Profiles # 7 and # 8 are presented in Table 4.7 and Figures 4.18, 4.19, and 4.20, and Table 4.8 and Figures 4.21, 4.22, and 4.23, respectively. The following stratigraphic and pedologic summary of Trench 3 reviews the complex alluvial sequences responsible for landform development and evolution.

Soil-Stratigraphic Profile # 7 (Trench 3 at 10.0 m)

Profile # 7 was described at 10.0 m along the south wall of Trench 3 (see Plate 3). This location was selected for pedologic description and sampling because it exhibited all of the stratigraphic groups and pedologic horizons occurring along the upper section of the trench. In total, four major stratigraphic units representing seven pedologic horizons were described at Profile # 7 (Figures 4.17, 4.18, 4.19, 4.20 and Table 4.7). A complete summary of results from Profile # 7 is presented below.

Stratigraphic Unit VIII

Near the upper terminus of Trench 3, the trench floor was excavated by backhoe to a maximum depth of approximately 2.50 meters. The lowest materials described at Profile # 7 consist of an undifferentiated sequence of alluvial flagstones, channers, cobbles, and gravels in a sandy clay loam matrix (Unit VIII). Unit VIII is the basal complex along the entire length of the trench, exhibiting a wide variety of coarse fragment sizes throughout. Plate 3 shows the field approximation of coarse fragment percentages for this unit as measured every two meters along the trench. In general, large sandstone coarse fragments occupy between 15 and 75 % of the total matrix volume, with percentages increasing considerably with depth. The upper component of this unit (ca. upper 30 centimeters) consists of coarse alluvial sands with a distinct reduction in total coarse fragments. The lower boundary of Unit VIII was not observed, thus limiting estimates of unit thickness and depth to bedrock determinations.

Stratigraphic Unit VIII is designated as horizon 4C at Profile # 7. Horizon 4C measured greater than 85 centimeters thick and has an extremely gravelly clay

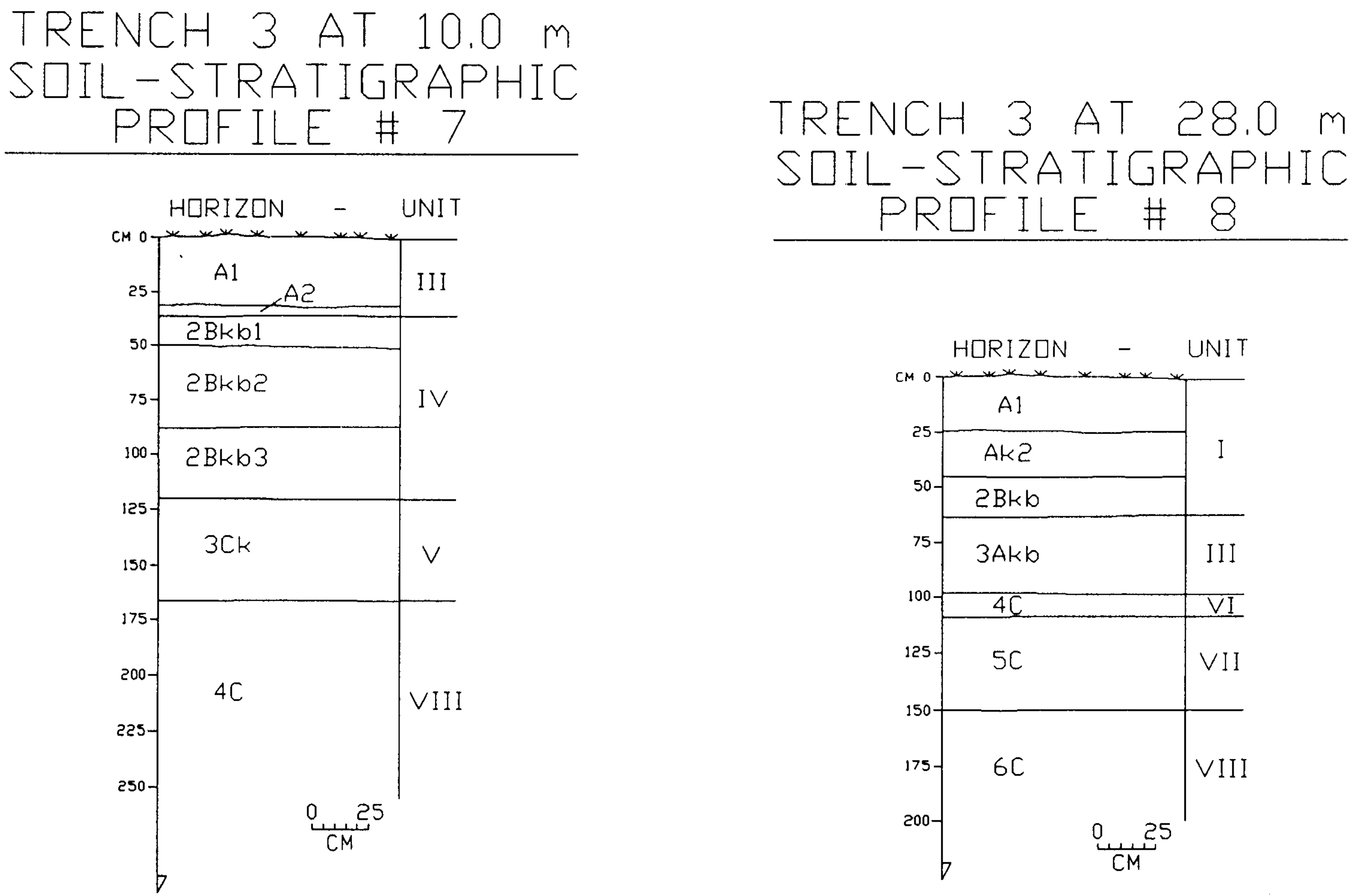

Figure 4.17. Trench 3 soil-stratigraphic profile composite.

Table 4.7. Soil-Stratigraphic description and laboratory results for Profile # 7 (Trench 3 at 10.0 m).

Unit	Horizon	Depth (cm.)	Color (moist)	Color (dry)	Texture	Structure	Consistence	Boundary	pH	TOC %	Coarse Frags. %	Sand %	Silt %	Clay %
III	A1	0-31	10YR 2/2-3/2	10YR 4/2	cl/l	-	wss,mvfi,dvh	cw	7.6	2.0	2.8	38.1	33.0	28.9
III	A2	31-36	10YR 4/2	10YR 5/3	scl	-	wss,mvfi,dvh	aw	8.2	1.2	1.9	47.3	25.0	27.7
IV	2Bkb1	36-50	10YR 4/2	10YR 5/3	scl/l	1 m pr	wss,mfi,dh	gw	8.5	1.1	1.1	47.6	26.4	25.9
IV	2Bkb2	50-88	10YR 4/2	10YR 5/3	cl/scl	1 m pr	wss,mfi,dh	gw	8.6	0.8	0.3	44.9	27.2	27.9
IV	2Bkb3	88-120	10YR 5/3-4/3	10YR 6/3	scl/sl	m	wss,mfr,dh	aw	8.5	0.4	1.8	61.5	18.0	20.5
V	3Ck	120-165	10YR 5/3	-	exgrsl	m	wso,mvfr,dlo	gw	7.9	0.3	35	70.4	13.6	16.0
VIII	4C	165-250+	10YR 5/3 10YR 6/4	-	exgrcl/scl	m	ws,mvfr,dsh	-	8.1	0.5	40	43.9	25.8	30.4

Table 4.8. Soil-Stratigraphic description and laboratory results for Profile # 8 (Trench 3 at 28.0 m).

Unit	Horizon	Depth (cm.)	Color (moist)	Color (dry)	Texture	Structure	Consistence	Boundary	pH	TOC %	Coarse Frag %	Sand %	Silt %	Clay %
I	A1	0-24	10YR 3/2	10YR 4/3-5/3	scl/sl	-	wss,mvfr,dvh	gw	6.8	2.5	2.1	60.5	18.7	20.9
I	Ak2	24-44	10YR 3/2	10YR 4/2-5/2	scl	1 m sbk	wss,mvfr,dh	gw	8.7	1.7	0.7	55.8	21.6	22.5
I	2Bkb	44-63	7.5YR 4/3	7.5YR 5/2	sl/scl	1 m sbk	wss,mvfr,dsh	gw	8.7	1.3	0.4	57.7	22.4	19.9
III	3Akb	63-98	10YR 3/2-2/2 7.5YR 4/6	10YR 4/2-5/2 7.5YR 6/6	sl/scl	m	wss,mvfr,dsh	dw	8.5	1.2	1.6	59.0	21.1	19.9
VI	4C	98-110	10YR 4/3	10YR 5/2-5/3	exgrsl	m	wso,mvfr,dsh	aw	7.9	0.7	10-25	65.3	18.6	16.1
VII	5C	110-150	5YR 3/4-4/4	5YR 5/6-4/6	exgrsl	m	wso,mlo,dlo	aw	7.8	0.5	80	68.2	15.5	16.3
VIII	6C	150+	10YR 4/2	-	exgrsl	m	wso,mvfr,dsh	-	7.9	0.4	50	63.3	20.0	16.7

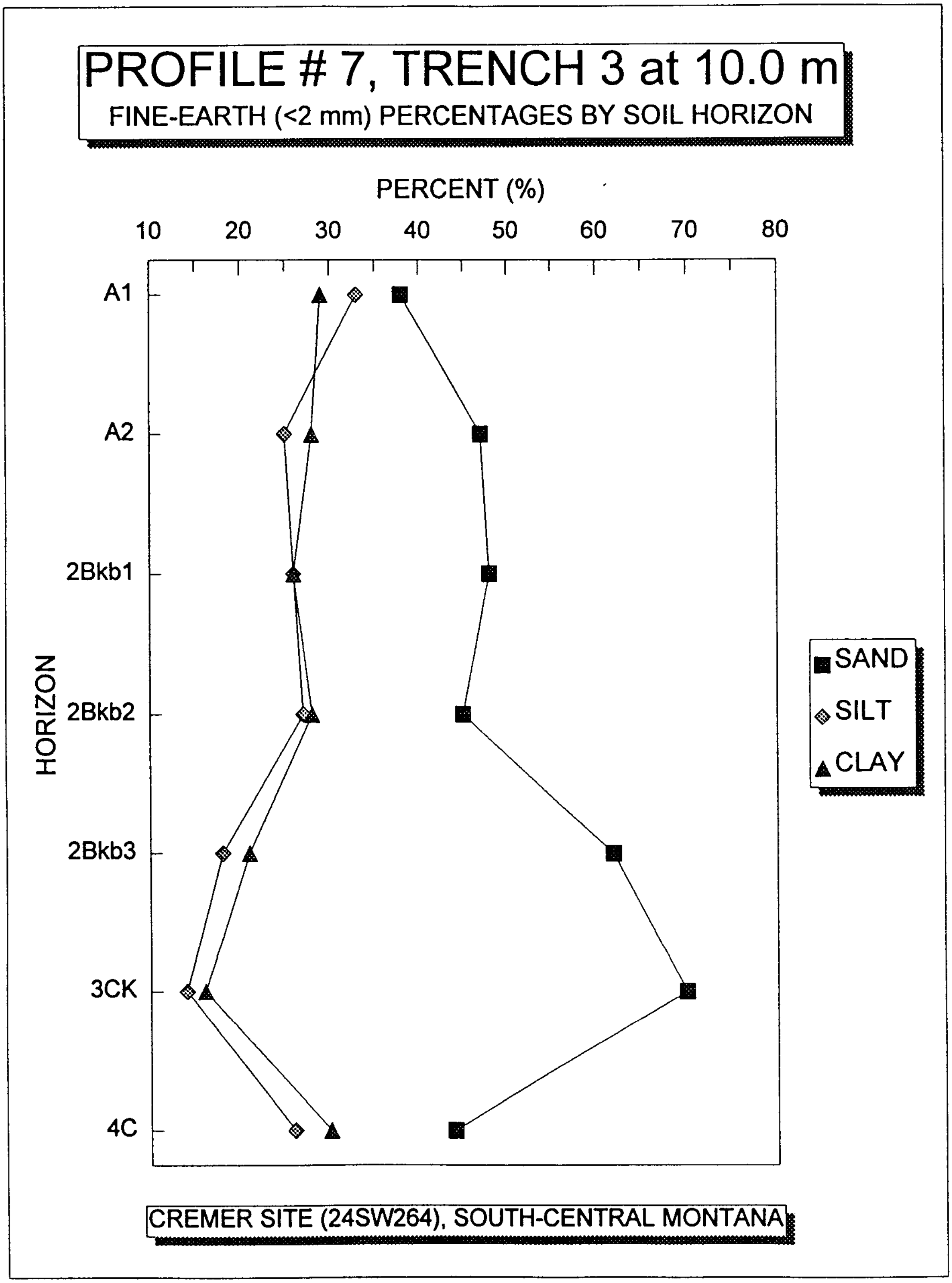

Figure 4.18. Fine-earth (< 2.0 mm in diameter) percentages by soil horizon at Profile # 7 (Trench 3 at 10.0 m)

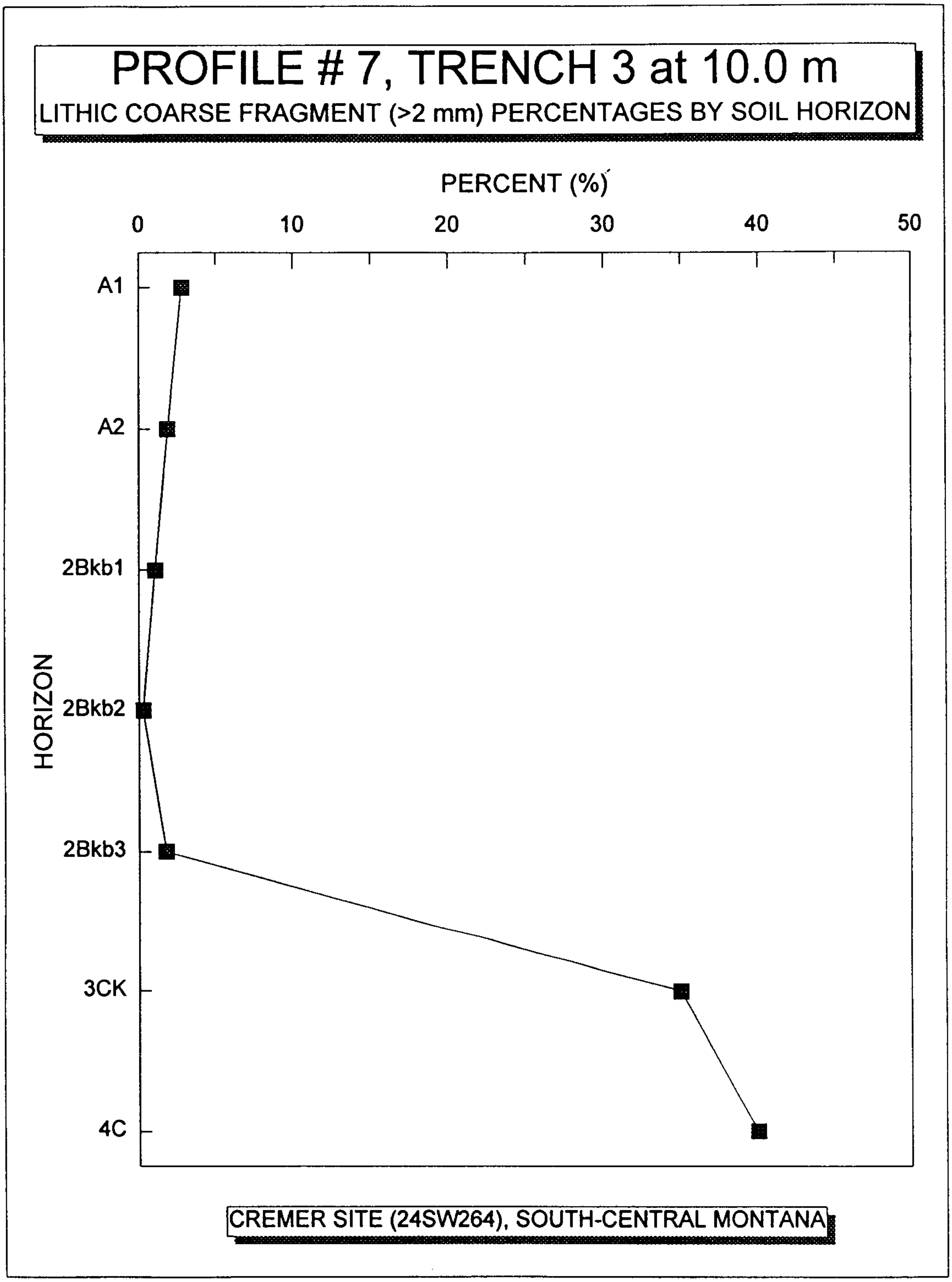

Figure 4.19. Lithic coarse fragment (> 2.0 mm in diameter) percentages by soil horizon at Profile # 7 (Trench 3 at 10.0 m).

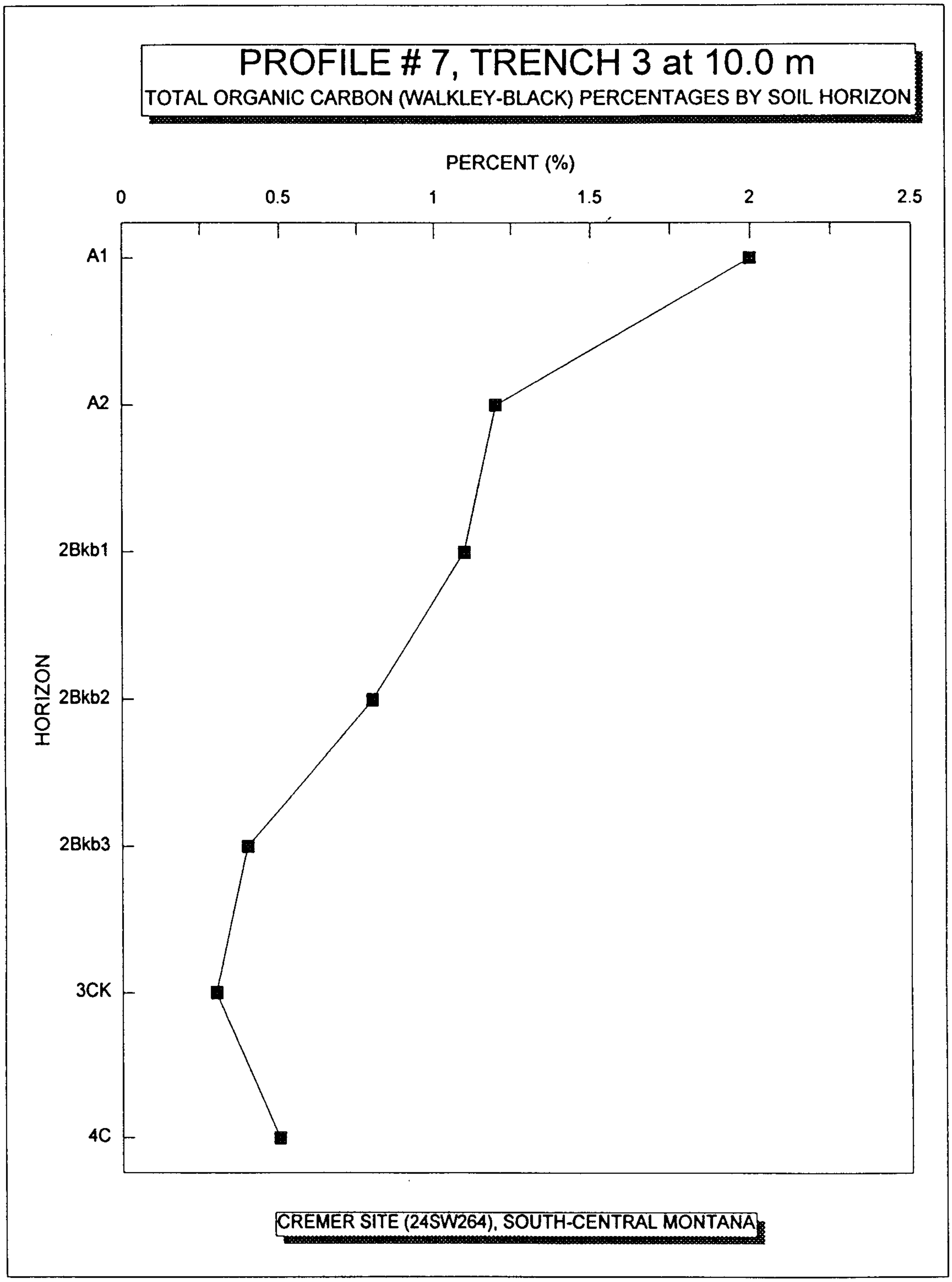

Figure 4.20. Total organic carbon (Walkley-Black) percentages by soil horizon at Profile # 7 (Trench 3 at 10.0 m).

loam/sandy clay loam matrix texture. Field observations and sieving in the laboratory revealed that coarse fragments occupy approximately 40 % of the total volume in horizon 4C at Profile # 7. This horizon lacks effervescence to HCl (pH 8.1) and has a brown (10YR 5/3) moist matrix color and a total organic carbon content of 0.5 %. Many fine to medium faint mottles occur within this horizon beginning at a depth of 185 centimeters below the surface.

Stratigraphic Unit V

Overlying Unit VIII is another sequence of alluvial flagstones, channers, cobbles and gravels in a matrix of sandy loam (Unit V). Unit V extends from the upper terminus of the trench to 21.0 m, ranging between 25 and 50 centimeters in thickness. At 21.0 m, Unit V is truncated by Stratigraphic Unit VI (see discussion of Profile # 8). Plate 3 shows the field approximation of sandstone coarse fragment percentages for this unit as measured every two meters along the trench exposure. In general, 20 to 50 % of the total matrix volume of this unit consists of angular to subangular sandstone gravels and cobbles, 5 to 35 % sandstone channers, and occasional flagstones.

Pedologic descriptions at Profile # 7 designated Stratigraphic Unit V as horizon 3Ck. Horizon 3Ck is an extremely gravelly sandy loam approximately 45 centimeters thick, with coarse fragments occupying approximately 35 % of the horizon's total volume. Horizon 3Ck (Unit V) is distinguished from underlying Unit VIII/horizon 4C by a distinctly sandier textural change and a less reduced matrix character (mottling absent). Horizon 3Ck exhibits very slight effervescence to HCl (pH 7.9) and has a brown (10YR 5/3) moist matrix color and a total organic carbon content of 0.3 %.

Stratigraphic Unit IV

Overlying Unit V is a series of carbonate-rich (Bk) horizons that comprise Stratigraphic Unit IV. This unit was deposited as colluvium from sources to the east of the trench. Unit IV is between 60 to 90 centimeters thick and extends from the upper terminus of Trench 3 to 21.0 m, where it is truncated (along with underlying Unit V) by Stratigraphic Unit VI (see discussion of Profile # 8 and Plate 3). Unit IV is distinguished from underlying Unit V by an abrupt reduction in sandstone coarse fragments, darker color and higher total organic carbon content, high accumulation of leached carbonates, and evidence of structural development.

Stratigraphic Unit IV consists of three pedologic horizons at Profile # 7. Horizon 2Bkb3 is approximately 30 centimeters thick and has a sandy clay loam/sandy loam texture. This horizon has a brown (10YR 5/3) moist matrix color and contains few coarse fragments (1.8 % of the total volume). Horizon 2Bkb3 exhibits moderate effervescence to HCl (pH 8.5) and has a total organic carbon content of 0.4 %. Horizon 2Bkb2 is approximately 40 centimeters thick and has a clay loam/sandy clay loam texture with sandstone coarse fragments nearly absent (0.3 % of the total matrix volume). This horizon is darker (10YR 4/2 m) than underlying horizon 2Bkb3 and has a weak medium prismatic structure. Horizon 2Bkb2 effervesces slightly with HCl (pH 8.6) and has a total organic carbon content of 0.8 % and a gradual wavy boundary with underlying horizon 2Bkb3. Horizon 2Bkb1 is approximately 15 centimeters thick and has a sandy clay loam/loam texture. This horizon has a brown (10YR 4/2) moist matrix color and contains few sandstone coarse fragments (1.1 % of the total volume). Other properties characteristic of horizon 2Bkb1 include a weak medium prismatic structure, moderate to strong effervescence to HCl (pH 8.5), moderately high total organic carbon content (1.1 %), and a gradual wavy lower boundary with underlying horizon 2Bkb2.

Stratigraphic Unit III

Overlying this series of Bk horizons (Unit IV) is a sequence of A horizons that comprise Stratigraphic Unit III. Unit III is approximately 35 to 50 centimeters thick and consists of surface A horizons between 0.0 m to 19.0 m along the upper section of the trench, before being buried between 19.0 m to 30.0 m by renewed alluvial deposition (see discussion of Profile # 8 for description of this Ab component) (see Plate 3). Unit III (as described at Profile # 7) is distinguished from underlying Unit IV by having a darker color, overall reduction in sandy texture, and lacking effervescence to HCl.

Pedologic horizons A2 and A1 comprise Stratigraphic Unit III at Profile # 7. Horizon A2 is a thin (ca. 5 centimeters thick) dark grayish brown (10YR 4/2 m) sandy clay loam with relatively few coarse fragments occupying its matrix (1.9 % of the total volume). This horizon has a total organic carbon content of 1.2 %, a pH of 8.2, and an abrupt wavy boundary with underlying Unit IV. Overlying horizon A2 is a distinctly darker (10YR 2/2-3/2 m) soil designated as horizon A1. Horizon A1 extends from the modern surface to a depth of approximately 30 centimeters and has a clay loam/loam texture. This surface horizon has a total organic carbon content of 2.0 % and a pH of 7.6, with a clear wavy boundary with underlying horizon A2 and a slight increase in coarse fragments (2.8 % of the total volume). Both horizons A1 and A2 have been artificially disturbed (i.e., "compacted") by traffic (profile location near regularly used gate in fence-line), thus interfering with observations of soil structural properties.

Soil-Stratigraphic Profile # 8 (Trench 3 at 28.0 m)

Profile # 8 was described in detail at 28.0 m along the south wall of Trench 3 (see Plate 3). This location was selected for soil-stratigraphic description and sampling because it exhibited nearly all of the alluvial sequences occurring along the lower (west) section of the trench which are not found further upslope (to the east). In total, five major stratigraphic units representing seven pedologic horizons were described at Profile # 8 (see Figures 4.17, 4.21, 4.22, 4.23 and Table 4.8). These results are presented below.

Stratigraphic Unit VIII

The lower (west) section of Trench 3 (between 20.0 m to 40.0 m) was excavated by backhoe to an average depth of approximately 1.50 meters below the surface (see Plate 3). The basal materials (Unit VIII) described at Profile # 8 consist of a similar sequence of subangular alluvial flagstones, channers, cobbles and gravels as that described at Profile # 7 (Unit VIII). This undifferentiated alluvial sequence differs slightly from that described along the upper section of the trench by having a generally sandier texture and darker color.

Pedologic descriptions at Profile # 8 designated Unit VIII as horizon 6C. Horizon 6C consists of an abundant accumulation of sandstone coarse fragments (occupying between 40 and 50 % of the total volume) in a matrix of coarse sandy loam. This

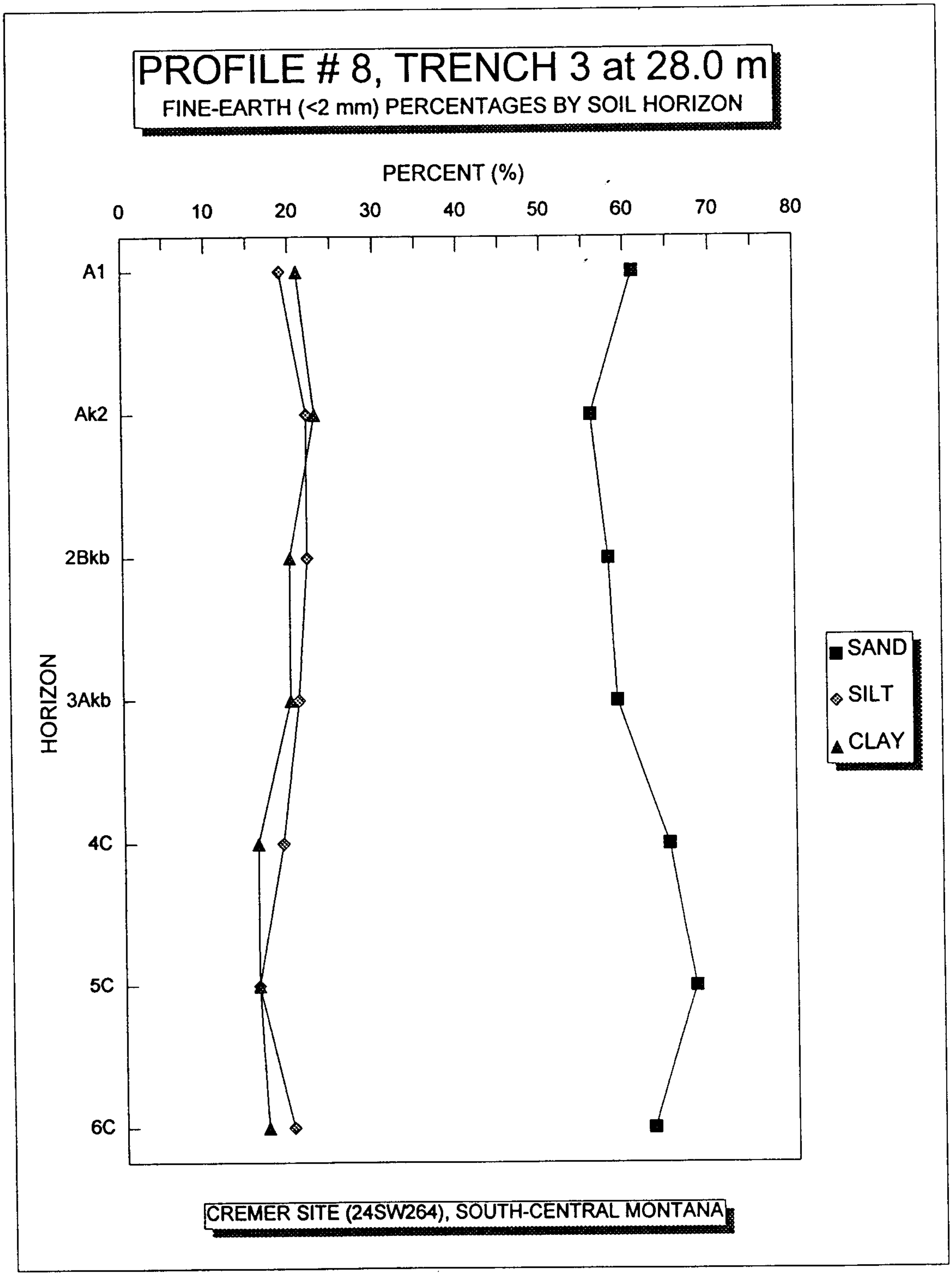

Figure 4.21. Fine-earth (< 2.0 mm in diameter) percentages by soil horizon at Profile # 8 (Trench 3 at 28.0 m)

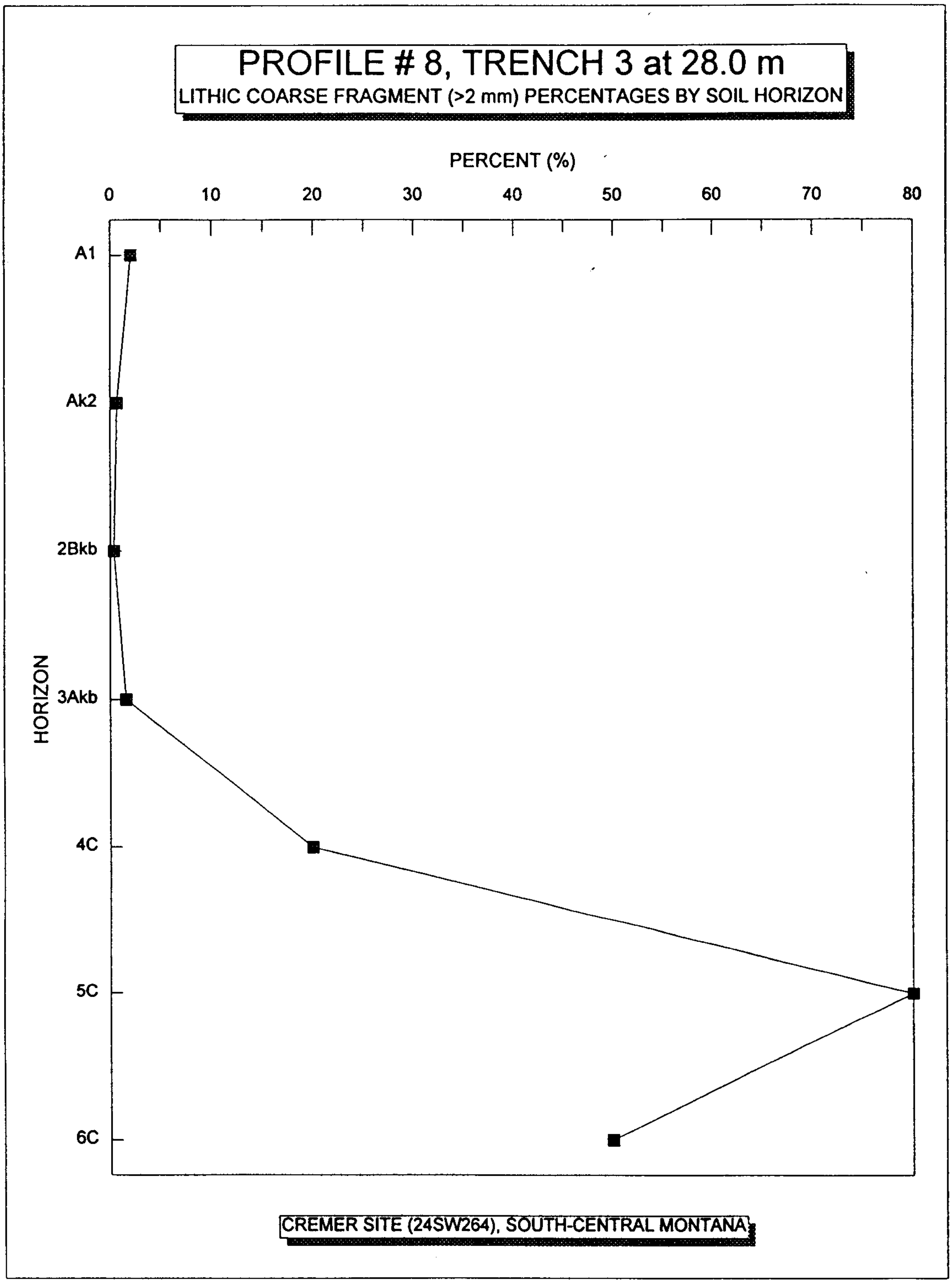

Figure 4.22. Lithic coarse fragment (> 2.0 mm in diameter) percentages by soil horizon at Profile # 8 (Trench 3 at 28.0 m).

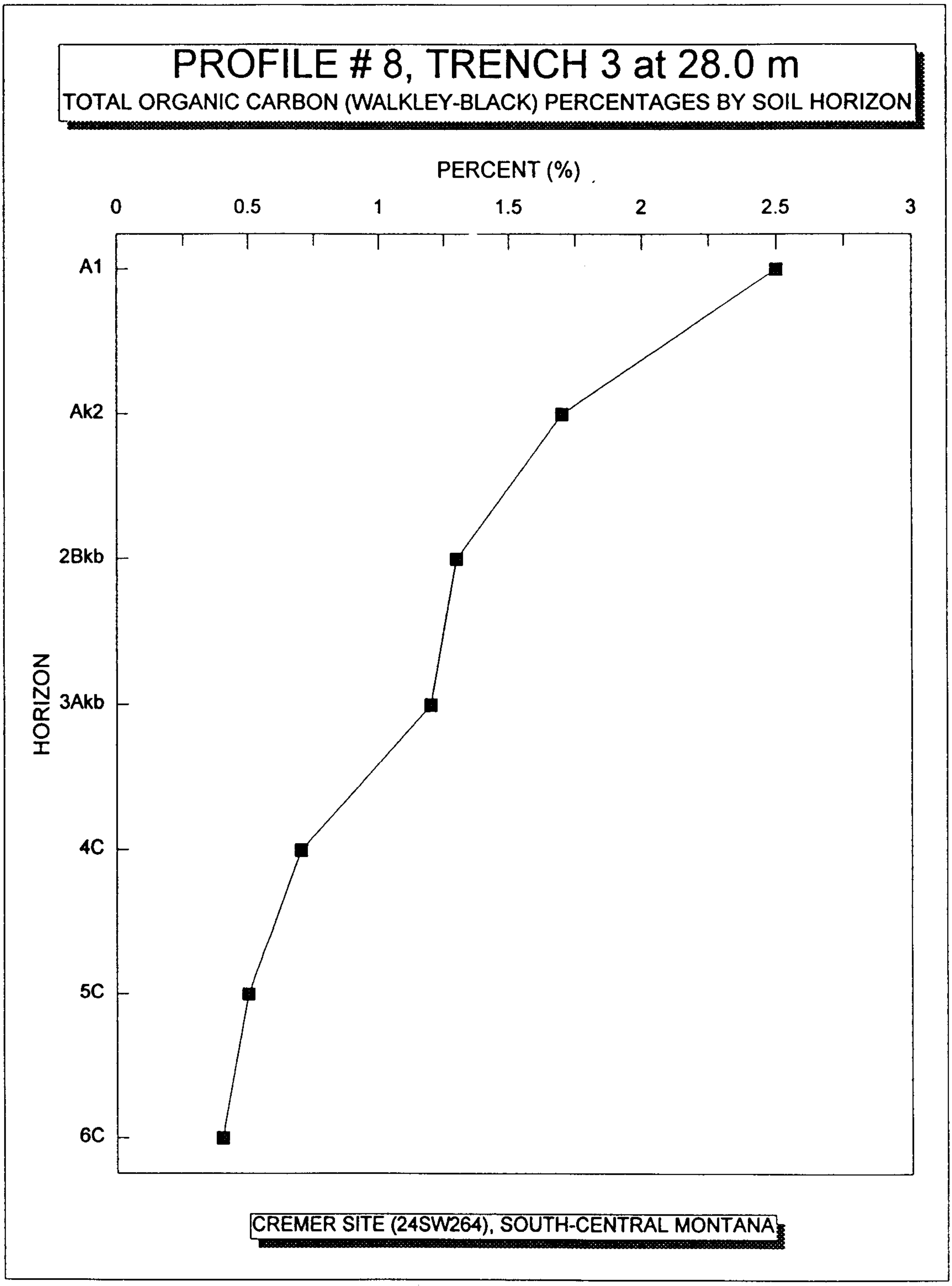

Figure 4.23. Total organic carbon (Walkley-Black) percentages by soil horizon at Profile # 8 (Trench 3 at 28.0 m).

structureless horizon has a dark grayish brown (10YR 4/2) moist matrix color, a total organic carbon content of 0.4 %, and lacks effervescence to HCl (pH 7.9). A charcoal sample collected from this unit was identified as *Salix* spp. (willow) (Table 3.1) (McWeeney 1997).

Stratigraphic Unit VII

Overlying Stratigraphic Unit VIII between 26.0 m to 38.0 m along Trench 3 is a distinctive alluvial deposit appropriately recognized as the "Red Bed" (Unit VII). Unit VII ranges between 20 and 70 centimeters in thickness and consists of an extremely gravelly sandy loam with subangular gravels and cobbles occupying over 80 % of the total matrix volume at Profile # 8. This unit is distinguished from adjacent strata by an extremely high concentration of sandstone coarse fragments and its characteristic reddish color.

Pedologic descriptions at Profile # 8 designated Unit VII as horizon 5C. Horizon 5C contains highly weathered coarse sands and gravel with a predominantly reddish brown to yellowish red (5YR 4/4-4/6) moist matrix color, with some inclusions of brown (7.5YR 4/4 m) subangular gravels. The distinctive reddish coloring of this unit/horizon is a result of iron staining on the exterior surfaces of the gravel and sand particles. The source of this staining is unknown and similar patterns of coloring were not observed in other deposits found at the site. The distinctive presence of iron coated particles in Unit VII could be attributed to a unique mineralogical component (i.e., "clinker") in part of the Fort Union bedrock. Horizon 5C lacks effervescence to HCl (pH 7.8), has a total organic carbon content of 0.5 %, and an abrupt wavy boundary with underlying 6C.

Stratigraphic Unit VI

Overlying sections of both Stratigraphic Units VIII and VII is another coarse alluvial deposit identified as Unit VI. Unit VI extends between 21.0 m to 30.0 m along Trench 3 and represents another ancestral stream channel of Antelope Creek. This relatively thin unit ranges between 10 and 25 centimeters in thickness and is interpreted as being emplaced during an interval of high stream flow which truncated Stratigraphic Units V and IV near 21.0 m (see Plate 3). A considerable reduction in coarse fragments and a distinctive change in matrix color distinguish Unit VI from underlying strata.

Unit VI is designated as horizon 4C at Profile # 8. Horizon 4C has an extremely gravelly sandy loam texture with sandstone coarse fragments occupying between 10 and 25 % of the total matrix volume. This horizon has a brown (10YR 4/3) moist matrix color with a total organic carbon content of 0.7 %. Horizon 4C lacks effervescence to HCl (pH 7.9) and has an abrupt wavy boundary with underlying deposits. Two charcoal samples collected from this unit were identified as *Salix* spp. (willow) (Table 3.1) (McWeeney 1997).

Stratigraphic Unit III

Overlying Unit VI is the buried section of the soil previously identified as Stratigraphic Unit III (see discussion of Profile # 7). The buried component of Unit III ranges between 30 and 40 centimeters thick before becoming discontinuous near 30.0 m along the trench (see Plate 3). At Profile # 8, Unit III is distinguished from underlying

Unit VI by a darker color and higher total organic carbon content (1.2 %), and a distinctly reduced percentage of coarse fragments (1.6 % of the total matrix volume).

Unit III is designated as horizon 3Akb at Profile # 8. Horizon 3Akb has a massive sandy loam/sandy clay loam texture with a very dark grayish brown to very dark brown (10YR 3/2-2/2) moist matrix color. Common coarse prominent strong brown (7.5YR 4/6 m) mottles become apparent in this horizon with both increased depth and distance down slope. Horizon 3Akb has a strong reaction (effervescence) to HCl (pH 8.5) and a diffuse wavy boundary with underlying horizon 4C. Two charcoal samples collected from this buried A horizon were identified as *Salix* spp. (willow) (Table 3.1) (McWeeney 1997).

Stratigraphic Unit II

Between 21.0 m to 25.5 m along Trench 3, a thin (ca. 5 to 15 centimeters thick) lens of coarse alluvium (Unit II) overlies Stratigraphic Unit III. Unit II consists predominantly of subangular sandstone gravels (40 to 70 % of the total volume) in a matrix of sandy loam. This unit has a brown (10YR 5/3) moist matrix color and effervesces strongly with HCl. Unit II is interpreted as a former stream channel with deposits emplaced during an episode(s) of increased precipitation and accelerated erosion and alluviation along Antelope Creek.

Stratigraphic Unit I

Overlying Stratigraphic Units II, III, VII and VIII along the lower (west) section of Trench 3 (between 20.5 m to 0.0 m) is a thick sequence of fine alluvium and soil development comprising Stratigraphic Unit I. This youthful series of soil horizons ranges between 50 to 80 centimeters thick and is distinguished from underlying strata by a darker color, higher total organic carbon content, and relative absence of coarse fragments. Pedologic horizons associated with Unit I were deposited and/or formed along the edge of the former floodplain of Antelope Creek, burying the lower (western) section of Stratigraphic Unit III. Stratigraphic Unit I thins considerably between 36.0 m to 40.0 m along the trench, where the terrace escarpment intersects the modern floodplain surface of Antelope Creek.

Stratigraphic Unit I consists of three pedologic horizons at Profile # 8. Horizon 2Bkb is approximately 20 centimeters thick and has a sandy loam/sandy clay loam texture. This horizon has a brown (7.5YR 4/3) moist matrix color, weak medium subangular blocky structure, moderate effervescence to HCl (pH 8.7), near absence of coarse fragments (0.4 % of the total volume), total organic carbon content of 1.3 %, and a gradual wavy boundary with underlying horizons. Horizon A2 is approximately 20 centimeters thick and has a sandy clay loam texture containing few coarse fragments (0.7 % of the total matrix volume). This horizon has a very dark grayish brown (10YR 3/2) moist matrix color with a weak medium subangular blocky structure. Horizon A2 has a total organic carbon content of 1.7 %, effervesces slightly with HCl (pH 8.7), and has a gradual wavy boundary with underlying horizon 2Bkb. Horizon A1 extends from the modern surface to a depth of approximately 25 centimeters. This horizon is a sandy clay loam/sandy loam and has a very dark grayish brown (10YR 3/2) moist matrix color. Horizon A1 has a low percentage of coarse fragments (2.1 % of the total volume), a total organic carbon content of 2.5 %, a pH of 6.8, and a gradual wavy boundary with underlying horizon A2. Due to artificial compaction at the surface, soil structure could not be determined for horizon A1.

Evolutionary History of the Trench 3 Landform

The Trench 3 landform is located near the intersection of the site's three converging streams (see Figure 4.1). As a result, deposits revealed in Trench 3 excavations are predominantly alluvial in origin and most contain high percentages of coarse fragments. Sedimentological data reflects the dynamic pattern of stream adjustment during periods of active climatic and environmental change at the Cremer site. Due to financial limitations, radiocarbon samples from Trench 3 were not submitted for dating. Although absolute chronological controls for Trench 3 are presently absent, available evidence suggests that the basal alluvial stratigraphic sequences of this landform date to the late-Pleistocene, having undergone repeated episodes of stream erosion during the Holocene.

Backhoe excavations along Trench 3 were unsuccessful in locating bedrock. The lowest deposits observed consisted of thick (> 1 m) sequences of alluvial gravels, channers, and flagstones comprising Stratigraphic Unit VIII (see Plate 3). This unit is interpreted as a broad alluvial bottom having developed from repeated intervals of accelerated streamflow and erosion along the two tributary streams that today border the landform. Charcoal identified from this unit indicates the presence of *Salix* spp. (willow) growing along these alluvial bottoms as well.

Three other distinctly alluvial deposits (Stratigraphic Units VII, VI and V) also comprise the basal stratigraphy of the Trench 3 landform (see Plate 3). Along the upper (east) section of the trench, Stratigraphic Unit V generally has similar attributes and depositional patterns as that of underlying Unit VIII. Further downslope, Stratigraphic

Units VII and VI reveal characteristics indicating their deposition resulted from the repositioning of either the main channel of Antelope Creek or one of the tributary stream channels. In either event, these latter two depositional units resulted from generally increased precipitation and streamflow at the site. This evidence for a period of generally wetter conditions at the site is also supported by the presence of *Salix* spp. (willow) identified from charcoal samples collected from Unit VI.

A relatively straightforward pedologic sequence overlies this complex series of alluvial channels. Along the upper (east) section of Trench 3, Stratigraphic Unit IV (Bkb horizonization) was deposited as fine-earth colluvium from sources to the east. Periods of increased colluviation at the Cremer site typically result from devegetated upland slopes depleted of soil moisture. Consequently, climatic conditions during the initial deposition of Unit IV were likely quite dry, but becoming increasingly less arid as indicated by the higher total organic carbon contents present in the upper pedologic horizons of Unit IV (Figure 4.20).

An interval of prolonged landform stability is indicated by the pedologic development associated with Stratigraphic Unit III. Unit III contains a series of A horizons which exist at the surface between 0.0 m to 19.0 m along Trench 3 before being buried by renewed alluviation near 20.0 m (see Plate 3). Pedologic properties of Unit III and CaCO3 accumulation in underlying Unit IV implies pedogenesis occurred under well drained conditions characteristic of a warm and generally dry climate. However, identified charcoal samples from Unit III indicates the local presence of *Salix* spp. (willow) as well.

The accelerated alluviation which buried part of Stratigraphic Unit III was driven by increased precipitation in which Antelope Creek flooded its banks and created a secondary stream channel (Stratigraphic Unit II) between 21.0 m to 25.5 m along Trench 3. This episode of flooding was likely of short duration, but significant enough to impede further development of the buried portion of Unit III. Renewed pedogenesis and periodic floodplain deposition of fines comprise overlying Unit I, which is thought to have formed under essentially modern climatic conditions.

Significance of Site Stratigraphy to Paleoclimatic Reconstructions of Central Montana

The principal paleoclimatic inferences derived from the Cremer site soil-stratigraphic record include the following:

1) the first evidence of post-glacial landscape stability and soil development occurred at the site sometime around 10,000 yr B.P. (Trench 2: Stratigraphic Unit IX). Climatic conditions are inferred to have been generally warmer and wetter than those occurring during the late-glacial period.
2) accelerated upland erosion and colluvial deposition (Trench 2: Stratigraphic Units VIII, VII and VI) immediately following the earliest interval of pedogenesis implies increased aridity at the site. This period of general landscape instability may indicate that maximum post-glacial drought conditions occurred at the Cremer site during the early Holocene.
3) the effects of early Holocene warmth and aridity seem to have moderated by about 7,500 yr B.P. as renewed pedogenesis (Trench 2: Stratigraphic Unit V) accompanied by general landscape stability returned to the site.

4) another period of general landscape instability was initiated when increased colluviation (Trench 2: Stratigraphic Unit IV) attributed to upland erosion buried the soil dating to ca. 7,500 yr B.P. This interval of renewed sedimentation also implies the recurrence of drought conditions at the Cremer site.

5) by about 6,000 yr B.P., climatic conditions seem to have become significantly less arid as soils once again began forming at the Cremer site. Chronologic controls for this proposed climatic shift come from radiocarbon ages (5,920 ± 80 and 5,100 ± 70 yr B.P.) assigned to the lowest soil horizon (12Akb) from Trench 1.

6) late-Holocene climatic conditions have episodically fluctuated between wetter and drier periods at the site, resulting in repeated cycles of pedogenesis and subsequent burial by renewed sedimentation along the Trench 1/Northeast Streamface landform.

Chapter 5

Regional Paleoclimate History

Introduction

Having reviewed some of the principal paleoclimatic inferences derived from the Cremer site soil-stratigraphic record, it is now important to present a regional paleoecological context of the northwestern Great Plains in general. This regional approach is necessary considering the near absence of paleoenvironmental data available for central Montana. In accomplishing this objective, a brief review of regional environmental proxy records (glacial stratigraphy and pollen cores) will be presented to develop a general paleoclimatic framework of the study area. These results will then be compared to both regional and site-specific climate simulations from numerical models. An understanding of the collective paleoecological data from this region is necessary in order to evaluate how large-scale climatic changes have influenced the post-glacial evolution of the Cremer site.

Regional Climate Research in Areas Surrounding the Cremer Site

Climate has long been considered a principal mechanism responsible for environmental and cultural changes. Variations in climate patterns are thought to result from two primary forces, changes in the earth-sun geometry (Hays et al. 1976; Kutzbach and Webb 1993) and the general circulation of air masses (Bryson and Wendland 1967). These topics have been reviewed in numerous publications and will not be elaborated upon here. In short, interactions between orbital cycles and atmospheric circulation provide a general understanding of spatial and chronological trends in global climate change (COHMAP 1988).

Several models have been used to illustrate the general sequence of post-glacial climatic succession in the western United States. Antevs (1955) developed a three-part Neothermal climate chronology (Anathermal- cool/moist period from about 9,000 to 7,000 yr B.P.; Altithermal- warm/dry period from about 7,000 to 4,500 yr B.P.; and Medithermal- varying condition generally cooler and moister than preceding interval) based on data collected from the Great Basin. This model is now considered to be oversimplified and fails to distinguish regional climatic dissimilarity (Bryan and Gruhn 1964; Bryson et al. 1970; Thompson et al. 1993). Others have proposed the adoption of the Blytt-Serander nomenclature from Europe. Climatic episodes from this system are thought to also reflect significant environmental (and cultural) changes in North America (Bryson et al. 1970). Other systems have been used as well. However, regardless of nomenclature, defining temporal intervals of uniform climate change over large and topographically diverse geographic areas will always be problematic. This is particularly true concerning the timing of maximum Holocene warming and aridity on the northern Great Plains, as palynological data from eastern sites indicate maximum drought conditions occurred during the middle Holocene and western sites record maximum warmth and aridity during the early Holocene (Barnosky 1987b). Despite the problems of extrapolating paleoclimatic data from one region to another, it is a necessary consequence of conducting research in areas which have yet to be systematically investigated. Continued interdisciplinary field research in marginally studied areas should help to clarify the apparent dissimilar nature of post-glacial climate chronologies in western North America.

Much of the regional chronology for late-Quaternary climate change of the northwestern Great Plains and bordering northern Rocky Mountains is based on glacial stratigraphy and palynological investigations. However, these indicators of past environments can have significantly different response times to changing climatic conditions (Bryson et al. 1970). As such, a degree of caution should be exercised in comparing these data sources over large and topographically complex landscapes.

The glacial chronology of Montana and western North America has been extensively reviewed by Alden (1932, 1953), Porter (1988), Porter et al. (1983), Richmond (1986a), and many others, and will only be briefly addressed here. It is generally believed that at the height of the late-Wisconsin glacial maximum (20,000 to 18,000 years B.P.), much of the northern half of North America was covered by large continental ice sheets. During this glacial period, the Laurentide Ice Sheet (LIS) was centered over central/eastern Canada and extended as far south as the northern contiguous states (Mickelson et al. 1983). At its maximum height, the LIS was as much as 3,500 meters thick (Porter et al. 1983), reaching an altitude sufficient to split the westerly jet stream into northern and southern branches over North America (COHMAP 1988; Kutzbach and Guetter 1986). To the west, the Cordilleran Ice Sheet and alpine glaciers enveloped the higher elevations of the Rocky Mountains.

In Montana, the maximum extent of these ice sheets covered approximately the northern one-third of the state, extending as far south as the present course of the Missouri River (Colton et al. 1961). Fullerton and Colton (1986) report that surface till on most of the Montana plains is late-Wisconsin ("Pinedale") in age, with till units of middle and early Wisconsin age absent. The close geographic proximity of continental ice and the associated climatic expression during the late-Wisconsin glacial maximum created a periglacial landscape across much of the northern Great Plains (Pewe 1983). The unglaciated portions of the Montana plains during this glacial peak witnessed a cold and windy climate with areas of continuous to discontinuous permafrost supporting tundra-steppe vegetation. Although punctuated by several regional advances, between 14,000 and 12,000 yr B.P., the cessation of full-glacial climates led to the rapid retreat of Laurentide and Cordilleran ice from Montana, initiating a sequence of late-glacial and post-glacial environmental changes (Carrara et al. 1986; Mickelson et al. 1983).

During the period of maximum Laurentide and Cordilleran ice advance, extensive alpine glaciers were forming in mountainous areas throughout the western United States. Of particular importance for understanding the late/post-glacial climatic succession of the general study area is the paleoenvironmental record of the Yellowstone Plateau region, located approximately 110 miles (177 km) to the southwest of the Cremer site. The last major interval of ice accumulation in this region occurred between 25,000 and 14,000 yr B.P. when Pinedale ice caps covered the Yellowstone Plateau (Pierce 1979; Porter et al. 1983; Richmond 1986b). The Pinedale glaciation featured as many as four ice advances in the Yellowstone Plateau region. Aten (1974) reports a similar sequence (only three identified Pinedale advances) of ice advance along the eastern flank of the Crazy Mountains (approximately 30 miles to the west of the Cremer site). He concluded that the glacial chronology of the Crazy Mountains is consistent with other regional glacial sequences, and reinforces the generally accepted glacial chronology for the Rocky Mountain System (Aten 1974: 128).

After about 11,000 yr B.P., following late-glacial climatic fluctuations and the onset of the Holocene Interglacial, the general warming trend in the Yellowstone Plateau region was interrupted periodically by climates cool enough to allow small cirque glaciers to grow in higher mountains. This neoglacial till sequence has been mapped throughout mountain ranges in western North America. However, these intervals of cooler climate were generally of limited magnitude and did not result in significant growth of most alpine glaciers.

Following the retreat of late-Pinedale age ice from the Yellowstone Plateau region, floral communities began rapidly adjusting to late-glacial and post-glacial climatic changes. A number of palynological studies provide important insights into the nature of the last glacial/interglacial transition in the Rocky Mountains/Yellowstone Plateau region (Baker 1976, 1983; Gennett and Baker 1986; Waddington and Wright 1974; Whitlock 1993; Whitlock and Bartlein 1993). Although temporal variability exists within this region, the recent synthesis reported by Whitlock (1993) forms the basis of the following summary of the late-glacial and post-glacial flora succession in northwest Wyoming.

At the close of the late-Wisconsin full-glacial interval (ca. 14,000 yr B.P.), pollen records in the Grand Teton-Yellowstone National Parks area (GTYNPA) reveal the presence of alpine meadow communities (with *Betula* and *Juniperus*) between 14,000 and 11,500 yr B.P., indicating a lowering of upper treeline by at least 600 m (nearly 2,000 ft) and a climate that was approximately 5 to 6°C (9 to 11°F) cooler than present. By about

11,500 yr B.P., increased warmth and precipitation resulted in a shift from herbaceous taxa to spruce (*Picea*) parkland and from fir (*Picea-Abies*)- whitebark pine (*Pinus albicaulis*) parkland to closed lodgepole pine (*Pinus contorta*) forest at approximately 9,500 yr B.P. Continued warmth and increased aridity during the early Holocene established lodgepole pine forests in the GTYNPA, as well as Douglas fir (*Pseudotsuga menziesii*) and Quaking Aspen (*Populus tremuloides*). Beginning at about 5,000 yr B.P., a return to cool, relatively moist conditions is indicated by the spread of spruce, fir, and pine forests in the GTYNPA (Whitlock 1993).

Although the geographic context (i.e., landscape character) of the Yellowstone Plateau region is quite distinct from the Cremer site, the relative close proximity between the two locations (ca. 110 miles) provides a general sequence of late-glacial and post-glacial climate and vegetation changes in mountainous regions to the south and west of the study area. Field research at localities in ecological settings more similar to that of the Cremer site (i.e., shortgrass plains) have until recently been completely lacking from the High Plains of Montana. Despite this limited data set, pollen records from two localities which have relatively similar geographic contexts as the Cremer site have recently been published by Barnosky (1989). These new pollen assemblages provide a regional framework for assessing late-glacial and post-glacial environmental changes on the northwestern Great Plains.

Barnosky (1989) reports that sediment cores taken from Guardipee Lake and Lost Lake in north-central Montana together span most of the late-glacial and Holocene periods. Barnosky (1989: 57-58, 69-70) states that:

> Guardipee Lake (Glacier Co., lat. 48° 33' N., long. 112° 43' W., elev. 1233 m) lies in shortgrass prarie 50 km east of Glacier National Park.....Temperate grassland, with shrubs growing in mesic habitats, occupied the region ca. 12,200 yr B.P. A trend toward drier conditions after 11,500 yr B.P. is indicated by the increase in sagebrush relative to grass in the Guardipee core.....Increasing drought is registered beginning between ca. 9500 and 9300 yr B.P. with the spread of Chenopodiaceae/Armaranthaceae taxa, *Ambrosia,* and *Sphaeralcea.* Recurrent prairie fires may have favored grass over sagebrush in many areas, and the vegetation probably was discontinuous during the remainder of the Holocene...... Lost Lake (Chouteau Co., lat 47° 38' N., long. 110° 20' W., elev. 1019 m) is in shortgrass prairie at the northern margin of the Highwood Mountains, 65 km east of Great Falls.....Accelerated alluvial fan development at Lost Lake ca. 9400 yr B.P., perhaps resulting from vigorous soil erosion of poorly vegetated surfaces during sporadic storms, may in itself signify warmer and drier conditions concurrent with the climate signal at Guardipee Lake.....After ca. 8300 yr B.P. the predominance of *Ruppia* and Chenopodiaceae/Amaranthaceae relative to Poaceae and *Artemisia* further implies drought.....Wetter and cooler conditions were initiated ca. 6000 yr B.P., as indicated by the increase in Poaceae and *Artemisia* relative to Chenopodiaceae/Amaranthaceae and the increase in spruce, pine, alder, birch, willow, and various herbs. The conifer pollen is attributed to the expansion of forest in nearby mountain ranges. Further cooling during the last 3400 yr B.P. is inferred from the decline in Chenopodiaceae/Amaranthaceae and the increase in pine.

The Guardipee Lake and Lost Lake records represent the only published palynological studies from the northwestern Plains of Montana. However, both of these post-glacial pollen assemblages are in distinct contrast to vegetation sequences from the eastern Great Plains and Midwest, and also from the Prairie/boreal forest transition in Alberta (Barnosky 1989). Rather than showing late-glacial spruce forest replaced by pine or deciduous woodland before prairie development, pollen spectra at Guardipee and Lost Lakes record treeless vegetation throughout the last 12,000 years B.P. (Barnosky 1989: 71). The treeless vegetation may have been a response to prolonged and locally severe conditions near the confluence of Cordilleran and Laurentide ice, or may have developed in response to early post-glacial warming (Barnosky et al. 1987a: 302).

Taken together, the Guardipee and Lost Lakes records provide important chronologic boundaries for the proposed maximum drought conditions of the early-middle Holocene period on the High Plains of Montana. The Guardipee Lake pollen assemblage places the beginning of the warm and dry "altithermal" period at ca. 9,400 yr B.P. as temperate grassland was replaced by a xerophytic grassland (Barnosky 1989). The Lost Lake record indicates the presence of a xerophytic grassland between 9,400 and ca. 6,000 yr B.P., with climatic conditions becoming more mesic (cooler and wetter) after 6,000 yr B.P., marking the end of the "altithermal" period (Barnosky 1989). These data provide an important ecological context for evaluating the paleoclimatic inferences derived from the Cremer site soil-stratigraphic record.

The proposed temporal boundaries for maximum Holocene aridity on the northwestern High Plains of Montana (Barnosky 1989) seem to match the soil-stratigraphic record from the Cremer site quite well. Following a generally warm and wet period of soil formation about 10,000 yr B.P., climatic conditions at the Cremer site seem to have become significantly more arid. Barnosky (1989) reports that this climatic shift occurred at ca. 9,400 yr B.P., which is consistent with evidence from the Cremer site. This period of increased aridity on the northwestern plains of Montana is reported to have persisted relatively uninterrupted until ca. 6,000 yr B.P. Although punctuated by pedogenesis at ca. 7,500 yr B.P., this interval of intensified Holocene drought also diminished by 6,000 yr B.P. at the Cremer site with a return to wetter condition and renewed soil development.

The collective evidence from the Cremer site generally supports Barnosky's (1989) research at Guardipee Lake and Lost Lake in that the period of greatest Holocene aridity on the central and northwestern Montana Plains occurred between 9,400 and ca. 6,000 yr B.P. Although climatic conditions were not necessarily uniform over this nearly 3,500 year period, it is apparent that maximum drought conditions existed during the early Holocene (prior to ca. 6,000 yr B.P.). Our attention now turns to attempts at modeling past climates of this region to see if modeled results match evidence from the field.

Paleoclimate Modeling

Over the past several years there have been significant efforts to develop paleoclimatic models which simulate how large-scale climatic changes have contributed to regional and local paleoecological records. These models are based on a fairly complex set of climatic variables and boundary conditions and generally require great computational power. Here I present data from two different paleoclimatic models. The general circulation model (GCM) developed by the COHMAP group provides paleoclimatic data on both a global and regional scale (Kutzbach 1987, Wright et al. 1993). GCMs have been used widely in North America to test inferred regional paleoenvironmental patterns derived from proxy records with model outputs (Barnosky et al. 1987a; Kutzbach et al. 1993; Thompson et al. 1993). Additionally, Bryson and Bryson (personal communication 1996) have recently developed a modeling technique which provides data for specific sites known as archaeoclimatic modeling. Each of these models will be discussed below as they pertain to the Cremer site.

General Circulation Model (GCM) Developed by COHMAP

The development of large-scale paleoclimatic models have contributed greatly to our understanding of global climate change since the last glacial maximum. Methodological considerations underlying GCM output have been reviewed by Kutzbach and Guetter (1986), Kutzbach (1987), COHMAP (1988), Kutzbach and Ruddiman (1993) and many others. Results from extensive research by the COHMAP group has recently been summarized in Wright et al. (1993). These papers describe in detail the variety of input parameters used to generate model results as well as regional paleoclimatic histories.

Because GCMs are global and regional in scope, a number of the parameters used in model design are generalized. This generalization stems from the coarse spatial resolution of the model (cell size is 4.4° latitide by 7.5° longitude), the "smoothing" of regional topography, and the coarse temporal resolution of the model (simulations are typically spaced 3,000 yr apart) (Kutzbach et al. 1993). These factors, and others, limit the degree in which model output accurately reflects past climatic conditions at the site level. Mock and Bartlein (1995: 425) state that GCMs have sufficient resolution to describe variations in large-scale atmospheric circulation patterns, but they cannot accurately simulate smaller-scale circulation features and their interactions with topography that may explain some of the spatially varying climatic changes in the western United States. Despite these limitations, GCM output can provide a regional paleoclimatic framework to which local or site-specific research can be integrated.

In cooperation with the Center for Climatic Research at the University of Wisconsin-Madison, I obtained recently updated climate data for four cells of the

Community Climate Model (part of the GCM) for the general region surrounding the Cremer site (Pat Behling, personal communication, 1996). The cells occupy an area that includes nearly all of Montana and parts of adjacent states, as well as southern portions of the neighboring Canadian provinces of Alberta and Saskatchewan. This broad geographic area is topographically complex, with mountainous regions occupying much of the western section and rolling plains extending eastward.

Temperature and precipitation data were obtained for the time intervals of 21,000 yr B.P., 16,000 yr B.P., 14,000 yr B.P., 11,000 yr B.P., 6,000 yr B.P., and the present. These data are reported by season (i.e., winter (Dec-Jan-Feb), spring (Mar-Apr-May), summer (Jun-Jul-Aug), and fall (Sep-Oct-Nov)) for the time intervals indicated to illustrate the seasonal distribution of climate change since the last glacial maximum. Figures 5.1 and 5.2 show the GCM results for temperature and precipitation, respectively.

At the height of the late-Wisconsin glacial maximum (ca. 21,000 yr B.P.), seasonal temperatures over the modeled region ranged from 18 to 26°C lower than present (Figure 5.1). By 16,000 yr B.P. seasonal temperatures only modestly increased from the full-glacial conditions at 21,000 yr B.P., ranging between 13 and 18°C lower than present. By 14,000 yr B.P., temperatures begin to reflect the initial shift from a full-glacial to late-glacial climate. Seasonal temperatures at 14,000 yr B.P. ranged from 3 to 10°C lower than present. At 11,000 yr B.P., both winter and spring temperatures were between 3 and 4°C lower than present. However, increased solar insolation during the summer and fall seasons resulted in temperatures higher than present. Summer temperatures at 11,000 yr B.P. were approximately 2°C warmer than present and fall temperatures were about 8°C warmer than present. By 6,000 yr B.P., temperatures in all

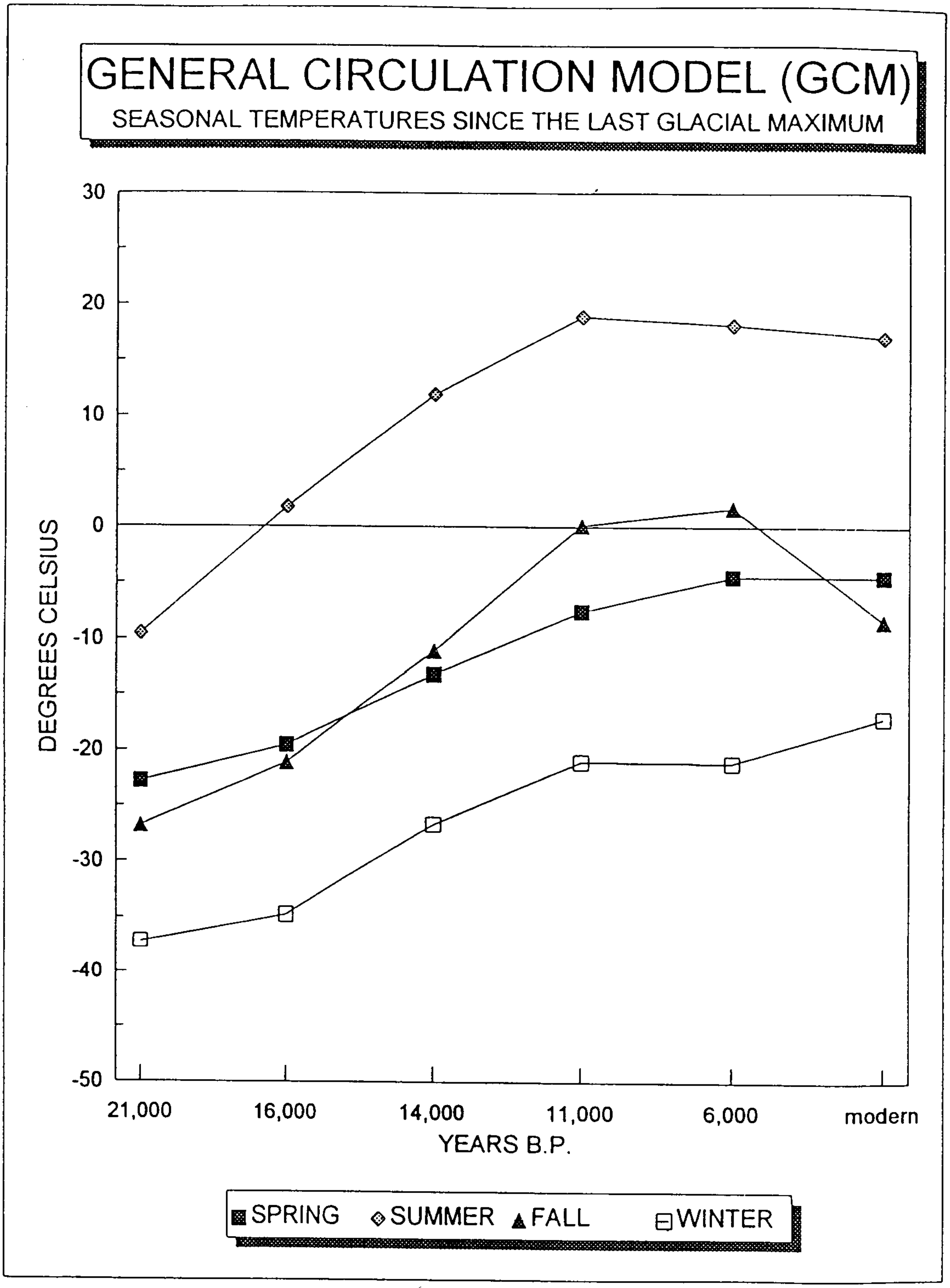

Figure 5.1. General Circulation Model (GCM) results of seasonal temperatures from 21,000 yr B.P. to the present.

seasons but winter were similar to or warmer than present. While the spring and summer seasons were only slightly warmer, fall temperatures were as much as 10°C warmer than present.

Seasonal precipitation patterns since the last glacial maximum are presented in Figure 5.2. During full glacial conditions at 21,000 yr B.P., precipitation totals ranged from 30 to 41% below present amounts for the spring, summer and fall seasons, but only 4% below present in winter. At 16,000 yr B.P., low precipitation continued to dominate the region, ranging between 27 and 48% below present amounts for the spring, summer and fall seasons, with winter precipitation being approximately 8% below present values. By 14,000 yr B.P., precipitation during the spring and fall seasons continued to remain lower than present by 25 to 29%, with winter precipitation being approximately 6% below present amounts. However, summer rainfall at 14,000 yr B.P. sharply increased from the previous full-glacial totals and was about 9% higher than present. Summer precipitation continued to increase, and by 11,000 yr B.P., seasonal amounts reached 19% higher than present values. Fall, winter and spring precipitation at 11,000 yr B.P. remained between 9 and 29% lower than present. By 6,000 yr B.P., precipitation totals in all seasons ranged from 5 to 19% lower than present.

GCM output for precipitation patterns since the last glacial maximum indicates an overall greater aridity throughout most of the 21,000 yr interval than exists under the modern climate. Only during the summer season at both 14,000 and 11,000 yr B.P. do precipitation totals exceed present amounts. Temperatures were well below modern conditions for all seasons prior to 11,000 yr B.P. At both 11,000 and 6,000 yr B.P., summer and fall temperatures were higher than that of the present climate. A comparison

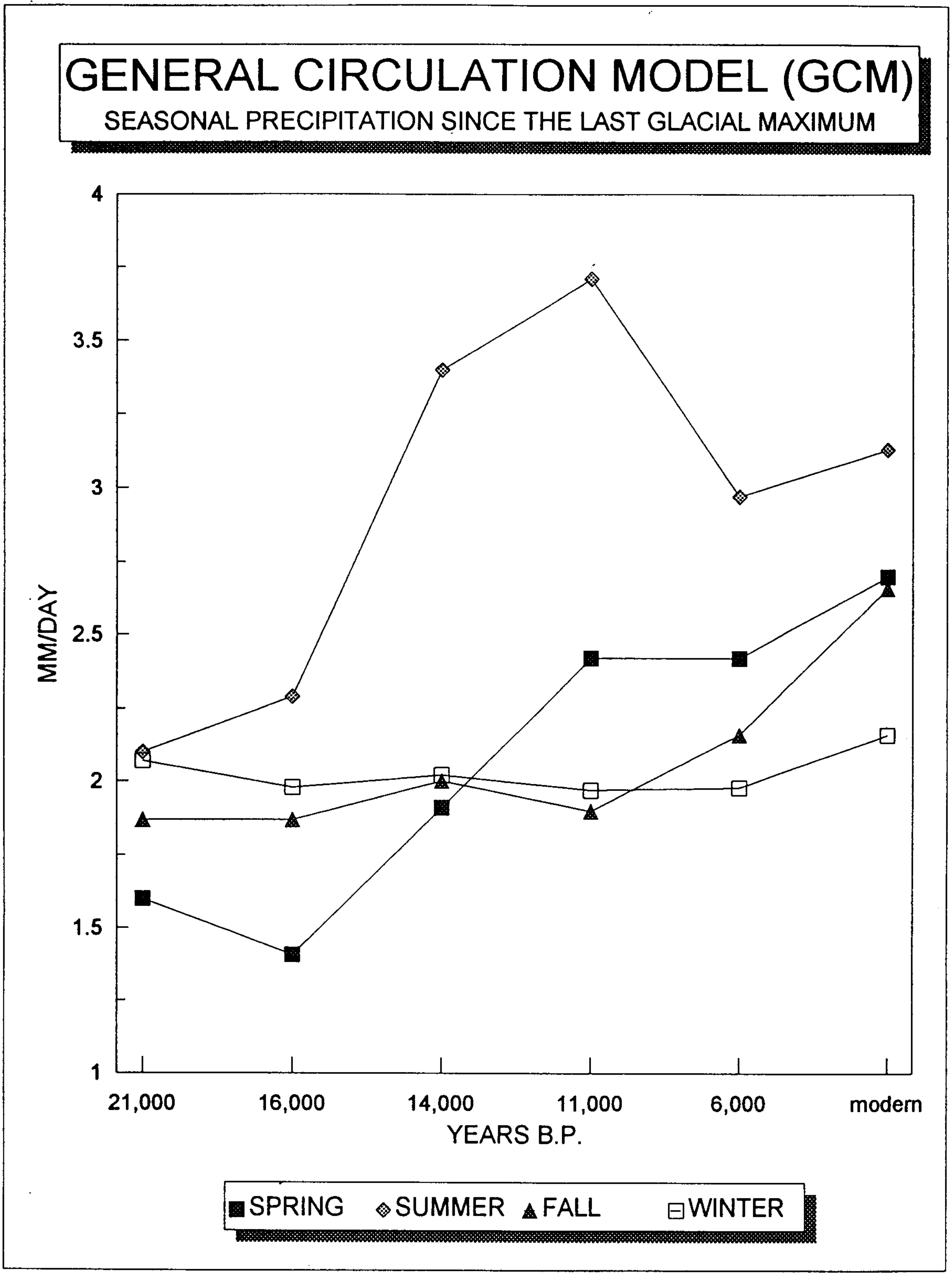

Figure 5.2. General Circulation Model (GCM) results of seasonal precipitation from 21,000 yr B.P. to the present.

between GCM results (and archaeoclimatic modeling results) with inferred paleoclimatic evidence from the Cremer site will be presented in the Discussion section at the end of this chapter.

Archaeoclimatic Modeling

Another technique used to model past climates has recently been developed by R.A. Bryson and R.U. Bryson (personal communication 1996). Known as archaeoclimatic modeling, this technique is capable of reconstructing site-specific, high resolution paleoclimatic models for almost any archaeological site in the world (Bryson and Bryson 1994, 1995a, and 1995b). Taking only seconds to run on a microcomputer, the climatic parameters of temperature and precipitation can be modeled by month at 200 year intervals back to 14,000 yr B.P. and at 500 year estimates from 14,000 to 40,000 yr B.P. (Bryson et al. 1996).

Bryson et al. (1996: 6) state that unlike general circulation models, archaeoclimatic modeling was developed to provide paleoclimatic reconstructions of use to field scientists whose interests focus on interpreting the relationship between climate change and environmental and/or cultural dynamics based on field data. Another important difference between archaeoclimatic modeling and GCMs is the former's inclusion of the effects volcanic eruptions have had upon climate change (Bryson 1989). The release of volcanic aerosols into the atmosphere is thought to modulate insolation rates, resulting in high frequency variance in the climate system. This innovative use of the global volcanic record offers a unique perspective on the interaction between climate and cultural change.

Archaeoclimatic modeling is site-specific because the means by which the synoptic relationships between precipitation (or temperature) and the major circulation features are calibrated utilizes modern climatic data from the site of interest (Bryson et al. 1996: 8). In the case of the Cremer site, climatic data was obtained from the Melville weather station located approximately 12 miles to the west of the site. Figures 5.3, 5.4 and 5.5 illustrate the modeled results for temperature, precipitation and snowfall, respectively.

Modeled estimates shown in Figure 5.3 are for mean annual and mean August temperatures (°C) from 14,000 yr B.P. to the present. These data indicate that a very dynamic post-glacial climate characterized the Cremer site region. During the late-Pleistocene (14,000 yr B.P.), annual mean temperatures were approximately 0°C and about 14°C in August. Temperatures generally increased by 2°C over the next millenium before lowering again by about 13,000 yr B.P. This cycle repeated itself over the next thousand years culminating with depressed temperatures associated with the Younger Dryas at about 11,800 yr B.P.

Between ca. 11,600 and 10,000 yr B.P. temperatures generally increased as the mean annual reached approximately 4°C and the mean August about 18°C. From ca. 10,000 to 8,400 yr B.P. the mean annual temperature remained fairly steady as August temperatures declined by approximately 2°C. Between ca. 8,200 and 6,000 yr B.P. both mean annual and August temperatures generally increased by 2 to 3°C. It is during this interval in which modeled summer (August) temperatures reach their Holocene maximum. Between 6,000 to just prior to 4,000 yr B.P. temperatures decrease only slightly (< 1°C). However, by ca. 4,000 yr B.P. temperatures dropped sharply by about

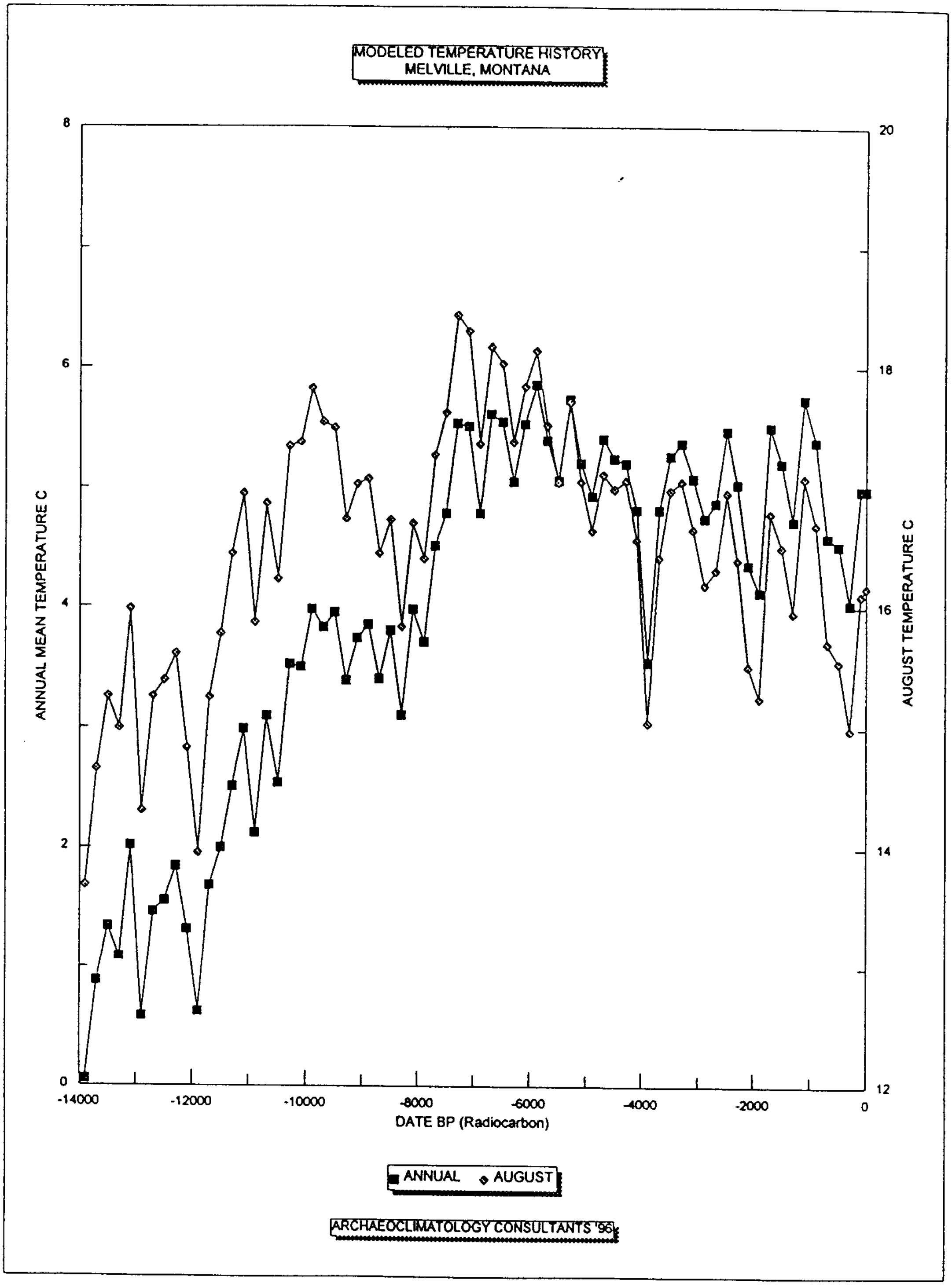

Figure 5.3. Archaeoclimatic (site-specific) model results of mean annual and August temperatures for Melville, Montana from 14,000 yr B.P. to the present (Bryson and Bryson, personal communication, 1996).

2°C before rebounding again by ca. 3,500 yr B.P. This sharp decrease in temperature between ca. 4,000 to 3,800 yr B.P. was reportedly driven by a global "burst" of volcanic activity known as the "Indus Event" (Bryson and Bryson 1995). From ca. 3,500 yr B.P. to the present, temperatures are modeled to have been generally more variable than during previous times, with mean annual temperatures ranging between 4 and 6°C and between 15 and 17°C in August.

Modeled estimates shown in Figure 5.4 are for mean annual and mean June precipitation from 14,000 yr B.P. to the present. Modeled precipitation corresponds well with the modeled temperature history, as precipitation totals generally increase with rising temperatures. During the late-Pleistocene (ca. 14,000 yr B.P.), annual mean precipitation was just over 300 mm/yr (approximately 30% less than present amounts) and June totals were about 62 mm/mo (approximately 16% less than present). Over the next two millenia precipitation patterns are generally quite variable. Between ca. 11,600 and 9,400 yr B.P. precipitation totals rise sharply. During this wetter interval, mean annual precipitation increases from 315 mm/yr to about 400 mm/yr. Similarly, mean June rainfall increases from approximately 63 mm/mo to about 80 mm/mo.

During the early Holocene, between ca. 9,400 and 8,000 yr B.P., precipitation totals decline only moderately. However, during the next thousand years precipitation amounts began to approach their Holocene maximum, with mean annual totals rising from 375 mm/yr to about 450 mm/yr and June totals increasing from approximately 73 mm/mo to 85 mm/mo. This pattern of generally increased precipitation continued until ca. 5,000 yr B.P. During the last 5,000 yr B.P., precipitation is modeled to have been

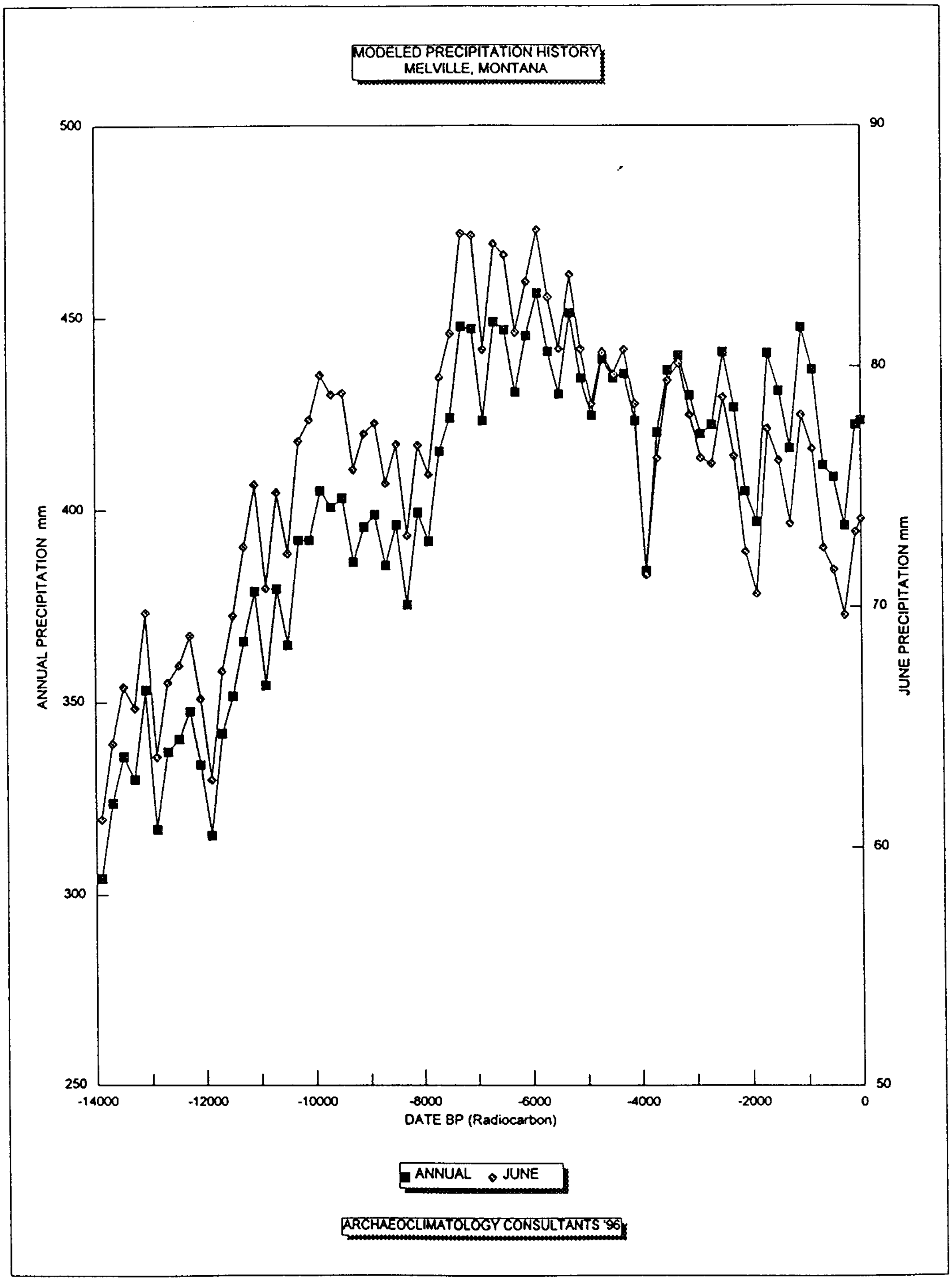

Figure 5.4. Archaeoclimatic (site-specific) model results of mean annual and June precipitation for Melville, Montana from 14,000 yr B.P. to the present (Bryson and Bryson, personal communication, 1996).

generally more variable than during previous times. Sharp decreases in precipitation are modeled to have occurred at approximately 3,800, 1,800 and 600 yr B.P.

Modeled estimates shown in Figure 5.5 are for mean annual snowfall from 14,000 yr B.P. to the present. During the late-Pleistocene (ca. 14,000 to 11,500 yr B.P.), annual snowfall totals are modeled to have fluctuated quite regularly, however they generally remained very high. During the end of the Pleistocene and early Holocene periods (ca. 11,500 to 8,000 yr B.P.), snowfall amounts declined sharply from their late-glacial levels, however they still remained moderately high. During the middle Holocene (ca. 8,000 to 4,000 yr B.P.), snowfall totals were at their post-glacial minimum. During the last 4,000 yr B.P. annual snowfall amounts are modeled to have been quite variable, with higher totals occurring at approximately 3,800, 2,000 and 800 yr B.P.

Discussion

Results from both GCM and archaeoclimatic modeling illustrate important post-glacial climate changes for the general region surrounding the Cremer site. Although comparisons between the two modeling techniques are limited by the defined temporal units and annual/seasonal contrasts, sufficient resolution exists to make a general assessment of the compatibility between these two approaches. These comparative results are also useful in determining which model output most closely matches the environmental record found at the Cremer site.

Both temperature and precipitation values simulated by the GCM are at their lowest levels between 21,000 and 16,000 yr B.P. (a time interval not covered by the site-specific modeling technique or represented in the Cremer site soil-stratigraphic record).

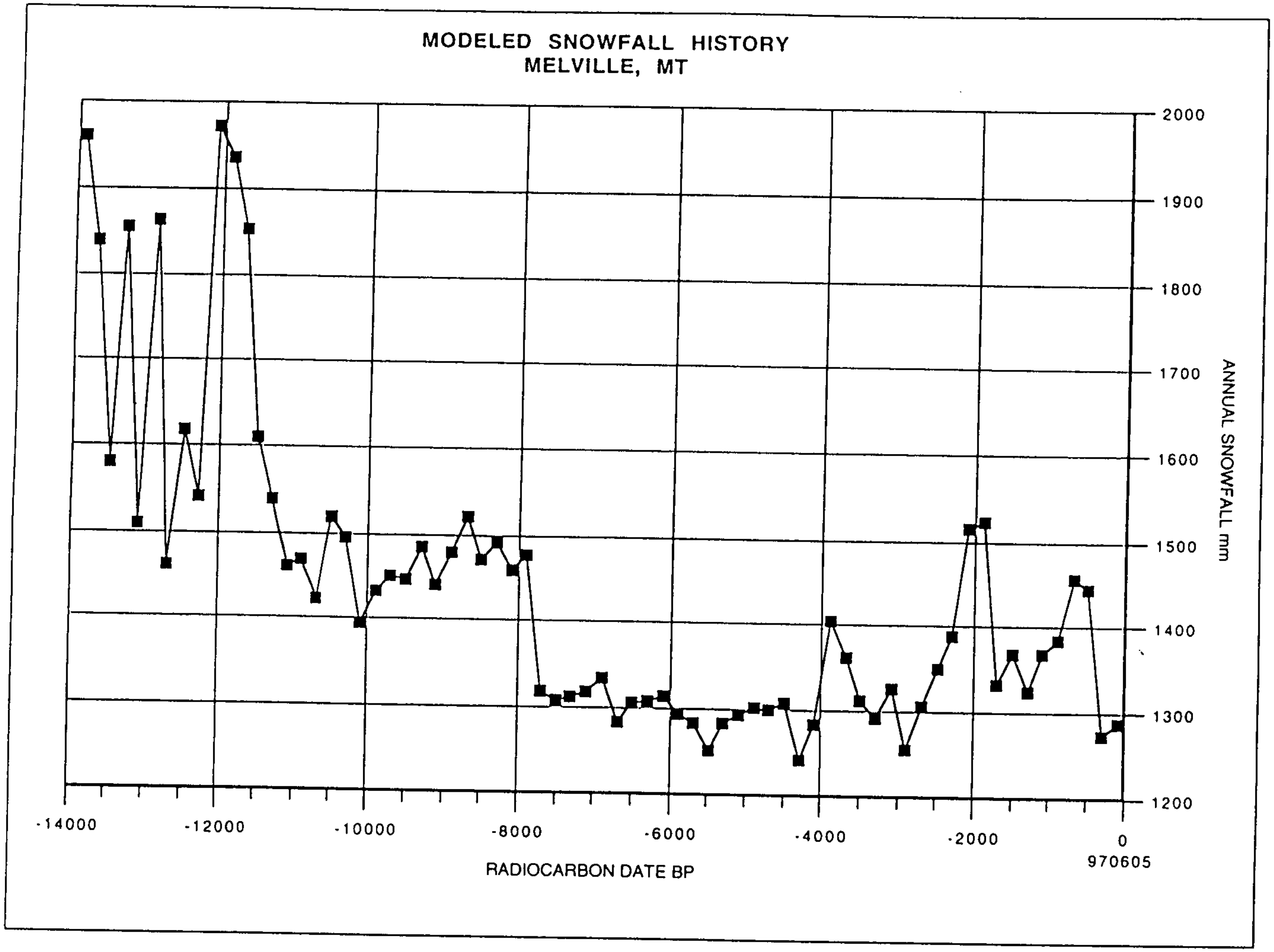

Figure 5.5. Archaeoclimatic (site-specific) model results of mean annual snowfall for Melville, Montana from 14,000 yr B.P. to the present (Bryson and Bryson, personal communication, 1996).

At 14,000 yr B.P., GCM output indicates a sharp rise in both spring and summer precipitation from previous full-glacial levels and temperatures significantly lower than that modeled specifically for the Cremer site. By 11,000 yr B.P., results from both GCM and archaeoclimatic modeling indicate increased temperatures and precipitation for the study area. Temperature and precipitation values continue to rise until just after 10,000 yr B.P. according to the Bryson and Bryson (1996) model. These data seem to accurately reflect the inferred climatic conditions at the Cremer site during the formation of the soil horizon dating to 10,090 yr B.P. (Trench 2: Stratigraphic Unit IX/horizon 10Ab).

The onset of Holocene warming cannot be reliably deduced from the available GCM, as the closest temporal unit modeled is at 6,000 yr B.P. GCM output indicates that temperatures increased slightly from 11,000 to 6,000 yr B.P. as summer precipitation totals declined sharply. However, the initial shift to increased aridity and the period of maximum expression cannot be determined from this particular GCM.

Site-specific modeling output indicates that both precipitation and temperature decreased during the early Holocene period (ca. 10,000 to 8,000 yr B.P.). Between ca. 8,000 to 6,000 yr B.P., temperature and precipitation amounts are modeled to have increased sharply. Soil development dating to ca. 7,500 yr B.P. at the Cremer site (Trench 2: Stratigraphic Unit V) very likely reflects this climate change. The collective archaeoclimatic evidence implies that the greatest period of early Holocene aridity occurred between ca. 9,400 to 8,000 yr B.P. and that both precipitation and temperatures reached their Holocene maximum between ca. 7,400 to 5,400 yr B.P. (although sharp precipitation decreases are modeled to have occurred at ca. 7,000, 6,400 and 5,600 yr at a

B.P.). In contrast, GCM output indicates that precipitation amounts at 6,000 yr B.P. were Holocene minimum.

Between ca. 6,000 yr B.P. to the present, GCM output reveals that precipitation totals in all seasons generally increased. Temperature estimates are more variable during this time period, with spring and summer totals remaining relatively unchanged, fall temperatures decreasing sharply and a moderate temperature increase during the winter season.

Archaeoclimatic modeling results reveal a much more dynamic climate during the last 6,000 yr B.P. Beginning at ca. 6,000 yr B.P. (when both temperature and precipitation are modeled to be at a Holocene maximum), climatic conditions appear to have fluctuated quite regularly over the next millenia as temperature and precipitation trends initially decrease, then rise and fall again. This period of variable climate coincides with the formation of several micro-Ab horizons and the lowest paleosol described along Trench 1. These weakly developed soil horizons are radiocarbon dated between ca. 5,920 to 5,100 yr B.P. and are inferred to have formed under oscillating conditions between wetter and drier climates in which organic matter began to accumulate as thin A horizons prior to burial by renewed sedimentation. The match between the modeled climate of the Cremer site and the existing soil-stratigraphic record appears to be quite reasonable for this mid-Holocene period.

Between ca. 5,000 to 4,200 yr B.P., the site's modeled climate remained relatively stable until an abrupt change by ca. 4,000 yr B.P. This period of climatic and environmental instability is modeled to have been relatively short lived as conditions returned to their pre-"Indus Event" levels by ca. 3,600 yr B.P. Soils began forming again at the Cremer site by ca. 3,730 yr B.P. (Trench 1: Stratigraphic Unit V), consistent with the archaeoclimatic model results.

During the remainder of the late-Holocene period, modeled climatic conditions at the Cremer site remain quite variable. Although no additional radiocarbon ages are available for the site, two other soil forming intervals from Trench 1 overlie the paleosol dating to ca. 3,730 yr B.P. These episodes of pedogenesis could arguably be related to climatic trends modeled for the site by Bryson and Bryson (1996).

In summary, the two techniques used to model past climates of the study area appear to be only partly in agreement, as the timing of maximum Holocene aridity and the cessation of drought conditions on the northwestern Plains remains disputed. Between ca. 11,000 to 10,000 yr B.P., both paleoclimatic models reflect increased temperature and precipitation values from previous levels. This climatic sequence is consistent with pedogenic development at the Cremer site by 10,090 yr B.P. The absence of higher resolution time intervals during the early Holocene limits the usefulness of the GCM in comparing model results with other available evidence. Site-specific modeling output indicates increased aridity by ca. 9,400 yr B.P., but this climatic change is also accompanied by reduced temperatures. Although field data indicate significantly decreased precipitation during the early Holocene, temperatures are inferred to have been relatively high, a direct contrast to the output modeled by Bryson and Bryson (1996).

There is some field evidence from the Cremer site which supports the site's archaeoclimtic modeled temperature and precipitation increase by ca. 7,400 yr B.P. Soil formation along the Trench 2 landform implies increased organic matter accumulation at the site by 7,490 yr B.P. Modeled climatic parameters for the site varied over the next ca.

1,400 years, but continued to remain high (at their Holocene maximum) at 6,000 yr B.P. This is in direct contrast to the GCM results which indicate that precipitation amounts at 6,000 yr B.P. were at a Holocene minimum. Field data from the Cremer site and that reported by Barnosky (1989) indicates that a return to more mesic conditions were initiated by ca. 6,000 yr B.P., evidence which is in better agreement with the archaeoclimatic modeling results.

From ca. 6,000 yr B.P. to the present, the Cremer site soil-stratigraphic record implies the existence of a fairly dynamic climatic regime. Although chronologic controls from the site are limited for this time period, repeated episodes of soil development and subsequent burial by renewed sedimentation along the Trench 1 landform seem to closely parallel the results modeled by Bryson and Bryson (1996). It is clear from the above discussion that archaeoclimatic modeling can offer a higher resolution of climate change than GCMs. The usefulness of such data to field scientists will only become known by continued interdisciplinary research. Results from archaeoclimatic modeling of the Cremer site appears to match the field data reasonable well.

Chapter 6

Conclusions

Paleoenvironmental Summary of the Cremer Site

For the vast region of the northern Great Plains, few studies concerning post-glacial climate and environmental change have been reported (Barnosky 1989: 57). This area exhibits substantial topographic and ecological diversity and has the potential to yield invaluable paleoenvironmental data. Additionally, a number of anthropological questions regarding prehistoric cultural patterns throughout this region have yet to be fully resolved. These factors make the Cremer site an ideal research locality for investigating the relationships between past environmental and cultural sequences in northwestern Plains prehistory.

The processes involved in landscape evolution are characteristically episodic, with relatively long periods of stability (i.e., soil formation) being separated by shorter intervals of instability (i.e., erosion and sedimentation). The stratigraphic and pedologic sequences preserved at the Cremer site provide a record of the environmental setting of the study area dating back to the late-Pleistocene period. The collective data indicate that a very dynamic post-glacial climate has characterized this region, reflecting both long intervals of geomorphic stability and significant periods of aridity and drought.

The earliest evidence for landscape stability and soil formation following the late-Wisconsin glacial maximum occurred at the Cremer site ca. 10,090 $\pm$ 130 yr B.P. (Trench 2: Stratigraphic Unit IX/horizon 10Ab). Climatic conditions are inferred to have exhibited both higher temperature and precipitation values during this interval of pedogenesis compared to previous levels. Both GCM and archaeoclimatic modeling results reflect this general climatic trend as well.

Increased aridity at the Cremer site is implied by accelerated colluvial deposition (Trench 2: Stratigraphic Units VIII, VII and VI) immediately following the earliest period of soil formation. Palynological evidence from Guardipee Lake and Lost Lake on the Plains to the northwest of the Cremer site indicate a similar sequence of warmer and drier conditions by ca. 9,400 yr B.P. (Barnosky 1989). Increased warmth and aridity by ca. 9,500 yr B.P. is also reported for the Yellowstone Plateau region (Whitlock 1993). These data suggest that a significant period of aridity characterized the northwestern Plains and parts of adjacent mountain regions during the early Holocene.

The effects of early Holocene aridity at the Cremer site seem to have moderated by ca. 7,490 ± 100 yr B.P. as renewed soil development (Trench 2: Stratigraphic Unit V) accompanied by general landscape stability returned to the site. Archaeoclimatic modeling results indicate increases in both temperature and precipitation during this general time period as well. This interval of pedogenesis ended as renewed erosion and sedimentation initiated another period of general landscape instability, burying the soil dating to ca. 7,500 yr B.P. This episode of colluvial deposition (Trench 2: Stratigraphic Unit IV) implies the recurrence of drought conditions at the Cremer site, resulting in poorly vegetated upland surfaces highly susceptible to erosion.

Climatic conditions seem to have become significantly less arid by ca. 6,000 yr B.P., as soils once again began forming at the Cremer site. Radiocarbon ages from the lowest soil sequence from Trench 1 (Stratigraphic sub-Unit VII1/horizon 12Akb) range between 5,920 ± 80 and 5,100 ± 70 yr B.P. Soil development occurs along this section of the trench as a series of weakly developed A horizons in which organic matter began to accumulate prior to burial by increased colluviation. The inferred climatic pattern of this soil forming interval is one of oscillating conditions between wetter and drier climates. Archaeoclimatic modeling results also reflect a period of variable climate during this interval of pedogenesis.

Climatic amelioration by ca. 6,000 yr B.P. at the Cremer site has important implications for determining the period of maximum Holocene aridity on the northwestern Great Plains. Geomorphic and pedologic evidence from the Cremer site indicates that the period of greatest Holocene aridity occurred immediately after soil development at ca. 10,090 yr B.P. and prior to renewed pedogenesis at ca. 7,490 yr B.P. The recurrence of drought conditions at the site immediately followed the soil forming interval dated to ca. 7,500 yr B.P. and lasted until ca. 6,000 yr B.P. This stratigraphic evidence indicates that the period of maximum post-glacial aridity at the Cremer site occurred during the early Holocene (prior to ca. 6,000 yr B.P.).

The evidence for early Holocene aridity at the Cremer site seems to be supported by the available palynological data from the northwestern Plains. The Guardipee and Lost Lakes records indicate that a shift to warmer and drier conditions occurred at ca. 9,400 yr B.P. and lasted until ca. 6,000 yr B.P., with climatic conditions becoming more mesic (cooler and wetter) after 6,000 yr B.P. (Barnosky 1989). These data support the paleoclimatic inferences derived from the Cremer site soil-stratigraphic record very well. The collective evidence indicates the period of maximum post-glacial aridity on the central and northwestern Plains of Montana occurred during the early Holocene (between ca. 9,400 to 6,000 yr B.P.).

The middle to late-Holocene period at the Cremer site witnessed a very dynamic climatic pattern. Repeated episodes of soil formation and subsequent burial by renewed sedimentation is recorded along the Trench 1 landform. Soil forming intervals are radiocarbon dated between ca. 5,920 and 5,100 yr B.P. (Stratigraphic sub-Unit VII1) and at ca. 3,730 (Stratigraphic Unit V). Two other periods of soil development overlie these lower soil sequences from Trench 1 (Stratigraphic Units III and I). Distinct episodes of colluvial and/or alluvial deposition separate each soil sequence from one another. This dynamic and high frequency record of middle to late Holocene environmental change is largely attributed to the responses the steep upland slopes immediately to the northeast (source of colluvial deposits) and Antelope Creek to the southwest (source of alluvial deposits) have with respect to changing climatic conditions. The upper soil sequences from Trench 2 do not record these higher frequency indicators of climate variability at the site due to the landform's more stable geomorphic position and lower slope gradient from the uplands. Archaeoclimatic modeling output for the study area also shows a very dynamic middle to late Holocene climatic regime, as do other regional environmental proxy records.

In summary, the Cremer site consists of well-stratified soil sequences that span the last 10,000 yr B.P. Stratigraphic and pedologic evidence indicates that the maximum expression of post-glacial aridity occurred at the site during the early Holocene period (prior to 6,000 yr B.P.), consistent with available evidence from the Montana Plains. These data contribute to a much needed research base for this sparsely studied region, and should assist in future reconstructions of post-glacial climate and environmental changes on the northwestern Great Plains, and responses in human adaptive strategies.

The Cremer Site Archaeological Record Re-visited

Research objectives during the 1995 and 1996 field seasons included both a complete geoarchaeological description of the Cremer site (the goals of this thesis) and efforts to further develop a systematic excavation strategy and recovery procedure for small-scale organic material, including human and animal hair (the goals of the C.S.F.A./Earthwatch project). Given the nature of these research methodologies and the resources available, only a limited area (less than 3-square meters) of the site was systematically excavated by traditional archaeological techniques. The findings from these limited archaeological excavations still await further analysis. As a result, the new descriptions of the soil-stratigraphic record and paleoenvironmental setting of the Cremer site will be related to the archaeological interpretations based on field work conducted at the site in 1979 and 1980 (Nowatzyk 1983).

The soil-stratigraphic assemblages found at the Cremer site preserve a sequence of post-glacial climatic and environmental changes, and the existing archaeological record shows how human activity correlates with these changes. Nowatzyk (1983) reports that stone artifacts found at the Cremer site have Early Plains Archaic (ca. 8,000 to 5,000 yr B.P.), Middle Plains Archaic (ca. 5,000 to 2,500 yr B.P.), Late Plains Archaic (ca. 2,500 to 1,500 yr B.P.) and Late Prehistoric (ca. 1,500 to 200 yr B.P.) period affiliations (see Figures 1.1 and 1.2). In general, the Archaic Period has traditionally been viewed as a continent wide shift in subsistence from Paleoindian (ca. 11,500 to 8,000 yr B.P.) dependence on large game animals to the exploitation of a broad variety of faunal and floral resources.

The 1979/1980 archaeological excavations at the Cremer site were conducted along a cutbank of Antelope Creek, adjacent to what would later become the lower section of Trench 1 and the Northeast Streamface (Figure 4.1). Based on radiocarbon and stratigraphic evidence from this part of the site, and given the association between artifact context with buried soils, there should be no signs of human occupation older than ca. 6,000 yr B.P. The lowest cultural level (Cultural Layer V) identified by Nowatzyk (1983) occurred within a very thin (less than 5 centimeters) and discontinuous "silty sand layer of dark brown shade" (Natural Layer 9). The corresponding matrix of Cultural Layer V was not identified during either the 1995 or 1996 field season, and thus renders any definitive interpretations difficult. It is possible that this "discontinuous" layer dates to the Early Plains Archaic Period. However, Natural Layer 9 is surrounded by alluvial sands (Natural Layer 8) and gravel (Natural Layer 7) which suggests that at least some of the 42 artifacts recovered from this cultural bearing stratum may have been redeposited.

Cultural Layers IV and III are also reported to date to the Early Plains Archaic period (Nowatzyk 1983). These occupation levels are embedded within fossil soils (buried A horizons) (Natural Layers 5b and 5a, respectively) separated by a thin lens of sandy alluvium (Natural Layer 4c), indicating a close temporal relationship. Both of these soil horizons correspond to Stratigraphic Unit V along Trench 1 and the Northeast Streamface (see Figure 4.11). A radiocarbon sample from Stratigraphic Unit V indicates an age of 3,730 $\pm$ 110 yr B.P. for the pedologic sequence. If this age assignment is correct, it would suggest that Cultural Layers IV and III date to the Middle Plains Archaic period, and not to the Early Plains Archaic as reported by Nowatzyk (1983).

Cultural Layer II is identified as a Middle Plains Archaic occupation sequence based on the diagnostic attributes of "McKean" and "Duncan" projectile points (Nowatzyk 1983). This cultural bearing stratum occurs within the buried soil horizon designated as Natural Layer 3a, which corresponds to Stratigraphic Unit III along Trench 1 and the Northeast Streamface. McKean projectile points date back as early as 4,500 yr B.P. on the northwestern Plains (see Figure 1.1). However, Cultural Layer II overlies the soil sequence dating to ca. 3,730 $\pm$ 110 yr B.P., indicating a more recent age for this artifact assemblage, closer to the Middle Plains Archaic/Late Plains Archaic transition. Either the Cremer site records evidence of a relatively late occurrence of the "McKean complex" or additional chronological controls (i.e., radiocarbon dates) are needed to clarify these contradictory findings.

Cultural Layer I is identified as a mixed assemblage with Late Plains Archaic and Late Prehistoric period affiliations (Nowatzyk 1983). This cultural level is designated as Natural Layers 3a, 2 and 1, which corresponds to Stratigraphic Unit I along Trench 1 and the Northeast Streamface. Nowatzyk (1983: 68) reports a radiocarbon age (in calendar years) of A.D. 170 $\pm$ 100 years for the lower component of Cultural Layer I. However, as mentioned previously, there remains some uncertainty as to the true provenience of this radiocarbon sample. As was the case of Cultural Layer II, diagnostic characteristics of the projectile point assemblage from Cultural Layer I (i.e., "Pelican Lake" and "Avonlea") imply an antiquity greater than that indicated by new radiocarbon ages for the Trench 1 landform. Without additional chronological controls for this upper soil sequence, the present temporal assessment remains inconclusive.

In summary, the findings from this thesis research do not entirely support the archaeological interpretations reported by Nowatzyk (1983). Although it is possible that Cultural Layer V dates to the Early Plains Archaic period, results from new radiocarbon determinations indicate a Middle Plains Archaic affiliation for Cultural Layers IV and III. If these new radiocarbon dates are reliable, then it would also imply a more recent antiquity for Cultural Layer II and for the lower component of Cultural Layer I.

Additionally, these new results suggest that the existing archaeological assemblage from the Cremer site does not constitute an "altithermal" occupation. The period of maximum Holocene warmth and aridity at the Cremer site appears to have occurred prior to ca. 6,000 yr B.P., and radiocarbon dated soil sequences from Trench 1 and the Northeast Streamface indicate a maximum age of ca. 6,000 yr B.P. for initial landform and site stability. This does not imply that earlier occupation sequences at the Cremer site do not exist. In fact, soil-stratigraphic evidence from the Trench 2 landform indicates stable geomorphic surfaces (i.e., buried soils) occurred at the site at both ca. 10,000 and 7,500 yr B.P. Although archaeological investigations of these earliest dated soils have yet to be systematically undertaken, the potential presence of cultural materials with Paleoindian and/or Early Plains Archaic period affiliations can not be ruled out. Future investigations at the Cremer site will be needed to resolve these issues.

Recommendations for Future Research

Scientists investigating the interactions between environmental and cultural changes must adopt an integrative research strategy which combines methodologies from a number of disciplines. This multidisciplinary approach will generally require collaboration among a number of research specialists. Collaboration among scientists with diverse backgrounds should be implemented early in research projects to assist in guiding research strategies and data interpretations. It is in this manner in which a more complete understanding of past environmental and cultural systems can best be evaluated.

Throughout North America, an increasing number of paleoclimatic and paleoenvironmental data are being incorporated into anthropologically oriented research projects. The northwestern Great Plains are no exception. However, there seems to be an unbalanced regional approach, with some areas having undergone extensive study while other areas have received relatively little attention. This may be in part due to a lack of suitable study sites in some areas; however, the potential for site preservation exists if we can develop better criteria for predicting their locations (i.e., where sites have not been eroded, they are often deeply buried). The need to find new research sites may require that trenching and/or coring become an integral part of archaeological and paleoenvironmental investigations. Additionally, as new field data become available, comparisons with paleoclimatic modeling techniques are essential to help refine the algorithms on which model outputs are based. With time, regional syntheses of both archaeological and paleoenvironmental evidence will provide a more complete understanding of the late-Quaternary evolutionary history of the North American landscape and the adaptive strategies of aboriginal populations.

Until then, however, we can take steps toward regional syntheses by abandoning outdated terminology such as the "altithermal," which holds little temporal meaning when applied across the entire American West. Post-glacial climate and environmental change throughout western North America has taken place at different times in different places, with varying degrees of severity. General notions of climatic and environmental change over broad geographic areas are of little use to field scientists working at the site-level. A more useful approach would be to develop a consistent temporal scale for smaller regions which have greater similarities in physiography and climatic conditions. Only through additional multidisciplinary research efforts can such an approach be accomplished.

And finally, a few comments on the Cremer site specifically. The soil-stratigraphic and paleoclimatic evidence from the Cremer site should be a welcome addition to this sparsely studied region. However, additional pedologic and palynological studies in the general area are needed to support the findings from this thesis research. Future investigations at the Cremer site have the potential to yield important new information on a number of yet unresolved issues.

The contradictory findings between radiocarbon results and typological interpretations of the soil-cultural sequences along the Trench 1/Northeast Streamface landform could benefit from both additional radiocarbon dates from this stratigraphic profile and better chronological controls for diagnostic artifacts on the northwestern Plains. Additionally, the Cremer site has the potential to provide invaluable new information regarding human adaptive strategies during the period of maximum early Holocene warming and aridity. In particular, the Trench 2 landform preserves evidence of geomorphic stability and soil formation (Stratigraphic Unit V) at a time when the Plains were thought to have been almost entirely abandoned. The potential presence of cultural material in this buried soil (radiocarbon dated to ca. 7,500 yr B.P.) could help resolve several longstanding issues concerning a cultural hiatus in northern Plains prehistory during the early-middle Holocene period. Furthermore, a potential Paleoindian occupation sequence(s) at the Cremer site can not be ruled out. If present, artifacts from this cultural period would likely be associated with the buried soil horizon (Trench 2: Stratigraphic Unit IX) dating to ca. 10,090 yr B.P.

The results from this thesis contribute to a better understanding of climatic and environmental patterns in northern Plains prehistory. However, future investigations can still yield invaluable new information on yet undiscovered parts of this record. By integrating anthropology and archaeology with the earth and atmospheric sciences, a more unified paradigm for understanding human prehistory can be achieved.

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Appendices

Appendix A. View of the Cremer Site Looking North.

Appendix B. View of the Cremer Site Looking South.

Appendix C. View of the Trench 1/Northeast Streamface Landform Looking Northeast.

Appendix D. View of the Trench 2 Landform Looking Southeast.