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Timing Of The Deposition Of Uppermost Cretaceous And Paleocene Coal-Bearing Deposits In The Greater Glendive Area, Montana And North Dakota

Topical Report
December 29, 1995

February 16, 1996

Work Performed Under Contract No.: DE-FC21-93MC30098

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
University of North Dakota
Energy & Environmental Research Center
Grand Forks, North Dakota

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Office of Fossil Energy
Morgantown Energy Technology Center
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By
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TIMING OF THE DEPOSITION OF UPPERMOST CRETACEOUS AND PALEOCENE COAL-BEARING DEPOSITS IN THE GREATER GLENDIVE AREA, MONTANA AND NORTH DAKOTA

ABSTRACT

With the aid of a grant from the National Geographic Society, a cooperative agreement with the State University of New York at Stony Brook, and contract with the U.S. Department of Energy, Late Cretaceous and Paleocene geologic and paleontologic field studies were undertaken in Makoshika State Park and vicinity, Dawson County, Montana. This region was chosen as a study area because of its potential for yielding new fossil localities and extensive exposures both above and below the K/T boundary, as suggested by previous research by David W. Krause and Joseph H. Hartman. Related field studies were also undertaken in areas adjacent to the Cedar Creek Anticline in North Dakota. This work was part of ongoing research to document change in the composition of mammalian and molluscan faunas during the Late Cretaceous and Paleocene and to relate observed patterns to floral and invertebrate changes in composition.

This study focuses on the record of mammals and mollusks in the Makoshika stratigraphic section and places old and new observations into a paleomagnetic and palynomorph framework. Of particular interest is the appearance and diversification of archaic ungulate mammals. Simultaneous dinosaur extinction with ungulate radiation has been invoked in gradual, as opposed to catastrophic, models of faunal change at the K/T boundary. However, supposed Cretaceous localities bearing archaic ungulates and other mammals of "Paleocene aspect" may be the product of faunal reworking. Elsewhere in the Williston Basin (e.g., Garfield and McCone Counties, Montana), the molluscan record of uppermost Cretaceous and Paleocene strata indicates the extinction of all of the highly sculptured unionid bivalves just prior to the onset of coal swamps and subsequent coal formation. This event does not appear to be exactly coincident with the K/T impact event and thus may be associated with a large-scale environmental change in some way related to events leading to coal-forming conditions.

The 1993 field season was concerned with the discovery of new mammalian and molluscan localities and the development of a stratigraphic framework for the study. Efforts in 1994 resulted in additional discoveries and large samples of mammalian fossils by concentrating collection activities on the most productive localities. Samples of fossil mammals now have been recovered from new localities of Late Cretaceous and Paleocene age. Of particular significance was the discovery of Hiatt South Locality, which represents a highly productive facies lateral to the previously known Hiatt Locality (early Paleocene). In addition to surface collection, approximately 2200 kg of matrix were processed for fossils.

The mammalian fauna recovered from horizons in the Upper Cretaceous Hell Creek Formation (Lancian) of Makoshika State Park and vicinity resembles faunas from elsewhere in Montana and Wyoming of Lancian age (Lance Creek and Flat Creek) in composition more than faunas in Alberta and Saskatchewan (Trochu and Gryde). At Makoshika, pediomyid marsupials are diverse, and the multituberculate *Meniscoessus* is abundant. No eutherians and only one peradectid marsupial, *Turgidodon rhaister*, have been recovered from these horizons. The mammalian fauna recovered from the lower part of the Paleocene Ludlow Formation resembles

other northern latitude Puercan faunas in composition. This fauna includes the multituberculates *Neoplagiaulax, Stygimys,* and *Ectypodus?*, the primitive taeniodont *Onychodectes*, and a diverse assemblage of archaic ungulates, including species of *Baioconodon, Eoconodon, Loxolophus, Tinuviel, and Oxyacodon*. From the upper part of the Ludlow Formation, the School Well local fauna (Torrejonian) is known as yet from fewer specimens than the other localities. It contains the plesiadapiform *Paromomys* sp., the multituberculate *Ptilodus montanus*, and the condylarths *Promioclaenus* sp. and *Litaletes* sp.

Strata yielding typical Late Cretaceous mammals are separated from those yielding early Paleocene mammals by about 20 m. The K/T boundary in this interval was recognized on the basis of palynomorphs through work conducted at the Energy & Environmental Research Center. Pollen studies also recorded the preliminary identification of the fern spike, noted elsewhere by others as a K/T boundary event. Lack of any type of Bug Creek vertebrate assemblage suggests that the controversial "Bugcreekian" biochron need not be extended into this area. This implies that the adaptive radiation of archaic ungulates may not have begun until after the dinosaur extinction.

Also in 1993 and 1994, sediment samples were taken for paleomagnetic analysis. Lithic samples for paleomagnetic analysis collected in 1993 (Section M6723) did not provide a clear or unambiguous signal of the sequence of paleomagnetic reversals. Sampling in 1994 (Section M7887b), however, permitted the identification of Chron 30n, Chron 29r, and Chron 29n. The results of the analyses of these samples confirm the palynomorph identification of the K/T boundary in Chron 29r. The study of the record of reversal stratigraphy also provides a concordant temporal framework to provide additional strength to interpretations regarding mammalian age determinations, placing the middle lower Paleocene mammalian faunas in Chron 29r.

The record of mollusks in Makoshika State Park is poor to virtually nonexistent. A few specimens of little value were collected from the Cretaceous-age Muddy Tork and Q.V. Localities and Locality L6467, the lowermost Paleocene-age Locality L6260 (just above the Contact lignite), and from the lower Paleocene Hiatt South and Deer Crash Localities and Locality L6425, both of which are at the same level. Most of the specimens are steinkerns of small specimens of mesogastropods of the families Pleuroceridae and Viviparidae. Specimens questionably identified as New Genus A *limneaformis* (family *incertae sedis*) were found both below and above the K/T boundary. Freshwater bivalves are represented by only a few specimens. One pisidiid is known from the Hell Creek Formation, and unionid impressions occur just above the Contact lignite. Although of limited systematic or biostratigraphic value, this depauperate fauna is representative of the limited species diversity found at many localities in the lowermost Paleocene in North America.

ABBREVIATIONS AND NOTES

The following institutional abbreviations are used in this report: DOE (U.S. Department of Energy), NGS (National Geographic Society), (EERC) Energy & Environmental Research Center, UND (University of North Dakota, Department of Geology and Geological Engineering), SUNY-SB (State University of New York at Stony Brook), and USGS (U.S. Geological Survey). Miscellaneous abbreviations include the following: PI (principal investigator), co-PI (coprincipal investigator), and K/T (Cretaceous–Tertiary).

All observations were plotted on U.S. Geological Survey 7.5-minute series topographic quadrangles. Geologists of the Montana Bureau of Mines and Geology are in the process of producing a new 1:500,000-scale state geologic map. Earlier preprint versions of maps at various scales were graciously provided by Susan Vuke (also cited as S.M. Vuke-Foster and S.M. Foster). The placement of some lithostratigraphic contacts and member nomenclature were revised subsequent to field work undertaken for this project. These changes have been incorporated in this report for the greater Glendive area, but direct correlation between North Dakota and Montana sections other than the K/T boundary interval must await further study.

Fossil locality and geologic observation numbering systems are employed throughout this report. Mammalian localities, as is generally the case, are given names (e.g., Hiatt Locality) for ease of reference. Although they are referred to by name throughout this report, all localities have an L-number for the purposes of computer-based data management (see Appendix I). Except for the co-occurrence of mollusks with mammals, all molluscan localities are simply referred to by an L-number (e.g., L6260). The location and geologic unit data for measured sections are referred to by an M-number (e.g., Section M4763) (see Appendix III). All locality and geologic observation data are maintained in databases designed in Version 4 of Q&A® by Symantec Corporation.

OVERVIEW OF COLLABORATION AND SUPPORT

This project was undertaken with the support of the DOE and the NGS. The latter grant was facilitated by The Research Foundation of the State University of New York at Stony Brook. The primary investigators were Joseph H. Hartman (PI on the DOE contract to the EERC, co-PI on NGS grant) and David W. Krause (PI on the NGS grant to SUNY-SB). Besides the principal investigators, the following individuals contributed their knowledge, resources, and/or facilities to aid in this research project: John P. Hunter (SUNY-SB), Timothy J. Kroeger (Bemidji State University), Steven P. Lund (University of Southern California), and Allen J. Kihm (Minot State University). The project also included the valuable field and/or laboratory assistance of the following students employed by J.H. Hartman at the EERC: T.J. Kroeger (graduated), Wesley D. Peck (graduated; now EERC staff), Michelle R. Rolland, and Daryl E. Heinen. Those who provided field support by the NGS grant and other support include Tony and Susan Falsetti, Ann Gilmartin, J.P. Hunter, Elizabeth M. McGee, R. Lee Cothran, Karen Samonds, Rob Asher, Suzanne G. Strait, and Roshna Wunderlich.

Geologic interpretations were aided through discussions and correspondence with recent or ongoing studies by Susan Vuke (Montana Bureau of Mines and Geology), Raymond Butler (High Plains Consortium, Inc., late of the EERC), David Fastovsky (University of Rhode Island),

Cathryn Newton (Syracuse University), Peter Sheehan (Milwaukee Public Museum), and Rob Kukowski (late of Makoshika State Park).

Important services and other forms of cooperation were also provided by Sam Undem, Chris Undem, and Joseph Blankenship of Glendive, Montana, and other ranchers who permitted access to their property for these studies. Other forms of assistance were rendered by Robert Hiatt of Glendive and Makoshika State Park rangers Mike Sullivan and Rob Kukowski. Wilbur Wallace (City of Glendive), Gary Kirkpatrick (US West), and Lois Ferguson (private land owner) kindly provided access to the top of Hungry Joe plateau. Access to study and collect fossils and sediment samples in Makoshika State Park was provided by the Montana Department of Fish, Wildlife & Parks. Appreciation is also expressed to Lance Phinney, who allowed use of the facilities at the Lions Camp in Makoshika State Park.

TIMING OF THE DEPOSITION OF UPPERMOST CRETACEOUS AND PALEOCENE COAL-BEARING DEPOSITS IN THE GREATER GLENDIVE AREA, MONTANA AND NORTH DAKOTA

PROJECT OBJECTIVE

This research concerns determination of the timing of coal deposition in the Fort Union Coal Region, as developed in the Glendive and adjacent areas in Montana and North Dakota (Figure 1). The project objective is to develop a time framework that allows for the temporal comparison of coal deposits and thus coal-forming conditions through the transition from non-coal-bearing to coal-bearing deposits in the Fort Union Coal Region. Such a regional coal chronostratigraphic (time–rock) framework permits local and regional interpretations of environments of coal deposition controlling coal quality and thickness, thus contributing significantly to effective resource evaluation and utilization.

APPLICABILITY TO FOSSIL ENERGY OBJECTIVES

This research is part of a larger program designed to provide information on the timing of deposition of coal beds in the Fort Union Coal Region. Such temporal data provide both a means and a framework to reconstruct the depositional history of coal. The derived chronostratigraphic foundation represents an earth-based, or natural, organizational system in which to place associated coal composition and quality data that are especially important in making soundly based decisions regarding coal extraction and utilization. Temporal characterization of coal-bearing strata is especially critical in considerations specific to nonstrippable coal, which represents the bulk (about 95 percent; see data in Averitt, 1975) of North Dakota coal resources and in which interest will increase as more accessible resources are depleted. Thus this study provides information of value to secure future energy supplies by expanding the recoverable coal resource through an understanding of when and how the peat that formed the coal deposit accumulated.

SUMMARY OF THE PROBLEM

Effective and efficient utilization of coal resources depends on appropriate characterization. To date, coal analysis and coal resource assessment have almost exclusively been conducted without regard for an understanding of the regional geologic setting and specific paleoenvironmental context. Varying coal composition and quality are documented largely as analytical results without reference to their environmental meaning or representation as environment trends. Coal sample characterization without temporal and geologic context represents isolated observations that are generally incapable of providing information that would lead to a determination of regional trends in coal distribution, geochemistry, preservation, and thickness. Expensive drilling programs provide valuable coal correlation data, but without an understanding of the timing of coal deposition, the reconstruction of paleoenvironments may easily compare coals of different times, thus leading to incorrect relationships and inaccurately interpreted environmental conditions. Changes in climates, vegetation and vegetational patterns, and past land and water configurations produce different depositional histories. Presently, an understanding of

trends in coal quality is made almost impossible by the absence of context for many, if not most, coal sample observations in the Fort Union Coal Region (Hartman, 1992b).

INTRODUCTION

The jointly sponsored research supports a number of activities that directly bear on providing a more thorough understanding of the transition between the Cretaceous and Tertiary periods of geologic time. This time boundary is well known to both the scientific community and the general public because of its association with the extinction of the dinosaurs (and many other plant and animal groups) and a bolide (large meteor) impact(s). In terms of mammalian evolution, the beginning of the Tertiary represents a time of diversification. At the beginning of the existence of coal-forming environments in the Tertiary, there were only four major groups of mammals, but by the end of 10 million years of Paleocene peat accumulation in the northern Great Plains, the mammalian fauna included 20 major groups, representing most of the mammalian orders seen today.

Across the K/T boundary in the northern Great Plains, a major change is also recorded in the deposition of sediments. This change, simply put, is from non-coal-forming environments to conditions under which peat accumulation was commonplace. The few coal beds that occur in the Upper Cretaceous are thin and insignificant. The coal beds of the northern Great Plains, representing the ancient drainage systems of what are now northeastern Wyoming, eastern Montana, southern Saskatchewan, and western North Dakota, are part of the basal epoch (or series) of the Tertiary known as the Paleocene. The Fort Union Coal Region takes its name from the Fort Union Formation (or Group as used in North Dakota) that includes most of the coal-bearing strata of the Paleocene (about 65 to 55 million years before present). As originally introduced by Meek and Hayden in 1862, the Fort Union Group was synonymous with the Great Lignite Basin (= Williston Basin). The Fort Union Group formations of specific interest to this study include the uppermost Cretaceous (= Lancian age) Hell Creek Formation and the overlying lower Paleocene (= Puercan age) Ludlow Formation (equivalent elsewhere to the Tullock).

This project is part of an EERC research program designed to document the timing of the deposition of peat in the Fort Union Coal Region. Temporal, or time-rock, data provide a means to relate the history of coal-bearing deposition across an entire region or between regions. Temporal data are primarily derived from the sequence of fossil occurrences and from paleomagnetic reversal anomalies recorded by magnetic minerals in geologic sections. These sequence-ordered observations can be significantly supplemented by geochemical data (such as impact fallout) that are usually derived from thin rock layers representing an instant in geologic time. A temporally controlled stratigraphic framework (= chronostratigraphy) in the context of this study is an organizational system that represents the accumulation of peat and associated fluvial and lacustrine deposits during a specified time interval. Without a temporally based framework, there is little hope of producing accurate models of the formation of coal-bearing strata throughout a coal region. Such models or reconstructions of ancient environments are important in understanding the reasons for and thus in being able to evaluate and predict the quality, thickness, and distribution of coal deposits. This becomes particularly important for the consideration of coal at depth, which cannot be observed directly.

PROJECT SCOPE

Ongoing research (Hartman, 1991a, b; Hartman and Kihm, 1991; Kihm and Hartman, 1991; Hartman and Kihm, 1992, 1995) is providing chronostratigraphic control for various portions of the Fort Union Group in the Fort Union Coal Region. To date, most of this research has focused on coal-bearing deposits of the middle and upper Paleocene. The research undertaken as part of the Makoshika study is focused on the transition from environments essentially devoid of peat accumulations to those in which peat is an important component of the paleoenvironment. Very frequently, this transition is lithostratigraphically marked by a laterally extensive lignite bed, such as the Z coal (or coal bed complex) in the western portion of the Fort Union Coal Region. This bed and its stratigraphic equivalents appear to represent a very nearly isochronous horizon, as indicated by paleontological and geochemical data. In the area of Glendive, the coal near the K/T boundary is referred to as the Contact lignite, in reference to its placement at the contact between the Hell Creek and Fort Union Formations (Figure 2). The K/T transition is, however, quite controversial and far from being understood precisely because of problems interpreting its stratigraphic setting.

The geologic section of the Makoshika State Park was chosen, in part, because the stratigraphy representing the K/T transition is sufficiently complete in a number of sections to avoid the controversies often associated with the proper sequencing of fossil occurrences and paleomagnetic samples in less complete sequences. However, even the evidence for the completeness of the Makoshika section has been argued by some (Peter Sheehan, written communication, 1993).

The project determined the timing of the transition from non-coal-forming to coal-forming environments to produce a reference standard that incorporates palynomorph, vertebrate, invertebrate, and paleomagnetic temporal control. This multidisciplinary determination was undertaken primarily in Dawson County, Montana, in the greater area of Makoshika State Park near Glendive. The main study area includes the Hell Creek Formation and the Ludlow Member of the Fort Union Formation in T. 15 N., R. 55-56 E., as shown on the Glendive Quadrangle (1967; see Figures 3 and 4). All available published and unpublished information on the stratigraphy was critiqued for the purposes of this project (e.g., Butler, 1980; Hance, 1912; Sholes and others, 1989; Vuke-Foster and Colton, 1989; Daly, 1991). In addition, Susan Vukes of the Montana Bureau of Mines and Geology has provided J. Hartman with detailed geologic maps documenting numerous unpublished field observations, as well as prepublication copies of maps concerning the Glendive area. Original maps and field data of the Glendive area were provided by Raymond D. Butler for use in this project. Other researchers familiar with the study area have also had input into the project. These individuals include Peter M. Sheehan of the Milwaukee Public Museum, David E. Fastovsky of the University of Rhode Island, and Katherine Newton of Syracuse University. All available paleontological data bearing on the project was incorporated into the research plan. This includes localities known to the investigators through previous preliminary research. Local individuals, specifically Robert Hiatt, an optometrist in Glendive, and Mrs. Bernice Vashus of Glendive, provided fossils and general site locations for investigation. Other areas along the Cedar Creek Anticline (which also bears the exposures of Makoshika State Park) were examined in Montana and North Dakota to provide both local and regional context for the Makoshika observations. Unpublished fossils and stratigraphic data from the studies of Dean

Pearson, of the Pioneer Trails Regional Museum, Bowman, North Dakota, were also incorporated into the project.

SPECIFIC OBJECTIVES

As mentioned above, the overall objective of the project is to better document the faunal transition from near the end the Cretaceous into the Paleocene. This task includes constructing a lithostratigraphic framework for all other observations, including geologic sections, to document the following:

- Stratigraphic placement of discovered fossil localities
- Lithic sampling for palynomorph studies
- Lithic sampling for paleomagnetic studies
- Stratigraphic correlation of all temporal data

All of these objectives were met and are discussed below.

A goal of this project was to document mammalian faunal turnover at the K/T boundary in a new field area near Glendive, Montana (Figure 1), and to relate observed patterns to other biotic and abiotic changes across the boundary. In so doing, we hoped to investigate patterns of terrestrial vertebrate extinction, mammalian biochronology near the K/T boundary, and the time of diversification of various eutherian groups, in particular the archaic ungulates of the Order Condylarthra. During field seasons in 1993 and 1994, activities were focused on accomplishing two major objectives:

- To find new localities in both the Hell Creek and Fort Union Formations and to screen wash matrix from these localities (Figure 2).
- To conduct detailed stratigraphic investigations in order to provide appropriate geologic context for paleontologic discoveries.

As a result of these efforts, four new fossil mammal localities were discovered, most notably the productive early Paleocene Hiatt South Locality from which at least 14 mammalian taxa have been recovered so far.

Another specific goal of this project was to document the occurrence of nonmarine mollusk species across the K/T boundary. The record of nonmarine mollusks adjacent to the boundary is very meager. Although emphasis was given to the discovery of mollusks, only a few localities of significance were found, and these are from slightly younger Paleocene rocks from both north and south of the park.

METHODOLOGY

Geology

Geologic studies in the Glendive area were conducted to provide a lithostratigraphic framework for all paleontologic and paleomagnetic observations (Figure 2). Thus geologic sections were made through strata in areas bearing mammalian and molluscan fossils and through intervals for which lithic samples were taken for palynologic and magnetic reversal studies. Geologic studies also included the geographic location of new and previously reported fossil localities (Figures 3 and 4). All fossil localities were cataloged as an L-number and maintained in a database. All observations were plotted on USGS 7.5-minute series topographic quadrangles. Some locations were determined using a global positioning system satellite receiver. Locality horizon elevation values were coordinated with section data to provide best-fit determinations. Geologic sections were measured by Timothy Kroeger (Bemidji State University and late of the Energy & Environmental Research Center), Wesley Peck (Energy & Environmental Research Center), and Joseph Hartman. Measured sections by Butler (1980 and unpublished data), Tschudy (1970 and unpublished data), K.R. Johnson (written communication, 1994), and Frye (1967) were updated and integrated into the current study (Figures 4 and 5). Sections were measured using a Jacob's staff, and lithic samples were described using a modified Munsell color chart (GSA, 1991). Stratigraphic location and section data were maintained in databases designed in Q&A®, with sections referred to by M-numbers. Stratigraphic sections were produced using a modified version of the program STRATCOL described elsewhere (Hartman, 1992a). Figure 5 illustrates STRATCOL-derived sections generated from prescribed data formats specified in reports from a Q&A® database. The lithic symbols used in the displayed sections are given in Figure 6. The location of many of the stratigraphic sections measured for this study are illustrated by figures presented in this report. For example, Section M4769a, which includes the Muddy Tork Locality, is shown in Figures 7 and 8. These sections are related to the Witches Hat sections (M4769b and M7887a) in Figure 9, which in turn can be related to the paleomagnetic (M7887b) and pollen sections (M4770) southeast of Witches Hat (Figure 10). These sections include the K/T fern spike locality, which is specifically shown in Figure 11.

Lithic samples for palynomorph studies were taken in detailed stratigraphic sections across the interval suspected to contain the K/T boundary at sites in Makoshika State Park (e.g., Figure 12). These samples were processed and examined by Timothy Kroeger. Thus the local K/T boundary was delimited on the basis of palynomorphs. Palynology studies also resulted in the identification of a fern spike in Section M4770 (Kroeger and others, 1993) (Figure 13a, b). This boundary interval is known to be effectively coincident, through the stratigraphic correlation of lignites, to an iridium anomaly observed near the Sand Creek Overlook, Makoshika State Park (Figure 14; D.E. Fastovsky, personal communication, 1995). Lithic samples for paleomagnetic study were taken by Steven Lund and Wesley Peck (Figure 15) and were analyzed by Steven Lund (Figure 16).

Paleontology

Fossil vertebrate localities were located by prospecting on foot and visually scanning the surface for fossils. All identifiable material from the surface was collected. The stratigraphic position of each locality bearing fossil mammal remains was determined relative to the K/T

boundary (Figure 2). Large amounts of sediment were processed from the most productive of the newly discovered localities, Hiatt South Locality (early Paleocene), in order to recover the mammalian fossils. This technique involved the underwater screening of sediment to remove the fine-grained mud matrix and examining the residual coarse-grained concentrate under microscopes to recover the fossils. Screen washing is an efficient means of obtaining large samples of fossils from poorly consolidated sediments, which disagregate during screening.

Transport of an adequate amount of sediment, typically measured in tons, to a source of moving water for screening can be difficult. Such was the case with the Hiatt and Hiatt South Localities since we could not access the locality by vehicle because of rugged topography within the park and placement of the locality several hundred feet above the nearest road (see Figures 17 and 18). At the Hiatt South Locality, therefore, we moved approximately 2200 kg of sediment using packhorses, with the aid of two local ranch hands, about one-half mile to where we could park the vehicles. From there we transported the sediment to the Yellowstone River for screening (Figure 19). At the Hiatt Locality, a tripod-pulley system (similar to that shown in Figure 8) was configured to pass 40-kg bags of matrix from an upland surface down bluffs to creek level, some 60 m down and 200 m away.

No fossil mollusk specimens were discovered in Makoshika State Park through surface prospecting. Mollusks were discovered at mammalian sites through extensive surface picking, dry- and wet-screen washing, and picking from bulk concentrate in the laboratory. This process, for example, produced three steinkerns at the Muddy Tork Locality and 28 steinkerns at the Hiatt South Locality. A few additional localities were discovered outside of the park through surface prospecting. All of these are of lower or middle Paleocene age.

EXPLANATION AND SUMMARY OF FINDINGS

Geology Studies

The geologic observations derived through the course of this study provided the basis for accurate placement of fossil localities relative to the K/T boundary. All of the mammalian localities (except Vashus Locality) that occur in the area of the Glendive Quadrangle can be shown to be within 15 m of the boundary. The precise placement of the K/T boundary was accomplished on the basis of palynomorphs at two locations, one in the area of the Hiatt and Hiatt South Localities (M4771) (Figure 17) and the other in the area southeast of Muddy Tork (M4770) (Figure 11). In addition, a fern spike was identified in the M4770 section corresponding to the 5-cm interval recognized as the boundary horizon (Kroeger and others, 1993) (Figure 13a, b). The K/T boundary is in close subjacent position to a lignite, which has been referred to as the "Contact Coal" by Sholes and others (1989). This lignite is named in reference to its position as the horizon approximating the Hell Creek–Fort Union formational contact in this area. The Contact lignite can be traced throughout Makoshika State Park. At the southern end of the park, just below the Sand Creek Overlook (near the center of the south edge of sec. 28, T. 15 N., R. 56 E.) C.J. Orth recognized a dispersed iridium anomaly in association with the same lignite (D.E. Fastovsky, personal communication, 1995) (Figure 14). The extinction of diagnostic uppermost Cretaceous palynomorphs just below the fern spike and its association with an iridium event horizon provide confirmation of our placement of the K/T boundary.

The Uppermost Cretaceous Muddy Tork Locality (Figures 4 and 8) occurs in the uppermost part of the Hell Creek Formation near the base of a major channel sandstone system found near the park entrance on the south side of the road (see Figure 7 and Appendix I). This sandstone comprises a pyramid-shaped butte on top of this ridge and forms a landmark referred to locally as the Witches Hat (Figure 9). Thus the sandstone has been referred to in this report as the Witches Hat sandstone. To the east, the Q.V. Locality occurs at a nearly identical horizon near the base of a similar channel sandstone. The lower Paleocene Hiatt, Hiatt South, and Deer Crash mammalian localities occur essentially at the same stratigraphic level above the base of the Ludlow Member of the Fort Union Formation (see Appendix I). Each of these localities occurs at or very near the base of a thick sequence of channel sandstones (e.g., Figure 18).

The middle Paleocene School Well Locality (Figure 3), located north of Glendive, south of Lower Sevenmile Creek, is known from the middle of the Ludlow Member at the base of stacked sandstone channels. The locality can be placed precisely relative to the Poverty Flats lignite bed, which has been identified in a minor outcrop just east of the locality. The exact local placement of the School Well Locality relative to the Contact lignite is somewhat less certain, but is estimated to be about 60 m. Uncertainty regarding this value exists as a result of assumptions about the dip of strata along this portion of the Cedar Creek Anticline and the inability to unequivocally identify the Contact lignite in its closest exposures to the east in the SW¼ NW¼ sec. 23, T. 17 N., R. 55 E., Stipek Quadrangle. Palynomorphs recovered from below the "Contact Coal" of Sholes and others (1989) have been identified by T.J. Kroeger as Paleocene in age, and not Cretaceous as might be expected (Hartman, unpublished data).

With the recognition of the K/T boundary on the basis of palynomorphs, the polarity patterns of magnetic minerals through the Makoshika section were identified. Figures 15 and 16 illustrate the interpretation of the reversal stratigraphy. The black dots next to the polarity column illustrate the sampling control. As recognized globally (Berggren and others, in press), the K/T boundary falls within reversed-polarity Chron 29r. The Makoshika data clearly indicate a reversed record for this interval. Thus the mammalian and molluscan localities in the lower part of the Ludlow Member of the Fort Union Formation lived near the end of the time represented by Chron 29r. The paleontologic age of the sediments bearing the mammalian fossils in the Ludlow have been interpreted to be Puercan, probably middle Puercan (Pu2?) in age. If this conclusion is correct, paleomagnetic data support a lower middle or upper lower Puercan age for the enclosing strata (see Prothero, in press). The Hell Creek Formation Lancian-age mammalian and molluscan fossils occur in Chron 30n. Thus, on the basis of the paleomagnetic section (Figure 15), these occurrences (e.g., Muddy Tork Locality), although within 10 to 15 m of the K/T boundary, do not represent uppermost Cretaceous strata (Cretaceous strata within Chron 29r).

Mammalian Studies

Mammalian fossil localities are listed in Appendix I, and lists of taxa for each fauna are compiled in Appendix II. We have recovered fossil mammals from three horizons representing three different evolutionary faunas. In this study area, mammals of undoubted Paleocene age were found superposed over mammals of undoubted Late Cretaceous age, with no transitional assemblages of mixed type interposed (such assemblages are called "Bug Creek"-type assemblages after the famous Bug Creek Anthills locality; Sloan and Van Valen, 1965). We interpret this to

mean that the transition between Cretaceous-type and Paleocene-type mammalian communities was geologically rapid.

Fossil mammals from the Upper Cretaceous Hell Creek Formation (Muddy Tork Fauna) are indicative of the Lancian Land Mammal Age (Lillegraven and McKenna, 1986). Lancian faunas are recognized by their similarity to fauna from the type Lance Formation, Wyoming (Clemens 1964, 1966, and 1973; Fox, 1974; Krause, 1992), and are known from discoveries in Colorado (Carpenter, 1979), Alberta (Lillegraven, 1969), elsewhere in Montana (Sloan and Van Valen, 1965; Archibald, 1982), New Mexico (Flynn, 1986), and Saskatchewan (Fox, 1989; Storer, 1991). The fauna present in the Muddy Tork Fauna includes stagodontid and pediomyid marsupial taxa that make unique appearances in Lancian time (Lillegraven and McKenna, 1986). The multituberculate *Meniscoessus robustus* and the peradectid marsupial *Turgidodon rhaister*—both present at Muddy Tork—last appear in Lancian time (Lillegraven and McKenna, 1986), precluding a younger age. No "Paleocene aspect" taxa are known from the Muddy Tork Fauna, making this fauna of undoubted Late Cretaceous age.

It has been suggested that latitudinal differences in faunal composition among Lancian sites—with greater abundance and diversity of eutherian mammals at northern latitudes—may reflect an initial migration from Asia and adaptive radiation of eutherian taxa (Lillegraven, 1969; Archibald, 1982; Fox, 1989). While this suggestion is controversial, the observation remains valid that eutherians seem to have been more diverse at higher latitudes during the Lancian. Lack of eutherian mammals in the Muddy Tork Fauna may be a sampling artifact, but tentatively supports placement of this fauna in a more southerly biogeographic realm with other localities from Montana to New Mexico. The multituberculate *Meniscoessus robustus* is common at Muddy Tork, while the abundance of this taxon declines further north (Lillegraven, 1969; Fox, 1989; Storer, 1991).

The Hiatt Locality Fauna (including material from the Hiatt Locality, Hiatt South Locality, and the Deer Crash Locality all from the lower part of the Ludlow Member of the Fort Union Formation) is the most intriguing of these three faunas because of the rarity of early Paleocene mammals, because of the many problems associated with the biochronology of the early Paleocene, and because of the importance of the early Paleocene in mammalian history. The fauna is similar to that recovered from other northern latitude, early Paleocene sites of the Puercan Land Mammal Age, notably Rav W-1 and Purgatory Hill. Rav W-1 may be early Puercan (Johnston and Fox, 1984) or middle Puercan (Archibald and others, 1987) in age, whereas Purgatory Hill probably represents the late Puercan (Van Valen and Sloan, 1965; Van Valen, 1978; Archibald and others, 1987). Numerous workers, however, have argued that middle and late Puercan cannot be distinguished outside of their type area in the San Juan Basin (e.g., Archibald and others, 1987). The Hiatt Locality Fauna and Rav W-1 share a number of taxa, including the multituberculate *Neoplagiaulax kremnus* (or a closely related species), as well as taxa of arctocyonid condylarths (*Baioconodon*, *Loxolophus schizophrenus*, *Oxyclaenus*?, and *Carcinodon*?). The Hiatt Locality Fauna also includes some very primitive taxa, such as a species of *Loxolophus*, which may indicate that this genus originated at the base of condylarth phylogeny. The species of *Eoconodon* present—a condylarth believed to be at the base of the whale lineage—may be conspecific with a form from Purgatory Hill, and one periptychid condylarth present, *Tinuviel eurydice*, is known elsewhere only from Purgatory Hill (Van Valen, 1978). Finally, the primitive taeniodont *Onychodectes* has been previously reported only from New Mexico and Utah (Schoch, 1986),

making our find of *Onychodectes* a significant geographic range extension for the genus. Given the diverse assemblage of condylarths and some negative evidence—the absence of the multituberculate *Taeniolabis taoensis*, the appearance of which marks the base of the late Puercan—we provisionally assign the Hiatt Locality Fauna to the middle Puercan (?Pu2; Archibald and others, 1987).

Present evidence suggests a Torrejonian age for the School Well Locality. The plesiadapiform (?primate) *Paromomys* makes its first appearance in the Torrejonian (Archibald and others, 1987). The mioclaenid condylarth *Litaletes* may occur as early as the Puercan (Johnston and Fox, 1984), but the species present is close to and perhaps conspecific with the Torrejonian *Litaletes mantiensis* (Gazin, 1939, 1941; Rigby, 1980). More complete material is needed to tell whether the large periptychid condylarth present is referable to the Torrejonian *Periptychus carinidens*, the Puercan *Periptychus* (*Carsioptychus*) *coarctatus*, or to a new species. The multituberculate *Ptilodus montanus* is also known from late Torrejonian localities in the Crazy Mountain Basin (Krause, 1982). Although this species is not known from the early Torrejonian, this may be an artifact of sampling. More material is needed before it will be possible to determine more precisely the age of the School Well Locality.

Molluscan Studies

The nonmarine molluscan fauna known from in and adjacent to Makoshika State Park is presently incapable of refining the molluscan interpretation of the K/T boundary signature. As noted, all specimens are preserved as steinkerns, which severely limits one's ability to identify species and determine species ranges. Maybe as few as four gastropod taxa are represented in the fauna, including species of *Viviparus, Campeloma, Lioplacodes*, the taxon New Genus A *limneaformis* (see Hartman, 1984), and three bivalve taxa, including a large unsculptured unionid; a few relatively small, elongate unionid steinkerns; and one steinkern of a pisidiid. The species of snail present in the lower part of the Ludlow in Makoshika State Park are sufficiently distinctive to indicate that they are presently unknown from the Cretaceous and thus potentially good indicators of Paleocene strata. New Genus A *limneaformis* is known to range across the K/T boundary and thus is of little value in these discussions. Although of limited systematic or biostratigraphic value, this depauperate fauna represents the limited species diversity typically found at many localities in the lowermost Paleocene in North America.

Williston Basin Correlations

The occurrence of numerous lignite beds in the Fort Union Formation (or Group) in the Williston Basin is well known. Many beds have been mapped in Montana and North Dakota in the lower part of the formation (Sholes and others, 1989; Hares, 1928). The age relations of the strata bearing lignites, however, have been considered only in general terms prior to recent research. This project has facilitated a reevaluation of the chronostratigraphy of coal-bearing strata in North Dakota. Figure 20 illustrates a summary determination of the age relations of lithostratigraphic units in the North Dakota portion of the Williston Basin. This figure presents for the first time a reversal stratigraphic framework for these units. A paleomagnetic framework, added to a radiometric time scale and relative mammalian biochrons, provides numerous opportunities to refine the history of coal formation in the Fort Union Coal Region.

In North Dakota, the K/T boundary is relatively well known by the lowest persistent lignite or carbonaceous bed above the highest dinosaur fossils. Exceptions occur where nonlignite environments persist through this section (see for examples Murphy and others, 1995). In southeastern North Dakota, in exposures along tributaries of the Missouri River; in southwestern North Dakota, in exposures along tributaries of the Little Missouri River; and in the Glendive area in easternmost Montana, the K/T boundary has been recognized on the basis of palynomorphs. Recognition of the formational contact between the Hell Creek and Fort Union Formations, however, has varied in interpretation (see for example, Lerbekmo and Coulter, 1984). However, the relative placement of the K/T boundary within Chron 29r varies only a few meters in sections as distantly separated as Huff (south of Bismarck), North Dakota, and Glendive, Montana. Lignites occurring in the underlying Hell Creek Formation are few, thin, and of limited value economically or for stratigraphic correlation studies. The quantity and quality of lignites vary in the overlying Fort Union Formation. Paleoenvironmental settings through the lower and middle Paleocene were undoubtedly influenced by the movements of the Cannonball Sea. Possible age relations of the tongues of the Cannonball Formation are presented in Figure 20. Numerous and relatively thick lignites do not appear to form until the middle Paleocene, at least in the drainages of the Little Missouri River, where these strata are well exposed. This section may temporally correlate to the strata about and above the Poverty Flats lignite (Figure 2), on the basis of the occurrence of Torrejonian-age mammals north of Glendive at the School Well Locality.

STATEMENT OF RESULTS

Fossil evidence tied to radiometric and paleomagnetic chronologies provides the basis for methodologies to refine the precise chronostratigraphic correlation of lignite beds. This ability permits a better interpretation of coal-forming environments over a broad region, such as the northern Great Plains. More realistic temporally controlled models for paleoenvironmental conditions will provide the potential for improved coal quality assessment in regional appraisals of available coal resources.

This project determined the timing of the transition from non-coal-forming to coal-forming environments to produce a reference standard that incorporates palynomorph, vertebrate, invertebrate, and paleomagnetic temporal control. This multidisciplinary determination was undertaken primarily in Dawson County, Montana, in the greater area of Makoshika State Park near Glendive. With the recognition of the K/T boundary on the basis of palynomorphs, the stratigraphy of polarity signals through the Makoshika section could be determined. The K/T boundary in the Makoshika section falls within reversed-polarity Chron 29r. The Makoshika data clearly indicate a reversed record for this interval. Thus the mammalian and molluscan localities in the lower part of the Ludlow Member of the Fort Union Formation lived near the end of the time represented by Chron 29r. The paleontologic age of the sediments bearing the mammalian fossils in the Ludlow have been interpreted to be Puercan, probably middle Puercan (Pu2?) in age. If this conclusion is correct, paleomagnetic data support a lower middle or upper lower Puercan age for the enclosing strata. The Hell Creek Formation Lancian-age mammalian and molluscan fossils occur in Chron 30n. On the basis of the paleomagnetic section, these occurrences (e.g., Muddy Tork Locality), although within 10 to 15 m of the K/T boundary, do not represent faunas at the very end of the Cretaceous (i.e., Cretaceous strata within Chron 29r).

The succession of fossil mammals in Makoshika State Park and surrounding areas spans the Late Cretaceous and early and middle Paleocene. The Muddy Tork Fauna (Late Cretaceous) is typical Lancian and includes no Paleocene-aspect taxa. The Hiatt Locality Fauna (early Paleocene) can be placed into the Puercan (probably the Pu2 interval zone) on the basis of its diverse condylarth fauna. The School Well Fauna (middle Paleocene) places the top of the Ludlow member of the Fort Union Formation into the Torrejonian Land Mammal Age. In the study area, localities of Late Cretaceous age are separated from those of early Paleocene age by about 20 m of intervening sediment containing no unconformity.

Despite intensive search, no Bug Creek-type assemblages, i.e., of mixed Cretaceous and Paleocene aspect, have been found in Makoshika State Park. Paleocene channels appear not to have eroded into Cretaceous sediment at our study locations, perhaps accounting for the lack of Bugcreekian sites. Thus our work provides no support for recognition of a Bugcreekian time interval. The presence of a diverse assemblage of condylarths just 11 m above the K/T boundary at the horizon of the Hiatt Locality suggests that the adaptive radiation of this group was extremely rapid, as it probably occurred only after the dinosaur extinction.

BIBLIOGRAPHY

Archibald, J. D., 1982, A study of Mammalia and geology across the Cretaceous–Tertiary boundary in Garfield County, Montana: University of California Publications in Geological Sciences 122, p. 1–286.

Archibald, J. D., Gingerich, P. D., Lindsay, E. H., Clemens, W. A., Krause, D. W., and Rose, K. D., 1987, First North American Land Mammal Ages of the Cenozoic Era, *in* Cenozoic Mammals of North America, ed. Woodbourne, M. O., p. 24–76: Berkeley, University of California Press, 336 p.

Averitt, P., 1975, Coal resources of the United States, January 1, 1974: U.S. Geological Survey, Bulletin 1412, 131 p.

Beggren, W.A., Kent, D.V., Swisher, C.C., III, Aubry, M.-P., in press, A revised Cenozoic geochronology and chronostratigraphy, *in* Berggren, W.A., Kent, D.V., and Hardenbol, J., eds., Geochronology, time scales and global stratigraphic correlations: A unified temporal framework for an historical geology: Society of Economic Paleontologists and Mineralogists Special Publication 54.

Butler, R.D., 1980, Stratigraphy, sedimentology, and depositional environments of the Hell Creek Formation (Late Cretaceous) and adjacent strata, Glendive area, Montana [Ph.D. thesis]: Grand Forks, University of North Dakota, 398 p.

Carpenter, K., 1979, Vertebrate fauna of the Laramie Formation (Maestrichtian), Weld County, Colorado: Contributions to Geology, University of Wyoming, v. 17, p. 37–49.

Clayton, L., 1980, Geologic map of North Dakota, 1:500,000: North Dakota Geological Survey, 1 sheet.

Clemens, W. A., 1964, Fossil mammals of the type Lance Formation, Wyoming. part I. introduction and Multituberculata: University of California Publications in Geological Sciences 48, p. 1-105.

Clemens, W. A., 1966, Fossil mammals of the type Lance Formation, Wyoming. part II. Marsupialia: University of California Publications in Geological Sciences 62, p. 1-122.

Clemens, W. A., 1973, Fossil mammals of the type Lance Formation, Wyoming. part III. Eutheria and summary: University of California Publications in Geological Sciences 94, p. 1-102.

Clyde, W.C., Stamatakos, J., and Gingerich, P.D., 1994, Chronology of the Wasatchian Land-Mammal Age (Early Eocene): Magnetostratigraphic results from the McCullough Peaks Section, northern Bighorn Basin, Wyoming: Journal of Geology, v. 102, p. 367-377.

Daly, D.J., 1991, The stratigraphy and depositional environments of the Fox Hills Formation, Bowman County, North Dakota, *in* Sixth International Williston Basin Symposium, Proceedings (Regina, Saskatchewan, Canada): Saskatchewan Geological Society, Special Publication 11, p. 193-205.

Flynn, L. J., 1986, Late Cretaceous mammal horizons from the San Juan Basin, New Mexico: American Museum Novitates 2845, p. 1-30.

Fox, R. C., 1974, *Deltatheroides*-like mammals from the Upper Cretaceous of North America. Nature, v. 249, p. 392.

Fox, R. C., 1989, The Wounded Knee local fauna and mammalian evolution near the Cretaceous-Tertiary boundary, Saskatchewan, Canada: Palaeontographica, v. 208, p. 11-59.

Fox, S.K., Jr., and Olsson, R.K., 1969, Danian planktonic foraminifera from the Cannonball Formation in North Dakota: Journal of Paleontology, v. 43, no. 6, p. 1397-1404.

Frye, C.I., 1967, The Hell Creek Formation in North Dakota [Ph.D. thesis]: Grand Forks, University of North Dakota, 411 p., 8 pls.

Gazin, C. L., 1939, A further contribution to the Dragon Paleocene fauna of central Utah. Journal of the Washington Academy of Sciences, v. 29, p. 273-286.

Gazin, C. L., 1941, The mammalian faunas of the Paleocene of central Utah, with notes on the geology: United State National Museum, Proceedings, v. 91, p. 1-53.

GSA (Geological Society of America), 1991, Rock Color Chart: Boulder, Geological Society of America.

Gunnell, G.R., Bartels, W.S., and Gingerich, P.D., 1993, Paleocene-Eocene boundary in continental North America: Biostratigraphy and geochronology, northern Bighorn Basin, Wyoming: New Mexico Museum of Natural History and Science, Bulletin 2, p. 137-144.

Hance, J.H., 1912, The Glendive lignite field, Dawson County, Montana: U.S. Geological Survey, Bulletin 471-D, p. 271-283.

Hares, C.J., 1928, Geology and lignite resources of the Marmarth field, southwestern North Dakota: U.S. Geological Survey, Bulletin, v. 775, 110 p., 14 pls.

Hartman, J.H., 1984, Systematics, biostratigraphy, and biogeography of latest Cretaceous and early Tertiary Viviparidae (Mollusca, Gastropoda) of southern Saskatchewan, western North Dakota, eastern Montana, and northern Wyoming [Ph.D. Thesis]: Minneapolis, University of Minnesota, 928 p., 19 pls.

Hartman, J.H., 1991a, Coal science: Earth resource evaluation and management: Semiannual technical report for the period January through June 1991, DE-FC21-86MC10637: EERC Publication.

Hartman, J.H., 1991b, The stratigraphic distribution of nonmarine Mollusca across the Cretaceous-Tertiary boundary in the northern Great Plains: Geological Society of America Annual Meeting (invited participant to the theme session on the Nonmarine Fossil Record at the Cretaceous-Tertiary Boundary, October 21-24, 1991), v. 23, no. 5, p. A359.

Hartman, J.H., 1992a, Coal science: Earth resource evaluation and management: Semiannual technical report for the period July through December 1991, DE-FC21-86MC10637: EERC publication.

Hartman, J.H., 1992b, Coal science: Earth resource evaluation and management: Semiannual technical report for the period January through June 1992, DE-FC21-86MC10637: EERC Publication.

Hartman, J.H., and Butler, R.D., 1995, Extinction and recovery of nonmarine molluscan assemblages in the Late Cretaceous and early Tertiary (Symposium on Patterns and Processes of Mass Extinctions: An Integrated Approach): Geological Society of America (Rocky Mountain Section), Abstracts with Programs, v. 27, no. 4, p. 13.

Hartman, J.H., and Kihm, A.J., 1992, Chronostratigraphy of Paleocene strata in the Williston Basin, p. 52-75, *in* Finkelman, R.B., Tewalt, S.J., and Daly, D.J., eds., Geology and utilization of Fort Union lignites: Reston, Virginia, Environmental and Coal Associates, 359 p.

Hartman, J.H., and Kihm, A.J., 1991, Stratigraphic distribution of *Titanoides* (Mammalia: Pantodonta) in the Fort Union Group (Paleocene) of North Dakota: Sixth International Williston Basin Symposium, Regina, Saskatchewan, Canada, p. 207-215.

Hartman, J.H., and Kihm, A.J., 1995, Age of Meek and Hayden's Fort Union Group (Paleocene), upper Missouri River, North Dakota-Montana: Seventh International Williston Basin Symposium, 1995 Guidebook, Billings, Montana, p. 417-428.

Hartman, J.H., Roth, B., and Kihm, A.J., 1993, Stratigraphy and paleontology of a diverse assemblage of nonmarine mollusks and associated mammals from the Sentinel Butte Formation of North Dakota: North Dakota Academy of Science, Proceedings, v. 47, p. 50.

Hickey, L.J., 1977, Stratigraphy and paleobotany of the Golden Valley Formation (Early Tertiary) of western North Dakota: Geological Society of America, Memoir 150, 183 p, 55 pls.

Johnston, P. A., and Fox, R. C., 1984, Paleocene and Late Cretaceous mammals from Saskatchewan, Canada: Palaeontographica, v. 186, p. 163–222.

Kihm, A.J., and Hartman, J.H., 1990, Chronostratigraphic implications of the mammal and nonmarine mollusk record of the Paleocene Fort Union Group in North Dakota: North Dakota Academy of Science (82nd Annual Meeting), Proceedings, v. 44, p. 70.

Kihm, A.J., and Hartman, J.H., 1991, The age of the Sentinel Butte Formation, North Dakota: Society of Vertebrate Paleontology (Annual Meeting, October 24–26, 1991), Journal of Vertebrate Paleontology, v. 11, supplement to no. 3, p. 40a.

Kihm, A.J., Hartman, J.H., and Krause, D.W., 1993, The Red Spring local mammal fauna, Sentinel Butte Formation (Paleocene), Mercer County, North Dakota: Journal of Vertebrate Paleontology (Society of Vertebrate Paleontology, 53rd Annual Meeting, Albuquerque), v. 13, supplement to no. 3, p. 44a.

Krause, D. W., 1982, Evolutionary history and paleobiology of early Cenozoic Multituberculata (Mammalia), with emphasis on the family Ptilodontidae [Ph.D. Dissertation]: Ann Arbor, University of Michigan, 575 p.

Krause, D. W., 1992, *Clemensodon megaloba*, a new genus and species of Multituberculata (Mammalia) from the Upper Cretaceous type Lance Formation, Powder River Basin, Wyoming: PaleoBios, v. 14, p. 1–8.

Krause, D.W., Wunderlich, R., Hartman, J.H., and Kroeger, T.J., 1992, Latest Cretaceous and early Paleocene mammals from Makoshika State Park, Williston Basin, eastern Montana: Journal of Vertebrate Paleontology, Abstracts of Papers, 52nd Annual Meeting, Royal Ontario Museum (Toronto), v. 12, supplement to no. 3, p. 38a.

Kroeger, T.J., Hartman, J.H., and Peck, W.D., 1993, Provisional palynological recognition of the fern spike at the Cretaceous-Tertiary Boundary, Makoshika State Park, Dawson County, Montana: North Dakota Academy of Science (1993 Annual Meeting), v. 47, p. 48.

Lerbekmo, J.F., and Coulter, K.C., 1985, Magnetostratigraphic and biostratigraphic correlations of Late Cretaceous and Early Paleocene strata between Alberta and North Dakota: Canadian Society of Petroleum Geologists, Memoir 9, p. 313–317.

Lillegraven, J. A., 1969, Latest Cretaceous mammals of upper part of Edmonton Formation of Alberta, Canada, and review of marsupial–placental dichotomy in mammalian evolution: The University of Kansas Paleontological Contributions 50, p. 1–122.

Lillegraven, J. A., and McKenna, M. C., 1986, Fossil mammals from the "Mesaverde" Formation (Late Cretaceous, Judithian) of the Bighorn and Wind River Basins, Wyoming, with definitions of Late Cretaceous North American Land-Mammal "Ages": American Museum Novitates 2840, p. 1–68.

Lund, S.P., 1995 (written communication), Magnetostratigraphy of interfingering Upper Cretaceous and Paleocene marine and continental strata of the Williston Basin, North Dakota (unpublished manuscript).

Lund, S.P., and Hartman, J.H., in preparation, Paleomagnetic stratigraphy of the Cretaceous-Tertiary transition in south-central North Dakota and easternmost Montana.

Montana Department of Fish, Wildlife and Parks, 1985, Makoshika State Park Road Guide: Great Falls, Montana Department of Fish, Wildlife and Parks, 47 p.

Murphy, E.C., Nichols, D.J., Hoganson, J.W., and Forsman, N.F., 1995, The Cretaceous/ Tertiary boundary in south-central North Dakota: North Dakota Geological Survey, Report of Investigation 98, 73 p.

Prothero, D.R., in press, Geochronology and magnetostratigraphy of Paleocene North American Land Mammal "Ages": An update, *in* Berggren, W.A., Kent, D.V., and Hardenbol, J., eds., Geochronology, time scales and global stratigraphic correlations: A unified temporal framework for an historical geology: Society of Economic Paleontologists and Mineralogists Special Publication 54.

Rigby, J. K., Jr., 1980, Swain Quarry of the Fort Union Formation, middle Paleocene (Torrejonian), Carbon County, Wyoming: geologic setting and mammalian fauna. Evolutionary Monographs, v. 3, p. 1–178.

Schoch, R.M., 1986, Systematics, functional morphology and macroevolution of the extinct mammalian Order Taeniodonta: Yale University, Peabody Museum of Natural History, Bulliton 42, 307 p.

Sholes, M.A., Vuke-Foster, S.M., and Derkey, P.D., 1989, Coal stratigraphy and correlation in the Glendive 30x60-minute quadrangle, eastern Montana and adjacent North Dakota: Montana Bureau of Mines and Geology, Geologic Map 49, 4 sheets.

Sloan, R. E., and Van Valen, L., 1965, Cretaceous mammals from Montana: Science, v. 148, p. 220–227.

Storer, J. E., 1991, The mammals of the Gryde Local Fauna, Frenchman Formation (Maastrichtian: Lancian), Saskatchewan: Journal of Vertebrate Paleontology, v. 11, p. 350–369.

Tschudy, R.H., 1970, Palynology of the Cretaceous–Tertiary boundary in the northern Rocky Mountain and Mississippian embayment regions: Geological Society of America, Special Paper 127, p. 65–111.

Van Valen, L. M., 1978, The beginning of the age of mammals: Evolutionary Theory, v. 4, p. 45–80.

Van Valen, L., and Sloan, R. E., 1965, The earliest primates: Science, v. 150, p. 743–745.

Vuke-Foster, S.M., and Colton, R.B., 1989, Coal and clinker outcrop map of the Glendive 30x60-minute quadrangle, eastern Montana and adjacent North Dakota: Montana Bureau of Mines and Geology, Geologic Map 49, sheet 1.

Warwick, P.D., Murphy, E.C., and Obradovich, J.D., 1995, Parasequences in the Paleocene Ludlow and Cannonball Members of the Fort Union Formation, Williston Basin, North Dakota: Geological Society of America (Rocky Mountain Section), Abstracts with Programs, v. 27, no. 4, p. 60.

FIGURE CAPTIONS

Figure 1. **Williston Basin Glendive area studies, Dawson County, Montana.** The bedrock geology displayed on this map was derived from Clayton (1980) and unpublished data provided by S.M. Vuke of the Montana Bureau of Mines and Geology and Foster Sawyer of the South Dakota Geological Survey (see Hartman and Kihm, 1995).

Figure 2. **Glendive area fossil stratigraphy.** This figure represents the general stratigraphy of lithostratigraphic units in the Glendive study area. Basic unit data were derived from Butler (1980), Sholes and others (1989), S.M. Vuke (written communications, 1994, 1995), Daly (1991), and Hartman (unpublished observations). The placement of fossil localities and the fern spike were determined as part of the present study (see also Kroeger and others, 1993). All mammalian localities are referred to by name (see Appendix I) and all molluscan localities are referred to by number. Note that mollusks are also known from the School Well, Hiatt South, Deer Crash, and Muddy Tork Localities.

Figure 3. **Glendive area – Makoshika State Park fossil localities, Dawson County, Montana.** General location map of mammalian and molluscan Upper Cretaceous and Paleocene fossil localities. All mammalian localities are referred to by name (see Appendix I), and all molluscan localities are referred to by number. Note that mollusks are also known from the School Well, Hiatt South, Deer Crash, and Muddy Tork Localities. Mollusks were also discovered, collected, or previously known to the west on the Poverty Flat West Quadrangle (L4990, L6423) and Olson Coulee South (L6395, L6396, L6416, L6417) and to the south on the Upper Magpie Reservoir Quadrangle (L6432, L6433) and Hoyt Quadrangle (L952, L958, L1099, L1100, L1356, L5413, L6206, L6207, L6332, L6333).

Figure 4. **Makoshika State Park – Muddy Tork and Hiatt area fossil localities.** Base map derived from USGS Glendive Quadrangle (1967). Geology modified from Sholes and others, 1989, in fossil locality study areas. M-numbered lines are measured sections. Sections M3715, M3723, and M3724 are from Butler (1980). Section M156, which is placed approximately based on section thickness and available relative relief, is from Frye (1967). All other sections were measured through the course of present Glendive area studies. Other measured sections not displayed in this figure include M6723 (similar track as M7877b in the fern spike section) and M2114 and M2271, which represent sections for preliminary palynomorph age determinations in the area of the Hiatt Locality.

Figure 5. **Stratigraphy of fossil localities in Sec. 1, T. 15 N., R. 55 E., Makoshika State Park, Montana.** The measured sections illustrated in this figure are located on opposite sides of Cains Coulee, and document the stratigraphic position of the Muddy Tork, Hiatt, and Hiatt South mammalian localities. The first and last, along with localities L6260 and L6425, also contain a few poorly preserved mollusks. Also shown are K/T boundary and fern spike, which are illustrated in greater detail in

succeeding figures. See Figure 6 for interpretation of lithic symbols and the Appendix for measured section data.

Figure 6. **Lithic symbols for measured sections.** This figure illustrates the lithic interpretation of the symbols used in stratigraphic sections in this report.

Figure 7. **Muddy Tork Locality, Makoshika State Park, Montana.** This figure illustrates the location of measured Section M4769a, the Muddy Tork Locality, and the westward extent from the Witches Hat Sandstone (see Appendix for measured section data). The prominent conical feature representing Witches Hat occurs just to the east of this photograph (see Figure 9).

Figure 8. **Muddy Tork Locality, Makoshika State Park, Montana.** This figure shows the precise location of the Muddy Tork fossil locality. The foreground channelform sandstones are of the Witches Hat Sandstone. The tripod in this view was tethered to the south with ropes to permit a tripod trolley (pulley, rope, and matrix bag) system to be employed to transport bulk matrix directly to the road below. A similar system was first used at the Hiatt Locality.

Figure 9. **Witches Hat sections, Makoshika State Park, Montana.** This view is along the same east–west ridge as shown in Figure 8. Witches Hat consists of a sequence of channel sandstones. Sections M4769b and M7887a can be composited to form a continuous sequence from the road in the north along Cains Coulee (see Appendix for measured section data). Section M4769b was measured from the base of a substantial channel scour on the north face of the butte to the end of the white line illustrating the lowest part of the section in this view. The fern spike section (M7887b) was taken on the butte to the right of Witches Hat (Figure 10).

Figure 10. **Paleomagnetic, fern spike, and K/T boundary sections, Makoshika State Park, Montana.** Section M7887b was measured southeast of Witches Hat from the bottom of the coulee (out of view in this photograph). The locations of the Contact lignite and fern spike are shown (see Appendix for measured section data).

Figure 11. **Fern Spike Locality, K/T boundary interval, Makoshika State Park, Montana.** The fern spike pit is shown on the steep, south-facing slope of this butte. The Contact lignite and approximate location of unionid locality L6260 can be seen across the saddle. Sections M7921 and M7922 were taken on the east end of this butte through the K/T boundary interval.

Figure 12. **The placement of the K/T boundary in Makoshika State Park, Montana.** This figure illustrates Section M4770 and details the lithic sampling used in the recognition of the K/T boundary on the basis of palynomorphs. The section was measured and sampled by W.D. Peck and J.H. Hartman, and the palynomorphs were identified and interpreted by T.J. Kroeger (see Appendix for measured section data). The fern spike was reported by Kroeger and others (1993). Units 1–3 are clayey siltstones, Unit 4 is a lignite, and Unit 5 is a siltstone. Divisions within units represent sampling intervals.

Figure 13a. K/T boundary fern spike, Makoshika State Park, Montana. This figure (Kroeger and others, 1993) illustrates in detail the recognition of the fern spike in Section M4770 shown in Figure 12.

Figure 13b. K/T boundary interval pollen diagram. The increase in relative percentage of the fern pollen and concomitant decrease in other taxa are shown in this figure (Kroeger and others, 1993).

Figure 14. Sand Creek Overlook sections, Makoshika State Park, Montana. A dispersed iridium anomaly was reported from the interval of the Contact lignite below the Sand Creek Overlook at the south end of Makoshika State Park (D.E. Fastovsky, personal communication, 1995). The distinctive "pink" layer, very near the K/T boundary, was found elsewhere in the park, occasionally associated with silcretes (east of Q.V. Locality). Section M8282 is a boundary section measured by Cathryn Newton (Syracuse University) and others. Section M8283 was sampled for palynomorph studies through their section pit (see Appendix for measured section data).

Figure 15. Paleomagnetic stratigraphy – fern spike section, Makoshika State Park, Montana. Paleomagnetic samples were collected through the interval of the K/T boundary southeast of Witches Hat. The numbered samples are shown by black dots next to the polarity section. The radiometric dates for the magnetochron boundaries are from Berggren and others (1995).

Figure 16. Paleomagnetic data for Section M7887b, Makoshika State Park, Montana. This figure represents the basic paleomagnetic data for the samples shown in stratigraphic section in Figure 15. The samples were analyzed by S.P. Lund (written communication, 1995).

Figure 17. Hiatt and Hiatt South Localities, Makoshika State Park, Montana. This view is from the top of the butte bearing Section M7887b and overlooks the rifle range to the tributary of Cains Coulee. The Hiatt and Hiatt South mammalian localities occur on the north side of the side coulee in the basal light-colored units of a sequence of channelform sandstones. Section M4376 represents the major section through this stratal interval. Sections M4771 and M8279 place the localities relative to the Contact lignite and K/T boundary. The K/T boundary was recognized on the basis of palynomorphs in Section M4771.

Figure 18. Hiatt South Locality, Makoshika State Park, Montana. Of the two mammalian localities in this area, the Hiatt South Locality is the best documented. The Hiatt South Quarry can be seen in this view, along with the trend of Section M8279. The K/T boundary and Hell Creek–Fort Union (Ludlow Member) formational contact occurs below the view shown here. Bulk matrix sampled from this locality was taken to road access by pack horses.

Figure 19. Bulk sediment screen washing, Yellowstone River, Glendive, Montana. Bulk sediment samples are hauled to a "washing" site, preferably a flowing body of water with a firm substrate, so that the sediment can be wet-screened. The "concentrate" is

removed and allowed to dry. The processed sediment will be processed in the laboratory for small to minute fossils.

Figure 20. Chronostratigraphy of North Dakota strata. This figure represents the first detailed comparison of uppermost Cretaceous, Paleocene, and Lower Eocene nonmarine strata of North Dakota with the global paleomagnetic reversal record. Previous versions (e.g., Hartman and Kihm, 1995) have been modified with unpublished magnetic, radiometric, and paleontologic data. The radiometric dates on the boundaries of magnetochrons is from Berggren and others (in press). Interpretation of the correlation of mammalian ages with magnetochrons was derived from Clyde and others (1994), Gunnell and others (1993), and Prothero (in press). Other lowermost Paleocene paleomagnetic data were provided by Lund (written communication, 1995; Lund and Hartman, in preparation). Other radiometric dates were provided by D.A. Pearson (personal communication, 1995) and reported by Warwick and others (1995). Planktic foraminifera data of Fox and Olsson (1969) and correlation with radiometric dates were interpreted by L.S. Collins (written communication, 1994, 1995). Litho- and chronostratigraphic placement of mammalian localities was modified from Kihm and Hartman (1990, 1991), Hartman and Kihm (1991, 1992, 1995), Hartman and others (1993), and Kihm and others (1993). Other mammalian data on new localities were provided by J.P. Hunter and D.A. Pearson (personal communication, 1994, 1995). Interpretation of the stratigraphy of the transgressive and regressive histories of the tongues of the Cannonball Formation was modified from Hartman and Butler (1995; and unpublished data). Symbols: The dotted line, representing the contact between the Sentinel Butte and Golden Valley Formations is temporally uncontrolled. The Bear Den Member of the Golden Valley Formation was interpreted to be Clarkforkian by Hickey (1977) on the basis of plants, but the age of the uppermost part of the Sentinel Butte Formation is unknown. White dots with black rims indicate localities that have been placed in the diagram solely on the basis of their stratigraphic position. The possible age range of PTM V86005 is shown with a vertical line through a black dot. The Brown Ranch localities, which occur in a single lithosome, are shown as one black dot. The dot is placed on the diagram on the basis of the localities' stratigraphic position, but the few mammalian fossils from this locality also suggest a Torrejonian age.

Figure 1

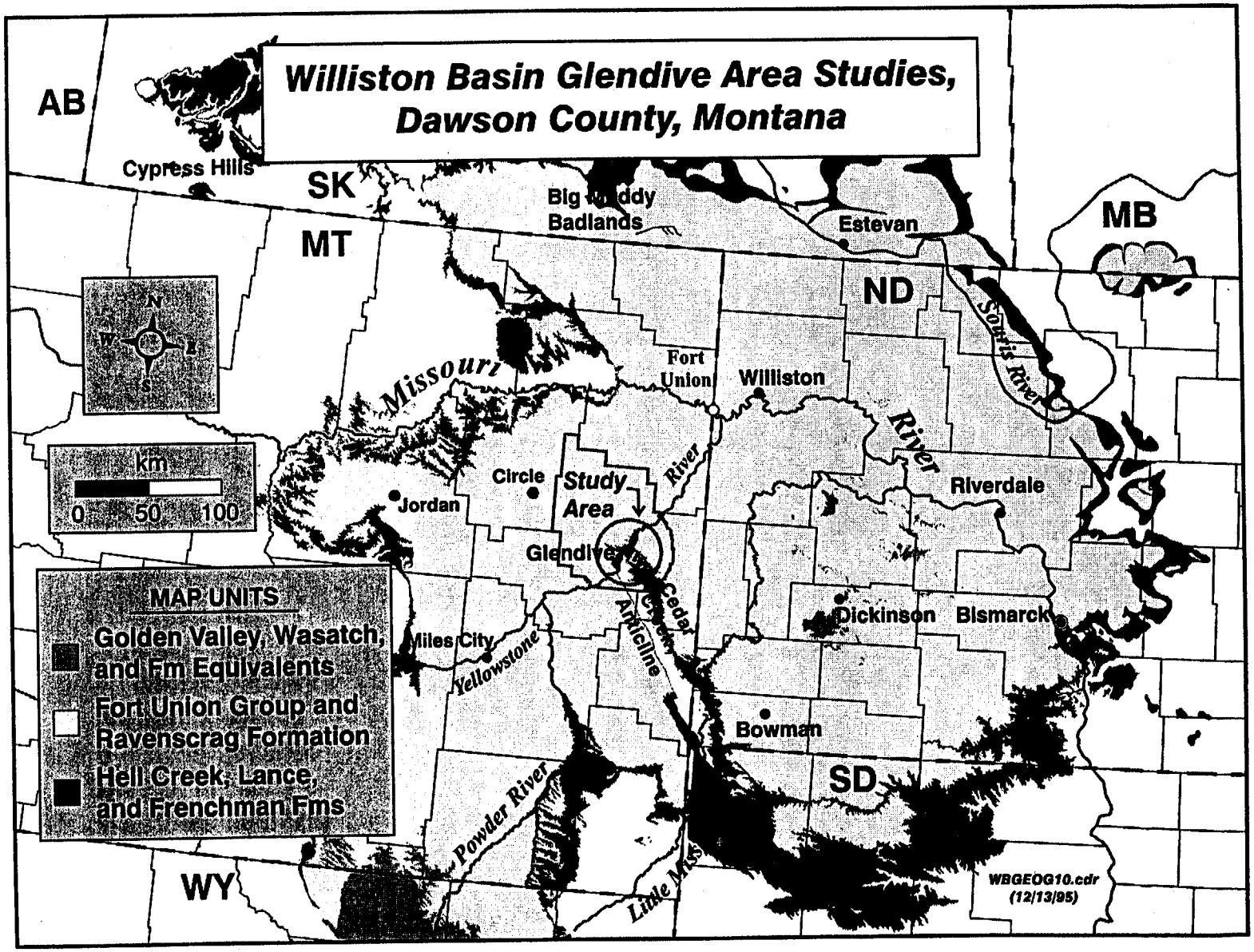
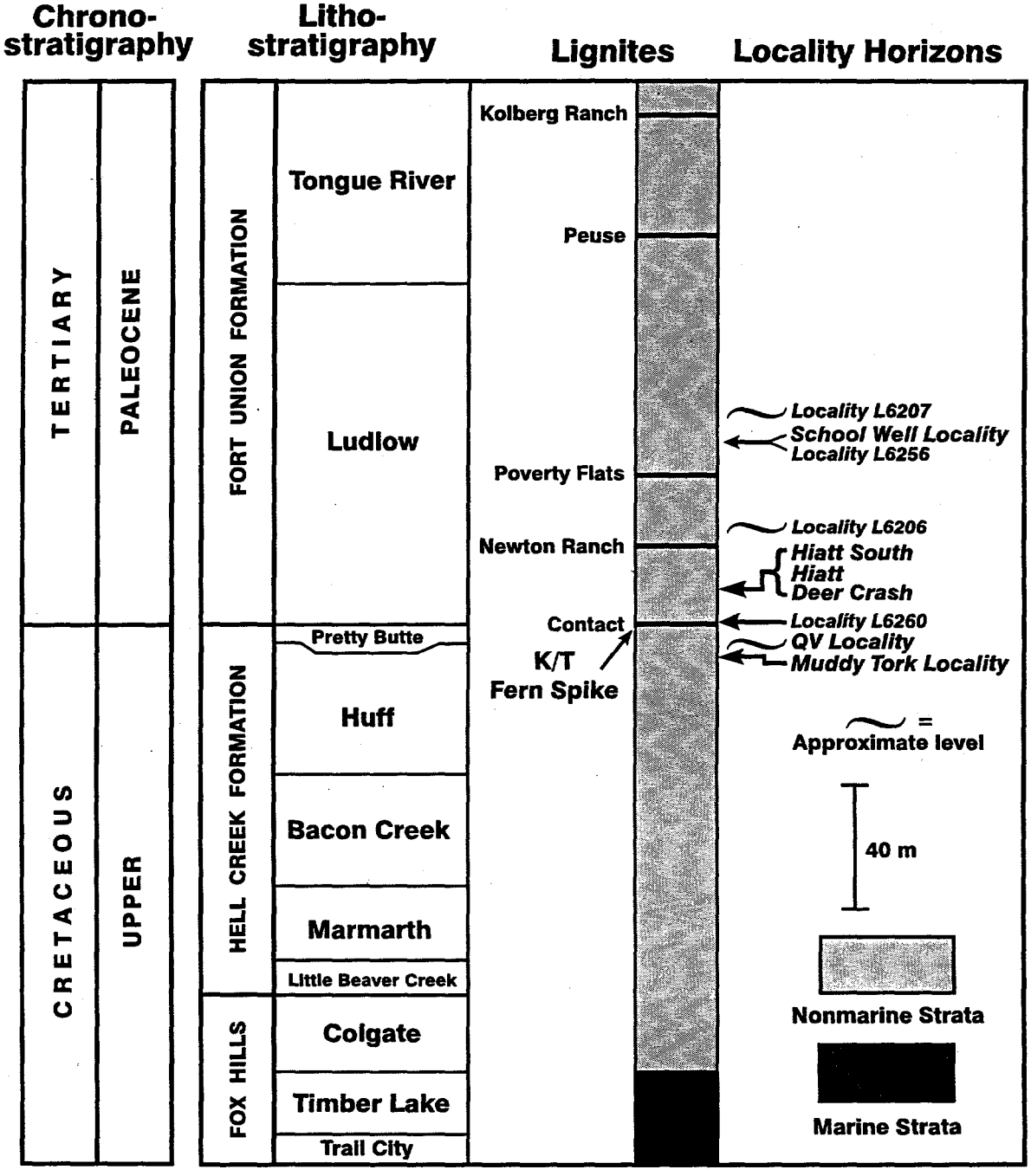

Williston Basin Glendive Area Studies,
Dawson County, Montana
AB
SK
MT
ND
MB
SD
WY
Cypress Hills
Big Muddy Badlands
Estevan
Missouri River
Fort Union
Williston
Souris River
Circle
Study Area
Jordan
Glendive
Riverdale
Dickinson
Bismarck
Miles City
Yellowstone
Cedar Creek Anticline
Bowman
Powder River
Little Mis
N
W
E
S
km
0 50 100
MAP UNITS
Golden Valley, Wasatch, and Fm Equivalents
Fort Union Group and Ravenscrag Formation
Hell Creek, Lance, and Frenchman Fms
WBGEOG10.cdr
(12/13/95)

Figure 2

Glendive Area Fossil Stratigraphy



MAK-FMS3.cdr (12/14/95)

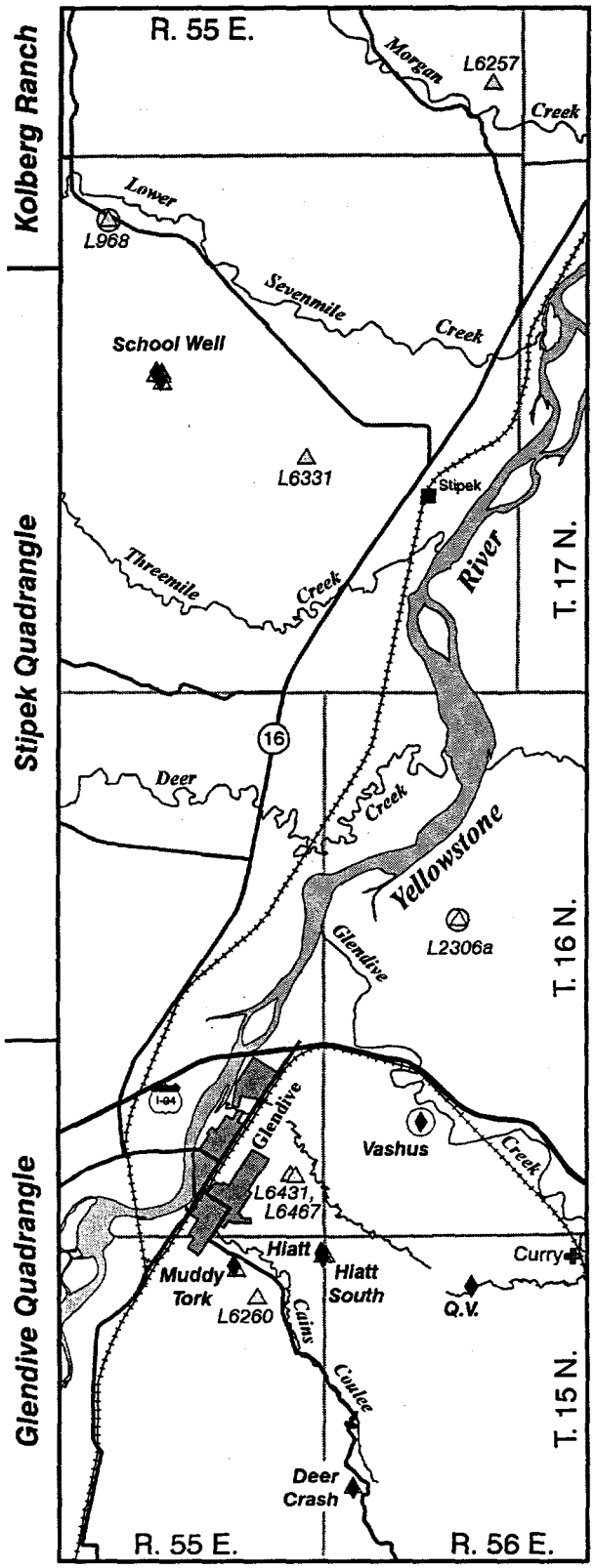
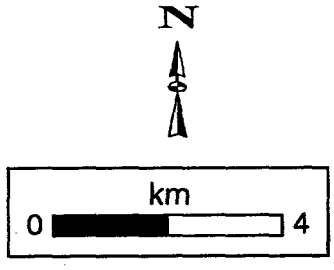


Figure 3

Glendive Area – Makoshika State Park Fossil Localities, Dawson County, Montana

- ***Mammalian Locality***
- ***Mammalian Locality of Uncertain Location***
- ***Molluscan Locality***
- ***Molluscan Locality of Uncertain Location***



MAK-MAP1.cdr (12/14/95)

Figure 4

Makoshika State Park – Muddy Tork and Hiatt Area Fossil Localities

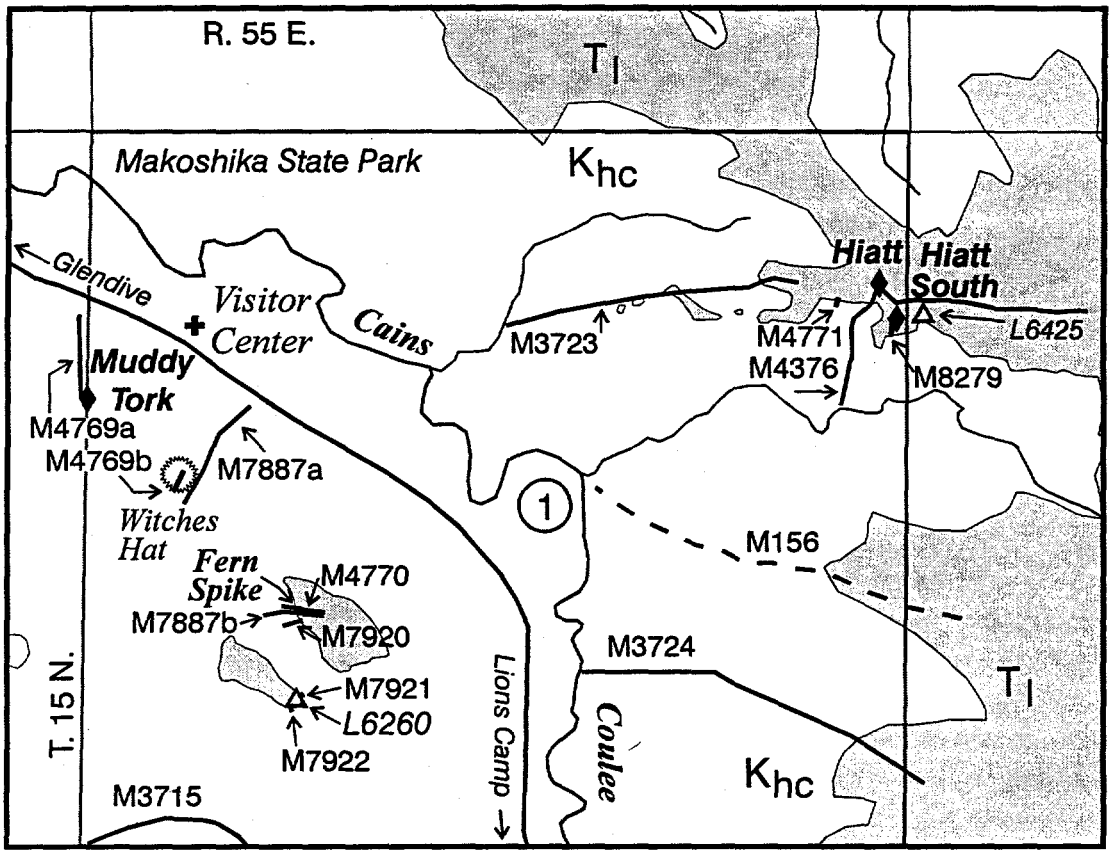


Figure 5

Stratigraphy of Fossil Localities in Sec. 1, T. 15 N., R. 55 E., Makoshika State Park, Montana

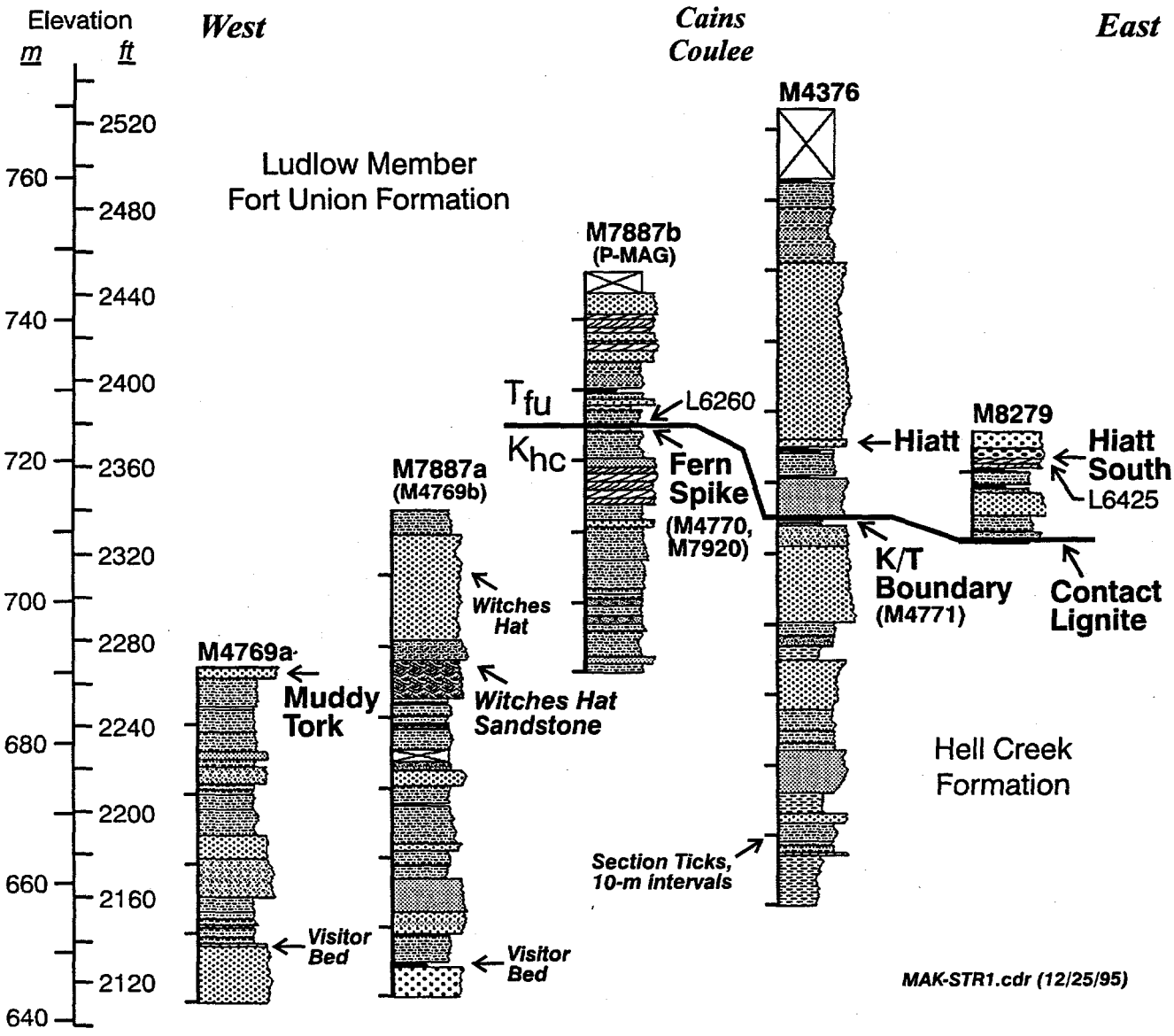
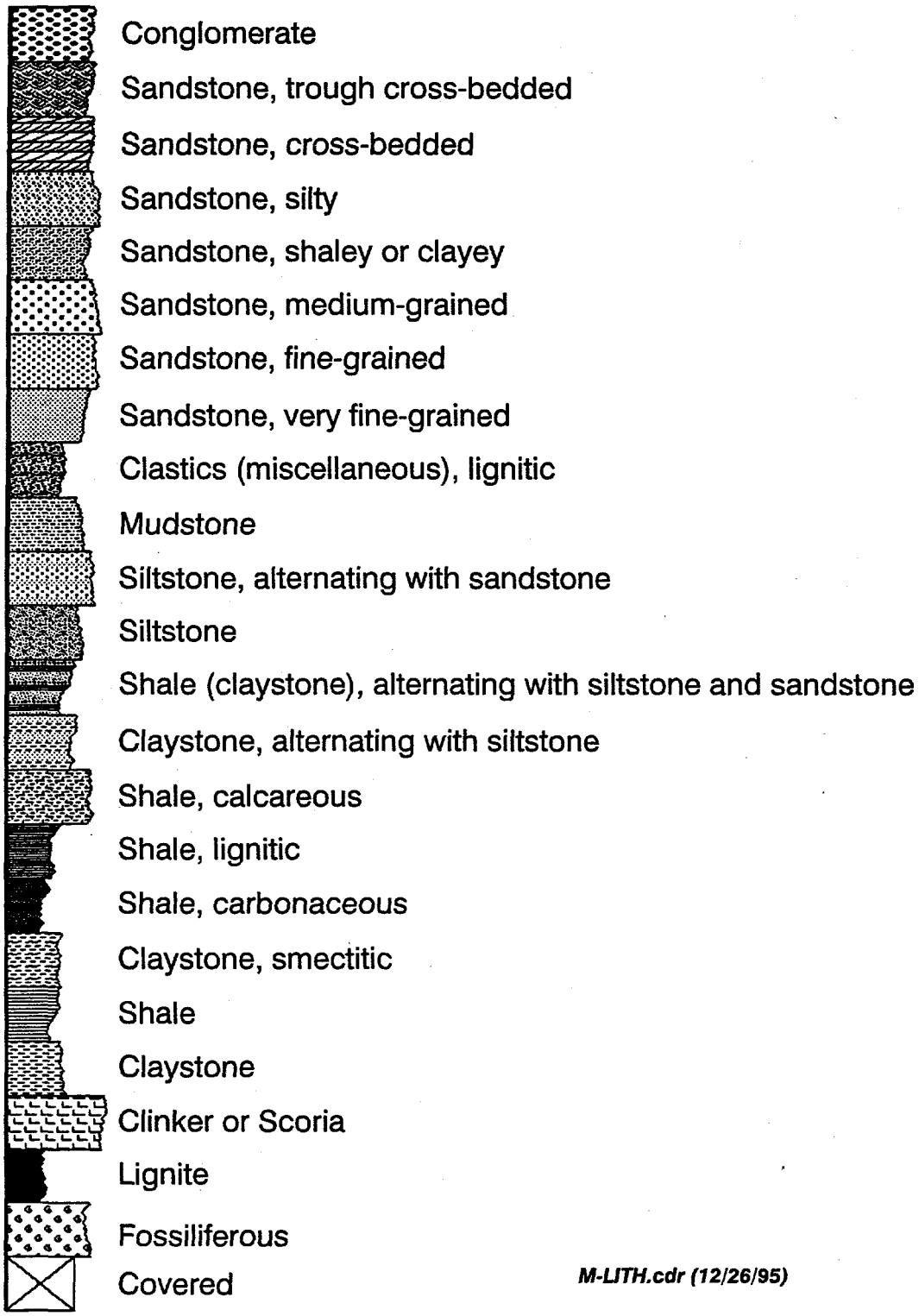


Figure 6

Lithic Symbols for Measured Sections



M-LITH.cdr (12/26/95)

Figure 7

Muddy Tork Locality,
Makoshika State Park, Montana

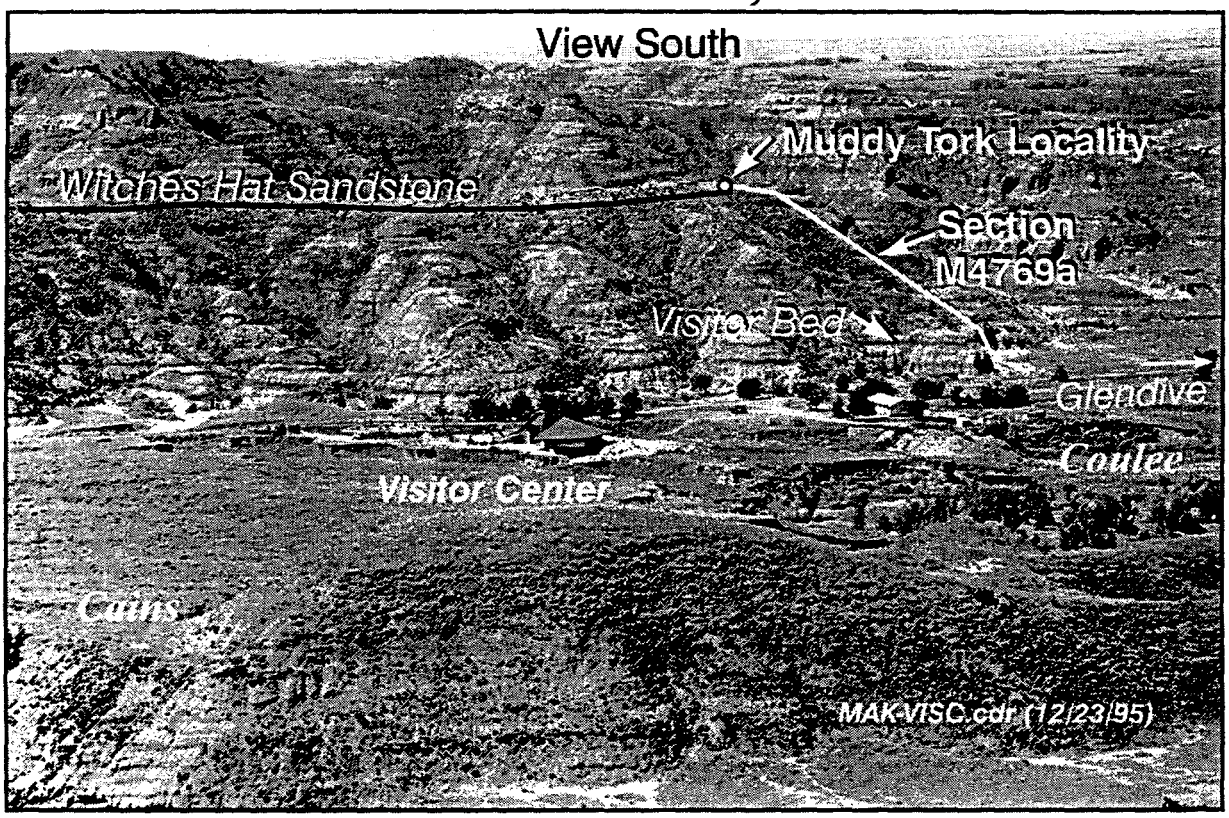


Figure 8

Muddy Tork Locality, Makoshika State Park, Montana

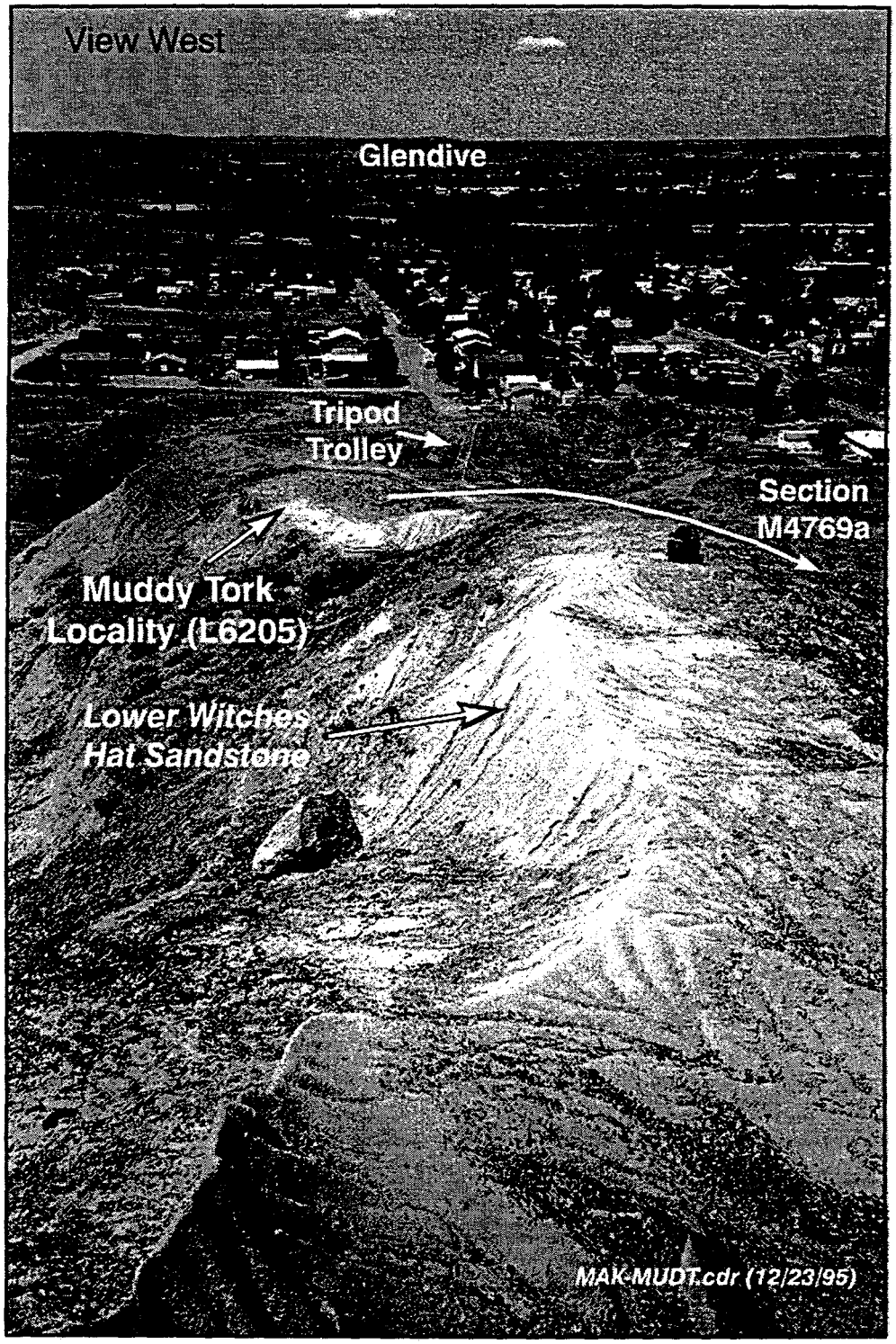


Figure 9

Witches Hat Sections, Makoshika State Park, Montana

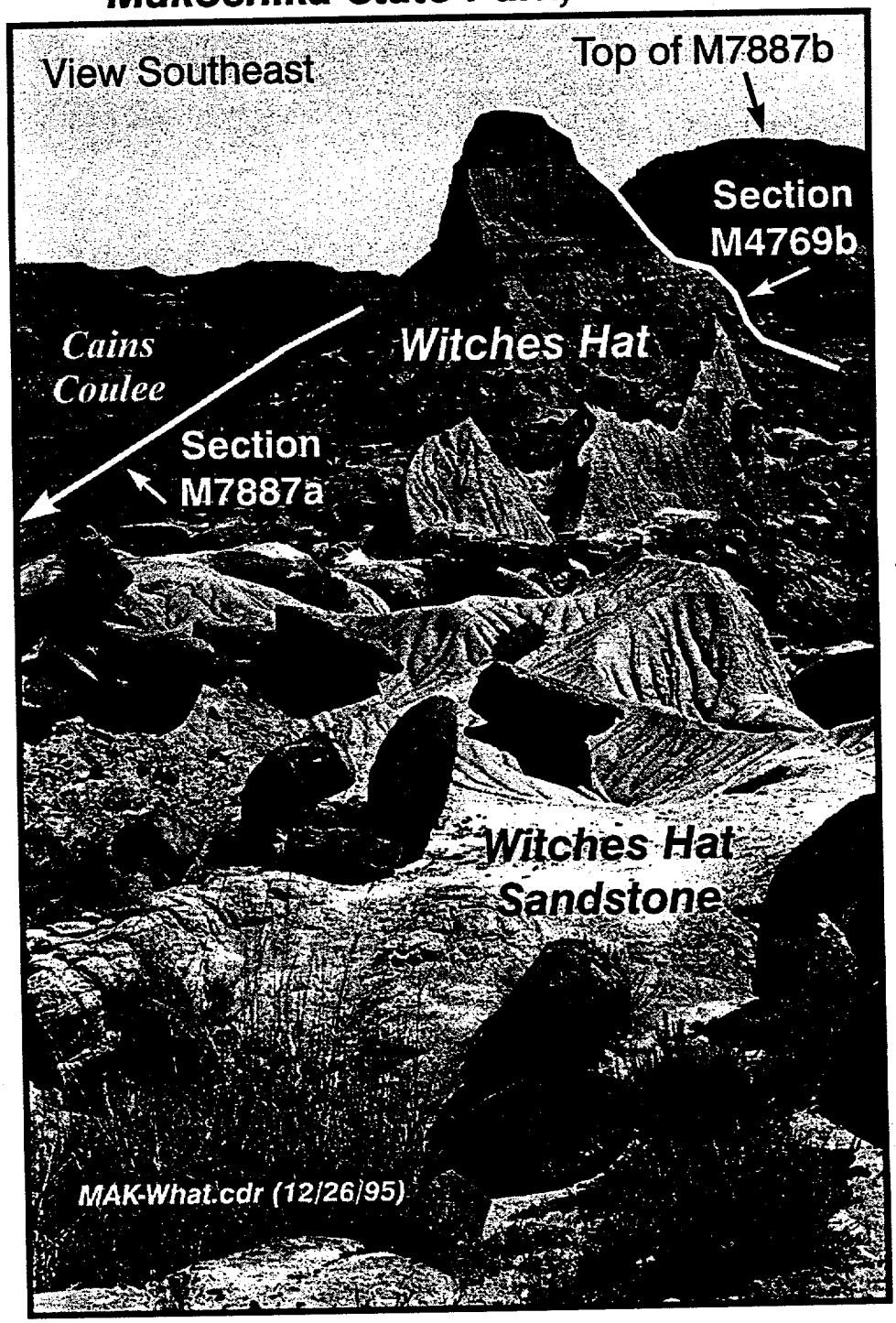


Figure 10

Paleomagnetic, Fern Spike, and K/T Boundary Section, Makoshika State Park, Montana

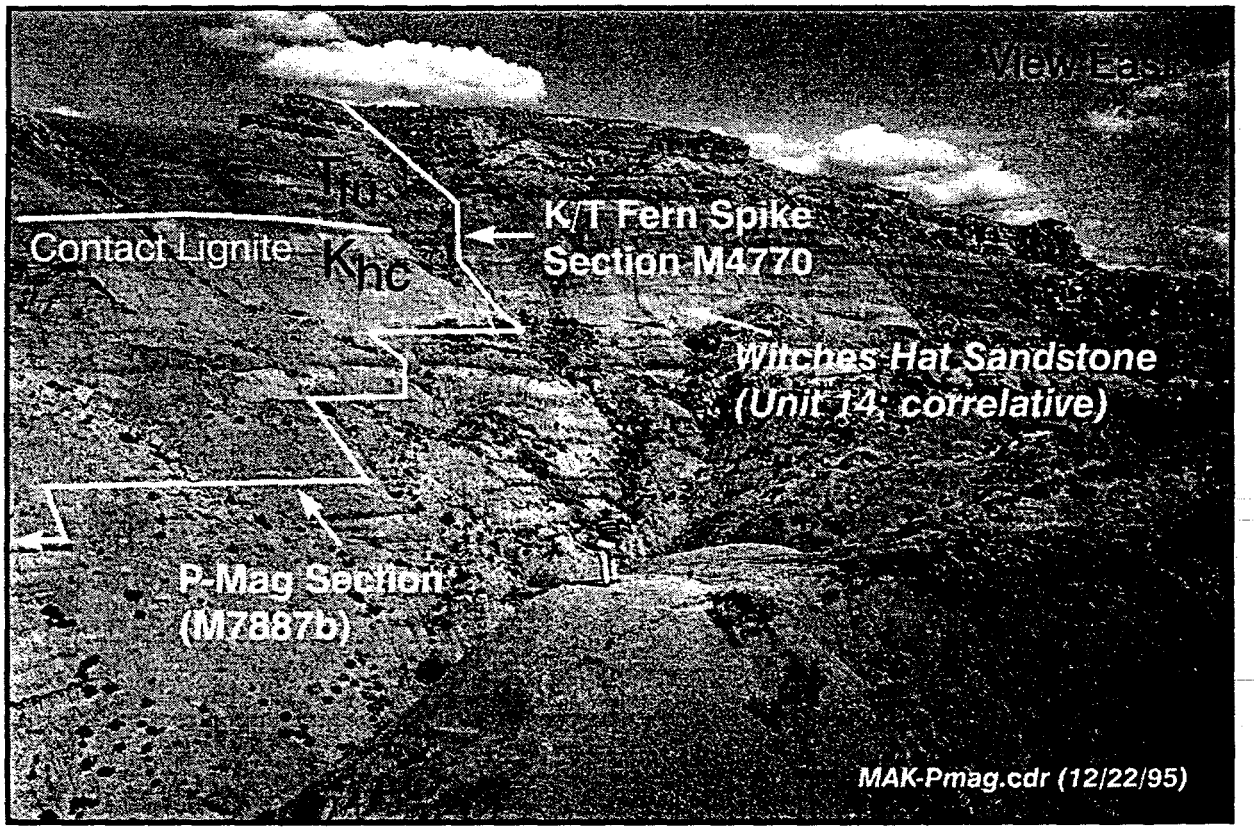


Figure 11

Fern Spike Locality, K/T Boundary Interval, Makoshika State Park, Montana

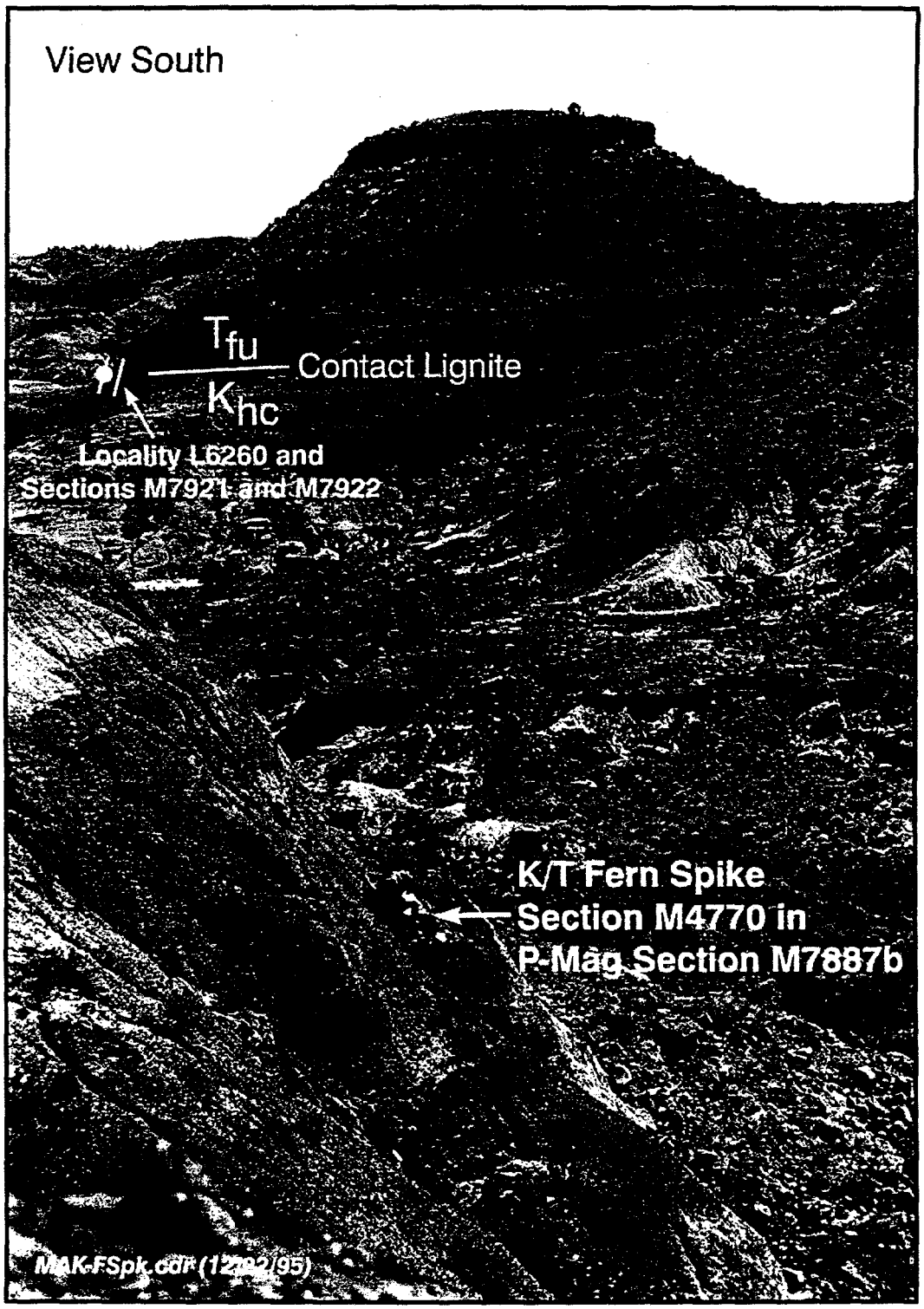


Figure 12

Placement of the K/T Boundary in Makoshika State Park, Montana

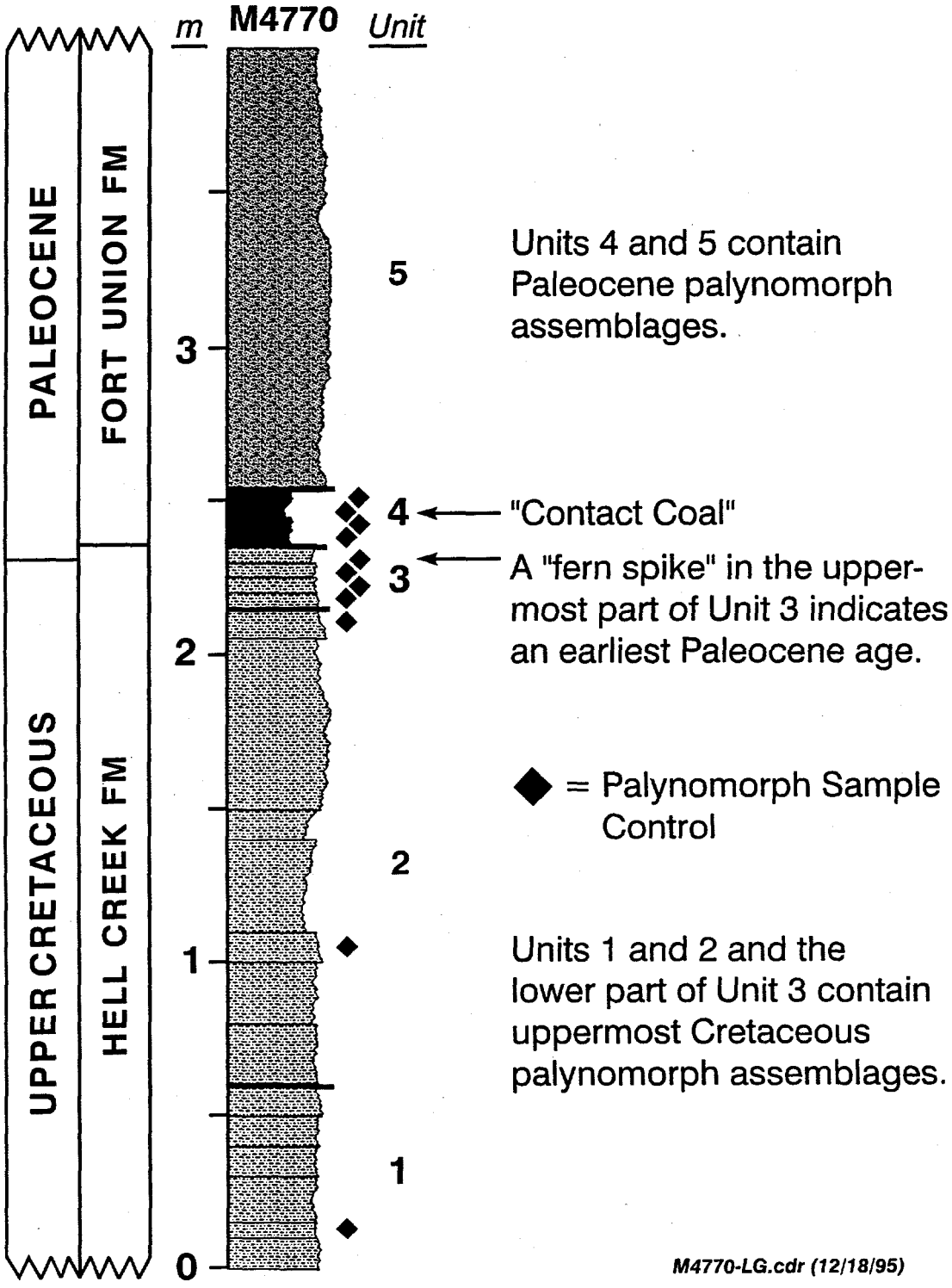


Figure 13a

K/T Boundary Fern Spike,
Makoshika State Park, Montana
Section M4770, Witches Hat Area

5-cm Sample Interval

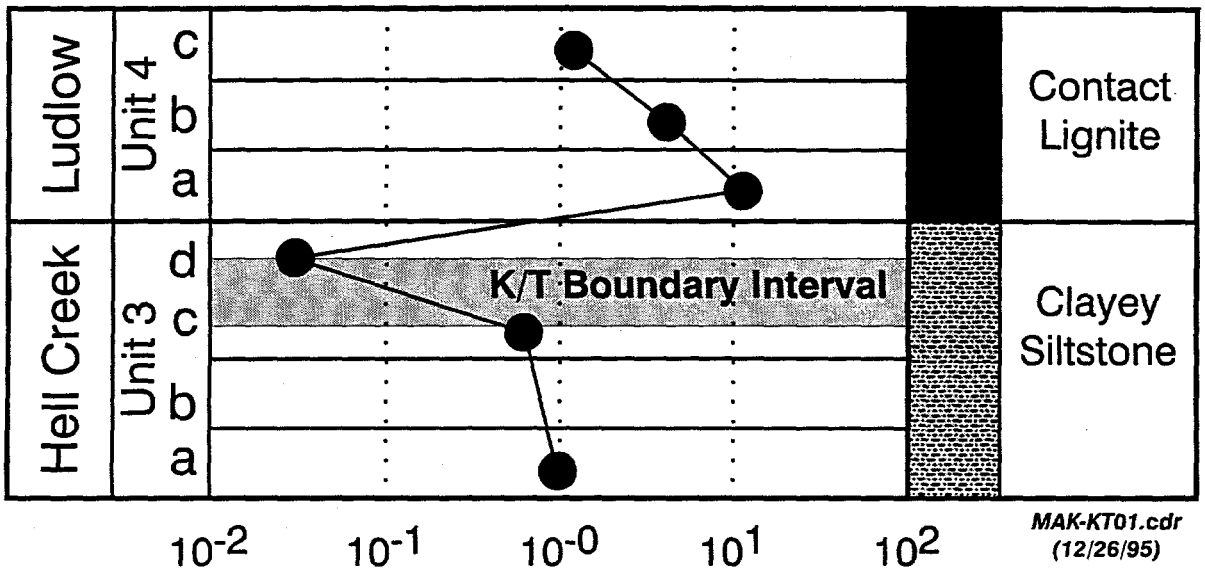


Figure 13b

K/T Boundary Interval Pollen Diagram
(excluding fungal and algal taxa)

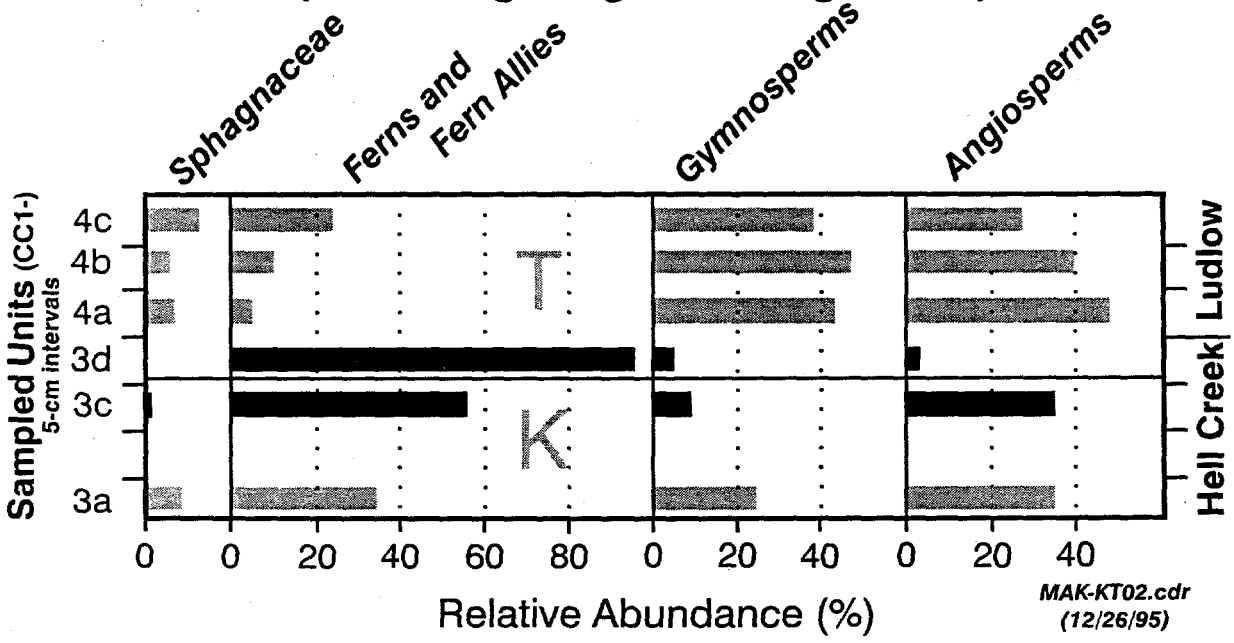


Figure 14

Sand Creek Overlook Sections, Makoshika State Park, Montana

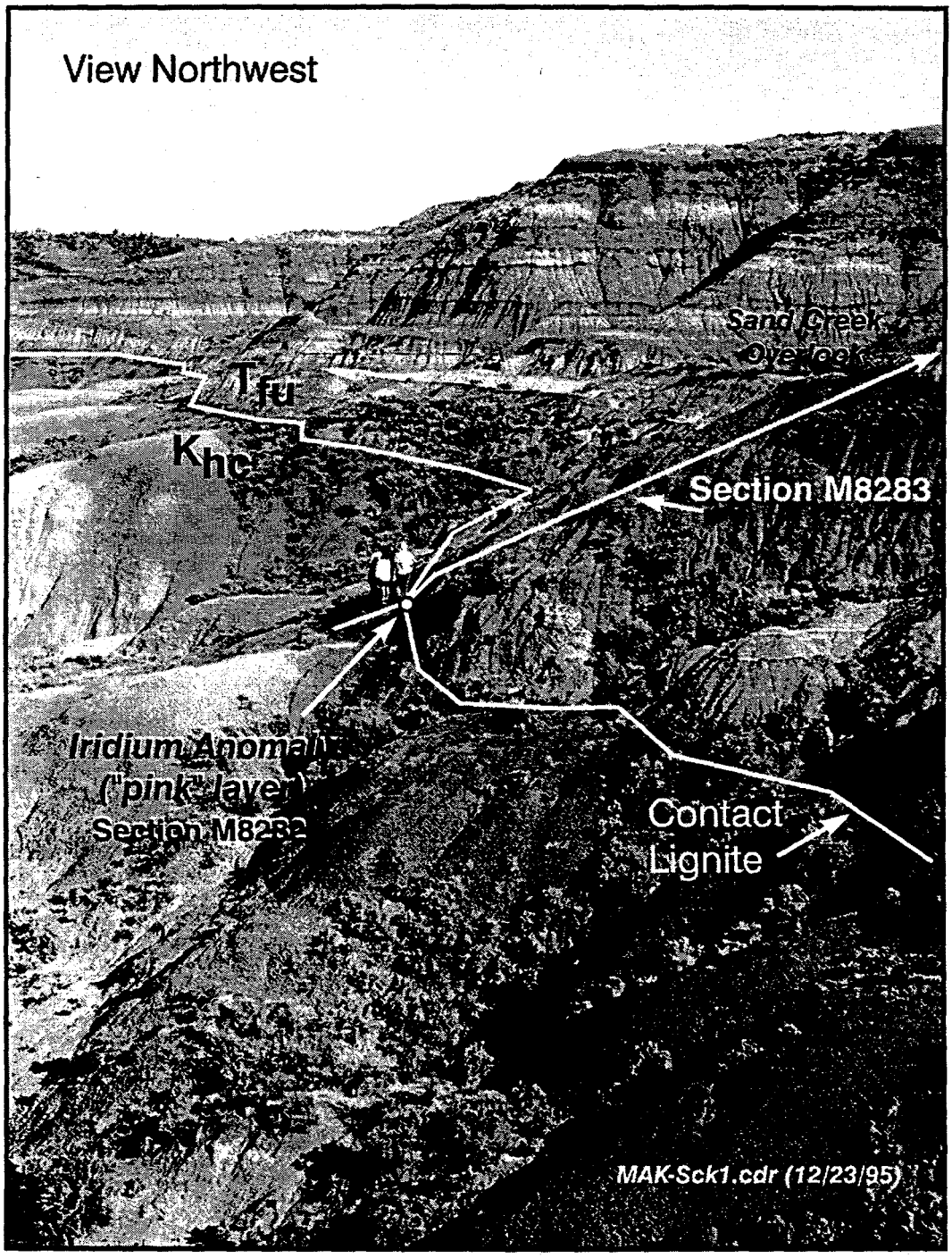


Figure 15

Paleomagnetic Stratigraphy – Fern Spike Section, Makoshika State Park, Montana

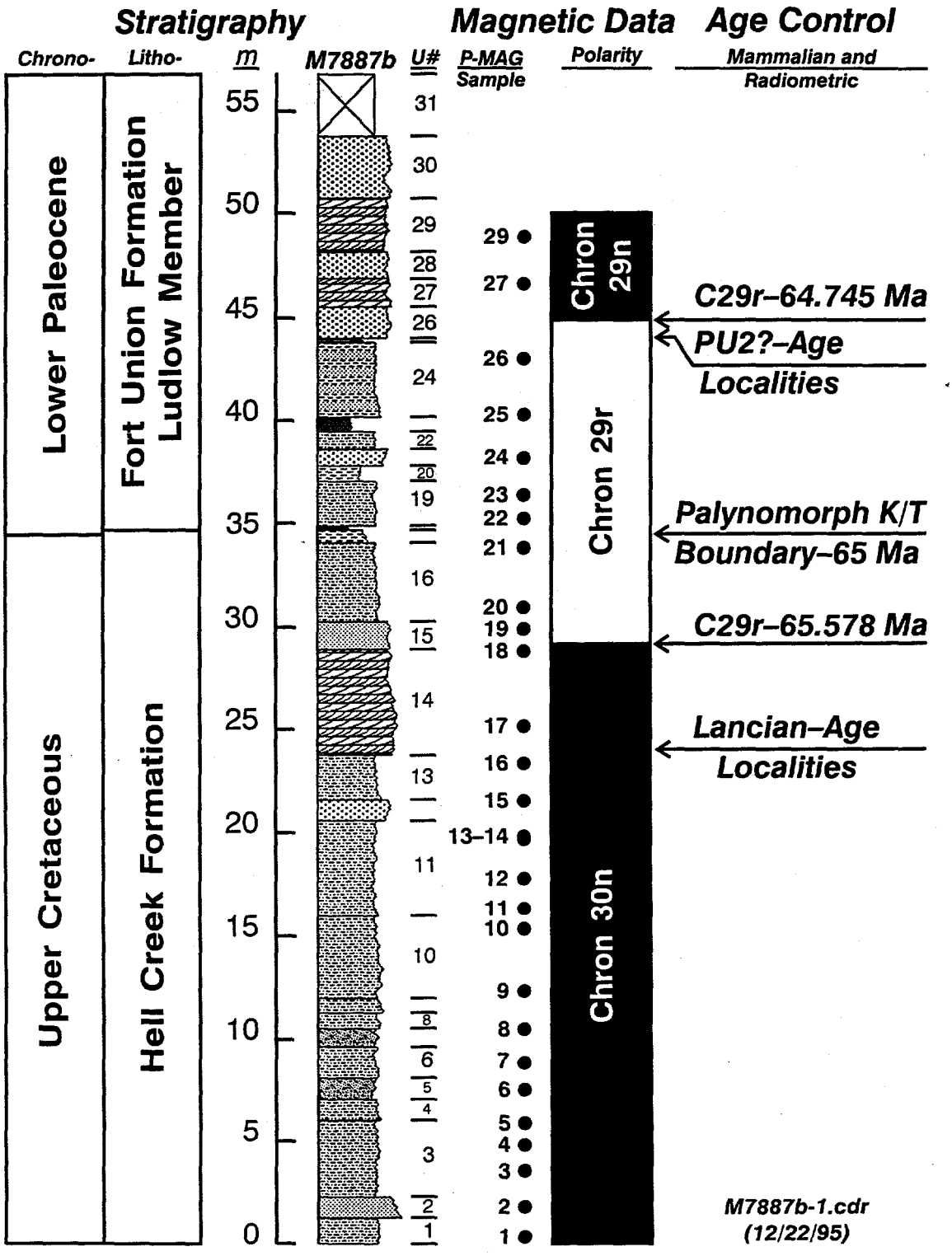


Figure 16

Paleomagnetic Data for Section M7887b, Makoshika State Park, Montana

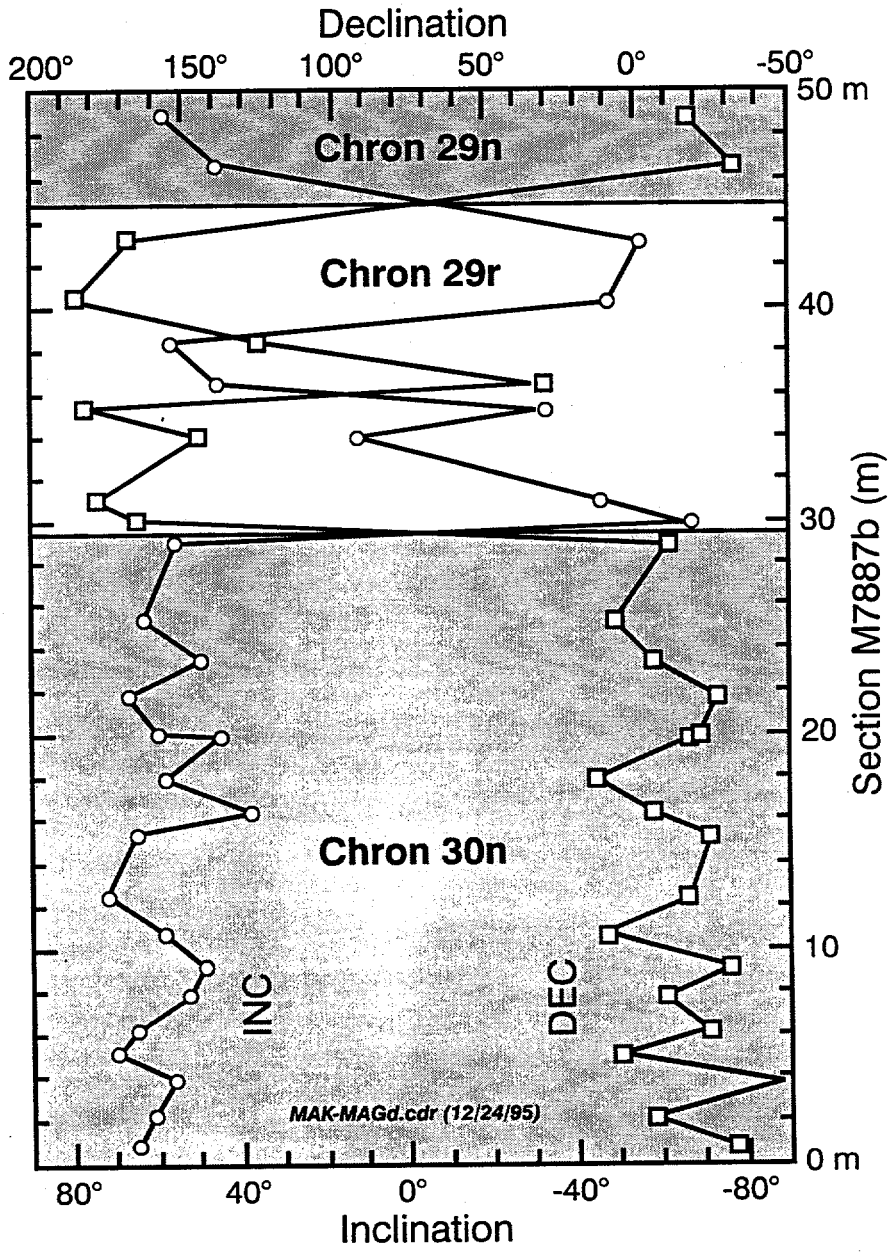


Figure 17

Hiatt and Hiatt South Localities, Makoshika State Park, Montana

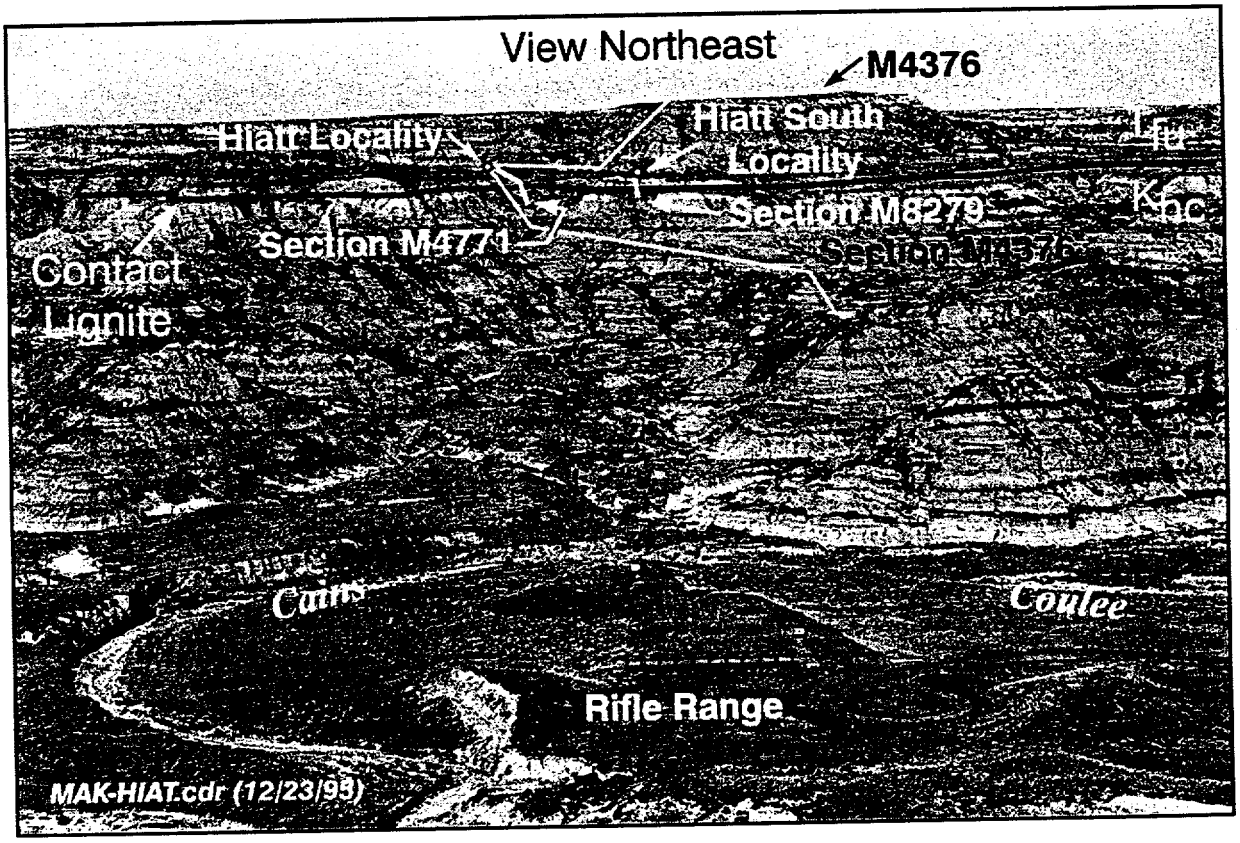


Figure 18

Hiatt South Locality,
Makoshika State Park, Montana

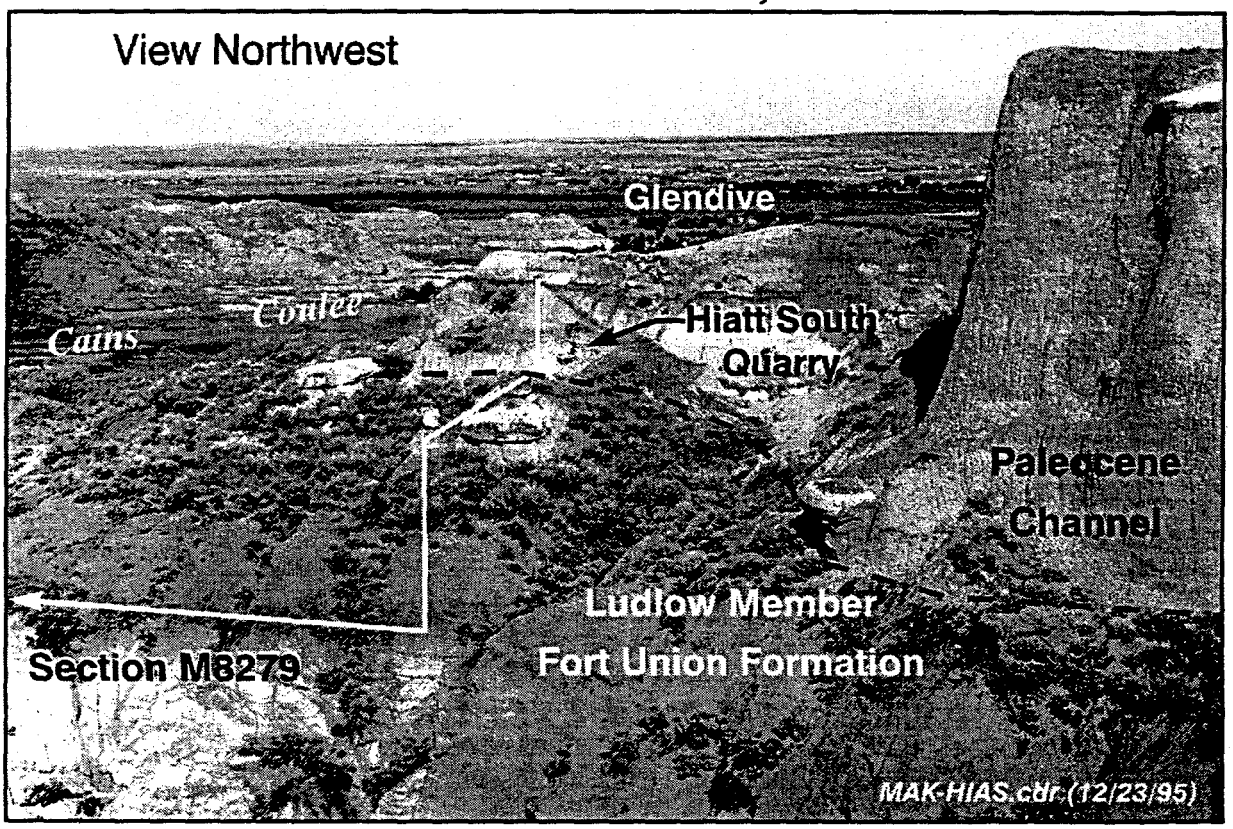


Figure 19

Bulk Sediment Screen Washing, Yellowstone River, Glendive, Montana

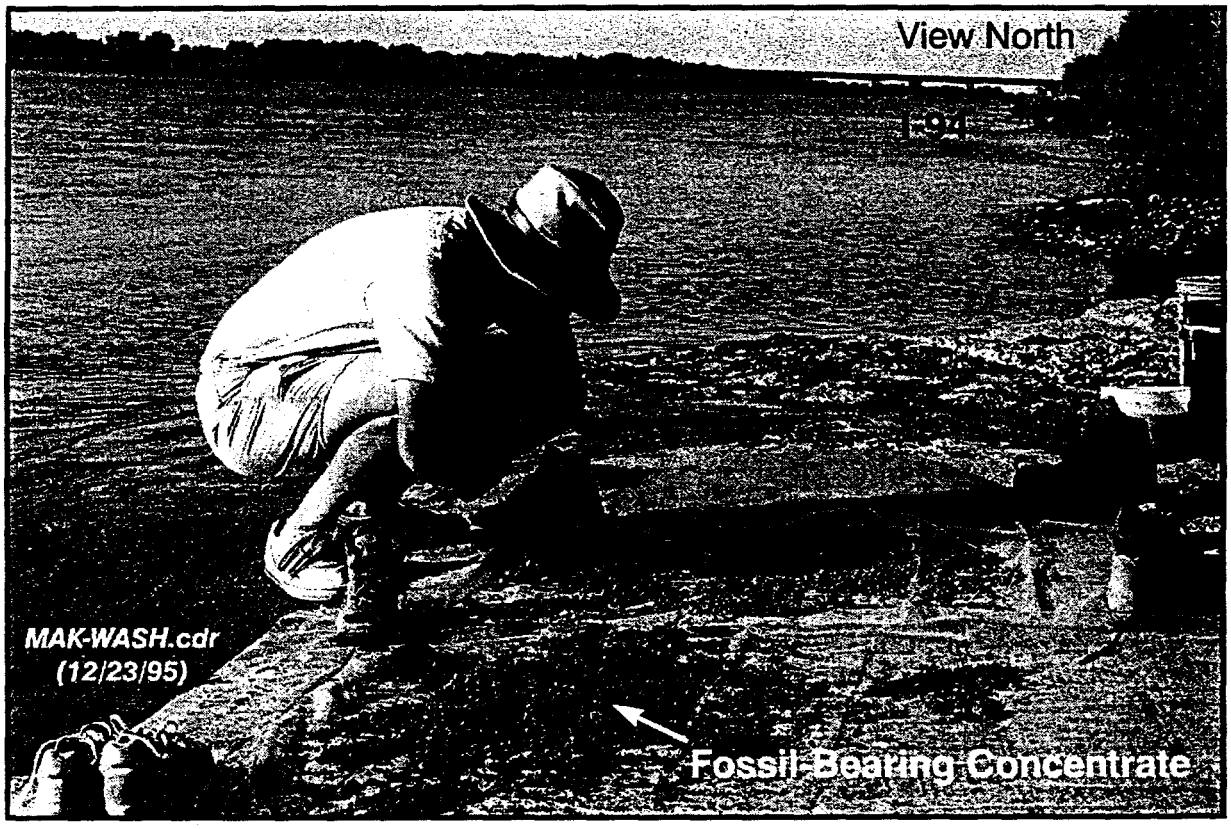
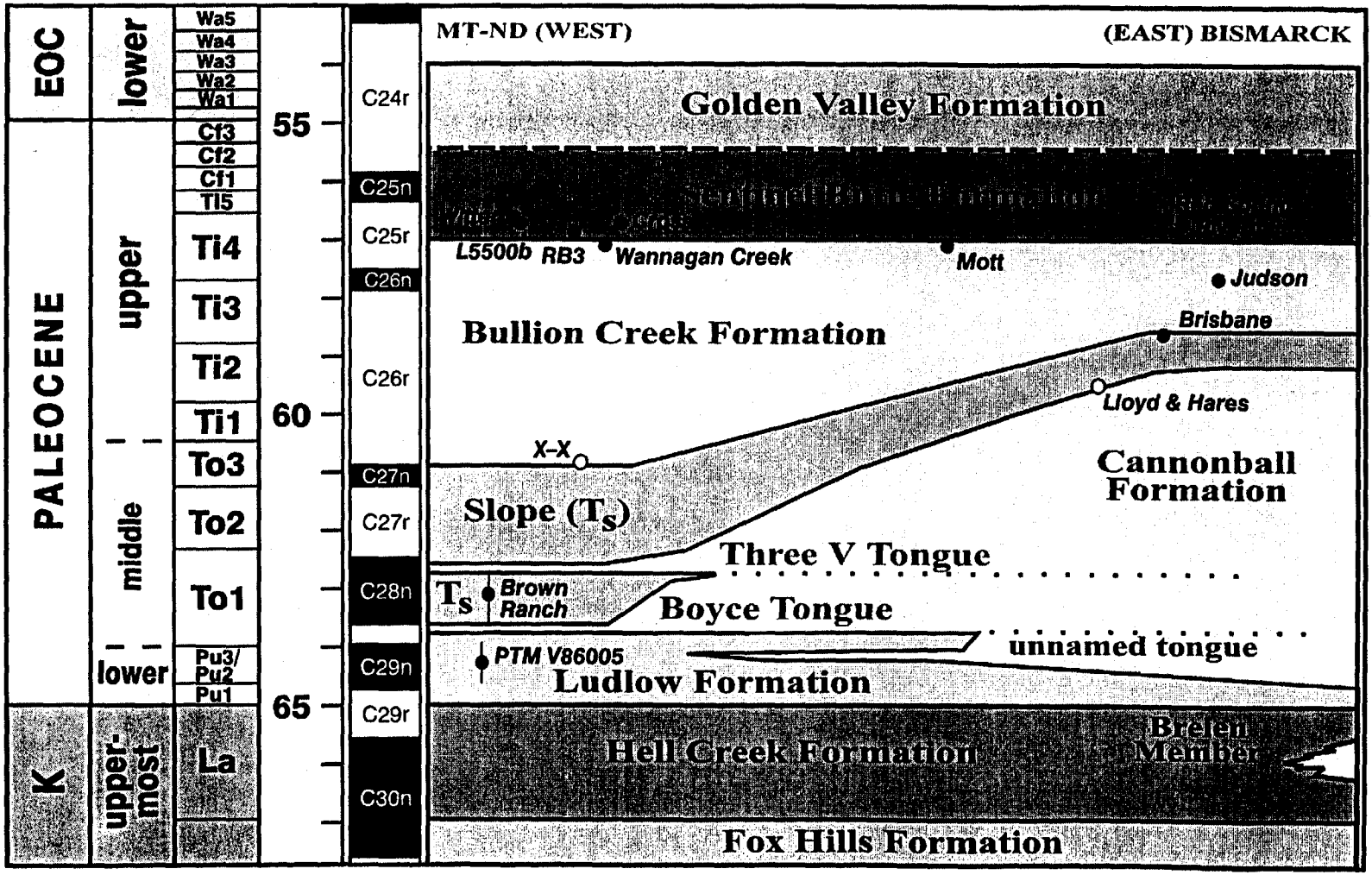


Figure 20

Chronostratigraphy of North Dakota Strata



Modified from Hartman and Butler (1995)

ND-STR01.cdr (12/26/95)

APPENDIX I

SUMMARY INFORMATION ON MAMMALIAN FOSSIL LOCALITIES, GLENDIVE AREA, MONTANA

APPENDIX I

Summary Information on Mammalian Fossil Localities, Glendive Area, Montana

Hell Creek Formation Localities

Muddy Tork Locality (L6205). This Upper Cretaceous locality is correlated to be about 11 m below the Cretaceous–Tertiary boundary and is in the basal part of the sandstone forming the feature known as Witches Hat. The Muddy Tork Locality occurs in sec. 2, T. 15 N., R. 55 E. on land owned by Dawson County Community College, located just outside of Makoshika State Park on the Glendive Quadrangle (1967), Dawson County, Montana. The locality was discovered by Dr. Robert Hiatt of Glendive as a nonmammalian vertebrate locality and has been locally referred to as *Tyrannosaurus* Peak (see Makoshika State Park Road Guide, Montana Department of Fish, Wildlife and Parks,, 1985). As a mammalian locality, Muddy Tork was rediscovered in 1992 and is locally the most productive Lancian-age locality. A few snail steinkerns were also found at this locality.

Q.V. Locality (L6261). This locality is stratigraphically nearly equivalent to the Muddy Tork Locality and is near the base of a thick channel sandstone complex. The Q.V. Locality occurs in sec. 5, T. 15 N., R. 56 E., in Makoshika State Park on the Glendive Quadrangle (1967), Dawson County, Montana. The Q.V. Locality was discovered in 1993 and to date has produced only a few teeth and one snail steinkern.

Vashus Locality (L6239). This locality is probably from the upper part of the Hell Creek Formation. The Vashus Locality, which may consist of sites at more than one location, is located south of Glendive Creek in the approximate area of sec. 29, T. 16 N., R. 56 E., Glendive Quadrangle, Dawson County, Montana. The three well-preserved jaws known from this locality were collected in the early or middle 1930s by the Vashus family.

Fort Union Formation (Ludlow Member) Localities

Hiatt Locality (L5418). This early Paleocene locality is about 10 m above the K/T boundary and is in the basal portion of a thick sequence of channel sandstones. The Hiatt Locality occurs in sec. 1, T. 15 N., R. 55 E., in Makoshika State Park, Glendive Quadrangle (1967), Dawson County, Montana. The Hiatt Locality was discovered in 1965 by Dr. Robert Hiatt of Glendive. Over the years, Dr. Hiatt and our research group have collected a number of surface-picked teeth. Bulk sampling of this locality has proven to be unproductive.

Hiatt South Locality (L6424). This locality is stratigraphically equivalent to the Hiatt Locality and is in the lowermost part of the intraclastic conglomeratic facies of a sequence of stacked channel sandstones. The Hiatt South Locality is located south of the Hiatt Locality along the same general upland surface in sec. 1, T. 15 N., R. 55 E., in Makoshika State Park, Glendive Quadrangle (1967), Dawson County, Montana. This highly productive locality was discovered in 1993, with significant collecting efforts occurring in 1994 centered on this locality. A few poor-quality freshwater mollusks have also been found at this locality.

Fort Union Formation (Ludlow Member) Localities (continued)

Deer Crash Locality (L6426). This site is also apparently stratigraphically equivalent to the horizons of the Hiatt and Hiatt South Localities and is likewise at the base of a major channel sandstone. The Deer Crash Locality is located in sec. 18, T. 15 N., R. 56 E., in Makoshika State Park, Glendive Quadrangle (1967), Dawson County, Montana. This locality was discovered in 1994 and has produced but one identifiable mammalian tooth. It is the only site in the park area that has produced specimens of freshwater clams (Unionidae).

School Well Locality (L6427a, b). The School Well Locality is the only mammalian locality known from the upper part of the Ludlow Member. Attempts to determine its exact stratigraphic horizon have proven difficult, as previously mapped interpretations of the Contact lignite at the base of the Fort Union Formation have been shown to be in error in this area (J.H. Hartman, unpublished data). The locality has been approximated to be about 60 m above the Hell Creek–Fort Union formational contact and occurs in the lowermost part of a thick channel sandstone. The School Well Locality is on private land to the northwest of Glendive in sec. 17, T. 17 N., R. 55 E., Stipek Quadrangle, Dawson County, Montana. The locality, which was discovered in 1993, has subsequently produced a few teeth and has laterally associated mollusk-bearing sediments (L6256a, b).

APPENDIX II

MAMMALIAN FAUNAS FOR FOSSILIFEROUS STRATA, GLENDIVE AREA, MONTANA

APPENDIX II

Mammalian Faunas for Fossiliferous Strata, Glendive Area, Montana

The Muddy Tork Fauna (Cretaceous – Lancian)

The mammals recovered from the Hell Creek Formation indicate a Late Cretaceous age (Lancian Land Mammal Age) and show ties with forms from localities elsewhere in Montana and in Wyoming differing from assemblages found at more northern latitudes in Canada. Pediomyid marsupials are diverse, and the multituberculate *Meniscoessus* is abundant. No eutherians and only one peradectid marsupial, *Turgidodon rhaister*, have been recovered.

Muddy Tork Fauna
- Multituberculata
  - *Meniscoessus robustus*
  - *Mesodma* cf. *M. thompsoni*
  - *Mesodma* sp. indet.
- Marsupialia
  - *Turgidodon rhaister*
  - *"Pediomys"* cf. *"P." krejcii*
  - *Pediomys elegans* or *"P." cooki*
  - *"Pediomys" hatcheri*
  - *"Pediomys" florencae*
  - *Didelphodon vorax*
  - ?*Didelphodon* sp.

The Hiatt Locality Fauna (Paleocene – Puercan)

The mammalian fauna recovered from the lowest part of the Fort Union Formation indicates an early Paleocene age (?Pu2 interval zone of the Puercan Land Mammal Age) and shows similarities to other early Paleocene faunas in Montana and Canada.

Hiatt Locality Fauna
- Multituberculata
  - *Neoplagiaulax* cf. *N. kremnus*
  - *Neoplagiaulax* sp.
  - Neoplagiaulacidae, gen. & sp. indet.
  - *Stygimys* sp.
  - ?*Ectypodus*
- Condylarthra
  - *Baioconodon* cf. *B. nordicum*
  - *Loxolophus schizophrenus*
  - *Loxolophus* sp.
  - ?*Oxyclaenus* sp.
  - ?*Carcinodon* sp.

The Hiatt Locality Fauna (continued)

Tinuviel eurydice
Oxyacodon ferronensis
Oxyacodon apiculatus
Eoconodon nidhoggi?
Taeniodonta
Onychodectes tisonensis

The School Well Fauna (Paleocene – Torrejonian)

The fauna recovered from the upper part of the Ludlow member of the Fort Union Formation is middle Paleocene in aspect (Torrejonian Land Mammal Age).

School Well Fauna
Multituberculata
Ptilodus montanus
Condylarthra
Litaletes sp.
Promioclaenus sp.
Periptychus sp.
Plesiadapiformes
Paromomys sp.

APPENDIX III

STRATIGRAPHIC SECTIONS FOR SIGNIFICANT LOCALITIES IN MAKOSHIKA STATE PARK

APPENDIX III

Stratigraphic Sections for Significant Localities in Makoshika State Park

See Figure 4 for section locations.

Measured Section M3723 (Butler, 1980, Section CCC2)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
025	2420.000	0.000	95.600				Top of Section. Formation (member) names assigned by Butler (1980).
024	2420.000	4.500	95.600		Ludlow		"Sandstone; no discernible structures; partly covered."
023	2405.236	7.500	91.100		Ludlow		"Sandstone, fine, yellowish gray to light olive gray; erosional base; very-large-scale sets; upper part poorly sorted, very silty; easterly trend."
022	2380.630	0.400	83.600	Contact lignite	Ludlow		"Lignite, black; persistent."
021	2379.318	4.800	83.200		Pretty Butte		"Siltstone, sandy (base) to shaly and lignitic (top)."
020	2363.570	25.200	78.400		Huff		"Sandstone, fine to very fine, clayey, yellowish gray to light olive gray; parts poorly consolidated; abundant concretions; erosional base; parts poorly sorted; large- and very-large-scale sets."
019	2280.894	11.900	53.200		Huff		"Sandstone, fine, light olive gray; large calcareous concretions; large-scale, weakly curved sets of cross strata, paleocurrent N87°E to easterly near top of unit, sets thin upward; small-scale, planar, convergent sets; some flat stratification (plane bed); top silty, shaly, lignitic, and concretionary."
018	2241.852	2.500	41.300		Huff		"Siltstone, sandy; loosely consolidated; jarosite nodules."
017	2233.650	0.300	38.800	lignite	Huff		"Lignite."
016	2232.666	2.800	38.500		Huff		"Shale, silty, olive gray, poorly sorted."
015	2223.480	0.200	35.700	lignite	Huff		"Lignite."
014	2222.824	0.900	35.500		Huff		"Shale, silty, olive gray; poorly sorted."
013	2219.871	10.500	34.600		Bacon Creek		"Sandstone, fine, yellowish gray; fines upward; tabular, calcareous concretions; fish vertebra; large-scale grouped, weakly curved to weakly planar sets of high-angle weakly concave to straight cross strata, paleocurrent S62°E; intraformational conglomerate (0.5 m) of shale pebbles; large-scale (1.5m), planar to weakly curved sets with organic matter on bedding planes, long foreset slopes, abundant shale clasts and pebble.."
012	2185.423	3.300	24.100		Bacon Creek		"Siltstone, yellowish gray; fines upward to shale and lignite shale in upper (1.3 m); abundant vertebrate fragments; jarositic and limonitic concretions; erosional top."
011	2174.596	2.900	20.800		Bacon Creek		"Siltstone, shale, and lignitic shale."
010	2165.082	0.300	17.900	lignite	Bacon Creek		"Lignite, laterally persistent."
009	2164.098	4.800	17.600		Bacon Creek		"Shale, silty to lignitic, and lignite, thin; a few thin siltstone and sandstone beds, yellowish gray, flatly bedded; thin, limonitic concretionary layers."
008	2148.350	4.800	12.800		Bacon Creek		"Shale, light olive gray to medium light gray; carbonaceous sequence; parts silty and sandy, brittle, fines up to lignitic shale (0.2 m), pale brown; vertebrate fossils; rootlets."
007	2132.602	1.000	8.000		Bacon Creek		"Shale, slightly lignitic."
006	2129.321	1.800	7.000		Bacon Creek		"Shale, slightly silty; laminated; hard; poorly sorted; limonite streaks, rootlets."
005	2123.416	0.500	5.200	lignite	Bacon Creek		"Lignite, black, laterally persistent."
004	2121.776	0.600	4.700		Bacon Creek		"Shale, lignitic."
003	2119.808	1.600	4.100		Bacon Creek		"Siltstone and shale; siltstone is sandy, yellow gray to dusky yellow, flatly stratified, rootlets; upper part of unit is shaly, lignitic; base is erosional."
002	2114.559	0.500	2.500	lignite	Bacon Creek		"Lignite, brown to black; well developed."
001	2112.919	2.000	2.000		Marmarth		"Sandstone, fine, silty, yellowish gray; top shaly; very-large-scale sets of sigmoidal cross strata."
000	2106.357	0.000	0.000				Base of section "Measured section CC2 - T. 15 N., R. 55 E., Sec. 1, NW quarter of NE quarter." Section measured by Butler (1980;

Measured Section M3723 (Butler, 1980, Section CCC2)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
							location determined from an unpublished field map (R.D. Butler, pers. comm.). The base and top of section CC2 are 2110 ft to 2320 ft, respectively, representing a thickness of 210 ft. The elevations given in this form conform to Butler's reported section thickness. Butler (1980, p. 253) stated the section top elevation as 2510 ft.

Measured Section M3724 (Butler, 1980, Section CC3)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Lithologic Description
034	2540.000		131.300				Top of Section. Formation (member) names assigned by Butler (1980).
033	2540.000	2.500	131.300		Ludlow		"Silt, grayish yellow; partly covered."
032	2531.798	7.000	128.800		Ludlow		"Claystone, partly covered."
031	2508.832	4.000	121.800		Ludlow		"Silt, partly covered."
030	2495.709	8.500	117.800		Ludlow		"Shale, silty, medium gray to light olive gray; lenticular; poorly sorted, grades laterally to cemented sandstone; erosional base."
029	2467.822	0.200	109.300	lignite	Ludlow		"Lignite."
028	2467.166	7.500	109.100		Ludlow		"Siltstone (base) and shale (top), dusky yellow to dark yellowish orange; siltstone flat bedded and interbedded with thin shale."
027	2442.560	4.800	101.600		Ludlow		"*Sandstone, fine to very fine, silty, light olive gray; thin repetitive concretionary layers; repetitive, evenly bedded flank; some small-scale sets of cross strata.*"
026	2426.812	0.100	96.800	lignite	Ludlow		"Lignite, black to brownish black; papery."
025	2426.484	5.800	96.700		Ludlow		"Siltstone and shale (top). dusky yellow; flat bedded."
024	2407.455	0.200	90.900	Contact lignite	Ludlow		"Lignite."
023	2406.799	3.200	90.700		Pretty Butte		"Shale, silty to lignitic; poorly sorted; limonite streaks and concretionary layers; upper 0.4 m lignitic."
022	2396.300	13.100	87.500		Huff		"Sandstone, fine up to very fine, light olive gray to yellowish gray; *large-scale, planar, convergent sets of high-angle (15°) cross strata* with lignitic matter on bedding planes; paleocurrent S85°E; very-large-scale sets of low-angle (13 deg.) cross strata, dip N 40 deg. W to north; near top, siltstone and organic matter more abundant, flat, irregular, and ripple lamination; very-large-scale sets also more abundant and thinner;.."
021	2353.322	12.000	74.400		Huff	bones	"Shale, lignitic shale, and lignite; oxidized; poorly sorted; interbedded; shale beds 1.5 m thick, lignitic shale 0.7 to 1.0m, and lignite (0.3 to 0.5 m); lignite is lenticular; vertebrate fragments 4.5 m *above base; dusky yellow siltstone 8 m above base.*"
020	2313.952	4.500	62.400		Huff		"Shale, gray; poorly sorted; limonite stained."
019	2299.188	0.200	57.900	lignite	Huff		"Lignite."
018	2298.532	6.800	57.700		Huff		"Shale and siltstone, interbedded; parts poorly sorted; siltstone, interlaminated with sandstone, shale, and lignite; flat to irregular stratification; rootlet zone 2 m thick."
017	2276.223	10.100	50.900		Huff		"Sandstone, fine to very fine, yellowish gray to light olive gray; tabular concretions; large-scale (0.5 m), planar, convergent sets of high-angle (22°), straight cross strata, paleocurrent S35°E; fines up to *siltstone (2 m thick) and silty shale with flat and ripple* stratification; rootlets."
016	2243.087	4.500	40.800		Bacon Creek		"Shale, poorly sorted; some lignitic silt and lignitic shale with gypsum crystals."
015	2228.323	0.100	36.300	lignite	Bacon Creek		"Lignite, pale brown; weathers into relief."
014	2227.995	3.700	36.200		Bacon Creek		"Siltstone, shale and lignitic shale."
013	2215.856	0.100	32.500	lignite	Bacon Creek		"Lignite, parts silty; papery, fissile."
012	2215.528	2.200	32.400		Bacon Creek		"Shale and siltstone; hard; limonite streaks; silts up."
011	2208.310	4.500	30.200		Bacon Creek		"Siltstone, sandy to clayey (30% clay) yellowish gray; hard; *interbedded with sandstone; limonite streaks, rootlets; shales up to* lignitic shale (0.4 m), shale (0.8 m), and lignitic shale (0.4 m); topped by cemented lignitic siltstone, poorly sorted."
010	2193.546	0.300	25.700	lignite	Bacon Creek		"Lignite, sandy to silty, pale brown to black; woody; laminated and poorly sorted."
009	2192.562	2.400	25.400		Bacon Creek		"Shale, yellowish gray, lower part interbedded with siltstone, middle

Measured Section M3724 (Butler, 1980, Section CC3)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Lithologic Description
							part bentonitic, and upper part lignitic."
008	2184.688	2.200	23.000		Bacon Creek		"Shale, yellowish gray; lower part interbedded with siltstone, middle part bentonitic, upper part slightly lignitic."
007	2177.470	1.500	20.800		Bacon Creek		"Shale, upper part slightly lignitic."
006	2172.549	1.600	19.300		Bacon Creek		"Siltstone and silty shale, yellowish gray; cemented to loosely consolidated."
005	2167.300	0.300	17.700	lignite	Bacon Creek		"Lignite, pale brown to black."
004	2166.316	3.900	17.400		Bacon Creek		"Siltstone, shale, and lignitic shale; siltstone is 1.5 m thick, interbedded with very fine sandstone; shale is olive gray; overall poorly sorted, flatly stratified, rootlets, erosional base."
003	2153.521	0.600	13.500	lignite	Bacon Creek		"Lignite, brown to black."
002	2151.553	0.900	12.900		Marmarth?		"Shale and lignitic shale."
001	2148.600	12.000	12.000		Marmarth?		"Sandstone, fine to medium, clayey (top); yellowish gray; fines upward; large-scale (0.1 to 0.5 m), grouped, planar sets of high-angle straight, tangential cross strata and irregular sets of straight to concave cross strata, paleocurrent S15°W; pyrite nodules at 6 m above base; very clayey at 12 m."
000	2109.230	0.000	0.000				Base of section "Measured section CC3 - T. 15 N., R. 55 E., Sec. 1, NE quarter of SE quarter." Section measured by Butler (1980); location determined from unpublished field map (R.D. Butler, pers. comm.). The base and top of Section CC3 were given as 2110 ft to 2450 ft, respectively, representing a thickness of 340 ft. The elevations given in this here represent Butler's given section thickness. The top elevation was estimated at 2540 ft to conform to the given section thickness, with the base minimized.

Measured Section M4376 (Hiatt Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Rock Sample No.	Lithologic Description
036	2525.727		113.000					Top of section has a surveyed elevation of 2510 ft. Assuming a greater thickness for the section than the available elevation (becase of variable thick channel sandstones), the top of the section will range to 2525 ft, so that the base may start at 2155 ft. This better places the Hiatt Locality elevation as determined through use of the topographic quadrangle.
035	2525.727	10.000	113.000		Ludlow			Covered to top.
034	2492.919	0.500	103.000		Ludlow			Claystone, carbonaceous; fissile; light brownish gray (5 YR 6/1).
033	2491.279	3.400	102.500		Ludlow			Claystone, silty; organic fragments on planar bedding; light brownish gray (5 YR 6/1).
032	2480.124	8.000	99.100		Ludlow			Siltstone, alternating with planar bedded silty claystone, with small scale ripples in the siltstone and multiple discontinuous concretionary layers; moderate yellowish brown (10 YR 5/4).
031	2453.878	25.000	91.100		Ludlow			Sandstone, fine-grained, with salt and pepper surface appearance; ripply trough cross-bedded, numerous reactivated surfaces, and intraclastic conglomerate layers; yellowish gray (5 Y 7/2).
030	2371.858	1.000	66.100		Ludlow	L5418		Sandstone, fine-grained, with salt and pepper surface appearance; large-scale cross-bedding in lowermost portion of unit, horizontally bedded above 1 m; yellowish gray (5 Y 7/2), dusty yellow (5 Y 6/4) in quarry, with a moderate brown (5 YR 3/4) color on planar surfaces; Hiatt locality (L5418) (0 to 1.0 m).
029	2368.577	0.500	65.100		Ludlow			Lignite.
028	2366.937	0.600	64.600		Ludlow			Covered.
027	2364.969	3.000	64.000		Ludlow			Claystone, silty, fissile; not rooted, very little plant debris; moderate yellowish brown (10 YR 4/2).
026	2355.127	0.100	61.000		Ludlow			Claystone, carbonaceous; pale yellowish brown (10 YR 6/2).
025	2354.799	0.250	60.900	unnamed lignite	Ludlow			Lignite.
024	2353.979	5.600	60.650		Ludlow			Sandstone, very fine-grained, with salt and pepper appearance, with some well lithified lenses, trough cross bedded; moderate yellowish brown surface (10 YR 5/4). with some claystone layers of a very light gray (N 8) (fresh).
023	2335.607	0.250	55.050	Contact lignite	Ludlow		Lithic sample	Lignite (Contact lignite of Sholes and others, 1989). This lignite was previously sampled by Peck and Hartman in July 1990.
022	2334.787	0.150	54.800		Hell Creek		Lithic sample	Claystone, roots and plants, with slickenslides; olive black (5 Y 2/1). Unit previously sampled for pollen by Peck and Hartman in July 1990.
021	2334.295	0.200	54.650		Hell Creek		Pollen 5	Claystone, roots and plants, with slickenslides; olive black (5 Y 2/1). Pollen sample 5 taken 0.5 m to 0.7 m above base of Unit 18.
020	2333.639	0.100	54.450		Hell Creek			Claystone; roots and plants, with slickenslides; olive black (5 Y 2/1).
019	2333.311	0.100	54.350		Hell Creek		Pollen 4	Claystone; roots and plants, with slickenslides; olive black (5 Y 2/1). Pollen Sample 4 taken 0.3 m to 0.4 m above

Measured Section M4376 (Hiatt Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Rock Sample No.	Lithologic Description
								base of Unit 18.
018	2332.983	0.300	54.250		Hell Creek			Claystone; roots and plants, with slickenslides; olive black (5 Y 2/1).
017	2331.999	2.800	53.950		Hell Creek		Pollen 3	Sandstone, clayey and silty very fine-grained (coarse mudstone); rooted; about dusky yellow (5 Y 6/4) to yellowish gray (5 Y 7/2). Pollen Sample 3 taken 2.5 m above base of unit.
016	2322.813	10.800	51.150		Hell Creek			Sandstone, fine-grained, salt and pepper appearance in general; light gray (N 7), with yellowish gray (5 Y 7/2) on some surfaces; steep slope-former, laterally continuous to south and west (as far as under tripod station); some major slumping occurs over this unit.
015	2287.380	1.900	40.350		Hell Creek		Pollen 1-2	Claystone, silty; root traces and organic debris abundant; light olive gray (5 Y 5/2), with rusty brown sandstone concretions. Pollen Samples 1 and 2 were taken at 0.5 and 1.25 m above the base of unit.
014	2281.146	1.500	38.450		Hell Creek			Siltstone, slightly clayey; root traces, planar bedded; yellowish gray (5 Y 7/2)
013	2276.225	2.000	36.950		Hell Creek			Claystone, slightly silty; root traces and plant fragments, bench former in part; light olive gray (5 Y 5/2)
012	2269.663	7.000	34.950		Hell Creek			Sandstone, fine-grained, salt and pepper surface appearance; fluted and trough bedded; surface cover on near vertical face, with some very soft sandstone through intervals, with some case-hardening; moderate yellowish brown (10 YR 5/4), some beds are darker red or other shades of brown color. This unit is lost or greatly reduced up tributary to northeast.
011	2246.697	3.000	27.950		Hell Creek			Siltstone, clayey, with clayey and silty lenses ,up to base of variably lithified cliff-forming sandstone channelform; large horizontal root traces; yellowish gray (5 Y 7/2). Lateral shift in section route to north along base of channel to incision-cut of steep rivulet.
010	2236.855	1.700	24.950		Hell Creek			Claystone, carbonaceous silty; laminated, no root traces, plant fragments, including large vitreous fragments; pale yellowish brown (10 YR 6/2) with darker shades. Unit is probably lacustrine.
009	2231.278	1.100	23.250		Hell Creek			Siltstone, clayey; abundant roots, with disseciated surface; yellowish gray (5 Y 8/1).
008	2227.669	6.000	22.150		Hell Creek			Sandstone, very fine-grained, salt and pepper appearance; trough bedded with cemented pods, otherwise friable; trend of 115° on small ripples in concretions; concretions common, with some fining-upwards evident; color difficult to assess, basically light gray (N 7); concretions variable color grayish brown (5 YR 3/2).
007	2207.984	2.900	16.150		Hell Creek			Claystone, with bands of silty claystone and clayey siltstone; without bedding; vertical and horizontal roots; yellowish gray (5 Y 7/2) (silty) to light olive gray (5 Y 6/1) (clayey).
006	2198.470	1.400	13.250		Hell Creek			Sandstone, finge-grained, slightly clayey, variegated, cross-stratified; with vertical roots; yellowish gray (5 Y 7/2) and some light olive gray (5 Y 5/2).
005	2193.877	2.600	11.850		Hell Creek			Siltstone, clayey; abundant roots, desiccated surface;

Measured Section M4376 (Hiatt Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Rock Sample No.	Lithologic Description
								dusky yellow (5 Y 6/4).
004	2185.347	0.600	9.250		Hell Creek			Siltstone, clayey, very blocky, but laminated in part; plant hash abundant; a laterally discontinuous ledge former; pale yellowish brown (10 YR 6/2).
003	2183.379	1.050	8.650		Hell Creek			Claystone, silkty, very thin silty layers (lenses) common; plant hash abundant and horizontal root traces common (0.5 cm); light olive gray (5 Y 5/2).
002	2179.934	0.400	7.600		Hell Creek			Sandstone, very fine-grained, small ripple laminated, ledge-former; moderate yellowish brown (10 YR 5/4), weathered (dry) dusky yellow (5 Y 6/4).
001	2178.622	7.200	7.200		Hell Creek			Siltstone, clayey; contains variable amounts of claystones and siltstones; banded fissile, clean, slickenside-bearing, with desiccated surface, abundant root traces, and plant parts; dusky yellowish brown claystone to yellowish gray (5 Y 7/2) to light olive gray (5 Y 5/2).
000	2155.000	0.000	0.000					Base of section.

Measured Section M4769a (Muddy Tork Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Lithologic Description
024	2267.807	0.000	48.100				Top of section at local top of east-west ridge.
023	2267.807	1.500	48.100	Witches Hat Sandstone	Hell Creek	L6205	Sandstone, large scale trough cross beds; large clayball concretion occurs 3 m above base of sandstone unit; nearly yellowish gray (5 Y 7/2) and slightly darker shades. This is the sandstone body that forms part of Witches Hat. Locality L6205 (WB92-15) is in the lowermost portion of this unit, with sampling about 3 m below local top of the measured section and ridge.
022	2262.886	4.200	46.600		Hell Creek	bones	Siltstone, clayey, with some interbedded organic rich horizons; yellowish gray (5 Y 7/2); surface of unit has bone material, which is derived from overlying unit.
021	2249.107	0.400	42.400		Hell Creek		Siltstone, clayey well laminated, abundant organic debris; dark yellowish brown (10 YR 4/2).
020	2247.795	3.150	42.000		Hell Creek		Siltstone, clayey, in upper and lower thirds and a silty claystone in the middle third; the gradations between these two lithologies are indistinguishable; root traces occur in upper third of the unit; the color in the lower and upper thirds of the unit is yellowish gray (5 Y 7/2), while the middle third is light olive gray (5 Y 6/1).
019	2237.460	2.700	38.850		Hell Creek		Siltstone, slightly clayey, grading upward into clayey siltstone; moderate yellowish brown (10 YR 5/4); resistant ironstone concretion layer at top of unit (present only locally).
018	2228.602	1.250	36.150		Hell Creek		Sandstone, very fine-grained, fining upward to a slightly clayey siltstone; some organic material present on bedding surfaces; bedding includes planar and small scale cross bedding; light olive gray (5 Y 5/2).
017	2224.501	0.900	34.900		Hell Creek		Siltstone, clayey; between dark yellowish brown (10 YR 4/2) and dusky yellowish brown (10 YR 2/2).
016	2221.548	2.500	34.000		Hell Creek		Siltstone, slightly sandy, appears to fine upwards, with the lower portion being a slightly silty, very fine-grained sandstone, with some root traces in upper portion; nearly light olive gray (5 Y 5/2).
015	2213.346	0.150	31.500		Hell Creek		Claystone, silty; dusky yellowish brown (10 YR 2/2).
014	2212.854	0.750	31.350		Hell Creek		Siltstone, clayey, planar laminated, with abundant coalified organic debris on the laminae; dark yellowish brown (10 YR 4/2).
013	2210.393	0.600	30.600		Hell Creek		Claystone, slightly silty, with some pedogenic slickensides; nearly olive gray (5 Y 4/1), and brown black (5 YR 2/1) in upper 10 cm.
012	2208.425	2.200	30.000		Hell Creek		Siltstone, clayey, with clay content increasing towards the top; light olive gray (5 Y 5/2).
011	2201.207	3.700	27.800		Hell Creek		Claystones, silty, and clayey siltstones, deeply weathered; this unit appears to be somewhat more organic rich in the upper 0.5 m; light olive gray (5 Y 5/2) in lower part, dark yellowish brown (10 YR 4/2) in upper part.
010	2189.068	3.400	24.100		Hell Creek	bones	Sandstone, fine-grained sandstone, with organic rich silty sandstone layers; planar bedding and small scale cross-bedding; indistinct upper contact; the color is slightly darker than yellowish gray (5 Y 7/2). Bone fragments appear to be weathering out of the base of this unit.
009	2177.913	5.400	20.700		Hell Creek	bones	Sandstone, silty, interbedded with clayey sandy siltstone, planar bedded in most places, with organic debris on bedding planes; some root traces noted in upper portion of unit; the color is slightly darker than yellowish gray (5 Y 7/2). Reptilian[?] remains (bone fragments) strewn about surface.
008	2160.197	2.150	15.300		Hell Creek		Claystone, silty; some root traces; light olive gray (5 Y 5/2), darker at the top of the unit indicating greater organic content; the upper portion of unit is nearly olive black (5 Y 2/1).

Measured Section M4769a (Muddy Tork Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Lithologic Description
007	2153.143	1.100	13.150		Hell Creek		Claystone, silty, lignitic stringers; upper 10 cm is very organic rich, with abundant plant fragments; the color is between dusky yellowish brown (10 YR 2/2) and brownish gray (5 Y 4/1), with the uppermost portion a pale brown (5 YR 5/2) in color.
006	2149.534	0.900	12.050		Hell Creek		*Claystone, silty, smectitic, some root traces; forms a popcorn* appearance when weathered; light olive gray (5 Y 6/1).
005	2146.581	0.400	11.150		Hell Creek		Claystone, silty, to clayey siltstone, with common plant fragments and root traces; color is between olive gray (5 Y 4/1) and light olive gray (5 Y 6/1).
004	2145.269	1.300	10.750		Hell Creek		Siltstone, clayey, with root traces and plant fragments throughout the unit; fairly sharp upper contact; yellowish gray (5 Y 7/2).
003	2141.004	0.750	9.450	Visitor bed	Hell Creek		Siltstone, clayey, organic rich; brownish black (5 YR 2/1). This unit is an extensive traceable unit in this area (Rob Kukowski's lignite).
002	2138.543	0.500	8.700		Hell Creek		*Siltstone, sandy, with root traces;* light olive gray (5 Y 6/1).
001	2136.903	8.200	8.200		Hell Creek		Sandstone, fine-grained, large scale trough cross-beds; unit is rilled, and a cliff former; concentration of organic debris on some of the large scale trough cross beds; uppermost portion of unit has root traces; color is dusky yellow (5 Y 6/4) to yellowish gray (5 Y 7/2).
000	2110.000	0.000	0.000				Base of section on pediment flats next to the Welcome sign at the entrance to Makoshika State Park (at park boundary).

Measured Section M4769b (Witches Hat Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Lithologic Description
003	2354.584	0.000	26.450			Top of section at top of Witches Hat.
002	2354.584	3.500	26.450	Witches Hat Sandstone	Hell Creek	Claystone, silty, smectitic, 3.0 to 4.0 meters to top of hat. This unit could not be examined in fresh exposure due to the precipitous nature of the exposure.
001	2343.101	22.950	22.950	Witches Hat Sandstone	Hell Creek	Sandstone, large scale trough cross beds; scoured base thickening local section.
000	2267.807	0.000	0.000			Base of section is local base of Witches Hat Sandstone at Witches Hat.

Measured Section M4770 (Fern Spike Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
040	020	2450.000		24.900				Top of section.
039	019	2450.000	3.000	24.900		Ludlow		Covered unit to top-most of ridge surface. Photos taken towards Hiatt Locality from northern portion of ridge. This view clearly shows measured Section M4376 (on bearing of 65°), *more or less directly over rifle range. The route of last year's* use of a front-end loader is clearly visible.
038	018	2440.158	3.000	21.900		Ludlow		Sandstone (continued), locally less well-lithified, but laterally with ledges and caprock; paleocurrent direction is to east at about 130°.
037	017	2430.316	3.800	18.900		Ludlow		*Sandstone, well lithified, channelform, large-scale trough cross* bedding, forms ledges and caprock locally (same lithology as underlying unit minus orange stringers). Surface weathered color is moderate yellowish brown (10 YR 5/4) to dark yellowish orange (10 YR 6/6) (various photos taken).
036	016	2417.849	3.000	15.100		Ludlow		*Sandstone, fine-grained, with some medium-grained clasts;* approximately yellowish gray (5 Y 8/1), with numerous thin orange layers about grayish orange (10 YR 7/4); forms a weathered surface with a bright reflectance.
035	015	2408.007	0.100	12.100		Ludlow		Lignite, poor, to carbonaceous shale; probably discontinuous.
034	014	2407.679	0.200	12.000		Ludlow		Claystone, with coaly stringers up to 3 cm thick and coaly debris on surfaces of laminae; "chocolate brown," pale yellowish brown (10 YR 6/2) to pale brown (5 YR 5/2).
033	013	2407.023	2.350	11.800		Ludlow		Siltstone, clayey, but forming heavily weathered slope, banded with oxidized layers of orange and grays and light browns. Unit forms a dissected surface typical of this lithology.
032	012	2399.313	0.500	9.450		Ludlow		Claystone, well laminated, plant rich; mottled pale yellowish brown (10 YR 6/2).
031	011	2397.673	0.400	8.950		Ludlow		Claystone, with plant stems; light olive gray (5 Y 5/2).
030	010	2396.361	0.350	8.550		Ludlow		Shale, paper, slightly silty; black (N 1); grading up into claystone, fissile, but not paper shale (does not break into sheets), grayish brown (5 YR 3/2), but varying in color.
029	009	2395.213	0.150	8.200		Ludlow	0-15 cm	Lignite. Sample taken for pollen analysis.
028	008c	2394.721	0.050	8.050		Ludlow	20-25 cm	Claystone (uppermost portion of lithic Units 26-28), irregularly bedded, root traces, dusky yellowish brown (10 YR 2/2). Sample for pollen analysis taken 20-25 cm above the base of unit.
027	008b	2394.557	0.100	8.000		Ludlow		Claystone, laminated (see Unit 26).
026	008a	2394.229	0.100	7.900		Ludlow	0-10 cm	Claystone, laminated, in lower portion of unit, with wood fragments, few root traces; variable color due to organic content, ranges from moderate brown (5 YR 3/4) to a pale yellowish brown (10 YR 6/2) (the latter is a more weathered *color), with black organic fragments. Uppermost portion is* claystone, irregularly bedded, root traces, dusky yellowish brown (10 YR 2/2). Samples for pollen analysis taken 0-10 cm and 20-25 cm above the base. Total thickness of Unit 26-28 is 0.25 m.
025	007	2393.901	1.950	7.800		Ludlow		*Siltstone, coarse, to very fine-grained sandstone, grading* upwards to clayey siltstone to slightly clayey siltstone; lower part is granular and friable, and yellowish gray (5 Y 7/2); upper part is about dusky yellow (weathered?) (5 Y 6/4).
024	006b	2387.503	0.350	5.850		Ludlow		Claystone, slightly silty (see Unit 23). Top of unit marked by oxidized limonitic concretionary chips.

Measured Section M4770 (Fern Spike Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
023	006a	2386.355	0.100	5.500		Ludlow	0-10 cm	Claystone, slightly silty, more silty towards the top, laminated, with disseminated organic debris and leaf fossils; pale yellowish brown (10 YR 6/2) with yellowish gray (5 Y 7/2). Sample for pollen analysis taken from 0-10 cm above base. Total thickness of Units 23 and 24 is 0.45 m. [Processed - Paleocene palynomorphs.]
022	005	2386.027	2.850	5.400		Ludlow		Siltstone, slightly clayey, well laminated, organic debris on bedding planes; light olive gray (5 Y 6/1) to, and may be predominantly, yellowish gray (5 Y 7/2); variegated oxidized orange bands; browns grade into grays; topped by claystone (about 20 cm thick), very light gray to gray (N 8-N 7). On very steep and weathered cliff (dangerous to measure).
021	004d	2376.677	0.050	2.550		Ludlow	15-20 cm	Lignite (see Unit 18). [Processed - Paleocene palynomorphs.]
020	004c	2376.513	0.050	2.500		Ludlow	10-15 cm	Lignite (see Unit 18). [Processed - Paleocene palynomorphs.]
019	004b	2376.349	0.050	2.450		Ludlow	5-10 cm	Lignite (see Unit 18). [Processed - Paleocene palynomorphs.]
018	004a	2376.185	0.050	2.400	Contact lignite	Ludlow	0-5 cm	Lignite, plant rich (Contact Coal of Sholes and others, 1989). Samples for pollen analysis taken every 5 cm through unit. Total thickness of unit 18-21 is 0.20 m. [Processed - Paleocene palynomorphs.]
017	003d	2376.021	0.050	2.350	Fern Spike	Hell Creek	15-20 cm	Siltstone, clayey, or silty claystone (see Unit 14). Samples for pollen analysis taken from 15-20 cm above the base of unit. [Processed - includes fern spike indicating lowermost Paleocene.]
016	003c	2375.857	0.050	2.300		Hell Creek	10-15 cm	Siltstone, clayey, or silty claystone (see Unit 14). Sample for pollen analysis taken from 10-15 cm above the base of unit. [Processed - Cretaceous palynomorphs.]
015	003b	2375.693	0.050	2.250		Hell Creek		Siltstone, clayey, or silty claystone (see Unit 14).
014	003a	2375.529	0.050	2.200		Hell Creek	0-5 cm	Siltstone, clayey, or silty claystone, coarsening upward from clayey to silty; root traces throughout, pedogenic slickensides in lower part, more laminated above; lower color mottled brownish black (5 YR 2/1) with olive black (5 Y 2/1) and lighter colors; upper color is pale yellowish brown (10 YR 6/2); Samples for pollen analysis taken from 0-5 cm, 10-15 cm, and 15-20 cm above the base. Total thickness of Units 14-17 is 0.20 m. [Processed - Cretaceous palynomorphs.]
013	002g	2375.365	0.100	2.150		Hell Creek	145-155 cm	Siltstone, clayey (see Unit 7). Sample taken for pollen analysis from 145-155 cm above the base of unit.
012	002f	2375.037	0.550	2.050		Hell Creek		Siltstone, clayey, laminated (see unit 7).
011	002e	2373.233	0.100	1.500		Hell Creek	80-90 cm	Siltstone, clayey (see unit 7). Sample taken for pollen analysis from 80-90 cm above the base of unit.
010	002d	2372.905	0.300	1.400		Hell Creek		Siltstone, clayey (see Unit 7).
009	002c	2371.921	0.100	1.100		Hell Creek	40-50 cm	Siltstone, clayey (see Unit 7). Sample taken for pollen analysis from 40-50 cm above base of unit. [Processed - Cretaceous palynomorphs.]
008	002b	2371.593	0.200	1.000		Hell Creek		Siltstone, clayey (see Unit 7).
007	002a	2370.937	0.200	0.800		Hell Creek	0-20 cm	Siltstone, clayey, fining upward to a silty claystone, and to a slightly silty claystone at top; laminated, some root traces and some plant fragments, more bioturbated toward top; variegated color (difficult to classify), pale yellowish brown (10 YR 6/2) to brownish black? (5 Y 2/1). Samples taken for pollen analysis from 0-20 cm, 40-50 cm, 80-90 cm, and 145-155 cm above the base. Total thickness of Units 7-13 is 1.55 m.
006	001f	2370.281	0.100	0.600		Hell Creek	50-60 cm	Siltstone, clayey (see Unit 1). Sample for pollen analysis taken

Measured Section M4770 (Fern Spike Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
								from 50-60 cm above base of unit.
005	001e	2369.953	0.100	0.500		Hell Creek		Siltstone, clayey (see Unit 1).
004	001d	2369.625	0.100	0.400		Hell Creek	30-40 cm	Siltstone, clayey (see Unit 1). Sample for pollen analysis taken from 30-40 cm above base of unit.
003	001c	2369.297	0.150	0.300		Hell Creek		Siltstone, clayey (see Unit 1).
002	001b	2368.805	0.050	0.150		Hell Creek	10-15 cm	Siltstone, clayey (see Unit 1). Sample for pollen analysis taken at 10-15 cm above base of unit. [Processed - Cretaceous palynomorphs.]
001	001a	2368.641	0.100	0.100		Hell Creek		Siltstone, clayey, with thin laminae of claystone and root traces; less silt and fewer root traces towards top; few macroplant remains; organic rich color, grayish black (N 2) to dark yellowish brown (10 YR 4/2). Samples for pollen analysis taken from 10-15 cm, 30-40 cm, and 50-60 cm above the base of unit. Total thickness of Units 1-6 is 0.60 m.
000	000	2368.313	0.000	0.000				Base of section. Contact Coal Section No. 1. Southwest-facing steep exposure below grassed-topped ridge, located southeast of Witches Hat (but on ridge north of the ridge bearing Witches Hat), southwest of tarred park road, south of Cains Coulee. Section base is on a bearing of 320° with the Witches Hat. Section begins above channel sandstone correlative with the Witches Hat Sandstone.

Measured Section M4771 (K/T Boundary Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
024	007	2333.003		7.620				Top of section.
023	006	2333.003	4.000	7.620		Ludlow		Sandstone, very fine-grained; light colored in weathered outcrop; very light gray (N 8), with very, very little yellow.
022	005c	2319.880	0.050	3.620	Contact lignite	Ludlow	10-15 cm	Lignite (see Unit 20).
021	005b	2319.716	0.050	3.570	Contact lignite	Ludlow	5-10 cm	Lignite (see Unit 20).
020	005a	2319.552	0.050	3.520	Contact lignite	Ludlow	0-5 cm	Lignite, with interlayers of laminated pale yellowish brown (10 YR 6/2) claystone, with black organic debris on laminae; lignite is poorly developed; Unit has coalified appearance in places, rather than as massive lignite; sharp upper contact. Pollen samples taken every 5 cm. Total thickness for old Unit 5 is 0.15 m (Units 20-22).
019	004b	2319.388	0.040	3.470		Hell Creek	3-7 cm	Claystone (see Unit 18). The upper pollen sample was taken within the upper 4 cm of the unit.
018	004a	2319.257	0.030	3.430		Hell Creek	0-3 cm	Claystone, with black organic debris on laminae and a few root traces. The color is more or less chocolate brown, which is primarily a pale brown (5 YR 5/2). The lower pollen sample was taken within the lower 3 cm of the unit. The total thickness of the old Unit 4 is 0.07 m (Units 18-19).
017	003o	2319.159	0.050	3.400		Hell Creek	70-75 cm	Claystone (see Unit 3).
016	003n	2318.995	0.050	3.350		Hell Creek	65-70 cm	Claystone (see Unit 3).
015	003m	2318.831	0.050	3.300		Hell Creek	60-65 cm	Claystone (see Unit 3).
014	003l	2318.667	0.050	3.250		Hell Creek	55-60 cm	Claystone (see Unit 3).
013	003k	2318.503	0.050	3.200		Hell Creek	50-55 cm	Claystone (see Unit 3).
012	003j	2318.339	0.050	3.150		Hell Creek	45-50 cm	Claystone (see Unit 3).
011	003i	2318.175	0.050	3.100		Hell Creek	40-45 cm	Claystone (see Unit 3).
010	003h	2318.011	0.050	3.050		Hell Creek	35-40 cm	Claystone (see Unit 3).
009	003g	2317.847	0.050	3.000		Hell Creek	30-35 cm	Claystone (see Unit 3).
008	003f	2317.683	0.050	2.950		Hell Creek	25-30 cm	Claystone (see Unit 3).
007	003e	2317.519	0.050	2.900		Hell Creek	20-25 cm	Claystone (see Unit 3).
006	003d	2317.355	0.050	2.850		Hell Creek	15-20 cm	Claystone (see Unit 3).
005	003c	2317.191	0.050	2.800		Hell Creek	10-15 cm	Claystone (see Unit 3).
004	003b	2317.027	0.050	2.750		Hell Creek	5-10 cm	Claystone (see Unit 3).
003	003a	2316.863	0.050	2.700		Hell Creek	0-5 cm	Claystone; with pedogenic slickensides and root traces; blocky, uniform; brownish black (5 YR 2/1) to black (N 1); unit is less blocky and more laminated to top. Pollen samples taken every 5 cm through Unit 3 (new Unit 3-17), which is 0.75-m thick.
002	002	2316.699	1.650	2.650		Hell Creek		Siltstone, slightly clayey (clay mostly as fine stringers); with root traces; about yellowish gray (5 Y 8/1), appearing more gray in places.
001	001	2311.286	1.000	1.000		Hell Creek		Sandstone, slightly clayey and silty, very fine-grained to fine-grained; yellowish gray (5 Y 7/2). Underlying unit of section forms a local bench.
000	000	2308.005	0.000	0.000				Base of section-Contact coal measured section 2 (CCS-2) was measured below the Hiatt Locality, about 15 m (50 ft) west of the trench dug for M4376 pollen sampling. The elevation of this section is based on the elevations determined from M4376.

Measured Section M6723 (First P-Mag Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
020	2424.409	0.000	41.300				Top of section. Top of elevation derived from elevation at top of Contact lignite in Section M7887b.
019	2424.409	5.000	41.300		Ludlow		Sandstone to top (use Section M4770 for remaining units and thicknesses).
018	2408.005	0.100	36.300		Ludlow		Claystone, lignitic.
017	2407.677	4.100	36.200		Ludlow	PM11	Siltstone, clayey, to silty claystone, heavily weathered; mottled, some banding, darker toward top. Paleomag sample taken 0.15 m below top of unit: PM11 323°-2.5°NE.
016	2394.226	0.150	32.100		Ludlow	PM10	Shale, carbonaceous. Paleomag sample taken from near middle of unit: PM10 030°-7°NW.
015	2393.734	0.150	31.950	lignite	Ludlow		Lignite.
014	2393.242	4.600	31.800		Ludlow	PM09	Claystone, silty, interbedded with clayey siltstone. Paleomag sample taken 1.8 m above base of unit: PM9 355°-11°E.
013	2378.150	0.250	27.200	Contact lignite	Ludlow		Lignite.
012	2377.330	0.100	26.950		Hell Creek		Shale, lignitic; dark brownish black (5 YR 2/1).
011	2377.002	1.100	26.850		Hell Creek	PM08	Claystone, silty; light olive gray (5 Y 5/2). Paleomag sample taken 40 cm above base of unit: PM8 247°-32°NE.
010	2373.393	0.200	25.750		Hell Creek		Claystone; gray.
009	2372.737	1.150	25.550		Hell Creek		Siltstone, clayey siltstone; root traces. Section route transferred 25 m to the north.
008	2368.964	1.400	24.400		Hell Creek		Siltstone, clayey; with root traces.
007	2364.371	2.000	23.000		Hell Creek		Sandstone, silty, very fine-grained, to (or interbedded) clayey siltstone; some cross bedding; some root traces.
006	2357.809	5.200	21.000		Hell Creek		Sandstone, fine-grained, fining upwards, cross bedded, with organic material defining the bedding surfaces; grayish (Hell Creek) color.
005	2340.749	2.400	15.800		Hell Creek	PM06, 7	Siltstone, clayey, smectitic; organic rich in lower portion; highly weathered "popcorn" surface; oxide shading near contact with underlying unit. Paleomag samples taken from lower 0.25 m of unit: PM6 330°-39°SW; PM7 015°-25°NW.
004	2332.875	3.900	13.400		Hell Creek		Sandstone, cross bedded; grayish color; top marked by a 20-cm thick resistent yellowish orange interval.
003	2320.080	3.000	9.500		Hell Creek	PM04	Claystone, silty, coarser grained near top; fairly sharp upper contact; grayish yellow (it's raining again). Paleomag sample taken 0.05 m above base of unit: PM4 030°-42°NW.
002	2310.238	0.300	6.500		Hell Creek	PM05	Siltstone, carbonaceous clayey. Paleomag sample taken from middle of unit: PM5 345°67°SW.
001	2309.254	6.200	6.200		Hell Creek	PM01-3	Siltstone, clayey, with silty laminae, three discontinuous carbonaceous horizons about 30 cm thick; root traces. Paleomag samples taken 1.2 m above creek bottom: PM1 345°-47°SW; PM2 354°-46°SW; PM3 355°-65°SW.
000	2288.913	0.000	0.000				Section begins at bottom of valley below the area of M4770, located southeast of Witches Hat section (M4769b) in E½ NE¼ NW¼ SW¼ sec. 1 T. 15 N., R. 55 E. Section measured by W.D. Peck for paleomagnetic studies.

Measured Section M7887a (Witches Hat Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Lithologic Description
027	2281.990	0.000	50.900				Top of section.
026	2281.990	2.900	50.900	Witches Hat Sandstone	Hell Creek		Sandstone, smectitic portion; Witches Hat Sandstone; represents unit of saddle, with thickness to top of saddle [old unit 23].
025	2272.476	5.400	48.000	Witches Hat Sandstone	Hell Creek		Sandstone, fine-grained, stacked channels, cross bedded units, large scale trough cross beds; Witches Hat Sandstone; yellowish gray (5 Y 8/1). Thickness to contour line (2380 ft) forming saddle [old Unit 22].
024	2254.760	0.600	42.600		Hell Creek	plants	Siltstone, clayey, fines upward to carbonaceous silty shale, *smectitic; popcorn weathered surface; dark yellowish brown* (10 YR 4/2); seeds [old Unit 20].
023	2252.792	0.250	42.000		Hell Creek	plants	Shale, carbonaceous, silty, with abundant plant fragments and charcoal; dusky brown to brownish black (5 YR 2/2 to 5 YR 2/1) [old Unit 19].
022	2251.972	1.600	41.750		Hell Creek	dinosaurs	Siltstone, clayey, fining to silty claystone, smectitic (same cycle as Unit 17 [-19]); yellowish gray (5 Y 7/2) to light olive brown (5 Y 5/6); dinosaur rubble [old Unit 18].
021	2246.723	1.100	40.150		Hell Creek		Claystone, silty, smectitic; yellowish gray (5 Y 7/2) to light olive brown (5 Y 5/6); clayey top is light olive gray (5 Y 6/1) [old Unit 17].
020	2243.114	0.300	39.050		Hell Creek		Siltstone; yellowish gray (5 Y 7/2) to light olive brown (5 Y 5/6) [old Unit 17, a layer 0.3-m thick at 0.4 m above base of unit].
019	2242.130	0.400	38.750		Hell Creek		Siltstone, clayey, fining upwards to silty claystone, with increasing organic content; smectitic; yellowish gray (5 Y 7/2) to light olive brown (5 Y 5/6).
018	2240.818	0.150	38.350		Hell Creek	plants	Shale, carbonaceous, brownish gray (5 YR 4/1) to dark yellowish brown (10 YR 4/2); leaves.
017	2240.326	2.900	38.200		Hell Creek		Claystone, silty, to clayey siltstone, popcorn weathered, with root traces; yellowish gray (5 Y 8/1).
016	2230.812	1.500	35.300		Hell Creek		Covered, with orange-brown and black ironstone concretions; forms nose of "flats" (rough and grass covered).
015	2225.891	1.300	33.800		Hell Creek		Siltstone, cemented, light olive gray to olive gray (5 Y 5/2 to 5 Y 4/1); lower part is fissile, grayish orange to moderate yellowish brown (10 YR 7/4 to 10 YR 5/4); upper part has limonitic concretions. This unit is the uppermost unit measured of this section in Trip 94f before moving up coulee to begin measuring M7887b.
014	2221.626	2.200	32.500		Hell Creek		*Sandstone, fine-grained, to siltstone, smectitic, soft, friable; coarser* at base (fining upwards); grayish orange (10 YR 7/4), with brown tints.
013	2214.408	2.500	30.300		Hell Creek		Siltstone, clayey, to silty claystone, smectitic surface, and quite moist; light olive gray to light gray (5 Y 6/1 to N 7), with limonitic stains along roots and plant stem trash.
012	2206.206	0.400	27.800		Hell Creek		Claystone, carbonaceous; black (N 1) and grayish brown (5 YR 3/2).
011	2204.894	5.500	27.400		Hell Creek		Claystone, silty, to clayey siltstone (similar to last); limonitic horizon at 0.8 to 1.5 m above base, representing debris on surface between two horizons; light brown (5 YR 6/4) to pale yellowish brown (10 YR 6/2); limonitic color is moderate brown to light brown (5 YR 4/4 to 5 YR 5/6), but variable.
010	2186.850	0.900	21.900		Hell Creek		Sandstone, fine-grained, fining upwards to a very fine-grained sandstone; clay content also increases upward; dark yellowish orange (10 YR 6/6); bedding colors include yellowish grays (5 Y 7/2).
009	2183.897	2.100	21.000		Hell Creek		Claystone, silty, to clayey siltstone (see Unit 7).
008	2177.007	0.100	18.900		Hell Creek		Claystone; moist color of dark yellowish brown (10 YR 4/2).

Measured Section M7887a (Witches Hat Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Lithologic Description
007	2176.679	1.800	18.800		Hell Creek		Claystone (Units 7 and 9), silty, to clayey siltstone, with smectitic surface and limonitic stains. The unit, as a whole, has variable surface colors, but the central theme is yellowish gray (5 Y 7/2); variably oriented colored bands have a subtle dark yellowish orange (10 YR 6/6).
006	2170.774	4.800	17.000		Hell Creek		Sandstone, fine- to very fine-grained, yellowish gray (5 Y 7/2); with a local, 0.3-m thick, cemented horizon about 2 m above base, moderate yellowish brown (10 YR 5/4); with collateral sequence of smectitic claystone layers in middle (high on point bar), starting below cemented zone; includes jarositic nodules.
005	2155.026	3.200	12.200		Hell Creek		Sandstone, very fine-grained, fining upwards to clayey siltstone in two cycles; the second cycle is less sandy at the bottom and ends on slightly darker gray yellow bands; the bands have a smectitic surface, with the upper cycle being largely covered; moist color on first "light brown" band is olive gray to light olive gray (5 Y 3/2 to 5 Y 5/2).
004	2144.527	0.300	9.000		Hell Creek		Claystone, lignitic; brownish gray to brownish black (5 YR 4/1 to 5 YR 2/1).
003	2143.543	3.700	8.700		Hell Creek		Claystone, silty, to clayey siltstone, with a a few ironstone concretions; light olive gray to yellowish gray (5 Y 6/1 to 5 Y 8/1) (difficult color).
002	2131.404	0.800	5.000	Visitor bed	Hell Creek		Shale, carbonaceous, with plant trash and roots; grayish brown to dusky brown (5 YR 3/2 to 5 YR 2/2). This unit forms a dark band above the light gray of Unit 1. This is "Rob Kukowski's" lignite.
001	2128.779	4.200	4.200		Hell Creek		Sandstone, medium- to fine-grained, fining upwards, with increasing clay content, smectitic; unit has a dry surface color of light gray (N 7) and a moist color of yellowish gray (5 Y 7/2). In the park, this unit, along with the darker overlying unit, form a distinctive couplet.
000	2115.000	0.000	0.000				Base of section on pediment at base of sharp demarcation of bluff face, about 15 m (50 ft) south of Makoshika State Park road along Cains Coulee. The section was measured up the promontory towards Witches Hat. The elevation of the base of the section is about 2115 ft (± 5 ft) (revised from 2110 ft of Trip 94f).

Measured Section M7887b (P-Mag Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
032	2450.000	0.000	56.750				Top of section at top of hill. Same section top as Sections M4770 and M6723.
031	2450.000	3.000	56.750		Ludlow		Grassed-covered interval to top of butte.
030	2440.158	3.000	53.750		Ludlow		Sandstone, soft, slope forming (thickness from M4770).
029	2430.316	2.600	50.750		Ludlow	Pmag 28	Sandstone, cross bedded, well cemented ridge (No. 2). Pmag 28 sample is from 0.8 m above base.
028	2421.786	1.250	48.150		Ludlow		Sandstone, less well cemented interval.
027	2417.685	1.400	46.900		Ludlow	Pmag 27	Sandstone, cross bedded, well cemented ledge (No. 1). Pmag 27 sample is from 1.2 m above base of unit.
026	2413.092	1.500	45.500		Ludlow		Sandstone, fine- to medium-grained; unit is less well cemented (than overlying unit), but is still locally cliff-forming.
025	2408.171	0.200	44.000		Ludlow		Shale, lignitic.
024	2407.515	3.600	43.800		Ludlow	Pmag 25, 26	Claystone, very slightly silty, clayey siltstone towards top; heavily smectitic and covered unit; well bedded in lower part; various colors including light gray (N 7) to light olive gray (5 Y 6/1); at top the color is more yellowish gray (5 Y 7/2). Pmag 25 and 26 samples are from 0.2 and 3.0 m, respectively, above base of unit.
023	2395.704	0.700	40.200		Ludlow		Shale, carbonaceous, silty, finely bedded, with clayey interbeds; brownish black (5 YR 2/1).
022	2393.407	0.900	39.500		Ludlow		Claystone, silty, to clayey siltstone; heavily weathered and surface rooted.
021	2390.454	0.800	38.600		Ludlow	Pmag 24	Sandstone, fine-grained, with a few clayey sandstone layers. Pmag 24 sample from 0.6 m above base of unit.
020	2387.829	0.750	37.800		Ludlow		Claystone, "pure," paper shale, numerous of plant fossils.
019	2385.368	2.200	37.050		Ludlow	Pmag 22, 23	Siltstone, clayey; interbedded limonitic horizons. Pmag 22 and 23 samples are from 0.45 and 1.7 m, respectively, above base of unit.
018	2378.150	0.220	34.850	Contact lignite	Ludlow		Lignite, black (N 1); represents same location as unit description from section M6723.
017	2377.428	0.600	34.630	Fern Spike	Hell Creek		Claystone, slightly silty, fissile, plant rich, leaves, Cercidiphyllum? seeds; dark yellowish brown (10 YR 4/2); represents same location as unit description from section M6723.
016	2375.460	3.800	34.030		Hell Creek	Pmag 20, 21	Claystone, silty, smectitic, with plants, and largely covered; light olive gray (5 Y 6/1) to yellowish gray (5 Y 7/2). Pmag 20 and 21 samples are from 0.8 and 3.8 m, respectively, above base of unit.
015	2362.993	1.330	30.230		Hell Creek	Pmag 18, 19	Sandstone, very fine-grained, clayey, interbedded with silty claystones (fining upwards); speckled yellowish gray to dusky yellow (5 Y 7/2 to 5 Y 6/4), with some light hues of minor limonitic banding. Pmag 18 and 19 samples are from 0.1 and 1.13 m, respectively, above base of unit.
014	2358.630	5.100	28.900	Witches Hat Sandstone	Hell Creek	Pmag 17	Sandstone, fine- to medium-grained, with cross-bedded sandstone concretions, speckled very light gray (N 8) and yellowish gray (5 Y 7/2). Pmag 17 sample is from 1.5 m above base of unit in well-lithified concretionary sandstone. This unit is laterally correlative with the Witches Hat Sandstone.
013	2341.898	2.200	23.800		Hell Creek	Pmag 15, 16	Siltstone, slightly clayey, to clayey siltstone towards top; limonitic about base, smectitic. Deeply weathered unit, largely covered; primarily yellowish gray (5 Y 7/2). Pmag 15 and 16 samples are from 0.2 and 1.9 m, respectively, above base of unit.
012	2334.680	1.000	21.600		Hell Creek		Sandstone, fine-grained, increasing in thickness to northwest (330°); fine speckles, very light gray (N 8) and yellowish gray (5 Y 8/1).
011	2331.399	4.600	20.600		Hell Creek	Pmag 11-14	Claystone, silty, to clayey siltstone, with lots of root traces; yellowish gray to light olive brown (5 Y 7/2 to 5 Y 6/4). Upper "red"

Measured Section M7887b (P-Mag Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
							tint, about 1-m thick, with 0.2-0.4-m thick ironstone concretion at top; ironstone surface is moderate reddish brown to dark yellowish orange (10 YR 5/4 to 10 YR 6/6). Pmag 11, 12, 13, and 14 samples are from 0.4, 2.0, 4.0, and 3.9 m, respectively, above base of unit. *Minor lateral shift in section route 30 m up coulee.* Pmag sample 14 was taken 10 m farther up coulee.
010	2316.307	4.000	16.000		Hell Creek	Pmag 9, 10	Claystone, silty, with much plant debris at base of unit; lower part has concretionary horizon directly below sample; sample horizon contains more silt; clayey siltstone is yellowish gray (5 Y 7/2). Four to five organic cycles, containing charcoal and amber; pale yellowish brown (10 YR 6/2). End of unit is at top of organic sequence. Pmag 9 and 10 samples are from 0.5 and 3.3 m, respectively, above base of unit. Minor lateral shift in section route 30 m up coulee.
009	2303.184	0.700	12.000		Hell Creek		Siltstone, clayey, hard; yellowish gray (5 Y 8/1), with brown tint.
008	2300.887	0.800	11.300		Hell Creek	Pmag 8	Claystone, silty; pale yellowish brown (10 YR 6/2), with gray tint. Pmag 8 sample is from 0.25 m above base of unit.
007	2298.262	0.900	10.500		Hell Creek		Siltstone, very slightly clayey; yellowish gray (5 Y 7/2), with yellow stringers.
006	2295.309	1.500	9.600		Hell Creek	Pmag 7	Siltstone, clayey, to silty claystone; has fining and coarsening upwards cycles; lower part is a smectitic muck; middle of unit is more pure silt and well laminated and light gray (N 7); at top the unit is a silty claystone and yellowish gray (5 Y 7/2). Pmag 7 sample is from 1.1 m above base of unit.
005	2290.388	1.100	8.100		Hell Creek	Pmag 6	Siltstone to very fine-grained sandstone; relatively clean at base, with clayey interbeds toward top; locally cemented; yellowish gray (5 Y 7/2); laminated, with different color shades of laminae. Pmag 6 sample is from 0.85 m above base of unit.
004	2286.779	1.000	7.000		Hell Creek	Pmag 5	Claystone, slightly silty, plant parts; light olive gray (5 Y 6/1), with pale yellowish brown (10 YR 6/2) tone. Unit coarsens upward increasing in silt content to clayey siltstone at top; upper part yellowish gray (5 Y 7/2) to light olive gray (5 Y 5/2). Pmag 5 sample is from 0.2 m above base of unit.
003	2283.498	3.700	6.000		Hell Creek	Pmag 3, 4	Siltstone, clayey, to silty claystone; yellowish gray (5 Y 7/2). Unit coarsens upward increasing in silt content. Pmag 3 and 4 samples are from 1.6 m and 2.8 m, respectively, above base of unit.
002	2271.359	1.000	2.300		Hell Creek	Pmag 2	Sandstone, very fine-grained, bedded, smectitic; yellowish gray (5 Y 7/2). Pmag 2 sample is from 0.9 m above base of unit.
001	2268.078	1.300	1.300		Hell Creek	Pmag 1	Claystone, silty, to clayey siltstone; pale yellowish brown (10 YR 6/2). Pmag 1 sample is from 0.8 m above base of unit.
000	2263.813	0.000	0.000				Base of local section on south-facing exposures in narrow to narrowing portion of unnamed coulee. Section taken on trend from west to east towards Contact lignite previously sampled in Section M6723.

Measured Section M7920 (Boundary Section CC1)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
015	004	2378.150	0.000	1.900				Top of section. Elevation for top of lignite taken from Section M7887b.
014	003	2378.150	0.220	1.900	Contact lignite	Ludlow	CC1-93-18, 19	Lignite. Samples CC1-93-19 and 18 taken 5 cm and 18 cm above base of lignite. Thickness of lignite not given, but taken as 0.22 m from local Section M6723.
013	002f	2377.428	0.010	1.680		Hell Creek	CC1-93-09	Shale, lignitic (see Unit 8).
012	002e	2377.395	0.020	1.670		Hell Creek	CC1-93-10	Shale, lignitic (see Unit 8).
011	002d	2377.329	0.020	1.650		Hell Creek	CC1-93-11	Shale, lignitic (see Unit 8).
010	002c	2377.263	0.020	1.630		Hell Creek	CC1-93-12	Shale, lignitic (see Unit 8); very thin (2-3 mm) lignitic lenses.
009	002b	2377.197	0.020	1.610		Hell Creek	CC1-93-13	Shale, lignitic (see Unit 8), color mottled (paleosol development?), very thin (2-3 mm) lignitic lenses.
008	002a	2377.131	0.020	1.590		Hell Creek	CC1-93-14	Shale, lignitic, with lignitic stringers; fractures blocky; dark brown; color mottled (paleosol development?), very thin (2-3 mm) lignitic lenses.
007	001g	2377.065	0.110	1.570		Hell Creek		Claystone (see Unit 1).
006	001f	2376.704	0.020	1.460		Hell Creek	CC1-93-15	Claystone (see Unit 1).
005	001e	2376.638	0.210	1.440		Hell Creek		Claystone (see Unit 1).
004	001d	2375.949	0.020	1.230		Hell Creek	CC1-93-16	Claystone (see Unit 1).
003	001c	2375.883	0.130	1.210		Hell Creek		Claystone (see Unit 1).
002	001b	2375.456	0.020	1.080		Hell Creek	CC1-93-17	Claystone (see Unit 1).
001	001a	2375.390	1.060	1.060		Hell Creek		Claystone, fractures blocky, grayish.
000		2371.912	0.000	0.000				Base of section. Section was measured by T.J. Kroeger for pollen studies.

Measured Section M7921 (Boundary Section CC4)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
031	005	2379.725	0.000	1.300				Top of section. Section CC4-93 reported as very similar to CC1-93. Elevation for top of lignite taken from Section M7887b (estimated ± 2 m).
030	004g	2379.725	0.030	1.300		Ludlow	CC4-93-42	Siltstone, clayey (see Unit 18).
029	004f	2379.627	0.120	1.270		Ludlow		Siltstone, clayey (see Unit 18).
028	004e	2379.233	0.030	1.150		Ludlow	CC4-93-41	Siltstone, clayey (see Unit 18).
027	004d	2379.135	0.120	1.120		Ludlow		Siltstone, clayey (see Unit 18).
026	004c	2378.741	0.050	1.000		Ludlow	CC4-91-40	Siltstone, clayey (see Unit 18).
025	004b	2378.577	0.080	0.950		Ludlow		Siltstone, clayey (see Unit 18).
024	004a	2378.315	0.050	0.870		Ludlow	CC4-93-39	Siltstone, clayey; discrete beds of silty clay interbedded with clayey silt on about 5 cm intervals; small-scale ripple marks; variegated color, brown with yellowish streaks.
023	003f	2378.151	0.020	0.820	Contact lignite	Ludlow	CC4-93-38	Lignite; contains silty stringers.
022	003e	2378.085	0.020	0.800	Contact lignite	Ludlow	CC4-93-37	Lignite.
021	003d	2378.019	0.020	0.780	Contact lignite	Ludlow	CC4-93-36	Lignite.
020	003c	2377.953	0.020	0.760	Contact lignite	Ludlow	CC4-93-35	Lignite.
019	003b	2377.887	0.020	0.740	Contact lignite	Ludlow	CC4-93-34	Lignite.
018	003a	2377.821	0.020	0.720	Contact lignite	Ludlow	CC4-93-33	Lignite.
017	002b	2377.755	0.020	0.700		Hell Creek	CC4-93-23	Claystone, lignitic (see Unit 14).
016	002a	2377.689	0.020	0.680		Hell Creek	CC4-93-24	Claystone, lignitic, with thin lignitic stringers; dark brown.
015	001o	2377.623	0.020	0.660		Hell Creek	CC4-93-25	Claystone, carbonaceous (see Unit 1).
014	001n	2377.557	0.020	0.640		Hell Creek	CC4-93-26	Claystone, carbonaceous (see Unit 1).
013	001m	2377.491	0.020	0.620		Hell Creek	CC4-93-27	Claystone, carbonaceous (see Unit 1); darker laminated lignitic clay zone.
012	001l	2377.425	0.020	0.600		Hell Creek	CC4-93-28	Claystone, carbonaceous (see Unit 1); darker laminated lignitic clay zone.
011	001k	2377.359	0.020	0.580		Hell Creek	CC4-93-29	Claystone, carbonaceous (see Unit 1).
010	001j	2377.293	0.020	0.560		Hell Creek	CC4-93-30	Claystone, carbonaceous (see Unit 1).
009	001i	2377.227	0.020	0.540		Hell Creek	CC4-93-31	Claystone, carbonaceous (see Unit 1).
008	001h	2377.161	0.020	0.520		Hell Creek	CC4-93-32	Claystone, carbonaceous (see Unit 1).
007	001g	2377.095	0.030	0.500		Hell Creek		Claystone, carbonaceous (see Unit 1).
006	001f	2376.997	0.020	0.470		Hell Creek	CC4-93-22	Claystone, carbonaceous (see Unit 1).
005	001e	2376.931	0.170	0.450		Hell Creek		Claystone, carbonaceous (see Unit 1).
004	001d	2376.373	0.020	0.280		Hell Creek	CD4-93-21	Claystone, carbonaceous (see Unit 1).
003	001c	2376.307	0.200	0.260		Hell Creek		Claystone, carbonaceous (see Unit 1).
002	001b	2375.651	0.020	0.060		Hell Creek	CC4-93-20	Claystone, carbonaceous (see Unit 1).
001	001a	2375.585	0.040	0.040		Hell Creek		Claystone, carbonaceous; horizontal and vertical root traces abundant, some pedogenic slickenslides present; brownish black (5 YR 2/1). Base of unit not exposed.
000	000	2375.454	0.000	0.000				Base of section. Section was measured by T.J. Kroeger for pollen studies.

Measured Section M7921 (Boundary Section CC4)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
031	005	2379.725	0.000	1.300				Top of section. Section CC4-93 reported as very similar to CC1-93. Elevation for top of lignite taken from Section M7887b (estimated ± 2 m).
030	004g	2379.725	0.030	1.300		Ludlow	CC4-93-42	Siltstone, clayey (see Unit 18).
029	004f	2379.627	0.120	1.270		Ludlow		Siltstone, clayey (see Unit 18).
028	004e	2379.233	0.030	1.150		Ludlow	CC4-93-41	Siltstone, clayey (see Unit 18).
027	004d	2379.135	0.120	1.120		Ludlow		Siltstone, clayey (see Unit 18).
026	004c	2378.741	0.050	1.000		Ludlow	CC4-91-40	Siltstone, clayey (see Unit 18).
025	004b	2378.577	0.080	0.950		Ludlow		Siltstone, clayey (see Unit 18).
024	004a	2378.315	0.050	0.870		Ludlow	CC4-93-39	Siltstone, clayey; discrete beds of silty clay interbedded with clayey silt on about 5 cm intervals; small-scale ripple marks; variegated color, brown with yellowish streaks.
023	003f	2378.151	0.020	0.820	Contact lignite	Ludlow	CC4-93-38	Lignite; contains silty stringers.
022	003e	2378.085	0.020	0.800	Contact lignite	Ludlow	CC4-93-37	Lignite.
021	003d	2378.019	0.020	0.780	Contact lignite	Ludlow	CC4-93-36	Lignite.
020	003c	2377.953	0.020	0.760	Contact lignite	Ludlow	CC4-93-35	Lignite.
019	003b	2377.887	0.020	0.740	Contact lignite	Ludlow	CC4-93-34	Lignite.
018	003a	2377.821	0.020	0.720	Contact lignite	Ludlow	CC4-93-33	Lignite.
017	002b	2377.755	0.020	0.700		Hell Creek	CC4-93-23	Claystone, lignitic (see Unit 14).
016	002a	2377.689	0.020	0.680		Hell Creek	CC4-93-24	Claystone, lignitic, with thin lignitic stringers; dark brown.
015	001o	2377.623	0.020	0.660		Hell Creek	CC4-93-25	Claystone, carbonaceous (see Unit 1).
014	001n	2377.557	0.020	0.640		Hell Creek	CC4-93-26	Claystone, carbonaceous (see Unit 1).
013	001m	2377.491	0.020	0.620		Hell Creek	CC4-93-27	Claystone, carbonaceous (see Unit 1); darker laminated lignitic clay zone.
012	001l	2377.425	0.020	0.600		Hell Creek	CC4-93-28	Claystone, carbonaceous (see Unit 1); darker laminated lignitic clay zone.
011	001k	2377.359	0.020	0.580		Hell Creek	CC4-93-29	Claystone, carbonaceous (see Unit 1).
010	001j	2377.293	0.020	0.560		Hell Creek	CC4-93-30	Claystone, carbonaceous (see Unit 1).
009	001i	2377.227	0.020	0.540		Hell Creek	CC4-93-31	Claystone, carbonaceous (see Unit 1).
008	001h	2377.161	0.020	0.520		Hell Creek	CC4-93-32	Claystone, carbonaceous (see Unit 1).
007	001g	2377.095	0.030	0.500		Hell Creek		Claystone, carbonaceous (see Unit 1).
006	001f	2376.997	0.020	0.470		Hell Creek	CC4-93-22	Claystone, carbonaceous (see Unit 1).
005	001e	2376.931	0.170	0.450		Hell Creek		Claystone, carbonaceous (see Unit 1).
004	001d	2376.373	0.020	0.280		Hell Creek	CD4-93-21	Claystone, carbonaceous (see Unit 1).
003	001c	2376.307	0.200	0.260		Hell Creek		Claystone, carbonaceous (see Unit 1).
002	001b	2375.651	0.020	0.060		Hell Creek	CC4-93-20	Claystone, carbonaceous (see Unit 1).
001	001a	2375.585	0.040	0.040		Hell Creek		Claystone, carbonaceous; horizontal and vertical root traces abundant, some pedogenic slickenslides present; brownish black (5 YR 2/1). Base of unit not exposed.
000	000	2375.454	0.000	0.000				Base of section. Section was measured by T.J. Kroeger for pollen studies.

Measured Section M7922 (Boundary Section CC5)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
037	005	2380.184	0.000	1.410				Top of section. Elevation for top of lignite taken from Section M7887b.
036	004m	2380.184	0.050	1.410		Ludlow	CC5-93-43	Siltstone, clayey (see Unit 22).
035	004l	2380.020	0.050	1.360		Ludlow		Siltstone, clayey (see Unit 22).
034	004k	2379.856	0.040	1.310		Ludlow	CC5-93-44	Siltstone, clayey (see Unit 22).
033	004j	2379.725	0.100	1.270		Ludlow		Siltstone, clayey (see Unit 22).
032	004i	2379.397	0.030	1.170		Ludlow	CC5-93-45	Siltstone, clayey (see Unit 22).
031	004h	2379.299	0.130	1.140		Ludlow		Siltstone, clayey (see Unit 22).
030	004g	2378.872	0.030	1.010		Ludlow	CC5-93-46	Siltstone, clayey (see Unit 22).
029	004f	2378.774	0.010	0.980		Ludlow		Siltstone, clayey (see Unit 22).
028	004e	2378.741	0.030	0.970		Ludlow	CC5-93-47	Siltstone, clayey (see Unit 22).
027	004d	2378.643	0.040	0.940		Ludlow		Siltstone, clayey (see Unit 22).
026	004c	2378.512	0.030	0.900		Ludlow	CC5-93-48	Siltstone, clayey (see Unit 22).
025	004b	2378.414	0.060	0.870		Ludlow		Siltstone, clayey (see Unit 22); a unionid impression was collected in the lower 10 cm of Unit 4 (new Units 22-24).
024	004a	2378.217	0.020	0.810		Ludlow	CC5-93-49	Siltstone, clayey, *massive (similar* to Unit 4 of CC4-93).
023	003d	2378.151	0.020	0.790	Contact lignite	Ludlow		Lignite.
022	003c	2378.085	0.030	0.770	Contact lignite	Ludlow	CC5-93-50	Lignite.
021	003b	2377.987	0.040	0.740	Contact lignite	Ludlow	CC5-93-51	Lignite.
020	003a	2377.856	0.040	0.700	Contact lignite	Ludlow	CC5-93-52	Lignite.
019	002o	2377.725	0.020	0.660		Hell Creek	CC5-93-53	*Shale, lignitic; well laminated and rooted; dark brown.*
018	002n	2377.659	0.020	0.640		Hell Creek	CC5-93-54	Shale, lignitic; well laminated and rooted; dark brown.
017	001q	2377.593	0.020	0.620		Hell Creek	CC5-93-55	Claystone (see Unit 13).
016	001p	2377.527	0.020	0.600		Hell Creek	CC5-93-56	Claystone (see Unit 13).
015	001o	2377.461	0.020	0.580		Hell Creek	CC5-93-57	Claystone (see Unit 13).
014	001n	2377.395	0.020	0.560		Hell Creek	CC5-93-58	Claystone, crumbly; rooted; lighter brown.
013	001m	2377.329	0.020	0.540		Hell Creek	CC5-93-59	Siltstone, clayey (see Unit 1).
012	001l	2377.263	0.020	0.520		Hell Creek	CC5-93-60	Siltstone, clayey (see Unit 1).
011	001k	2377.197	0.020	0.500		Hell Creek	CC5-93-61	Siltstone, clayey (see Unit 1).
010	001j	2377.131	0.020	0.480		Hell Creek		Siltstone, clayey (see Unit 1).
009	001i	2377.065	0.020	0.460		Hell Creek	CC5-93-62	Siltstone, clayey (see Unit 1).
008	001h	2376.999	0.020	0.440		Hell Creek		Siltstone, clayey (see Unit 1).
007	001g	2376.933	0.020	0.420		Hell Creek	CC5-93-63	Siltstone, clayey (see Unit 1).
006	001f	2376.867	0.060	0.400		Hell Creek		Siltstone, clayey (see Unit 1).
005	001e	2376.670	0.020	0.340		Hell Creek	CC5-93-64	Siltstone, clayey (see Unit 1).
004	001d	2376.604	0.170	0.320		Hell Creek		Siltstone, clayey (see Unit 1).
003	001c	2376.046	0.020	0.150		Hell Creek	CC5-93-65	Siltstone, clayey (see Unit 1).
002	001b	2375.980	0.110	0.130		Hell Creek		Siltstone, clayey (see Unit 1).
001	001a	2375.619	0.020	0.020		Hell Creek	CC5-93-66	Siltstone, clayey; well rooted, with abundant slickenslides; dark gray brown.
000	000	2375.553	0.000	0.000				Base of section. Section was measured by T.J. Kroeger for pollen studies.

Measured Section M8279 (Hiatt South Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Fossil Locality	Lithologic Description
015	2375.000	0.000	15.525				Top of section (local).
014	2375.000	2.250	15.525		Ludlow		*Sandstone, fine to medium-grained; dusky yellow (5 Y 6/4); to top of* local section above the locality.
013	2367.618	1.500	13.275		Ludlow	L6424	Conglomerate, intraclastic, forming Hiatt South Quarry (L6424). The rip-up clasts are silty claystones with stems and leaves; brown orange concretions are present above and lateral to conglomerate. Clasts are typically 20-30 cm with a variety of rounded and flattened shapes. Unit measured through thickest part of lithosome.
012	2362.697	1.250	11.775		Ludlow		Sandstone, channelform, to base of Hiatt South Locality (L6424); rip up clast conglomerate; variously calcified and cross bedded; medium grained (in concretions); very light gray (N 8), with yellowish gray tints (5 Y 8/1).
011	2358.596	0.500	10.525	unnamed lignite	Ludlow		Lignite, good (probably same lignite underlying the Hiatt Locality [L5418]).
010	2356.956	0.150	10.025		Ludlow		Shale, lignitic; brown, dark yellowish brown (10 YR 4/2), but the lignite is coaly plant material.
009	2356.464	1.700	9.875		Ludlow		Siltstone, clayey, to silty claystone; yellowish gray (5 Y 7/2) to (slightly) light olive gray; includes moderate brown (5 YR 4/4) chips of same lithology; laterally persistent unit.
008	2350.887	0.500	8.175		Ludlow		Shale, paper, carbonaceous; grayish brown (5 YR 3/2) to black (N 1).
007	2349.247	0.700	7.675		Ludlow		Siltstone; rooted; sharp upper contact; yellowish gray (5 Y 7/2).
006	2346.950	3.100	6.975		Ludlow		Sandstone, fine-grained, clayey, fining upward, cross bedded; orange-brown concretions in lower third; gray, salt and pepper; angular quartz, with calcite; cliff former.
005	2336.780	2.150	3.875		Ludlow		Claystone, slightly silty, smectitic, silt content increases upwards toward top; roots traces, slickensides, popcorn weathered; forms bench; sharp lower and upper contacts; light olive gray (5 Y 6/1) (near top); lighter colored at top.
004	2329.726	0.200	1.725		Ludlow	plants	Claystone, medium gray (N 5) to medium light gray (N 6), to yellowish gray (5 Y 7/2); cattail-like plants abundant (marshy).
003	2329.070	1.000	1.525		Ludlow		Sandstone, clayey, fining upwards to clayey siltstone; dark yellowish brown (10 YR 4/2); sharp upper contact.
002	2325.789	0.225	0.525	Contact lignite	Ludlow		Lignite, vitreous, good.
001	2325.051	0.300	0.300		Hell Creek		Claystone, slightly silty; roots from overlying lignite near the top of unit; dusky yellowish brown (10 YR 2/2) to brownish black (5 YR 2/1). The base of this unit was not determined.
000	2324.067	0.000	0.000				Base of section. Section begins directly adjacent to an unnamed tributary of Cains Coulee on south-facing exposures, just south of the Hiatt South Locality (L6424) (the Rifle Range is not in view from the base of the section).

Measured Section M8283 (Sand Creek Overlook Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
070	029	2637.624	0.000	29.704				Top of section at top of local high ground just west of abandoned trail and just south of turnaround at Sand Creek Overlook.
069	028	2637.624	0.500	29.704		Ludlow		Siltstone, clayey, calcareous; forms local bench.
068	027	2635.984	0.400	29.204		Ludlow		Sandstone, fine-grained; represents local ledge former.
067	026	2634.672	2.000	28.804		Ludlow		Siltstone, slightly clayey, fining upwards, more smectitic towards top.
066	025c	2628.110	0.060	26.804	lignite	Ludlow		Lignite.
065	025b	2627.913	0.010	26.744		Ludlow		Claystone, slightly silty, stringer.
064	025a	2627.880	0.430	26.734	lignite	Ludlow		Lignite, with charcoal.
063	024	2626.469	0.380	26.304		Ludlow		Shale, carbonaceous, well laminated; brown and black.
062	023	2625.222	3.340	25.924		Ludlow		Siltstone, clayey; heavily weathered, with bushes.
061	022	2614.264	0.090	22.584	lignite	Ludlow		Lignite, clayey.
060	021	2613.969	0.230	22.494		Ludlow		Claystone, organic rich.
059	020	2613.214	0.100	22.264		Ludlow		Shale, carbonaceous, coaly.
058	019	2612.886	1.100	22.164		Ludlow		Covered; heavily weathered, deeply dissected, with brush.
057	018	2609.277	3.500	21.064		Ludlow		Claystones and siltstones, coarsening upwards (lacustrine); ironstone bands in lower meter.
056	017	2597.794	0.180	17.564		Ludlow		Shale, book.
055	016	2597.203	0.800	17.384		Ludlow		Claystone, silty (moist).
054	015	2594.578	0.250	16.584	lignite	Ludlow		Lignite, poor, jarositic, with claystone stringers.
053	014	2593.758	0.200	16.334		Ludlow		Claystone, slightly silty.
052	013	2593.102	0.450	16.134		Ludlow		Shale, book; plant-rich.
051	012	2591.626	1.580	15.684		Ludlow		Siltstone, clayey.
050	011	2586.442	0.090	14.104	lignite	Ludlow		Lignite, poor (like Unit 48).
049	010	2586.147	0.280	14.014		Ludlow		Siltstone, chocolate brown.
048	009	2585.228	0.170	13.734	lignite	Ludlow		Lignite, poor, jarositic; with claystone stringers.
047	008	2584.670	0.830	13.564		Ludlow		Siltstone, clayey.
046	007	2581.947	1.540	12.734		Ludlow		Sandstone, fine-grained, with clayey interbeds (point bar), variable in thickness; gray, relatively brilliant.
045	006	2576.895	2.800	11.194		Ludlow		Claystones and siltstones (lacustrine); heavily ironstone banded.
044	005	2567.709	0.300	8.394	lignite	Ludlow		Lignite.
043	004	2566.725	0.730	8.094		Ludlow		Shale, book.
042	003	2564.330	1.360	7.364		Ludlow		Claystones and siltstones (lacustrine); no concretions.
041	002	2559.868	0.200	6.004		Ludlow		Shales, book-like.
040	001D	2559.212	4.450	5.804		Ludlow		Claystones and siltstones, ironstone banded (lacustrine) (the remaining portion of the section is given in less detail).
039	001Cd	2544.612	0.100	1.354		Ludlow	0.49-0.59	Claystone, silty (see Unit 36).
038	001Cc	2544.284	0.100	1.254		Ludlow	0.39-0.49	Claystone, slightly silty (see Unit 36).
037	001Cb	2543.956	0.100	1.154		Ludlow	0.29-0.39	Claystone, slightly silty (see Unit 36).
036	001Ca	2543.628	0.060	1.054		Ludlow	0.23-0.29	Claystone, slightly to very slightly silty; yellowish gray to light olive gray (5 Y 7/2 to 5 Y 6/1); scoured base.
035	001Bc	2543.431	0.020	0.994		Ludlow	0.21-0.23 (um)	Claystone, slightly silty; pale brown to brownish black (5 YR 2/2 to 5 YR 2/1).
034	001Bb	2543.365	0.064	0.974		Ludlow	0.146-0.21 (u)	Shale, book, silty; pale brown (5 YR 5/2) to brownish black (5 YR 2/1).
033	001Ba	2543.155	0.086	0.910		Ludlow	0.06-0.146 (l)	Siltstone, organic rich, finely laminated, grading into a book shale; dusky yellowish brown to dusky brown (10 YR 2/2 to 5 YR 2/2).
032	001Ab	2542.873	0.035	0.824		Ludlow	0.025-0.06	Claystone, silty; undulatory upper contact (see Unit 31). (Earlier measured value of 0.055 on 7/15.)
031	001Aa	2542.758	0.025	0.789		Ludlow		Claystone, silty; very light gray to light gray (N 8 N 7).

Measured Section M8283 (Sand Creek Overlook Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
								Remaining part of sequence measured from the bottom up. (Earlier measured value of 0.025 on 7/15.)
030	001	2542.676	0.004	0.764	iridium anomaly	Ludlow	Sample	Claystone, slightly silty; pale yellowish brown (10 YR 6/2) and pale brown (5 YR 5/2) (not a easy color to pick). This layer is relatively well lithified and forms a very minor ledge. It lies directly on top of, and adhered to, the pink layer. This and underlying units were reported to have a dispersed iridium anomaly (analysis by C.J. Orth; Fastovsky, personal comm., 1995). *Unit part of sequence measured from top down.*
029	002	2542.663	0.010	0.760	pink layer	Ludlow	Sample	Sandstone, very fine-grained; grayish orange pink (10 R 8/2) (not an easy color to pick); carbonaceous stringers are locally present. Unit part of sequence measured from top down.
028	003a	2542.630	0.030	0.750	Contact lignite	Ludlow	0.00-0.03 (u)	Lignite, highly fractured and vitreous, with amber. Unit part of sequence measured from top down.
027	003b	2542.532	0.030	0.720	Contact lignite	Ludlow	0.03-0.06 (l)	Lignite (see Unit 28).
026	004a	2542.434	0.020	0.690		Hell Creek	0.00-0.02	Claystone; laminated, undulating; mottled surface with vitreous sheen (probably of plant origin); moderate brown to grayish brown (5 YR 3/4 to 5 YR 2/3) to dusky brown (5 YR 2/2). The lithologies underlying the lignite are variable and include brown and green hues of silty claystones. The local thickness is also variable. Unit part of sequence measured from top down.
025	004b	2542.368	0.020	0.670		Hell Creek	0.02-0.04	Claystone, slightly silty; slightly darker than light olive gray (5 Y 5/2); plant debris.
024	004c	2542.302	0.020	0.650		Hell Creek	0.04-0.06	Claystone; slight increase in silt component, with more abundant plant stems.
023	004d	2542.236	0.020	0.630		Hell Creek	0.06-0.08	Claystone, silty (see Unit 24).
022	004e	2542.170	0.020	0.610		Hell Creek	0.08-0.10	Claystone, silty (see Unit 4).
021	004f	2542.104	0.020	0.590		Hell Creek	0.10-0.12	Claystone, silty, with carbonaceous and noncarbonaceous greenish shale clasts.
020	004g	2542.038	0.020	0.570		Hell Creek	0.12-0.14	Claystone, silty (see Unit 22).
019	004h	2541.972	0.020	0.550		Hell Creek	0.14-0.16	Claystone, silty, very organic rich, with greenish shale clasts.
018	004i	2541.906	0.020	0.530		Hell Creek	0.16-0.18	Claystone, silty (see Unit 19).
017	004j	2541.840	0.020	0.510		Hell Creek	0.18-0.20	Claystone, no silty; organic-rich surfaces; texture is more platy and fissile; moderate brown (5 YR 4/4) to moderate yellowish brown (10 YR 5/4). A black shale, with charcoal chips (coalification of plant debris), is located lateral to this unit. Sharp upper contact; the sediment is saturated and oozing, forming a local muck, with colors of yellowish brown; organic rich material can be found laterally.
016	004k	2541.774	0.020	0.490		Hell Creek	0.20-0.22	Claystone (see Unit 17).
015	004l	2541.708	0.020	0.470		Hell Creek	0.22-0.24	Claystone (see Unit 17).
014	004m	2541.642	0.020	0.450		Hell Creek	0.24-0.26	Claystone (see Unit 17).
013	004n	2541.576	0.020	0.430		Hell Creek	0.26-0.28	Claystone (see Unit 17). The base of this unit represents a transition to a more uniformly organic rich claystone.
012	005a	2541.510	0.020	0.410		Hell Creek	0.28-0.30	Claystone, organic rich; brownish black (5 YR 2/1). Unit part of sequence measured from top down.
011	005b	2541.444	0.020	0.390		Hell Creek	0.30-0.32	Claystone (see Unit 12).
010	005c	2541.378	0.040	0.370		Hell Creek	0.32-0.36	Claystone, slightly silty (see Unit 12).
009	005d	2541.247	0.020	0.330		Hell Creek	0.36-0.38	Claystone, silty; root traces, apparently in contact with underlying siltstone.
008	006a	2541.181	0.020	0.310		Hell Creek	0.38-0.40	Siltstone, very slightly clayey; with minor root traces and other organic fragments; brownish gray (5 YR 4/1) to light brownish

Measured Section M8283 (Sand Creek Overlook Section)
(Elevations given in feet for use with topographic quadrangle)

Unit No.	Old Unit No.	Elevation of Top of Unit (ft)	Unit THICK (m)	Meters Above Base of Section	Bed Name	Formation	Rock Sample No.	Lithologic Description
								gray (5 YR 6/1) (difficult color to pick). Unit part of sequence measured from top down.
007	006b	2541.115	0.030	0.290		Hell Creek	0.40-0.43	Siltstone, slightly clayey; pale yellowish brown (10 YR 6/2).
006	006c	2541.017	0.070	0.260		Hell Creek	0.43-0.50	Siltstone, slightly clayey (see Unit 8).
005	006d	2540.787	0.070	0.190		Hell Creek	0.50-0.57	Siltstone, slightly clayey (see Unit 8).
004	006e	2540.557	0.050	0.120		Hell Creek	0.57-0.62	Siltstone, slightly clayey (see Unit 8); moist color olive gray 5 Y 4/1).
003	006f	2540.393	0.030	0.070		Hell Creek	0.62-0.65	Siltstone, slightly clayey (see Unit 4).
002	006g	2540.295	0.020	0.040		Hell Creek	0.65-0.67	Siltstone, slightly clayey (see Unit 4).
001	006h	2540.229	0.020	0.020		Hell Creek	0.67-0.69	Siltstone, slightly clayey; dark yellowish brown (10 YR 4/2), with olive gray tint (5 Y 4/1).
000	000	2540.163	0.000	0.000				Base of section (not base of available strata).