Paleoenvironment and taphonomy of the fauna of the Tullock Formation (early Paleocene), McGuire Creek area, McCone County, Montana
by Yoshihiro Katsura

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University
© Copyright by Yoshihiro Katsura (1992)

Abstract:
Late Cretaceous to early Paleocene rocks are well exposed around Fort Peck Reservoir in Garfield and McCone Counties, Montana. Numerous fossil vertebrates were found in the lower part of the Tullock Formation (early Paleocene) in the south area of the McGuire Creek. Previous studies gave no consideration to taphonomy preferring instead to concentrate on one particular aspect such as paleontology or sedimentology. This study attempts to reconstruct the paleoenvironment and faunal content of the Tullock Formation in the local area through detailed sedimentologic, paleontologic, and taphonomic analysis.

Seven major sedimentary facies are recognized: 1) trough cross-stratified sandstones interpreted as main stream channel deposits, 2) inclined beds of sandstone and alternating sandstone and mudstone interpreted as point bar deposits of stream channels, 3) planar-laminated and/or massive mudstones containing parallel-bedded iron concretion bands interpreted as flood plain deposits, 4) a thin, clay pebble conglomerate associated with mudstone interpreted as a crevasse channel deposit, 5) lignites interbedded with the mudstone or lying on inclined beds of alternating sandstone and mudstone interpreted as swamp deposits, 6) a thin lignite associated with the bottom of inclined beds of sandstone interpreted as a channel lag deposit. Analyses of the taphonomy of the bones can be used to support the interpretation of the depositional environments of these facies.

The analyses suggest that broad alluvial systems consisting of a dominant flood plain with swamps and a few stream channels developed in the subsiding foreland basin in northeastern Montana during the early Paleocene. The fauna investigated in the study is considered to represent an early Paleocene aquatic and riparian fauna which inhabited alluvial plains. However, the vertebrates from sandstone and conglomerate-mudstone facies, including the microvertebrate assemblage, are possibly contaminated with Cretaceous ones because of the closeness of these localities to the K-T boundary and the allochthonous character of the fossils.

PALEOENVIRONMENT AND TAPHONOMY OF THE FAUNA OF THE TULLOCK FORMATION (EARLY PALEOCENE), McGUIRE CREEK AREA, McCONE COUNTY, MONTANA

by

Yoshihiro Katsura

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1992

COPYRIGHT

by

Yoshihiro Katsura

1992

All Rights Reserved

N378
K1568

APPROVAL

of a thesis submitted by

Yoshihiro Katsura

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dec. 30, 1992
Date

John R Horner
Chairperson, Graduate Committee

Dec 30, 1992
Date

James G. Schmidt
Chairperson, Graduate Committee

Approved for the Major Department

Dec. 31, 1992
Date

Head, Major Department

Approved for the College of Graduate Studies

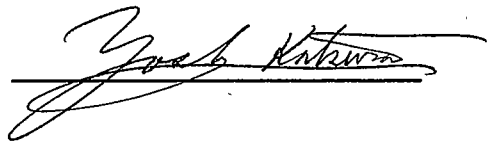
1/5/93
Date

R K Brown
Graduate dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature 

Date Jan 11, 1993

ACKNOWLEDGEMENTS

This thesis would not have been finished without the support of many people. I am most grateful to Dr. John R. Horner, Dr. James G. Schmitt and Dr. Robert E. Moore who suggested and supervised this thesis project and provided much useful advice as members of my thesis committee. I would like to thank the staff of the Museum of the Rockies, volunteers and graduate students studying under Dr. John R. Horner and in the Department of Earth Sciences at Montana State University who provided assistance in the field during 1991-1992 and great help to my studies. Also I thank Mr. Tom Wankel for permission to use his cabin during the field work in 1991. I am also grateful to Dr. John R. Horner and Dr. William A. Clemens for walking around my study area with me. I thank Dr. Bruce R. Erickson, Dr. J. H. Hutchison, and Dr. William A. Clemens who helped me to identify the fossils from the study area and Dr. Bruce R. Erickson, Dr. William A. Clemens, and Dr. Donald L. Lofgren for helpful discussions.

Dr. John R. Horner and the Museum of the Rockies provided financial aid. Also I thank the Charles M. Russell National Wildlife Refuge and Army Corps of Engineers who provided needed permission to work in the study area.

Finally I thank my family for allowing me to study in the United States. Their financial and spiritual support helped me to complete my thesis.

TABLE OF CONTENTS

Page

List of tables vii
List of figures viii
Abstract x

REGIONAL SETTING 1
Introduction 1
Geological Setting 4
Location 6
History of Geological Studies around Fort Peck Reservoir and the Problem of the Formation Names 10
The Problem of the Cretaceous-Tertiary Boundary 11
Methods 13

FACIES ANALYSIS OF THE TULLOCK FORMATION 15
Mudstone Facies 15
Description 15
Interpretation 16
Conglomerate-Mudstone Facies 18
Description 18
Interpretation 20
Lignite Facies 21
Description 21
Interpretation 23
Sandstone Facies 24
Description 24
Interpretation 27
Inclined Beds of Alternating Sandstone and Mudstone Facies 28
Description 28
Interpretation 29

TABLE OF CONTENTS (Continued)

Page

VERTEBRATE FOSSILS OF THE TULLOCK FORMATION 32
Vertebrate Fossils from Mudstone Facies 32
Vertebrate Fossils from Conglomerate-Mudstone Facies 34
Vertebrate Fossils from Lignite Facies 37
Vertebrate Fossils from Sandstone Facies 38

TAPHONOMY OF THE TULLOCK FORMATION 40
Criteria of Taphonomic Interpretation 40
Taphonomic Interpretation and the Depositional Environment of the Tullock Formation 46
Taphonomy of Mudstone Facies 46
Taphonomy of Conglomerate-Mudstone Facies 50
Taphonomy of Lignite Facies 54
Taphonomy of Sandstone Facies 56

DISCUSSION 59

CONCLUSION 63

REFERENCES 65

LIST OF TABLES

Table Page

1. List of vertebrate fossils from conglomerate-mudstone facies and microvertebrate assemblage..... 35

2. List of vertebrate fossils from sandstone facies..... 39

3. Taphonomic interpretation of fossils based on their preservation patterns..... 42

LIST OF FIGURES

Figure — Page

1. Generalized map showing location of the study area, McGuire Creek at Fort Peck Reservoir, McCone County, Montana 2

2. Correlation and stratigraphic relations of upper Cretaceous and Paleocene rocks in eastern Montana and western North Dakota 5

3. Topographic map of the study area 7

4. Exposures of Cretaceous-Paleocene strata in the study area 8

5. Stratigraphic columns 9

6. Rock sample of the basal conglomeratic part of conglomerate-mudstone facies 19

7. Channel lag lignite (Lg) at the bottom of gently-inclined beds of sandstone 22

8. Overview of a large-scale trough cross-stratified sandstone body 25

9. Close-up view of middle-scale trough cross-stratification in a sandstone body 25

10. Erosional contact of sandstone with underlying mudstone 26

11. Gently-inclined alternating beds of sandstone and mudstone 29

LIST OF FIGURES (Continued)

Figure Page

12. Champsosaur skull from mudstone facies (*Champsosaurus* sp. MOR 694-F-1)..... 32

13. Skull of a closely associated champsosaur from mudstone facies (*Champsosaurus ambulator* MOR 698)..... 34

14. Articulated champsosaur from a lignite layer (*Champsosaurus* sp. MOR 701)..... 38

15. Modeled graph of taphonomic interpretations of vertebrate fossils based on the preservation patterns..... 44

16. Section of map of the associated champsosaur skeletons in mudstone..... 48

17. Well abraded vertebra of champsosaur in conglomerate..... 53

18. Slightly abraded femur of champsosaur in conglomerate..... 53

19. Block diagram of a meandering river system..... 60

ABSTRACT

Late Cretaceous to early Paleocene rocks are well exposed around Fort Peck Reservoir in Garfield and McCone Counties, Montana. Numerous fossil vertebrates were found in the lower part of the Tullock Formation (early Paleocene) in the south area of the McGuire Creek. Previous studies gave no consideration to taphonomy preferring instead to concentrate on one particular aspect such as paleontology or sedimentology. This study attempts to reconstruct the paleoenvironment and faunal content of the Tullock Formation in the local area through detailed sedimentologic, paleontologic, and taphonomic analysis.

Seven major sedimentary facies are recognized: 1) trough cross-stratified sandstones interpreted as main stream channel deposits, 2) inclined beds of sandstone and alternating sandstone and mudstone interpreted as point bar deposits of stream channels, 3) planar-laminated and/or massive mudstones containing parallel-bedded iron concretion bands interpreted as flood plain deposits, 4) a thin, clay pebble conglomerate associated with mudstone interpreted as a crevasse channel deposit, 5) lignites interbedded with the mudstone or lying on inclined beds of alternating sandstone and mudstone interpreted as swamp deposits, 6) a thin lignite associated with the bottom of inclined beds of sandstone interpreted as a channel lag deposit. Analyses of the taphonomy of the bones can be used to support the interpretation of the depositional environments of these facies.

The analyses suggest that broad alluvial systems consisting of a dominant flood plain with swamps and a few stream channels developed in the subsiding foreland basin in northeastern Montana during the early Paleocene. The fauna investigated in the study is considered to represent an early Paleocene aquatic and riparian fauna which inhabited alluvial plains. However, the vertebrates from sandstone and conglomerate-mudstone facies, including the microvertebrate assemblage, are possibly contaminated with Cretaceous ones because of the closeness of these localities to the K-T boundary and the allochthonous character of the fossils.

REGIONAL SETTING

Introduction

During the summers of 1989 and 1990 an articulated champsosaur, remains of other champsosaurs, crocodiles, turtles, and other vertebrate fossils were found in the lower parts of the early Paleocene Tullock Formation in the McGuire Creek area near Fort Peck Reservoir in northeastern Montana (Figure 1). Numerous bones were collected from several different rock units during the summer of 1991. Of particular significance are a well-preserved champsosaur skull and an almost complete juvenile champsosaur collected from the mudstone facies. Surface collecting also yielded many bones.

The region around Fort Peck Reservoir has been studied extensively because of the presence of abundant vertebrate fossils, especially dinosaurs, and because the Cretaceous-Tertiary transition is observable in the region although the boundary is not clearly defined (Brown, 1907; Jensen and Varnes, 1964). The paleoenvironments of late Cretaceous to early Paleocene age (Hell Creek and Tullock Formations) in this region have been studied recently (Fastovsky and Dott, 1986; Fastovsky, 1987; Smit et al., 1987; Rigby and Rigby, 1990). The faunas present during the Cretaceous-Tertiary transition also have been studied (Simpson,

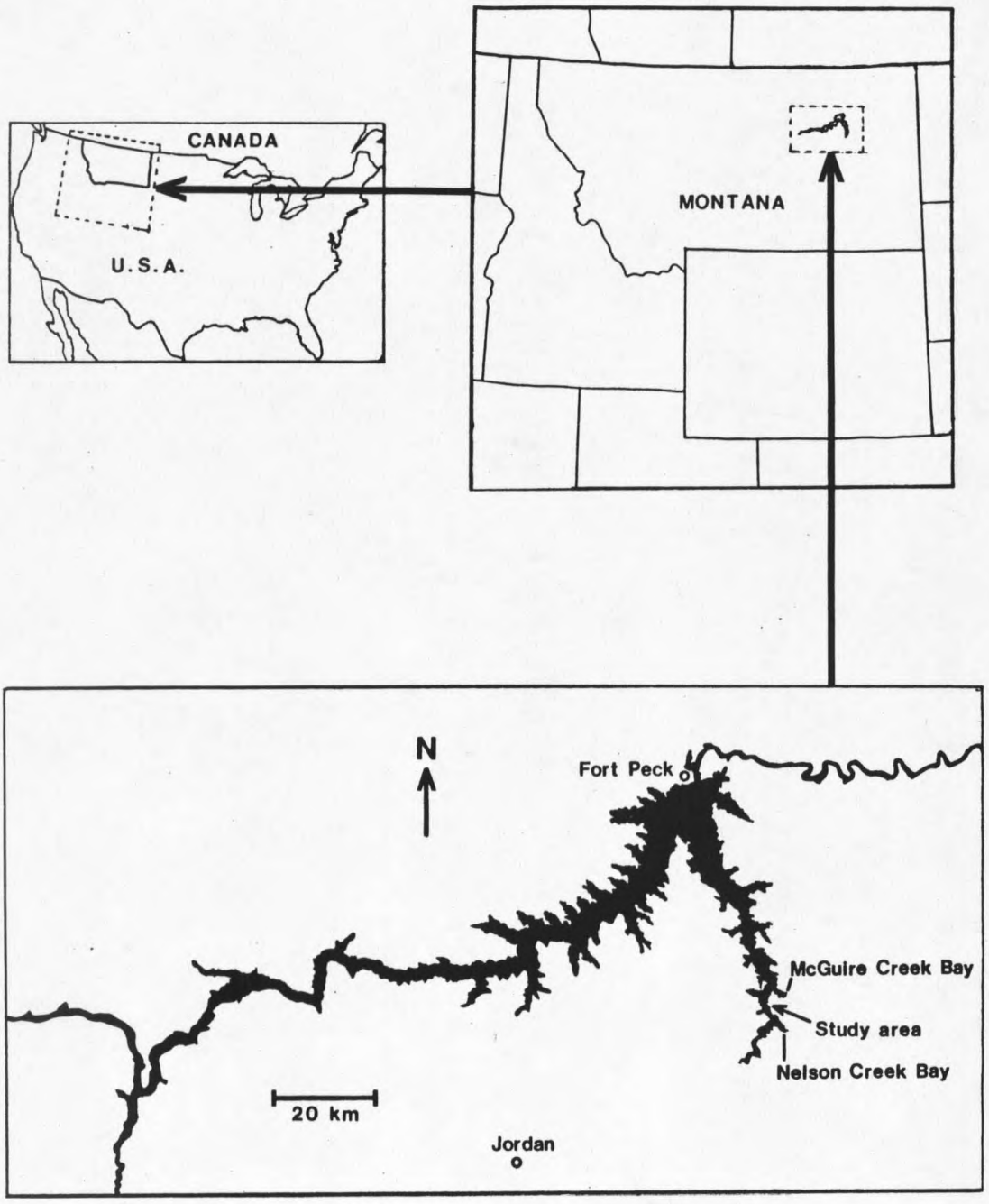


Figure 1. Generalized map showing location of the study area, McGuire Creek at Fort Peck Reservoir, McCone County, Montana.

1927; Sloan and Van Valen, 1965; Estes et al., 1969; Sloan, 1969; Estes and Berberian, 1970; Clemens and Archibald, 1980; Lupton et al., 1980; Archibald, 1982; Clemens, 1982; Hutchison, 1982; Hutchison and Archibald, 1986; Lofgren, 1990).

The Tullock Formation in the study area consists of seven main sedimentary facies; planar and/or massive mudstone, two varieties of lignite, large-scale cross-stratified sandstone, conglomeratic deposits in mudstone, and gently dipping inclined beds of sandstone and alternating sandstone and mudstone. Each facies essentially lies horizontally so that it is relatively easy to trace them laterally and vertically. Each also contains taphonomically characteristic fossils which reflect the local depositional environment.

Previous researchers have focused on either the sedimentology or paleontology (Fastovsky and Dott, 1986; Rigby and Rigby, 1990). Such a one sided approach produced incomplete taphonomic interpretations. This study attempts to describe the taphonomic and sedimentologic characteristics of the seven major sedimentary facies, interpret the depositional significance of each, and reconstruct the paleoenvironment of the Tullock Formation in this area. Comparisons will be drawn between the interpretation here and those of prior workers. Identifiable vertebrate fossils collected from the Tullock Formation of the study area are also described to illuminate the area's early Paleocene terrestrial fauna.

Geological Setting

The North American continent was divided into two parts during the Cretaceous period by the Western Interior Seaway which ran north-south from the Gulf of Mexico to the Arctic (Kauffman, 1977). During late Cretaceous time the seaway regressed to the east, and upward-shallowing marine sediments were deposited. In northeastern Montana the coastal deposits are recorded by the Fox Hill Sandstone (Meek and Hayden, 1862), and the offshore deposits by the Bearpaw Shale (Hatcher and Stanton, 1903). A broad alluvial plain opened on the east side of the Sevier highlands as a result of the withdrawal of the sea. Consequently these marine strata were overlain disconformably by the Hell Creek Formation (Late Cretaceous) and the Tullock and Lebo Formations (early Paleocene), deposits of terrestrial origin which lie conformably upon one another in ascending order around Fort Peck Reservoir (Figure 2) (Brown, 1907; Jensen and Varnes, 1964). Archibald (1982) documented the thickness of the Tullock Formation as 88.4 m to 93 m in the valley of Hell Creek. This compares favorably with Rogers and Lee (1923) who reported a thickness of approximately 90 m in the type area, Tullock Creek, Treasure County, Montana. However, the thickness of the formation is approximately 50 m in McCone County (Collier and Knechtel, 1939) and 55 m in the Bug Creek area (Rigby and Rigby, 1990). This difference in thickness is considered to be related to the problem regarding definition of the formation discussed below.

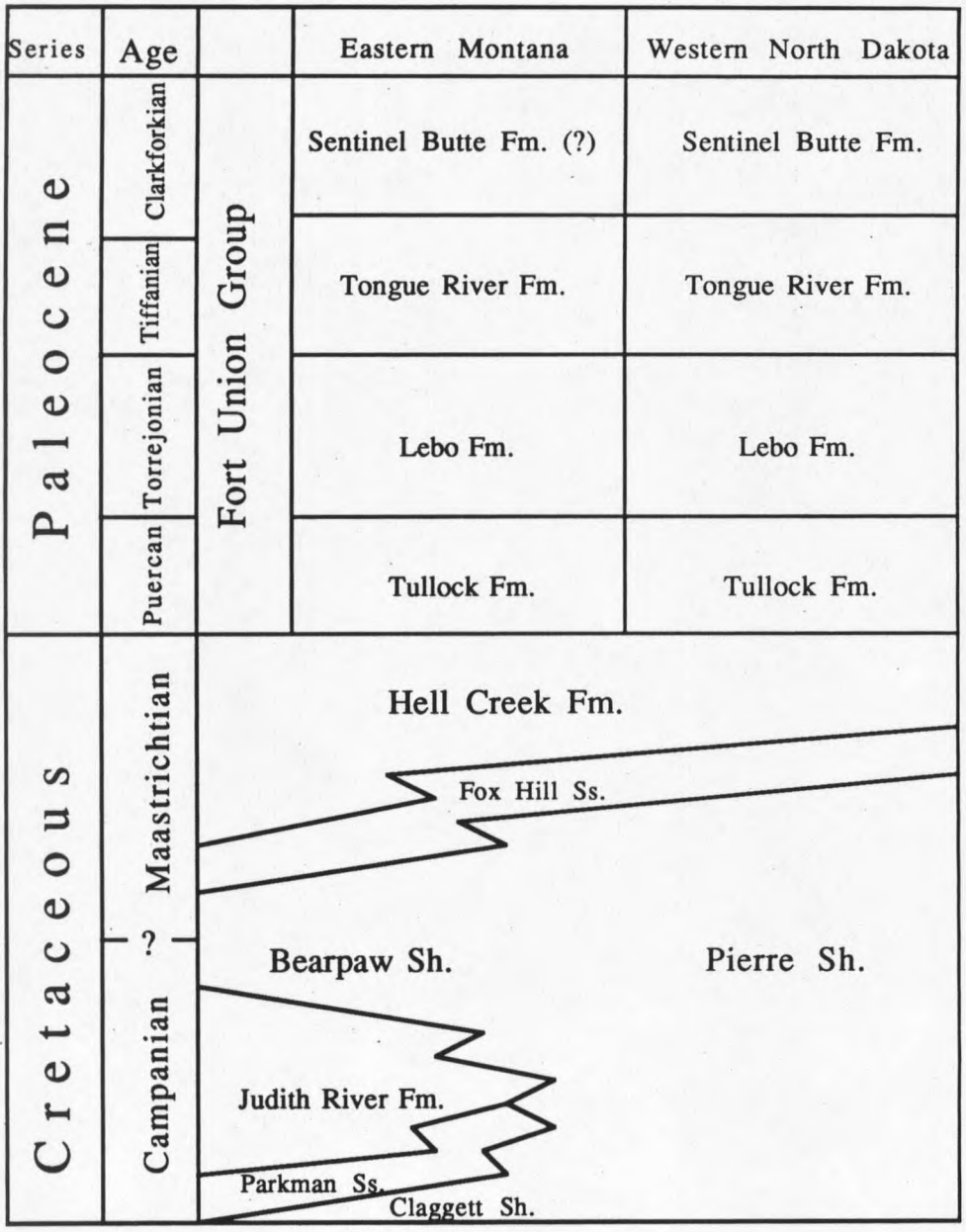


Figure 2. Correlation and stratigraphic relations of upper Cretaceous and Paleocene rocks in eastern Montana and western North Dakota (Sloan, 1969; Erickson, 1972; Gill and Cobban, 1973; Jacob, 1976; Moore, 1976).

Location

The study area is located between Nelson and McGuire Creeks of the Fort Peck Reservoir, McCone County, Montana (Figure 1). An enlarged topographic map of the study area is shown in Figure 3. The area is located in Sections 8 and 9 of the standard USGS 7.5 minute Nelson Creek Bay quadrangle (1973).

Rock outcrops are well exposed because of sparse vegetation, and sedimentary layers can be traced laterally because of their nearly horizontal attitude (Figure 4). Relatively dense vegetative cover is present in some areas in close association with coal/lignite layers. Structural deformation is rare but some folds are recognized in this region (Rigby and Rigby, 1990). The stratigraphic position of the Cretaceous-Tertiary boundary coal layer (Figure 5), therefore the boundary of the Hell Creek and Tullock Formations, in one section (Section 5 in Figure 5 and Figure 3) is remarkably different from the other sections. This is thought to be the result of structural deformation, such as a fault or a fold, though evidence of such structural deformation is absent because of erosion. Sandstone bodies tend to form steeper lands than mudstone bodies because sandstone bodies are friable and more easily eroded.

The Hell Creek Formation is dominated by large-scale cross-stratified and/or massive sandstone with dark massive bentonitic mudstone becoming more predominant near the top of the unit,

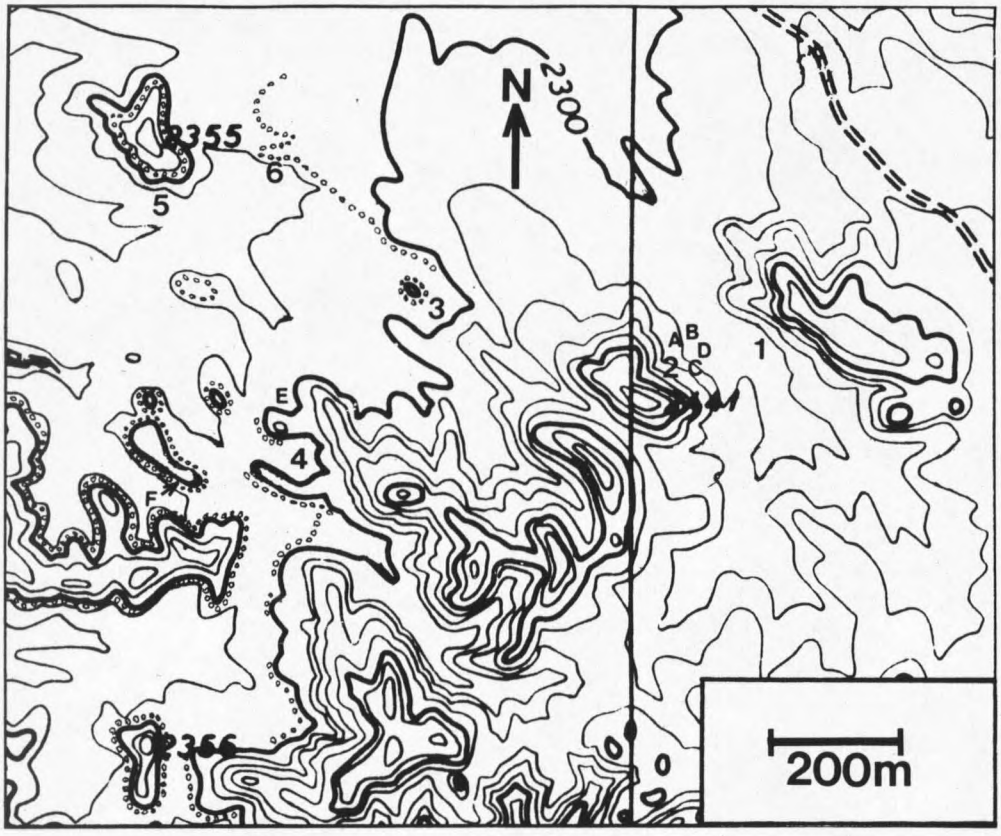


Figure 3. Topographic map of the study area. Section 8 and 9 of the standard USGS 7.5 minute Nelson Creek Bay quadrangle (1973) (Contour interval 20 feet).

°°°°° McGuire Creek Cretaceous-Tertiary boundary coal (lignite) layer (The boundary between the Hell Creek and Tullock Formations)

A-F Fossil localities
- A. Isolated champsosaur skull in mudstone
- B. Associated champsosaur skeletons in mudstone
- C. Vertebrate fossils in a lignite layer
- D. Microvertebrate assemblage
- E. Vertebrate fossils in and from sandstone
- F. Associated champsosaur in mudstone

1-6 Section numbers of measured sections

especially close to the K-T boundary. The mudstone contains fewer iron concretion horizons than that of the Tullock Formation, and the color of the rocks of the Hell Creek Formation is, therefore, monotonous. In contrast, the Tullock Formation is composed of bentonitic mudstone which contains many iron concretion bands, sandstone, lignite, and clinker, and, therefore, has a much more colorful and variable appearance.

Figure 4. Exposures of Cretaceous-Paleocene strata in the study area.

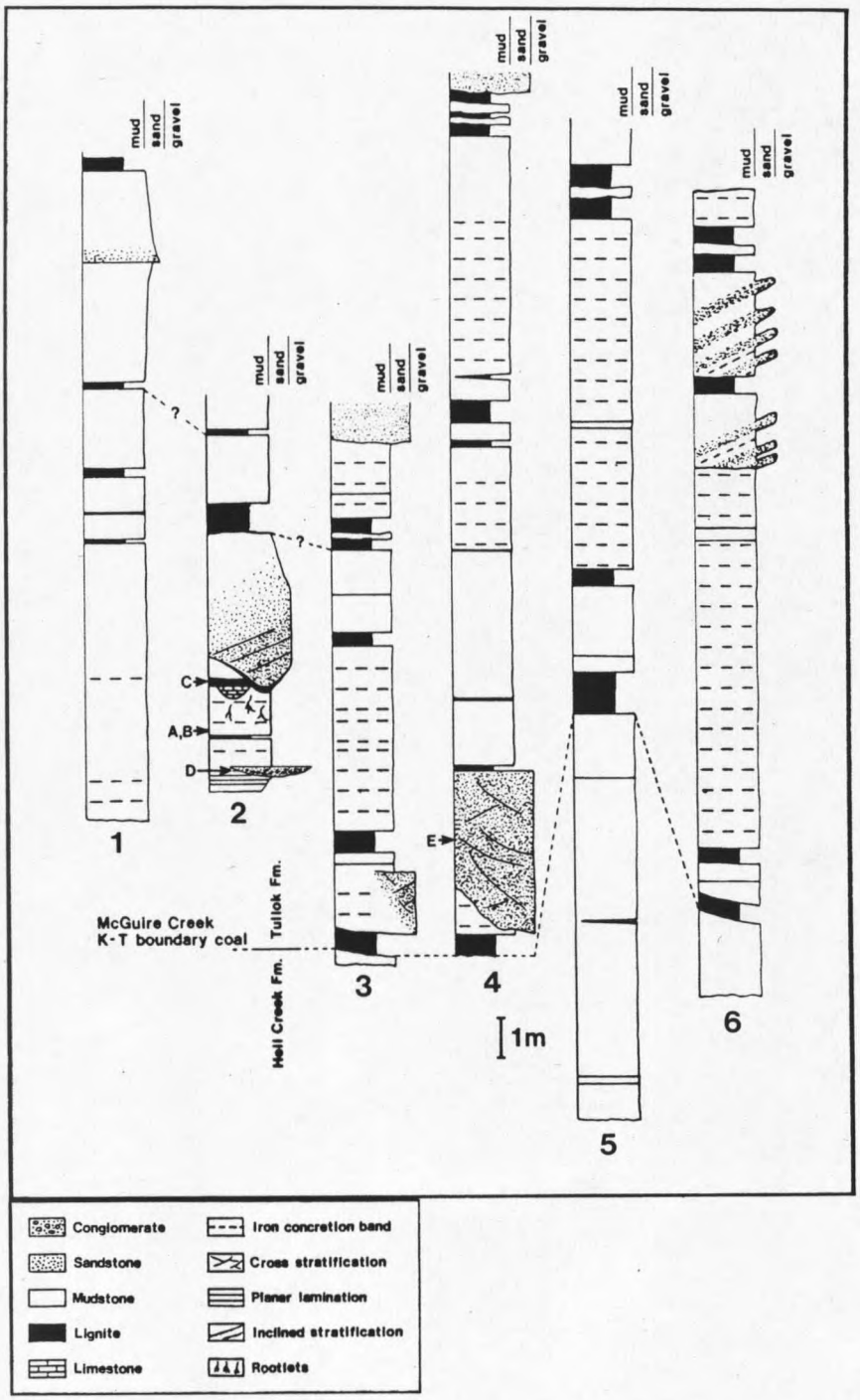


Figure 5. Stratigraphic columns.
All measured locations are plotted on Figure 3.
A-E. Fossil localities (see Figure 3)

History of Geological Studies around Fort Peck Reservoir and the Problem of Formation Names

Meek and Hayden (1862) surveyed the geology in the region of Fort Union, Nebraska Territory (Wyoming), and named the early Tertiary terrestrial deposits the Fort Union Group or Great Lignite Group. Brown (1907) was the first to study and describe the sedimentary rocks in the Hell Creek area, Garfield County, Montana, and named the upper Cretaceous terrestrial deposits the Hell Creek Bed. Leonard (1911) considered the Hell Creek Bed to be the upper part of the Lance Formation and also described all of the Paleocene and early Eocene non-marine deposits overlying the Lance Formation as Fort Union Formation. Rogers and Lee (1923) examined the sedimentary rocks exposed in the Tullock Creek area, Treasure County, Montana, and named the Tullock Member as a member of the Fort Union Formation. Collier and Knechtel (1939) considered both the Hell Creek Bed and Tullock Member as members of the Lance Formation (Tertiary(?); Eocene(?)). Just after Collier and Knechtel (1939) wrote the report mentioned above, the Hell Creek and Tullock members were raised to the rank of formation officially by the U. S. Geological Survey so that rocks belonging to the Hell Creek Formation were Cretaceous in age while Tullock Formation strata were "Cretaceous or Eocene" in age (see the footnote of P. 10, Collier and Knechtel, 1939). Dorf (1940) suggested that the Tullock Formation was the lowest formation of the Fort Union Group. Sloan

(1964) suggested placing the Cretaceous-Tertiary boundary at the boundary between the Hell Creek and Tullock Formations.

The Problem of the Cretaceous-Tertiary Boundary

Problems related to the Cretaceous-Tertiary boundary have been discussed for some time. There are two principal definitions of the boundary in North America. One states that the K-T boundary is placed at the base of the lowest coal/lignite layer above which dinosaurs have not been found Brown (1952); this coal/lignite horizon was termed "the Z coal" by Collier and Knechtel (1939). Therefore, strata below the coal/lignite layer are included in the Hell Creek Formation and are latest Cretaceous in age. The coal/lignite and overlying strata are included in the Tullock Formation and are early Paleocene in age. There are three major problems with this definition. Firstly, the Z coal is discontinuous laterally; the layer probably pinches out and/or is partly eroded by ancient channel streams or modern erosional processes. Secondly, there is considerable difference in the thickness of the layer; a thinner Z coal may be overlooked by researchers. Thirdly, the Z coal layer may coalesce with another coal/lignite layer so that the two coal/lignite layers become one layer. Therefore, it is difficult to correlate the coal/lignite layer between sites for the reasons outlined above.

The coal/lignite layers above the Z coal are termed the Y, X, W, ... C, B, A coal in ascending order (Collier and Knechtel, 1939). Newly found coal/lignite layers between already known coal/lignite layers

were given specific names such as the upper Z coal or the ZY coal. It is equally difficult to correlate these layers between sites because of the same problems outlined above for the Z coal.

The boundary between the Tullock and Lebo Formations is at the bottom of the U coal, and therefore the Tullock Formation is considered to contain the Z to V coals (Collier and Knechtel, 1939). The variable thickness of the Tullock Formation, mentioned above, may be attributed to the definition of the U coal. Identification of the U coal is very difficult for the same reasons outlined for the Z coal above. Therefore, identification of the U coal depends on the location and/or the researcher so that the thickness of the Tullock Formation is also dependant on the location and/or the researcher.

A second definition of the K-T boundary relates to the extinction of dinosaurs which marks the end of Cretaceous. According to this definition, the boundary between the Hell Creek and Tullock Formations is still the Z coal, but the Hell Creek Formation contains Paleocene age strata at the top because the dinosaur extinction took place at a stratigraphic position a few meters below the Z coal. Thus, the Hell Creek Formation is late Cretaceous and earliest Paleocene in age, and the Tullock Formation is early Paleocene in age. Problems with this definition include the fact that there are no significant lithological changes at the stratigraphic position where the extinction of dinosaurs took place, and the stratigraphic position of the last dinosaurs is not well known (Archibald, 1982).

The first definition given above for the K-T boundary is thought to be more useful because the lithofacies change at the

formational boundary at the level of the Z coal. The change is a gradual one, but the stratigraphic position of the last dinosaurs is much more obscure. Lofgren (personal communication, 1991) suggested the use of specific names for the Z coal in each area. Therefore, in the study area the Z coal which marks the boundary between the Hell Creek (Cretaceous) and Tullock (Paleocene) Formations is termed " McGuire Creek K-T boundary coal ". It is also proposed not to use any specific names for the coals/lignites above the K-T boundary coal because of the difficulties of correlation.

Methods

All outcrops in the study area were prospected for fossils, and most of the bones exposed on surfaces were collected. At some places quarrying was required. Some articulated, associated, and fragile bones were encased in plaster jackets. The surface sediments from a microvertebrate site were collected and screenwashed in the paleontology laboratory of the Museum of the Rockies (MOR). The collected fossils were prepared in the laboratory. All of the bone localities were mapped on an enlarged standard USGS 7.5 minute quadrangle (Figure 3). Associated vertebrate remains were photographed and mapped in detail. The classification scheme for vertebrates used in this paper follows that of Carroll (1988). Some geologically important outcrops were photographed.

Six stratigraphic sections were measured in the study area with a theodolite (Figure 5). The measured section locations are shown on

a topographic map (Figure 3). The lignite layer thought to indicate the Cretaceous-Tertiary boundary and, therefore, the boundary between the Hell Creek and Tullock Formations, was traced as far as possible and mapped on an enlarged standard USGS 7.5 minute quadrangle (Figure 3).

FACIES ANALYSIS OF THE TULLOCK FORMATION

Mudstone Facies

Description

The Tullock Formation in the study area is composed mainly of bentonitic mudstone derived from alteration of volcanic ash. The mudstone is vertically and laterally continuous, interbedded with lignite, and has erosional contacts with sandstone bodies and inclined beds of alternating sandstone and mudstone. The outcrops usually exhibit popcorn-like surface textures because bentonitic rocks are composed of clay minerals (mainly montmorillonite) which swell with the addition of water. The popcorn-like appearance often prevents accurate observation of sedimentary structures, but horizontal planar laminae are visible in finer-grained rocks (claystone). Many parts of the mudstone are massive.

The color of mudstone is variable among brown, grey, blue, green, and purple and seems to be dependant on the quantity of organic matter. The purple mudstone appears to contain the highest amount of organic matter (Fastovsky, 1987) and is usually found beneath or above lignites.

Many parts of the mudstone facies contain regularly-spaced, parallel-bedded iron concretion bands. The thickness of any one

individual band is variable but usually not greater than 3 cm. Many iron concretion bands are recognized just as brownish orange lines in the outcrops, and others are relatively thick, firmly cemented rocks.

Many uncarbonized or weakly carbonized plants occur in the mudstone. The finer parts (claystone) contain fewer and smaller plant fragments than the remainder of the mudstone. Some concentrated plant remains form plant mud layers in mudstone. Long plant remains which dip randomly with no specific orientation are thought to be rootlets. The mudstone occasionally contains some vertebrate fossils which are commonly associated with plant fossils.

Massive limestone occurs at the bottom of a lignite in the mudstone (see Section 2 of the stratigraphic column in Figure 5). Although the lateral and vertical extent of the limestone is not determined, it is considered to be limited because no evidence of this type of rock is found at the same horizon elsewhere in the study area.

Interpretation

The fine grain size and sheet-like horizontal planar laminae are comparable to parallel stratification in silt- or clay-sized sediments (Harms and Fahnestock, 1965) which are attributed to deposition from suspended load. Therefore, the mudstone is considered to have been deposited from suspension by slowly flowing to standing water. Vertical and lateral continuity of the mudstone indicates the repeated and extensive deposition of mud.

The massive nature of many parts of the mudstone is considered to have resulted from reworking by ancient pedoturbation, and lateral change in mudstone color supports this idea (Horner, personal communication, 1992). Plant fossils, rootlets, and evidence of pedogenic processes suggest discontinuous deposition of sediment although no direct sedimentary structures indicating subaerial exposure, for example mud cracks, were found in the facies. Allen (1965) mentioned that development of massive limestone (calcrete) resulted from high evaporation caused by downward movement of water. Miall (1985) and Collinson (1986) noted that the formation of caliche resulted from pedogenic processes. Therefore, the features which probably indicate soil development are also indicative of subaerial exposure in the environment where the mudstone was deposited.

The mudstone is considered to have been deposited from suspension by slow water with depositional intervals, which is attributed to flooding water, and is, therefore, interpreted as a flood plain deposit. Although evidence of crevasse splay and levee deposits is not found in the mudstone, the sedimentary features of the mudstone facies mentioned above are consistent with the facies model of flood plain deposits detailed by Allen (1964, 1965) and Miall (1985).

In eastern Montana and western North Dakota, Fastovsky (1987) distinguished an iron-oxide-stained, banded siltstone facies, which he referred to as a variegated facies, a term originally used by Archibald (1982), from siltstone facies. The variegated facies is

interpreted as extensive, quiescent pond deposits because of sedimentary structures such as thin, continuous laminae of silt and grey mudstones, and the existence of articulated aquatic vertebrate remains, aquatic plants, probable remnant animal burrows, and crushed stem, root and leaf remains. However, these rocks are interpreted in this study as flood plain deposits because of their considerable vertical and lateral extent. These iron concretion bands are thought to be derived from organic materials and formed by diagenetic processes (Berner, 1980, p. 130-132). Iron concretion bands are present in sandstone and mudstone beds of inclined beds of alternating sandstone and mudstone, too. Therefore, the existence of iron concretion bands is not considered to be a diagnostic feature of depositional environments. The sedimentary structures and existence of characteristic organic matter which Fastovsky (1987) used to interpret this facies are not considered to be diagnostic features of pond deposits because those features are found in other depositional environments.

Conglomerate-Mudstone Facies

Description

A thin conglomeratic deposit was found in mudstone facies at one locality in the study area (see the section 2 of the stratigraphic column in Figure 5). The deposit rests upon the underlying planar-laminated claystone along a concave-up erosional surface (Figure 6)

and grades into overlying mudstone which contains many gastropods (snails). The observed maximum thickness of the deposit including the snail-bearing mudstone is approximately 30 cm. The lateral extent can not be determined because of erosion, but it is thought to be limited because of a lack of evidence of this type of rock and its characteristic vertebrate assemblage at the same horizon elsewhere in the study area.

Figure 6. Rock sample of the basal conglomeratic part of conglomerate-mudstone facies. Note the erosional contact with underlying planar-laminated claystone.

Although the deposit does not have any sedimentary structures, it can be separated into three portions, a basal conglomeratic portion, a middle mudstone-dominant part with

relatively large carbonized plant remains, and an upper snail-bearing mudstone. The basal portion is composed of a matrix of fine-grained white sand with grains of claystone intraclasts, well-coalified plant fragments, and relatively small vertebrate fossils. The claystone intraclasts are weakly sorted and rounded but usually less then 15 mm in diameter. The middle part consists of abundant plant-rich mudstone as matrix and claystone intraclasts, vertebrate skeletons, and large plant fragments as grains. The upper part is composed of bluish green mudstone containing many gastropods (snails). The distribution of the gastropods seems to be limited to this conglomeratic deposit.

Interpretation

The concave-up erosional contact with the underlying claystone (flood plain deposit), sandstone matrix, coarse grains, and presence of claystone intraclasts indicate that flowing water incised the flood plain, carried large particles including bones and plant fragments, and deposited them together with eroded underlying claystone as intraclasts. These features are common in channel lag deposits (Happ et al., 1940; Allen, 1965; Collinson, 1986). In addition to these sedimentary features, the limited vertical and lateral extent of the deposit on the flood plain suggests that it is of a crevasse channel origin (Miall, 1985). Miall (1985) also noted the common existence of abundant bones and plant fragments in crevasse channel and splay deposits, which is consistent with the conglomeratic deposit in the

study area. Bridge (1984) mentioned that fining-upward sequences were produced by abandonment of individual crevasse channels in one splay. The fining-upward sequence in this crevasse deposit is shown as the grading of the conglomeratic deposits into overlying mudstone. A crevasse splay deposit in association with a crevasse splay channel was not found.

Lignite Facies

Description

Lignites are the characteristic rocks of the Tullock Formation in contrast to the Hell Creek Formation. Two different types of lignites are recognized in the study area. One group of lignite layers is interbedded with mudstone or lies on inclined beds of sandstone and alternating sandstone and mudstone. The thicknesses of lignite layers range from 10-100 cm. The thickness of each layer also varies along strike. Their distributions are vertically and laterally irregular. Relatively thick lignites (more than 50 cm) are continuous and traceable more than hundreds of meters; thinner ones are less continuous and pinch out. Some lignites grade into organic-rich mudstone above and below; hence, their boundaries are obscure. The lignite layers are usually horizontal. Some lignites are interconnected. Some parts of the lignites contain well-coalified plants and plant chips, and others are muddy. Only one layer of this type of lignite contained many vertebrate fossils, and there was no evidence of

invertebrate remains (see Locality C in Figure 3 and Section 2 of the stratigraphic columns in figure 5).

Another type of lignite was observed only at one locality (see the bottom of the inclined beds of sandstone which is about 2 m above the bottom of Section 2 of the stratigraphic columns in Figure 5), below a sandstone unit with largely inclined beds (Figure 7). It is relatively thin with a variable thickness not exceeding 40 cm. It contains abundant sand grains giving it a granular texture and has a sharp erosional contact with the underlying rocks, but grades into the overlying sandstone. No fossils were found in the unit.

Figure 7. Channel lag lignite (Lg) at the bottom of gently-inclined beds of sandstones. Note the erosional contact with underlying mudstone and lignite layer.

Interpretation

A lignite is derived from plant materials and therefore, the presence of lignite indicates existence of dense vegetation. The laterally and vertically irregular distributions of the first type of lignite in mudstone suggest that organic accumulations built up in depressions on the flood plain occupied by standing water. These depositional conditions are consistent with the facies model of backswamps on a flood plain around main stream channels given by Horne et al. (1978), Ethridge et al. (1981), Flores (1981, 1983), Gersib and McCabe (1981) and Collinson (1986).

The erosional contact with underlying rocks of the second type of lignite and its position at the base of gently dipping inclined beds of sandstone suggest that plant materials accumulated on the bottom of a laterally migrating stream channel as a channel lag. A channel lag deposit is usually represented by coarser grains, intraclasts, and/or plant fragments and logs (Happ et al., 1940; Allen, 1965; Collinson, 1986). In this case it appears that only plant fragments accumulated as a channel lag deposit in a laterally-migrating channel which was eventually abandoned. The water flow may not have been strong enough to produce intraclasts, and there were no coarse grains because of the distance between the source rock and the study area. This type of lignite is observed in the Bug Creek area just north of the study area, and the facies including the lignite were interpreted

as abandoned channel deposits (Fastovsky and Dott, 1986; Smit et al., 1987).

Some lignites are replaced by clinker. This replacement of any one layer may be complete or partial. The clinkers indicate that the lignites combusted although the time when the burning process occurred is unknown. They are bright red to orange in color and are rather hard. The attached mudstone was also burned in some parts and converted to hard, black rock. Plant remains are preserved in some of the clinkers.

Sandstone Facies

Description

The sandstone is fined-grained and well sorted. It is usually weakly cemented, but some parts are well cemented, appearing as rounded boulders on the outcrops. The color is usually white or grey and partly brown. Invertebrate remains were not found in any sandstone units.

Two different types of sandstone bodies are recognized in the study area on the basis of differing geometry. The first type of sandstone has two kinds of lithofacies. Large-scale trough cross-stratification is present throughout the first type of sandstone bodies (Figure 8). Medium-scale cross-laminae are also present in some parts of the sandstones (Figure 9). It has erosional surfaces with underlying rock units; some parts of the erosional surfaces show a

Figure 8. Overview of a large-scale trough cross-stratified sandstone body (↟).

Figure 9. Close-up view of middle-scale trough cross-stratification in a sandstone body.

sharp concave-up basal contact (Figure 10). These sandstone bodies are distributed randomly in the mudstone facies. The true lateral extent of each sandstone unit is unknown because of erosion. The

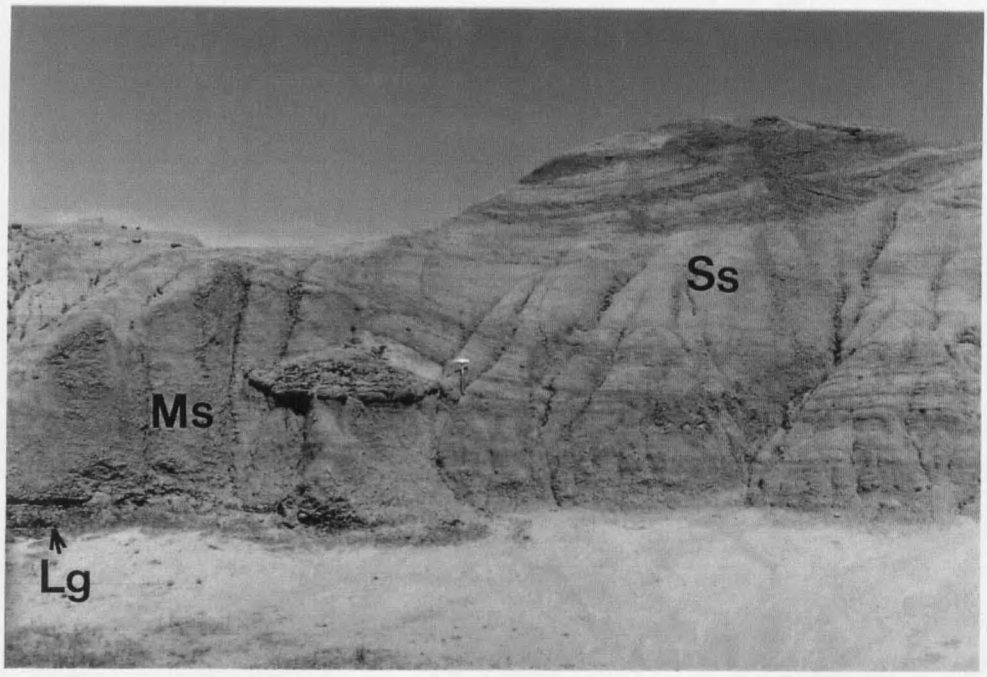


Figure 10. Erosional contact of sandstone with underlying mudstone. The large-scale trough cross-bedded sandstone (Ss) overlies mudstone with iron concretion bands (Ms). Note the concave-up erosional contact. This sandstone contains many vertebrate fossils. The lignite layer (Lg) at the bottom of the hill is the McGuire Creek K-T boundary coal.

maximum measured thickness of the sandstone bodies is about 5 m. Iron concretion bands are present in the sandstone. Some vertebrate fossils were found in a body of this type of sandstone (see Locality E in Figure 3 and Section 4 of the stratigraphic columns in Figure 5),

and many isolated or possibly associated vertebrate fossils on the unit are considered to be eroded from the unit.

The second type of sandstone body is similar in geometry to the first type of sandstone body but consists of gently inclined beds of sandstone. Only one unit of this type of sandstone is observed in the study area (see Section 2 of stratigraphic columns in Figure 5). The unit is about 4 m thick and grades laterally into inclined beds of mudstone-dominant rock. The sandstone body has a planar-inclined erosional basal contact with underlying rock units. A concave-up erosional contact is also present. A thin lignite layer is associated with the second type of sandstone body (Figure 7). Some upper parts of the sandstone unit are massive and show a tendency toward upward fining.

Interpretation

The relatively coarse grains and concave-up erosional contacts with underlying rocks of the trough cross-stratified sandstone indicate that water flows incised the previously deposited sediments and deposited sand. The large-scale trough cross-stratification with medium-scaled laminae is attributed to migration of dunes in the lower flow regime in a stream channel (Harms and Fahnestock, 1965; Collinson, 1986). Therefore, these sedimentary structures indicate that the sandstones are of stream channel origin and are consistent with the facies description of stream channel deposits provided by Allen (1964, 1965) and Miall (1985).

The gently inclined beds of the second type of sandstone are comparable to epsilon cross-bedding (Allen, 1963). The lateral replacement by inclined beds of mudstone-dominant rock indicates lower energy deposition and therefore suggests an abandoned point bar deposit in a stream channel (Allen, 1965). The fining-upward of some upper parts of the sandstone and the gradation of some upper parts of the sandstone into overlying mudstone also indicates a decrease in flow energy and hence supports the abandonment of the stream channel. The lateral gradual replacement indicates that the abandonment of the channel loop took place gradually, which may have resulted from chute cut-off of the meandering channel (Allen, 1965; Walker, 1976).

Inclined Beds of Alternating Sandstone and Mudstone Facies

Description

Beds of alternating sandstone and mudstone are inclined less than 10 degrees (see Section 6 of stratigraphic columns in Figure 5 and Figure 11). The units grade into mudstone laterally and have a planar disconformable contact with the overlying and underlying rocks. All of the units in the study site are capped by lignites. The measured thicknesses of the units range from 2.5 to 4.5 m. The sandstones are white or grey in color and fine-grained. Mudstone contain iron concretion bands which are parallel to the bedding. Each

sandstone or mudstone bed is usually less than 30 cm in thick, and the thickness of successive beds does not alter dramatically. No fossils were found in these beds with the exception of a few unidentifiable plant remains in the mudstone beds.

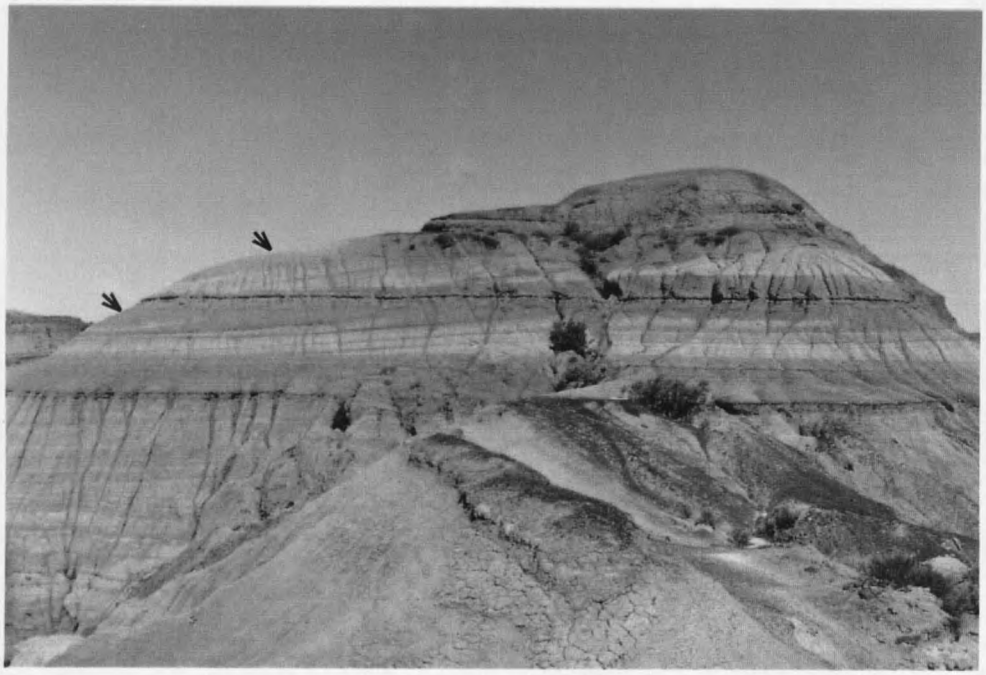


Figure 11. Gently-inclined alternating beds of sandstone and mudstone (↟).

Interpretation

The gently-inclined beds with planar erosional contacts with underlying rocks suggests that the water flow which deposited this facies eroded previously deposited rocks and deposited the sediments with lateral migration. The lateral accretion of sediments with accompanying erosion of underlying sediments indicates lateral

growth of inner bands of channel meanders and is comparable to epsilon-cross-stratification (Allen, 1963) which is interpreted as a point bar deposit.

Thomas et al. (1987) described similar deposits as inclined heterolithic stratification (IHS) separately from other varieties of this type of deposit and mentioned that IHS deposits are mainly derived from point-bar deposits within tidally influenced meandering channels. Allen (1963) mentioned that the lithologically heterogeneous sediments on a point bar were formed by the variation in strength of tidal currents. Wood et al. (1988) studied the Judith River Formation in Dinosaur Province Park, Alberta, Canada, and interpreted the large-scale inclined heterolithic strata associated with trough cross-bedded sandstone as point bar deposits influenced by tides although the strata were of freshwater origin. The Judith River Formation is of deltaic origin so that the deposition of sediments was considered to be influenced by tide. However, it is not considered that the deposition of the rocks of the Tullock Formation was tidally influenced because there is no biological and sedimentologic evidence of marine deposition in the study area.

Stewart (1983) studied the Wealden Group (Lower Cretaceous) of South England and stated that the mudstone beds in the inclined heterolithic units were of suspended-load origin, and the variation in lithology indicated wide fluctuations in river stage. Mossop and Flach (1983) studied the McMurray Formation (Lower Cretaceous), Athabasca Oil Sands, Alberta, and stated that sandstone beds of IHS were deposited during flood stages, and finer grain portions

accumulated as mud drapes during low flow stages. Thomas et al. (1987) mentioned that sandstone-mudstone couplets are caused by fluctuations in energy levels which are related with flow velocity and water level.

The lateral termination of the beds and gradation of the units into mudstone indicate that the channels which deposited the beds were abandoned by avulsion or neck cut-off (Collinson, 1986). Mudstone associated with the point bar deposits is described as abandoned channel mud fill by Stewart (1981). The lignites capping these beds, which indicate the existence of dense vegetation and accumulation of plants in a depression, support the contention that the channel was abandoned and left as a depression with standing water much like an ox-bow lake (Fisk, 1947; Allen, 1964; Collinson, 1986).

VERTEBRATE FOSSILS OF THE TULLOCK FORMATION

Vertebrate Fossils from Mudstone Facies

An isolated skull of a champsosaur was found in mudstone (see Locality A in Figure 3 and Section 2 of the stratigraphic columns in Figure 5). The delicate bones of the back of the skull, the jugal, quadratojugal, postorbital, squamosal, and parietal, were removed or compressed (Figure 12). Nonetheless, the skull is preserved in three dimensions. Most of the maxillary teeth were also removed. The anterior end of the snout was broken off by recent weathering. The species can not be identified because of this damage.

Figure 12. Champsosaur skull from mudstone facies (*Champsosaurus* sp. MOR 694-F-1).

Associated champsosaur skeletons were recovered near the isolated champsosaur skull on almost the same horizon (see Locality B in Figure 3 and Section 2 of the stratigraphic columns in Figure 5). The associated skeletons represent at least two individuals. The anterior portion of a snout and a left femur are derived from one or two individuals, and the species can not be identified. All of the other skeletons are considered to belong to one individual. The proximal anterior branch of the ventral ridge system of the femur is not connected to the articular surface of the head, and the distal end is relatively flat and triangular. Brown (1905) suggested that these features of the femur may be used to identify *Champsosaurus ambulator*.

A closely associated juvenile champsosaur was also found in mudstone although the locality is about 725 m southwest from other champsosaur remains mentioned above and is 2 or 3 m above the K-T boundary (see Locality F in Figure 3). It is complete except for distal caudal vertebrae and some limb, pes, and manus bones. The skull is preserved in three dimensions except for the posterior portion (Figure 13). Many teeth are present in the premaxillae, maxillae and mandibles, and small teeth are well preserved on the palatines, vomers, and ectopterygoids. The anterior end of the snout is broken off and shows a slight lateral expansion. All cervical vertebrae (9 including atlas and axis), dorsals (17), and sacrals (3) are present, and some proximal caudals are also present. Many neural arches are present, but a number of them were separated from their centra. Examination of the humerus, the most diagnostic

bone of champsosaurs, allows this individual to be identified as *Champsosaurus ambulator* (Erickson, 1972). One questionable point is that the femora do not possess the characteristic features of *Champsosaurus ambulator* mentioned above.

Figure 13. Skull of a closely associated champsosaur from mudstone facies (*Champsosaurus ambulator* MOR 698).

Vertebrate Fossils from Conglomerate-Mudstone Facies

The microvertebrate assemblage is composed of turtles, champsosaurs, crocodiles, fish, lizards, amphibians, and mammals. The most dominant elements are champsosaur centra and turtle shell fragments. Other parts of the skeletons of crocodiles, turtles and champsosaurs are also common elements. Small bone fragments of

fish, amphibians, and lizards are minor elements in the assemblage. Scales of gar fish and teeth of fish and crocodiles are also present in the assemblage.

Identifiable specimens are listed in Table 1. Most of the turtles are identified by shell fragments. All of the champsosaur bones are postcranial elements which are not sufficiently diagnostic to allow species identification. This is also the case with the crocodilian remains. Five isolated mammal teeth were collected and identified (Table 1).

Table 1. List of vertebrate fossils from conglomerate-mudstone facies and microvertebrate assemblage. Classification follows Carroll (1988).

CLASS OSTEICHTHYES
SUBCLASS ACIPENSERIFORMES
INFRACLASS NEOPTERYGII
Order Lepisosteiformes
Family Lepisosteidae
Lepisosteus sp.
Order Amiiformes
Family Ammidae
Amia sp.

CLASS AMPHIBIA

CLASS REPTILIA
SUBCLASS TESTUDINATA
Order Chelonia
Family Baenidae
Family Neurankylidae
Compsemys victa

Table 1 (continued)

CLASS REPTILIA
SUBCLASS TESTUDINATA
Order Chelonia
Family Emydidae
"Clemmys" backmani
Family Trionychidae
Aspideretes sp.
Plastomenine
SUBCLASS DIAPSIDA
Order Choristodera
Family Champsosauridae
Champsosaurus sp.
INFRACLASS LEPOIDOSAUROMORPHA
Order Squamata
INFRACLASS ARCHOSAUROMORPHA
Order Crocodylia
Family Crocodylidae
Leidyosuchus sp. (?)

CLASS MAMMALIA
SUBCLASS ALLOTHERIA
Order Multituberculata
Family Taeniolabididae or Family Cimolomyidae
cf. *Catopsalis* sp. cf. *Meniscoessus* sp.
Family Neoplagiaulacidae
cf. *Mesodma formosa*
SUBCLASS THERIA
INFRACLASS EUTHERIA
Order Condylarthra
Family Arctocyonidae
Protungulatum donnae

Vertebrate Fossils from Lignite Facies

Many fossil vertebrates were found in a lignite layer in the study area (see Locality C in Figure 3 and Section 2 of the stratigraphic columns in Figure 5).

Fragments of a crocodile skull were found with many scutes. Both mandibles are also preserved but badly deformed, and no teeth are present. The skull is identified as *Leidyosuchus* sp. (Erickson, 1976).

An articulated champsosaur was preserved in the lignite and is nearly complete but compressed. A number of bones were dislocated. Dorsal vertebrae are preserved in order despite the dislocation (Figure 14). All neural arches are still attached to their centra. The species can not be identified because of the deformation and is described as *Champsosaurus* sp.

Many isolated and associated bones occur in the lignite. There are deformed champsosaur vertebrae, many champsosaur gastralia and other postcranial elements which might be derived from the same individuals, fragments of turtle shells, and some crocodile teeth. An associated turtle is also preserved.

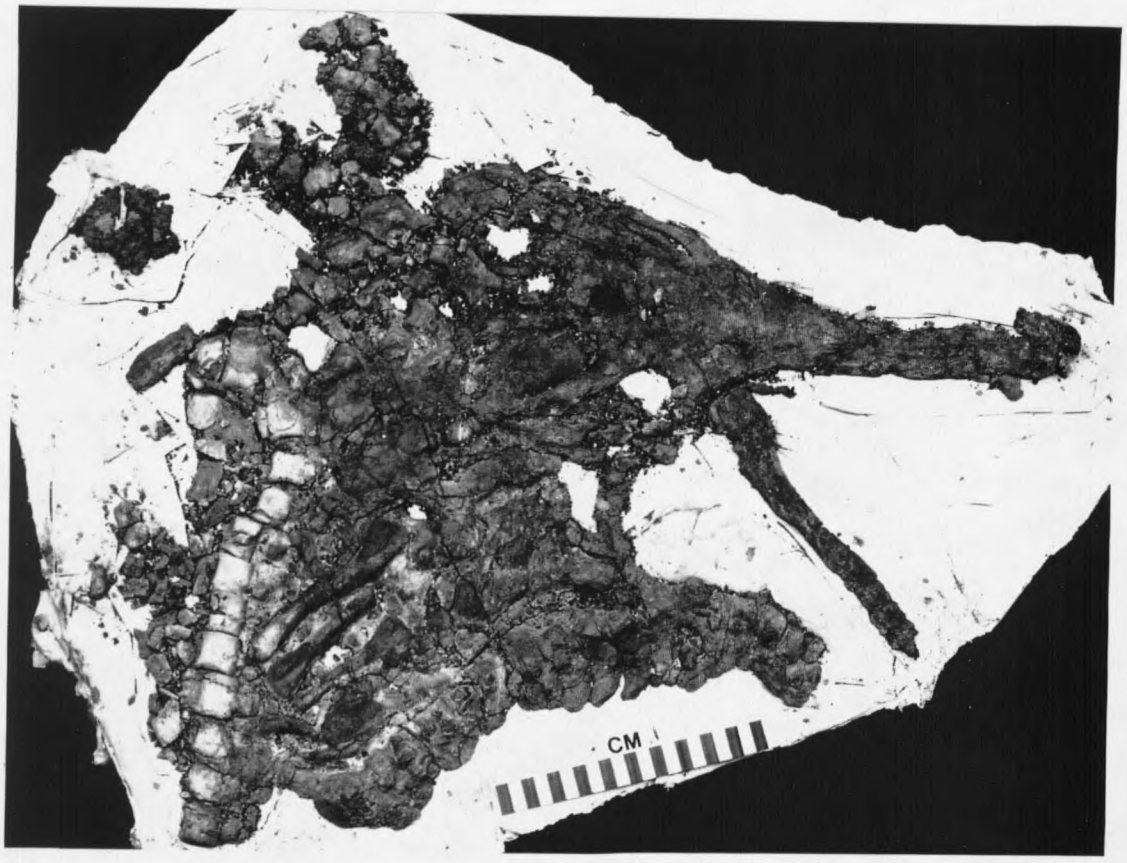


Figure 14. Articulated champsosaur from a lignite layer (*Champsosaurus* sp. MOR 701).

Vertebrate Fossils from Sandstone Facies

Some isolated bones were found in a trough cross-stratified sandstone body, and many isolated and probably associated fossil bones were found on a sandstone body from which these bones were weathered (see Locality E in Figure 3 and Section 4 of stratigraphic column in Figure 5).

Turtle shell fragments are dominant. Many postcranial elements of champsosaurs were found. The relatively large

champsosaur vertebrae, distal ends of humeri, proximal end of a femur, and many rib fragments are thought to be derived from the same individual because of the close proximity and similar size range of the elements. Parts of one or more skulls, scutes, teeth, and postcranial elements of crocodiles were recovered, and bone fragments of fish were also found. The identifiable specimens among these fossils are listed in Table 2.

Table 2. List of vertebrate fossils from sandstone facies. Classification follows Carroll (1988).

CLASS OSTEICHTHYES
SUBCLASS ACIPENSERIFORMES
INFRACLASS NEOPTERYGII
Order Lepisosteiformes
Family Lepisosteidae
Lepisosteus sp.

CLASS REPTILIA
SUBCLASS TESTUDINATA
Order Chelonia
Family Baenidae
Family Trionychidae
Aspideretes sp.
Plastomenine
SUBCLASS DIAPSIDA
Order Choristodera
Family Champsosauridae
Champsosaurus sp.
INFRACLASS ARCHOSAUROMORPHA
Order Crocodylia
Family Crocodylidae
Leidyosuchus sp.

TAPHONOMY OF THE TULLOCK FORMATION

Criteria of Taphonomic Interpretation

The particular pattern of preservation of a fossil is dependant on whether it is influenced by biological and/or non-biological factors. Transportation by flowing water in an alluvial environment is a very important factor in determining the degree of dispersal of bones. Dispersal is also strongly influenced by the density, size and shape of bones and additionally fluid density and the bottom condition of the fluvial system (Voorhies, 1969; Behrensmeyer, 1975; Hanson, 1980). Rapid burial (sedimentation) is essential for bones to be preserved without becoming disassociated (Behrensmeyer, 1975, 1991). Therefore, a balance between transportation and sedimentary accumulation rates determines the pattern of bone preservation, from which the depositional environment can be inferred. The depositional environment where a carcass is buried is significantly related to predeath circumstances (e.g. habitat) and activities (Behrensmeyer and Kidwell, 1985).

The primary condition of a carcass before burial is thought to depend on mainly mega- and micro-biological and chemical factors. Death is often caused by predation, and animals that die naturally may be scavenged by other animals (Weigelt, 1927; Behrensmeyer, 1975, 1991; Hill, 1980). Therefore, mega-scale dislocation and/or

disarticulation of bones before burial is thought to result from the feeding activities of carnivores, which is strongly related to the ecological setting of a carcass (Behrensmeyer, 1991). In carcasses that are not disturbed by other animals, the cartilage is broken down by microbial and/or chemical destruction (Weigelt, 1927; Allison and Briggs, 1991; Martill 1991). The microbial and chemical destruction of bones continues during burial. These mega- and micro- biological and chemical destructive processes can occur separately, simultaneously or prior to and during burial.

In summary, the condition of a carcass before and during burial and the balance between transportation and sedimentary accumulation rates are considered to be the most influential factors in determining the pattern of bone preservation in an alluvial environment (Miall, 1983). The detailed interpretations listed in Table 3, and the modeled graph with a condition that a carcass is complete before burial begins is shown in Figure 15.

In the case where a carcass is complete before burial begins two situations are considered. Under low sedimentary accumulation rates, soft tissues and cartilage of a carcass are completely broken down by microbial and chemical destruction before completion of burial. Given this condition, articulation of bones infers no transportation, and isolation infers high transportation. Articulation of bones occurs under conditions of no transportation (Type 1-A in Table 3 and Figure 15), and isolation of bones occur under high transportation (Type 4-A in Table 3 and Figure 15). Association of

Table 3. Taphonomic interpretation of fossils based on their preservation patterns.

Type 1-Articulated bones

Condition

The fossil is nearly complete and articulated with or without minor dislocation.

Interpretation

A. The animal is considered to disconnected without disturbed by other animals before and during burial. However, the bones are preserved without dislocation so that the fossil preserves the living appearance because water flow was too weak to dislocate bones.

B. The animal is considered to have died without any activities of predators. Burial was rapid enough so that cartilage was not broken down.

Type 2-Partly articulated bones

Condition

The fossil is partly complete, but bones are still articulated with or without minor dislocation.

Interpretation

A. The preserved bones were still connected by cartilage, but separated from other parts by non-biological factors (e.g., fluvial system) before or during burial. Burial was presumably rapid so that the remains were quickly buried before being disarticulated.

B. Lost parts were already separated by biological factors (e.g., predation) before burial. Burial was presumably rapid so that the remains were quickly buried before being disarticulated.

C. Lost parts were already separated by biological factors (e.g., predation) before burial. Burial was too slow to dislocate the remains although they are disconnected during burial.

Table 3 (Continued)

Type 3-Associated bones

Condition

The bones of the fossils are associated in reasonably wide area.

Interpretation

The cartilage of a carcass was broken down before completion of burial. The water flow, which was strong enough to disperse the bones but not to isolate them, separated bones from each other, but they were still associated in one area.

Type 4-Isolated bones

Condition

Bones of fossils are significantly isolated from one another.

Interpretation

A. The cartilage of a carcass was broken down before completion of burial. The water flow, which was strong enough to disperse bones significantly, isolated the bones from each other.

B. The bone was isolated by carnivore animals before burial.

Type 5-Assembled bones

Condition

Bones are disarticulated and apparently disassociated, but assembled.

Interpretation;

A. The assemblage was brought together through non-biological factors (e.g., water flow) whether or not they were already isolated before deposition. The burial rate may not be important, but the transportational energy was high enough to assemble bones.

B. Bones were collected by predators; this assemblage pattern is usually observed in or near a nest of a predator (e.g., a bird nest).

C. Bones were accumulated as incomplete digestive products of predators.

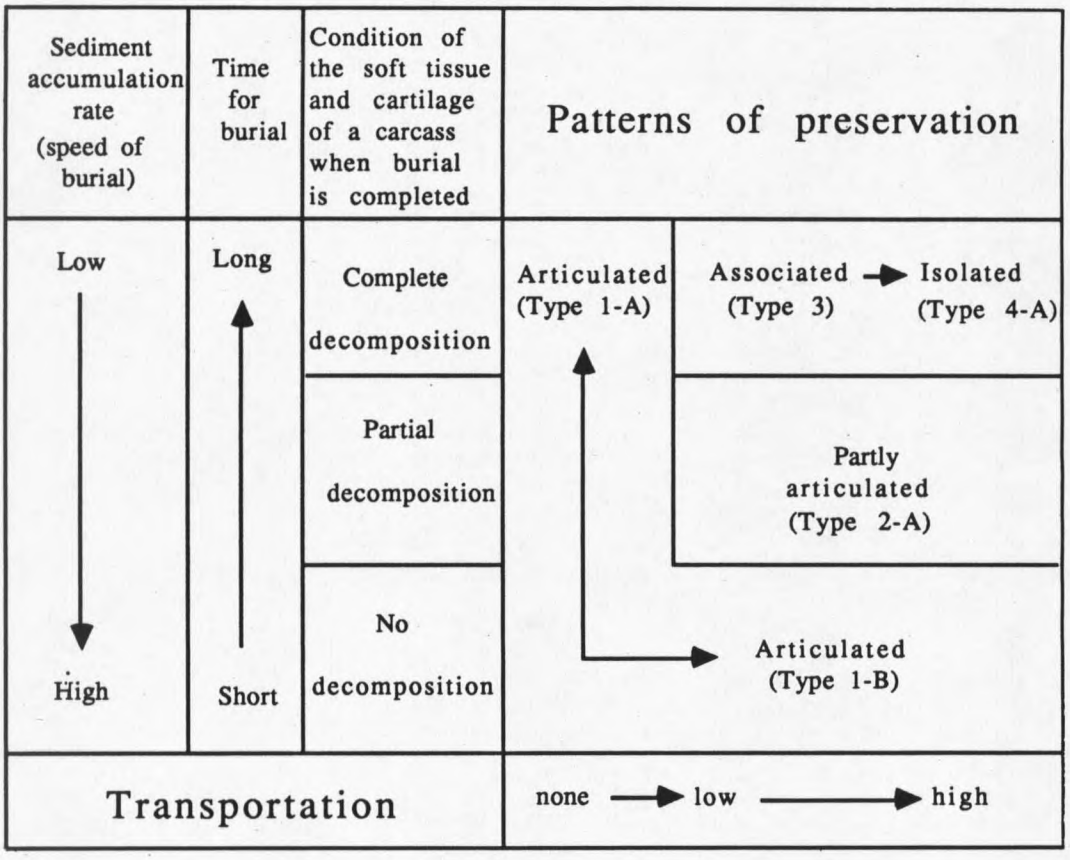


Figure 15. Modeled graph of taphonomic interpretations of vertebrate fossils based on the preservation patterns. The graph assumes the condition that the carcass is not disturbed by predators and/or scavengers prior to burial. (see detailed interpretations of the types of preservation pattern in Table 3).

bones exists as the intermediate situation (Type 3 in Table 3 and Figure 15).

Under high sedimentary accumulation rates, a carcass buried before the soft tissues and cartilage are completely broken down chemically and micro-biologically is preserved as an articulated skeleton (Type 1-B in Table 3 and Figure 15). If the soft tissues and cartilages are partly broken down during burial, the carcass is preserved with partial articulation (Type 2-A in Table 3 and Figure 15).

In the real world a carcass is more commonly incomplete than complete before burial because of the mega- and micro- biological and chemical destruction mentioned above. An incomplete carcass will be preserved with partial articulation (Type 2-B and C in Table 3) under the depositional environments in which bones are preserved with Type 1-A and B preservation patterns (see Table 3 and Figure 15). Isolated bones caused by biological factors (Type 4-A in Table 3) are difficult to distinguish from ones caused by non-biological factors (Type 4-B in Table 3). This is true even if some evidence of mega-biological activities (e.g. bite marks) are preserved on a bone.

Assemblage (accumulation) of bones is considered to occur under two types of situations. One type is the mechanical accumulation by hydraulic processes (Type 5-A in Table 3) (Dodson, 1971; Behrensmeyer, 1991). The other type is the biological accumulation resulting from predatory activities (e.g. bone accumulation in a nest) (Type 5-B in Table 3) (Brain, 1980, 1981;

Behrensmeyer, 1991) and ingestive and digestive processes of carnivores (incomplete digestive bones in pellet) (Mellett, 1974; Brain,1981) (Type 5-C in Table 3).

Because numerous combinations of the condition of a carcass before burial and balance between transportation and sedimentary accumulation rates characterize different depositional environments, every kind of preservation pattern is observed in each different kind of depositional environment in nature. It should also be noted that weathering, vegetation, and/or covering with overlying rocks prevent accurate determination of the real preservation patterns of fossils.

Taphonomic Interpretation and the Depositional Environment of the Tullock Formation

In the study area there are four different kinds of fossil-bearing rock facies; mudstone, sandstone, lignite, and conglomerate-mudstone facies. Each facies contains uniquely preserved fossils. Analyses of the taphonomy of the bones may be used to support the interpretation of the depositional environments of these rock facies provided above.

Taphonomy of Mudstone Facies

An isolated champsosaur skull was recovered with uncarbonized fossil leaves in mudstone (see Locality A in Figure 3 and Section 2 of stratigraphic columns in Figure 5). Deformation

caused by the weight of overlying rocks is most apparent in the back of the skull (Figure 12).

The lost of the anterior end of the snout and cracking of the snout resulted from recent weathering and erosional processes. Thin parts of the back of the skull and most of the maxillary teeth are thought to have been broken and removed before and/or during burial. Other weathering features such as abrasion, bite marks or other cracks caused by predatory activities are not observed. The skull was oriented with the snout towards 59 degrees and lay up side down on a near-horizontal plane. This preservation pattern is considered to belong to Type 4 (Table 3).

Associated champsosaur remains were also found in mudstone close to the isolated champsosaur skull on almost the same horizon (see Locality B in Figure 3 and Section 2 of stratigraphic columns in Figure 5). The bones occurred in a thin, plant-rich mudstone. The plant remains are paper-thin and stacked one on top of the other. The bone bed dips gently to the NE (Figure 16). Long bones were oriented N-S and E-W. The bones represent at least two champsosaur individuals. The bones derived from one individual are all postcranial elements. No weathering, deformation, or damage caused by feeding activities are observed on the bones, although a number of them are broken. The breaks may have occurred during recovery of the specimen.

A left femur and an anterior portion of a snout were present on the same horizon, but surrounded by soil and the roots of modern plants. They were badly-weathered because of the pedogenic

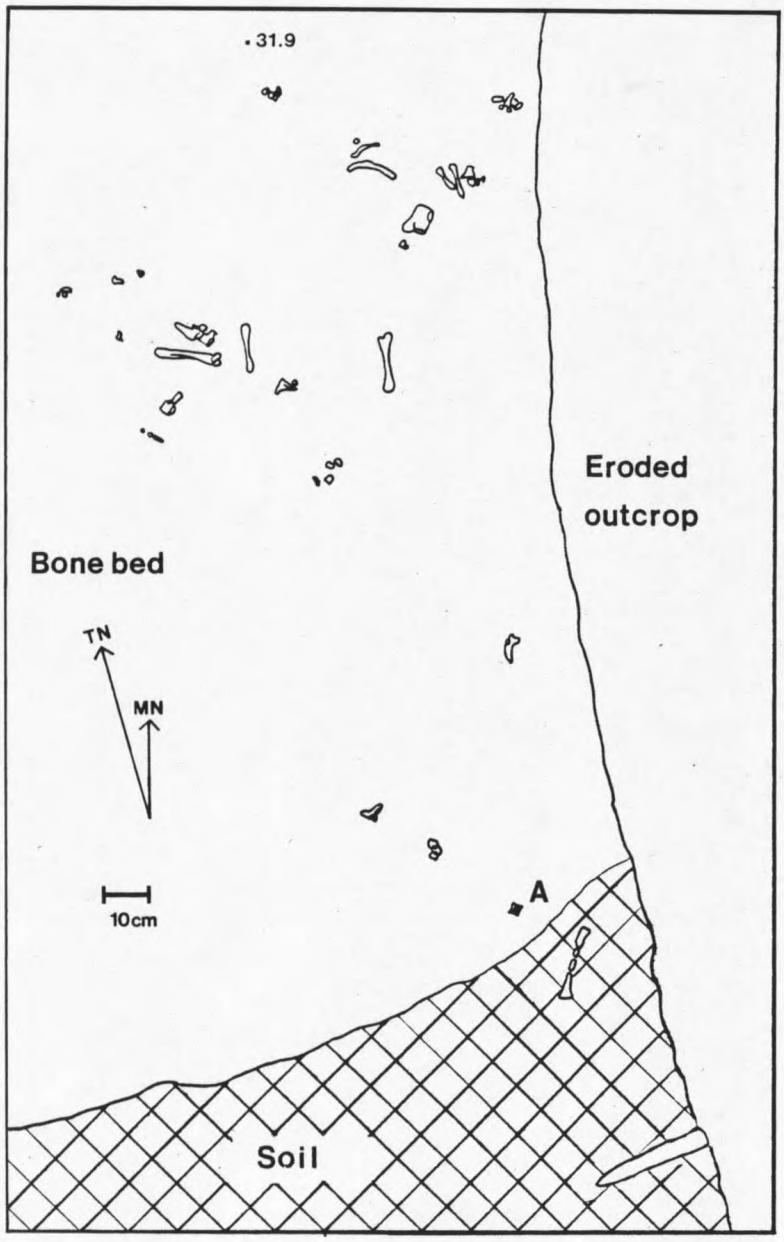


Figure 16. Section of map of the associated champsosaur skeletons in mudstone (see Locality B in Figure 3 and Section 2 of stratigraphic columns in Figure 5).
The number shows the depth from the highest point, A (cm). This bone bed strikes ENE abd dips NNE gently. The cross-hached area was modified by recent pedogenesis.

development of the host rock. No teeth are present in the maxillae. The snout is thought to have been broken off the skull by recent weathering. No evidence of predatory activities can be detected on any of the bones. This situation is considered to be Type 3 (Table 3).

A closely associated juvenile champsosaur was also recovered in mudstone with plant fossils, but the locality is distant from the other champsosaurs mentioned above (see Locality F in Figure 3). The bone bed is 2 or 3 m above the K-T boundary coal. Although the remains were jumbled, many long and large bones lay in one plane with plant remains. Neither the plants nor the long bones provided any indication of the direction of water flow. The champsosaur gastralia were still articulated and lay in the same layer as the long bones. The vertebrae gathered together, but were randomly oriented so that they did not show any preferred orientation. Some of the neural arches were still attached to centra in the host rock. Many of the teeth are still present in the premaxillae, maxillae and dentaries. This situation is between type 2 and 3 (Table 3).

The disarticulation of these bones in mudstone without weathering suggest that the carcasses had minimum subaerial or subaqueous exposure. The association of the bones maintaining the pristine surfaces indicate that the carcasses were disrupted, and the bones were deposited quickly just after disconnection without significant transportation. Therefore, these taphonomic features, by extrapolation, indicate that they were deposited by slowly flowing water. The jumble of the juvenile champsosaur may indicate that the carcass was exposed and disarticulated during a depositional

interval. The carcass was then jumbled by a relatively strong current although coarse grains (e. g. sands), which are expected to have been carried by the strong current, were not associated with the champsosaur. This interpretation, by extrapolation, indicates that the champsosaur was deposited with depositional intervals much like a flood plain. Most of the marxillay teeth of the isolated champsosaur skull were removed, but many of the teeth of the closely associated champsosaur are still attached on the premaxillae, maxillae and dentaries. This difference may indicate the difference of time of exposure during depositional intervals rather than difference in speed of burial.

Taphonomy of Conglomerate-Mudstone Facies

The microvertebrate assemblage, collected from the ground surface, is composed of champsosaurs, crocodiles, turtles, fish, lizards, amphibians, and mammals. There are two main hypotheses regarding the formation of microvertebrate assemblages. One is a scatological hypothesis. Mellett (1974) suggested microvertebrate concentrations were derived from the incompletely digested remains of animals consumed by predators. McGrew (1963) interpreted that microvertebrate concentrations represent the incomplete digested meals of crocodilians.

The second hypothesis suggests that microvertebrate assemblages are formed by hydraulic processes (Dodson, 1971). Wolff (1973) emphasized that size and shape of bones and

depositional action are the most important factors in hydrodynamic sorting. Korth (1979) observed under experimental conditions that bones of microvertebrate assemblages most closely resembled bones which are abraded by water transport rather than those from predator scats. Fisher (1981) concluded that crocodilian digestion is not an important factor in the formation of microvertebrate concentrations although enamel-less teeth are considered to be derived from this source.

It is suggested that the microvertebrate assemblage in the study area was formed by fluvial processes for two reasons: 1) the high frequency of occurrence of such assemblages in this region and 2) the fact that the assemblage in the study area is located adjacent to the crevasse channel deposit. Many crocodiles and other predators were present when and where microvertebrate concentrations were deposited. However, it is unreasonable to expect that all of the concentrated microvertebrate fossils resulted from incomplete digestion by crocodiles and/or other predators. Some bones may have been derived from the incomplete sources, but it is considered to be very minor in the formation of microvertebrate assemblages.

It is also significant that the microvertebrate assemblage in the study area was found on the ground surface adjacent to the crevasse channel deposit mentioned above (see Locality D in Figure 3 and Section 2 of stratigraphic columns in Figure 5). Most of the bones of the assemblage are thought to have been washed out of the splay deposit by modern erosional processes, and furthermore, similar vertebrate fossils were found in the crevasse channel deposit. Most

bones in the crevasse channel deposit exhibit a random orientation and are jumbled randomly with sandstone matrix and other grains (plant fragments, and intraclastic claystone). Long bones, however, are oriented in a NW-SE direction.

It is remarkable that the bones in the channel deposit exhibit a significant variation in the degree of weathering. Relatively small, round bones are well abraded (Figure 17). The abraded bones in the deposits are thought to have been carried for a long distance in the main stream channel and crevasse channel. The chipped plant fragments may have been subjected to the same process. In contrast relatively large and long bones are not or weakly weathered and maintain the pristine surfaces (Figure 18). These bones may have been transported a shorter distance or introduced into the channel from an adjacent flood plain. The bones on the surface also show this bias although many bones are weathered by recent weathering. This character, by extrapolation, suggests that the microvertebrate assemblage was formed by fluvial transport and deposition. It is possible that bones maintaining the pristine surfaces in the assemblage were washed out from mudstone adjacent to the crevasse channel.

It is interpreted that the microvertebrate assemblage on the ground surface was formed by a combination of ancient and modern fluvial processes. Thus, the preservation pattern of the microvertebrate assemblage is Type 5 (Table 3).

Champsosaur centra and turtle shell fragments are the most common elements in the assemblage. Their abundance is thought to

Figure 17. Well abraded vertebra of champsosaur (⮝) in comglomerate.

Figure 18. Slightly abraded femur of champsosaur in conglomerate.

reflect their mechanical durabilities rather than any dominance in the community. Existence of some crocodile centra and articular ends of limb bones of crocodiles and champsosaurs can also be attributed to their robustness. The dominant existence of mechanically durable parts of bones in the assemblage indicates the mechanical sorting of bones by fluvial systems. The minority of small bone fragments of fish, amphibians, and lizards in the assemblage is, thus, attributed to their lower resistance and the difficulty in finding small bones. The presence of teeth of crocodiles and fish is thought to reflect both mechanical and chemical durability. Of course it must be remembered that in life the dominant elements of the assemblage (e.g. vertebrae) are much more numerous than the less dominant elements, such as skulls.

The crevasse channel deposits grade upward into overlying mudstone with many gastropods. The limited distribution of these gastropods in the splay deposit and their preservation in fine-grained rocks can be taken as an indication that they were not carried onto the splay deposits, but lived in this channel; in other words they are autochthonous. Therefore, the channel must have existed long enough to be inhabited by snails.

Taphonomy of Lignite Facies

An articulated champsosaur, and associated and isolated bones of champsosaurs, turtles, and crocodiles were discovered from a relatively thin lignite layer interpreted as a swamp deposit (see

Locality C in Figure 3 and Section 2 of stratigraphic columns in Figure 5). The fossil-bearing lignite layer is traceable about 200 m. The bones were found with concentration from spot to spot in the layer although overlying rocks and erosion prevent finding the real distribution of the bones. Most of them are compressed as a result of compaction of the lignite. All the bones are black or brown in color and very fragile and soft indicating that chemical decomposition occurred in the lignite.

When an animal dies in water, it first sinks, and then often floats upside-down before sinking again or reaching a shore line (Allison and Briggs, 1991). During this process, the carcass rots and may be scavenged (Hill, 1980). The articulated champsosaur was preserved dorsal side up and shows no evidence of disturbance caused by feeding activities (Figure 14). It is suggested therefore that the champsosaur did not float or suffer scavenging after death. The skeleton was recovered from lignite, a swamp deposit, and thus, the water flow may have been so slow that the bones of the carcass were not dispersed although the soft tissues could have been completely destroyed before burial was completed. The preservation pattern of the completely preserved champsosaur is Type 1-B (Table 3). Therefore, by extrapolation, the presence of the articulated champsosaur suggests that lignite was deposited in standing water.

However, the slight dislocations of some bones of the articulated champsosaur and presence of many isolated and associated bones indicate that transport by currents occurred in the swamp. The dorsal vertebrae of the articulated champsosaur are still

ordered despite of the dislocation (Figure 14). This situation indicates that the transport took place before all of the soft tissues were destroyed. This presents a discrepancy in the interpretation although sands, which are expected to have been carried by the water flow, were not found in the lignite.

The presence of fossils with different patterns of preservation in the same layer may indicate that significant periods of time separated the deaths of the animals. The autochthonous character of the fossils suggests that the swamp provided a suitable habitat for leidyosuchids and champsosaurs.

There are many plant fossils in the lignite. Some are preserved as small chips, but others maintain their elongate shapes which are not oriented in any specific direction. All of the plant fossils are coalified, and thus, none can be identified.

Taphonomy of Sandstone Facies

A number of vertebrate fossils were found dispersed through a trough cross-stratified sandstone body (see Locality E in Figure 3 and Section 4 of stratigraphic columns in Figure 5). Many isolated and assembled fossil bones were also recovered from the surface. Some bones on the surface are thought to be derived from the same individuals because of the similarity in their sizes and their close proximity to one another. Therefore, they are considered to have been at least associated in the channel fill sandstone. Eberth (1990) suggested that associated bones in channel deposits are indicative of

introduction into a channel from a flood plain during overbank flooding. Accordingly, the probably associated bones, which were already washed out from the sandstone by surficial weathering, are considered to have been disarticulated on the flood plain and then introduced into the channel.

The fossil bones represent champsosaurs, crocodile, turtles, and fish. Most of the bones still maintain their pristine surfaces although they are often cracked and sharply broken. The minimal abrasion of the bones probably reflects rapid burial and little transportation.

The preservation pattern of the isolated bones in the sandstone unit is Type 4 (Table 3). Overall the preservation pattern of the bones probably washed out from the sandstone is Type 5 (Table 3) and is similar to that of the crevasse channel deposits so that all the bones on the sandstone can be considered as a vertebrate assemblage.

Behrensmeyer (1988) divided taphonomic modes for attritional vertebrate assemblages in channels into two end members, channel-fill and channel-lag modes, based on the sedimentary context of the vertebrate fossils and their taphonomic characters. Channel-lag fossils are represented by abraded, well sorted and disassociated bones with sedimentary features of channel lag in the host rock. On the other hand, channel-fill fossils are characterized mainly by no or weak abrasion. The fossils in and from the sandstone under study are thought to represent a channel-fill mode because the bones are less abraded, some are probably associated, and there is a lack of sedimentary features of channel lag deposits in the sandstone. It can

not be concluded that the crocodiles, champsosaurs, and turtles lived in the stream channel because of the allochthonous character of these fossils. No plant and invertebrate fossils were found from this unit.

DISCUSSION

The dominant mudstone with interbedded coal/lignite and less dominant channel-fill sandstones of the Tullock Formation probably indicate that a few stream channels were developed on broad flood plains with swamps. Also the point bar deposits, which are large-scale, gently-inclined beds of sandstone and alternating sandstone and mudstone, may indicate that a few channels migrated laterally on the wide food plains.

Many geologists have analyzed and described the fluvial pattern in this region during early Paleocene time with facies analyses. Fastovsky and Dott (1986), Fastovsky (1987), and other researchers suggested a meandering fluvial pattern in this area in this time. Rigby and Rigby (1990) suggested that parts of the Tullock Formation are derived from cyclic lacustrine-deltaic sediments. In the study area the sedimentary structures and interpretations of depositional environments of the rock units are very similar to the facies model of the meandering system described by Allen (1964) (Figure 19) and are, on a whole, consistent with the result from facies analyses of Fastovsky and Dott (1986) and Fastovsky (1987). However, Bridge (1985) noted that lack of three-dimensional analyses of facies and paleocurrent information limit the value of studies of diversity of different channel types. Brierley (1989) concluded that it is hard to distinguish a fluvial pattern from facies

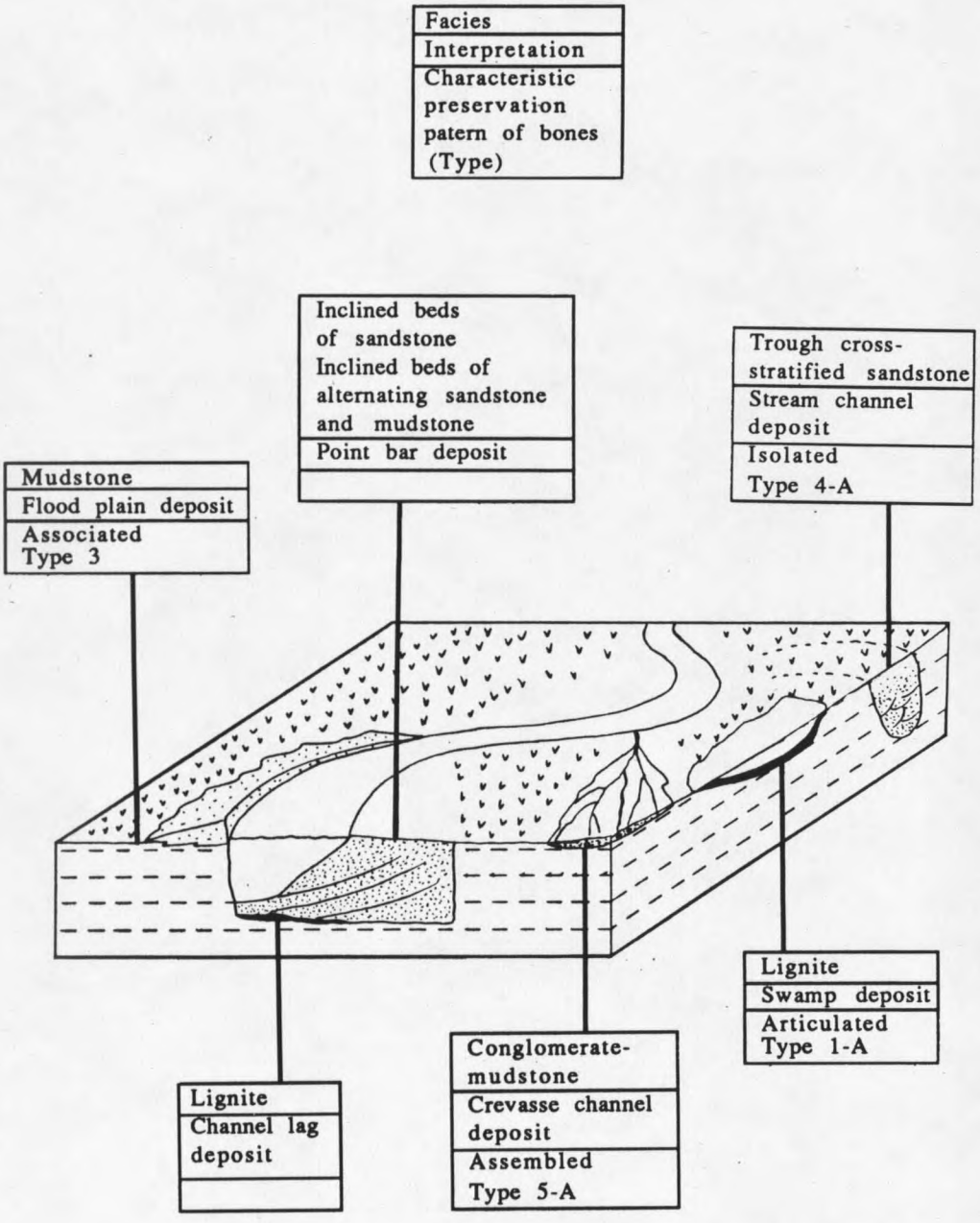


Figure 19. Block diagram of a meandering river system. It is based on Allen (1964). Each local environment is indicated with the facies and characteristic preservation pattern of bones (see detailed interpretations of the types of preservation pattern in Table 3)

analyses because of the similarity of facies of all fluvial patterns and the limited size of outcrops. The outcrops around Fort Peck Reservoir are extensive, but it is still difficult to determine the sinuosity, lateral and vertical extent of the sandstone units, and the lateral limit of the fluvial system. Thus, the fluvial pattern in the area during early Paleocene is not certain. The cyclic lacustrine-deltaic environment suggested by Rigby and Rigby (1990) was not supported by this study. Furthermore, the fluvial pattern could not be determined from this study because the study area was too small.

The fossil vertebrate localities in mudstone and lignite are about 6 m above the K-T boundary coal except for the localities of the juvenile champsosaur which are 2 or 3 m above from the K-T boundary coal. These fossils are thought to be autochthonous, and, therefore, the vertebrates represented are part of the early Paleocene fauna.

Although no dinosaur bones, the index fossil of the Cretaceous period, were found in the microvertebrate assemblage and the crevasse channel deposit located about 5 m above the K-T boundary coal, it is difficult to conclude that these fossils represent the local Paleocene fauna because most were reworked and are allochthonous.

The erosional lower bounding surface of the fossil-bearing channel-fill sandstone unit is very close to the K-T boundary coal, but there is no evidence that the channel cut into the lignite layer and underlying rocks in the study area. However, it is highly possible that the channel cut down to the level of the K-T boundary coal and

the underlying rocks elsewhere. Therefore, vertebrates from the sandstone may not completely represent the early Paleocene fauna because it may have been contaminated with latest Cretaceous vertebrates.

CONCLUSION

The Western Interior seaway began to withdraw during late Cretaceous and early Paleocene time, and as a result extensive basins opened on the eastern side of the highlands, which is now represented as the Rocky Mountains, during this time. A large amount of sediment was transported from the uplifted highlands into the basins by many large fluvial systems resulting in the formation of the Tullock Formation. Because the area where the formation crops out was far from the sediment source area, extrabasinal gravels were rarely deposited. Bentonitic rocks in the formations reflect extensive volcanic activities in and around the highlands during this time.

In early Paleocene time, the alluvial system was dominated by standing water with development of broad flood plains and large swamps. Stream channels migrated laterally and were of lesser importance on the flood plain. Study of late Cretaceous and early Paleocene floras (Johnson and Hickey; 1990) suggest that a late Cretaceous tropical climate changed to a sub-tropical or warm climate in early Paleocene in this region. This warm alluvial environment provided an ideal habitat for aquatic and riparian vertebrates. Plants also flourished in the environment.

It appears that the preservation of fossils and their accumulation into assemblages resulted from mechanical processes associated with alluvial systems, and not from biological processes. It

is probable that some of the preserved animals suffered predation or scavenging, but this does not seem to have had a direct influence on the modes of preservation.

Turtles, champsosaurs, crocodiles, amphibians, lizards, fish and mammals were found in the Tullock Formation in the study area. However, only the fossil vertebrates from mudstone and lignite are considered to represent the early Paleocene fauna in the Tullock Formation because of their autochthonous character. The stratigraphic positions of the fossil-bearing sandstone and conglomerate, including the microvertebrate assemblage, are close to the Cretaceous-Tertiary boundary, and these fossils are allochthonous. Therefore, these fossils were possibly contaminated with vertebrates from the Cretaceous Hell Creek Formation so that they cannot be considered representative of the Paleocene fauna.

REFERENCES

Allen, J. R. L. 1963. The classification of cross-stratified units with notes on their origin. Sedimentology, vol. 2, p. 93-114.

_____ 1964. Studies in fluviatile sedimentation: Six cyclothems from the Lower Old Red Sandstone, Anglo-Welsh Basin. Sedimentology, vol. 3, p. 163-198.

_____ 1965. A review of the origin and characteristics of recent alluvial sediments. Sedimentology, vol. 5, p. 89-191.

Allison, P. A., and Briggs, D. E. G. 1991. Chapter 2. Taphonomy of nonmineralized tissues. In P. A. Allison and D. E. G. Briggs eds., Taphonomy. Plenum Press, p. 25-70.

Archibald, D. J. 1982. A study of Mammalia and geology across the Cretaceous-Tertiary Boundary in Garfield County, Montana. University of California Publications in Geological Science, vol. 122, 286 pp.

Behrensmeyer, A. K. 1975. The taphonomy and paleoecology of Plio-Pleistocene vertebrate assemblages east of Lake Rudolf, Kenya. Museum of Comparative Zoology Bulletin, vol. 146, p. 473-578.

_____ 1988. Vertebrate preservation in fluvial channels. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 63, p. 183-199.

_____ 1991. Chapter 6. Terrestrial vertebrate accumulations. In P. A. Allison and D. E. G. Briggs eds., Taphonomy. Plenum Press, p. 291-335.

Behrensmeyer, A. K., and Kidwell, S. M. 1985. Taphnomy's contributions to paleobiology. Paleobiology, vol. 11, p. 105-119.

Berner, R. A. 1980. Early Diagenesis. Princeton University Press, 241 pp.

Brain, C. K. 1980. Some criteria for the recognition of bone-collecting agencies in African caves. In A. K. Behrensmeyer and A. P. Hill, eds., Fossils in the Making. University of Chicago Press, p. 108-130.

_____ 1981. The Hunters or the Hunted? The University of Chicago Press, 365 pp.

Bridge, J. S. 1984. Large-scale facies sequences in alluvial overbank environments. Journal of Sedimentary Petrology, vol. 54, p. 583-588.

_____ 1985. Paleochannel patterns inferred from alluvial deposits: a critical evaluation. Journal of Sedimentary Petrology, vol. 55, p. 579-589.

Brierley, G. J. 1989. River planform facies models: the sedimentology of braided, wandering and meandering reaches of the Squamish River, British Columbia. Sedimentary Geology, vol. 61, p. 17-35.

Brown, B. 1905. The osteology of *Champsosaurus* Cope. American Museum of Natural History, Memoirs vol. 9, 26 pp.

_____ 1907. The Hell Creek beds of the Upper Cretaceous of Montana. Bulletin of American Museum of Natural History, vol. 23, p. 823-845.

_____ 1952. Tertiary strata in eastern Montana and western North and South Dakota. U. S. Geological Survey, Third Annual Field Conference, p. 89-92.

Carroll, L. R. 1988. Vertebrate Paleontology and Evolution. W. H. Freeman and Company, 698 pp.

Clemens, W. A. 1982. Patterns of extinction and survival of the terrestrial biota during the Cretaceous/Tertiary transition. Geological Society of America Special Paper 190, p. 407-413.

Clemens, W. A., and Archibald, D. J. 1980. Evolution of terrestrial faunas during the Cretaceous-Tertiary transition. Mémoire de la Société Géologique de France, New Series, no. 139, p. 67-74.

Collier, A. J., and Knechtel, M. 1939. The coal resources of McCone County, Montana. U. S. Geological Survey Bulletin 905, p. 1-80.

Collinson, D. J. 1986. Alluvial Sediments, Chapter 3. In Reading, H. G. ed., Sedimentary Environments and Facies, second edition. Blackwell Scientific Publications, p. 20-62.

Dodson, P. 1971. Sedimentology and taphonomy of the Oldman Formation (Campanian) Dinosaur Provincial Park, Alberta (Canada). Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 10, p. 21-74.

Dorf, E. 1940. Relationship between floras of type Lance and Fort Union Formations. Geological Society of America Bulletin, vol. 51, p. 213-236.

Eberth, D. A. 1990. Stratigraphy and sedimentology of vertebrate microfossil sites in the uppermost Judith River Formation (Campanian), Dinosaur Provincial Park, Alberta, Canada. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 78, p. 1-36.

Erickson, B. R. 1972. The lepidosaurian reptile *Champsosaurus* in North America. Science Museum of Minnesota, Monograph 1, Paleontology, 91 pp.

_____ 1976. Osteology of the early eusuchian crocodile *Leidyosuchus formidabilis*, sp. nov.. Science Museum of Minnesota, Monograph 2, Paleontology, 61 pp.

Estes, R., Berberian, P., and Meszoely, C. A. M. 1969. Lower vertebrates from the Late Cretaceous Hell Creek Formation, McCone County, Montana. Breviora, Museum of Comparative Zoology, no. 337, 33 pp.

Estes, R., and Berberian, P. 1970. Paleontology of a Late Cretaceous vertebrate community from Montana. Breviora, Museum of Comparative Zoology, no. 343, 35 pp.

Ethridge, F. G., Jackson, T. J., and Youngberg, A. D. 1981. Flood basin sequence of a fine-grained meander belt subsystem: the coal-bearing lower Wasatch and Upper Fort Union Formations, southern Powder River Basin, Wyoming. In F. G. Ethridge and R. M. Flores eds. Recent and Ancient Nonmarine Depositional Environment: Model for Exploration. Society of Economic paleontologists and Mineralogists Special Publication, no. 31, p. 191-209.

Fastovsky, D. E. 1987. Paleoenvironments of vertebrate-bearing strata during the Cretaceous-Paleogene transition, eastern Montana and western North Dakota. Palaios, vol. 2, p. 282-295.

Fastovsky, D. E., and Dott, R. H. Jr. 1986. Sedimentology, stratigraphy, end extinctions during the Cretaceous-Paleogene transition at Bug Creek, Montana. Geology, vol. 14, p. 279-282.

Fisher, D. C. 1981. Crocodilian scatology, microvertebrate concentration, and enamel-less teeth. Paleobiology, vol. 7, p. 262-275.

Fisk, H. N. 1947. Fine Grained Alluvial Deposits and their Effects on Mississippi River Activity. Mississippi River Commission, Vicksburg, Mississippi, 82 pp.

Flores, R. M. 1981. Coal deposition in fluvial paleoenvironments of the Paleocene Tongue River Member of the Fort Union Formation, Powder River area, Powder River Basin, Wyoming and Montana. In F. G. Ethridge and R. M. Flores eds. Recent and Ancient Nonmarine Depositional Environment: Model for Exploration. Society of Economic paleontologists and Mineralogists Special Publication, no. 31, p, 169-190.

Flores, R. M. 1983. Basin facies analysis of coal-rich Tertiary fluvial deposits, northern Powder River basin, Montana and Wyoming. In J. D. Collinson and J. Lewin eds., Modern and Ancient Fluvial Systems. International Association of Sedimentologists Special Publications, no. 6, p. 501-515.

Gersib, G. A., and McCabe, P. J. 1981. Continental coal-bearing sediments of the Port Hood Formation (Carboniferous), Cape Linzee, Nova Scotia. In F. G. Ethridge and R. M. Flores eds. Recent and Ancient Nonmarine Depositional Environment: Model for Exploration. Society of Economic paleontologists and Mineralogists Special Publication, no. 31, p. 95-108.

Gill, J. R., and Cobban, W. A. 1973. Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, and North and South Dakota. Geological Survey Professional Paper 776, 37 pp.

Hanson, C. B. 1980. Fluvial Taphonomic process: models and experiments. In A. K. Behrensmeyer and A. P. Hill, eds., Fossils in the Making. University of Chicago Press, p. 156-181.

Happ, S. C., Rittenhouse, G., and Dobson, G. C. 1940. Some aspects of accelerated stream and valley sedimentation. U. S. Department of Agriculture and Technology Bulletin 695, 134 pp.

Harms, J. C., and Fahnestock, R. K. 1965. Stratification, bed forms, and flow phenomena (with an example from the Rio Grande). Society of Economic Paleontologists and Mineralogists Special Publication, no. 12, p. 84-115.

Hatcher, J. B., and Stanton, T. W. 1903. The stratigraphic position of the Judith River beds and their correlations with the Belly River beds. Science, new series, vol. 18, p. 211-212.

Hill, A. P. 1980. Early postmortem damage to the remains of some contemporary east African mammals. In A. K. Behrensmeyer and A. P. Hill, eds., Fossils in the Making. University of Chicago Press, p. 131-152.

Horne, J. C., Ferm, J. C., Caruccio, F. T., and Baganz, B. P. 1978. Depositional models in coal exploration and mine planning in Appalachian region. American Association of Petroleum Geologists Bulletin, vol. 62, p. 2379-2411.

Hutchison, J. H. 1982. Turtle, crocodilian, and champsosaur diversity changes in the Cenozoic of the north-central region of western united States. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 37, p. 149-164.

Hutchison, J. H., and Archibald, J. D. 1986. Diversity of turtles across the Cretaceous/Tertiary boundary in northeastern Montana. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 55, p. 1-22.

Jacob, A. F. 1976. Geology of the upper part of the Fort Union Group (Paleocene), Williston Basin, with reference to uranium. North Dakota Geological Survey, Report of Investigation, no, 58, 49 pp.

Jensen, F. S., and Varnes, H. D. 1964. Geology of the Fort Peck Area, Garfield, McCone and Valley Counties. Geological Survey Professional Paper 414-F, 48 pp.

Johnson, K. R., and Hickey, L. J. 1990. Megafloral change across the Cretaceous/Tertiary boundary in the northern Great Plains and Rocky Mountains, U. S. A. Geological Society of America Special Paper 247, p. 433-444.

Kauffman, E. G. 1977. Geological and biological overview: Western Interior Cretaceous basin. Mountain Geologist, vol. 14, p. 75-99.

Korth, W. W. 1979. Taphonomy of microvertebrate fossil assemblages. Annals of Carnegie Museum, vol. 48, p. 235-285.

Leonard, A. G. 1911. The Cretaceous and Tertiary formations of western north Dakota and eastern Montana. Journal of Geology, vol. 19, p. 507-547.

Lofgren, D. L. 1990. The Bug Creek problem and the Cretaceous-Tertiary transition at McGuire Creek, Montana. Unpublished doctoral thesis, University of California at Berkeley.

Lupton, C., Gabriel, D., and West, R. M. 1980. Paleobiology and depositional setting of a Late Cretaceous vertebrate locality, Hell Creek Formation, McCone County, Montana. Contributions to Geology, University of Wyoming, vol. 18, p. 117-126.

Martill, D. M. 1991. Chapter 12. Bones as stones: the contribution of vertebrate remains to the lithologic record. In S. K. Donovan ed., The Processes of Fossilization. Columbia University Press, p. 270-292.

McGrew, P. O. 1963. Environmental significance of sharks in the Shotgun Fauna, Paleocene of Wyoming. Contributions to Geology, University of Wyoming, vol. 2, p. 39-41.

Meek, F. B., and Hayden, F. V. 1862. Description of new Lower Silurian, (Primordial), Jurassic, Cretaceous, and Tertiary fossils collected in Nebraska with some remarks on the rocks from which they were obtained. Philadelphia Academy of Natural Sciences, Proceeding, 1861, vol. 13, p. 415-435.

Mellett, J. S. 1974. Scatological origin of microvertebrate fossil accumulations. Science, vol. 185, p. 349-350.

Miall, A. D. 1983. Basin analysis of fluvial sediments. In J. D. Collinson and J. Lewin eds., Modern and Ancient Fluvial Systems. International Association of Sedimentologists Special Publications, no. 6, p 279-286.

_____ 1985. Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. Earth-Science Reviews, vol. 22, p. 261-308.

Moore, W. L. 1976, The stratigraphy and environments of deposition of the Cretaceous Hell Creek Formation (reconnaissance) and the Paleocene Ludlow Formation (detailed), southwestern North Dakota. North Dakota Geological Survey, Report of Investigation, no, 56, 40 pp.

Mossop, G. D., and Flach, P. D. 1983. Deep channel sedimentation in the Lower Cretaceous McMurray Formation, Athabasca Oil Sands, Alberta. Sedimentology, vol. 30, p. 493-509.

Rigby, J. K., and Rigby, J. K. Jr. 1990. Geology of the Sand Arroyo and Bug Creek quadrangles, McCone County, Montana. Brigham Young University Geology Studies, vol. 36, p. 69-134.

Rogers, G. S., and Lee, W. 1923. Geology of the Tullock Creek coal Field, Rosebud and Big Horn counties, Montana. U. S. Geology Survey Bulletin 749, p. 1-181.

Simpson G. G. 1927. Mammalian fauna of the Hell Creek Formation of Montana. American Museum Novitates, no. 267, 7 pp.

Sloan, R. E. 1964. Paleoecology of the Cretaceous-Tertiary Transition in Montana. Science, vol. 146, p. 430.

_____ 1969. Cretaceous and Paleocene terrestrial communities of western North America. North American Paleontological Convention Proceedings E, p. 427-454.

Sloan, R. E., and Van Valen, L. 1965. Cretaceous mammals from Montana. Science, vol. 148, p. 220-227.

Smit J., Van Der Kaars, W. A., and Rigby, J. K. Jr. 1987. Stratigraphic aspects of the Cretaceous-Tertiary boundary in the Bug Creek area of eastern Montana, U. S. A. Mémoire de la Société Géologique de France, New Series, no. 150, p. 53-73.

Stewart, D. J. 1981. A meander-belt sandstone of the Lower Cretaceous of Southern England. Sedimentology, vol. 28, p. 1-20.

_____ 1983. Possible suspended-load channel deposits from the Wealden Group (Lower Cretaceous) of Southern England. In J. D. Collinson and J. Lewin eds., Modern and Ancient Fluvial Systems. International Association of Sedimentologists Special Publications, no. 6, p. 369-384.

Thomas, R. G., Smith, D. G., Wood, J. M., Calverley-Range, E. A., Visser, J., and Koster, E. H. 1987. Inclined heterolithic stratification - terminology, description, interpretation and significance. Sedimentary Geology, vol. 53, p. 123-179.

Voorhies, M. 1969. Taphonomy and population dynamics of an early Pliocene vertebrate fauna, Knox County, Nebraska. Contributions to Geology, University of Wyoming, Special Paper, no. 1, 69 pp.

Walker, R. G. 1976. Facies models 3. Sandy fluvial systems. Geoscience Canada, vol. 3, p. 101-109.

Weigelt, J. 1927. Recent vertebrate carcasses and their paleobiological implications. (translated by J. Schaefer; foreword by A. K. Behrensmeyer and C. Badgley in 1989). University of Chicago Press, 188 pp.

Wolff, R. G. 1973. Hydrodynamic sorting and ecology of a Pleistocene mammalian assemblage from California (U. S. A.). Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 13, p. 91-101.

Wood, J. M., Thomas, R. G., and Visser J. 1988. Fluvial process and vertebrate taphonomy: the Upper Cretaceous Judith River Formation, south central Dinosaur Provincial Park, Alberta, Canada. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 66, p. 127-143.

MONTANA STATE UNIVERSITY LIBRARIES
3 1762 10103365 0