24

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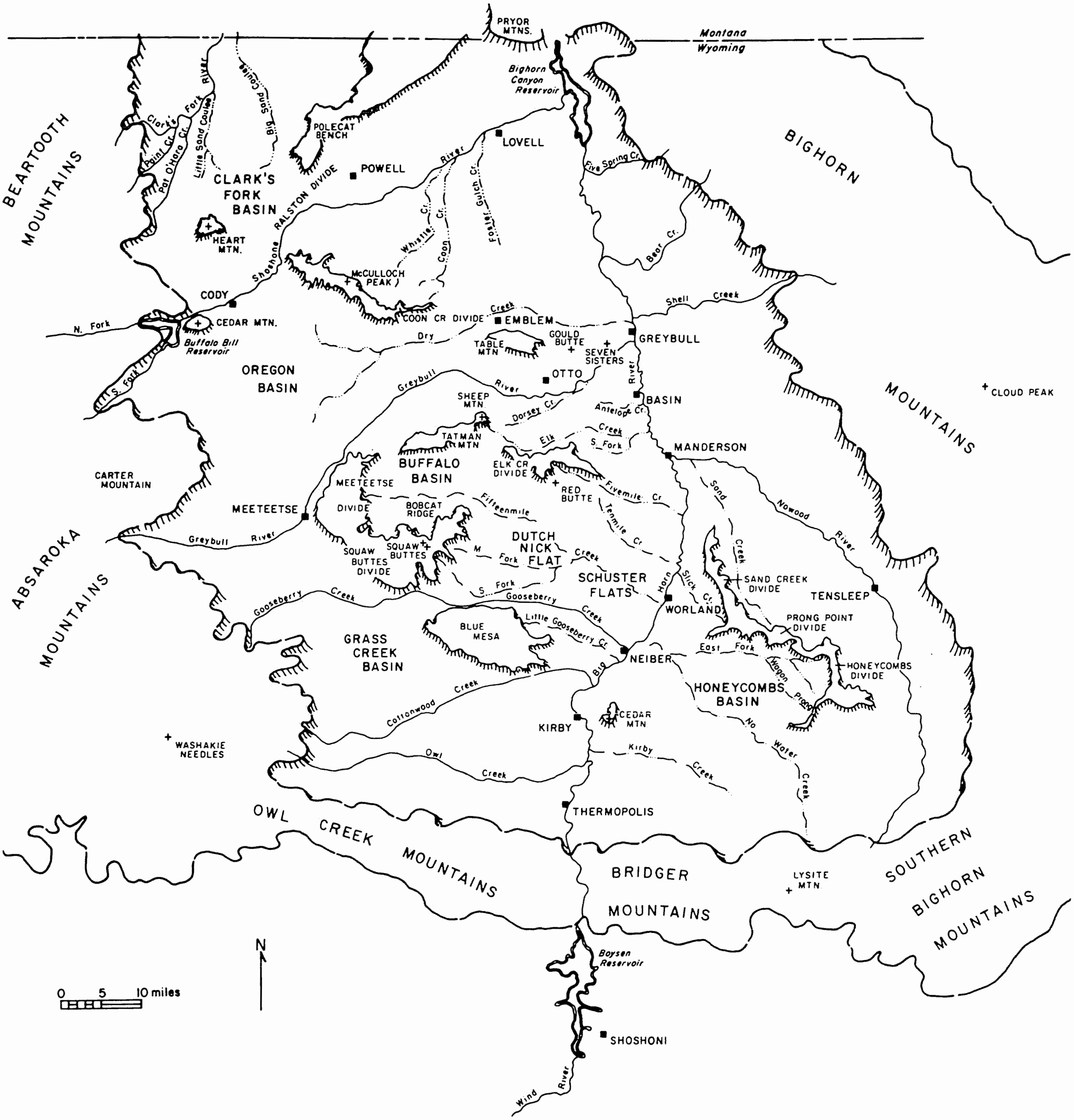
EARLY CENOZOIC PALEONTOLOGY AND STRATIGRAPHY OF THE BIGHORN BASIN



Frontispiece: Sketch map of the Bighorn Basin, northwestern Wyoming, showing major physiographic features (from Bown, 1979).

EARLY CENOZOIC PALEONTOLOGY AND STRATIGRAPHY OF THE BIGHORN BASIN, WYOMING

Commemorating the 100th Anniversary of
J. L. Wortman's Discovery of Fossil Mammals
in the Bighorn Basin

Edited by
Philip D. Gingerich

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CONTENTS

Preface and Acknowledgments vi

The Bighorn Basin—Why is it so Important?
PHILIP D. GINGERICH 1

History of Early Cenozoic Vertebrate Paleontology in the Bighorn Basin
PHILIP D. GINGERICH 7

Summary of Latest Cretaceous and Cenozoic Sedimentary, Tectonic, and Erosional Events, Bighorn Basin, Wyoming
THOMAS M. BOWN 25

Paleocene Stratigraphy and Flora of the Clark's Fork Basin
LEO J. HICKEY 33

Early Cenozoic Mammalian Faunas of the Clark's Fork Basin-Polecat Bench Area, Northwestern Wyoming
PHILIP D. GINGERICH, KENNETH D. ROSE, and DAVID W. KRAUSE 51

Early Tertiary Amphibians from the Bighorn Basin, Wyoming
DAVID W. KRAUSE 69

Early Cenozoic Reptiles and Birds from the Bighorn Basin, Wyoming
WILLIAM S. BARTELS 73

Taphonomy and Faunal Sampling in the Early Wasatchian of the Clark's Fork Basin
DALE A. WINKLER 81

Genesis of a Fluvial Sheet Sandstone, Willwood Formation, Northwest Wyoming
MARY J. KRAUS 87

Magnetic Polarity Stratigraphy and Paleocene-Eocene Biostratigraphy of Polecat Bench, Northwestern Wyoming
ROBERT F. BUTLER, EVERETT H. LINDSAY, and PHILIP D. GINGERICH .. 95

Faunal Zonation of the Willwood Formation in the Central Bighorn Basin, Wyoming
DAVID M. SCHANKLER 99

Turtle Stratigraphy of the Willwood Formation, Wyoming: Preliminary Results
J. H. HUTCHISON 115

Fossil Floras and Plant-bearing Beds of the Central Bighorn Basin
SCOTT L. WING 119

The Willwood Formation (Lower Eocene) of the Southern Bighorn Basin, Wyoming, and its Mammalian Fauna
THOMAS M. BOWN 127

Preliminary Report on Paleontological Exploration of the Southeastern Absaroka Range, Wyoming
JEFFREY G. EATON 139

Remaining Evidence of Oligocene Sedimentary Rocks Previously Present Across the Bighorn Basin, Wyoming
MALCOLM C. McKENNA 143

PREFACE AND ACKNOWLEDGMENTS

This volume was originally conceived as a guidebook for a field conference commemorating 100 years of Cenozoic vertebrate paleontology in the Bighorn Basin. The field conference itself, sponsored jointly by the Society of Vertebrate Paleontology and the Department of Geological Sciences and Museum of Paleontology at the University of Michigan, is scheduled for the first four days of August, 1980. The results of paleontological inquiry, like those of any scientific endeavor, are cumulative. As this book began to take shape, it became increasingly clear that there has been a tremendous increase in our understanding of early Cenozoic paleontology in the Bighorn Basin in the past twenty years, not only in vertebrate paleontology but also in the related fields of paleobotany, fluvial sedimentology, taphonomy, and paleomagnetic stratigraphy. The present volume represents an attempt to bring together summaries of results achieved to date by each of the principal research groups working on early Cenozoic and related problems in the Bighorn Basin. A guidebook format has been retained only in the three appendices giving road logs to be followed during the field conference.

I am confident that the papers presented here will have lasting value in promoting an integrated approach to paleontological field work in the Bighorn Basin. The kinds of evolutionary questions that are interesting in paleontology today require a holistic approach integrating faunas, floras, paleoenvironments, and refined geochronology. There is not a single paper on the Paleocene or early Eocene in this volume that does not relate in an important way to all of the other papers. Eaton's brief contribution on middle-late Eocene faunas and McKenna's paper on the Oligocene fit less obviously into the whole, but nonetheless contribute to understanding the later geological and faunal history of the Bighorn Basin.

Many people have helped to make this compilation a reality. Our present state of knowledge, as reflected in the following papers, is literally the result of a century of field work in the Bighorn Basin. Each of the contributions presented here builds on what Wortman, Cope, Osborn, Sinclair, Granger, Stein, Simpson, Jepsen, and others learned before us. Our association with the Churchill family of Powell, Wyoming, does not go back quite so far in time, but it is fitting to record here as well the debt of gratitude we owe three generations of Churchills for the many summers of support they have generously given to paleontologists working in the Bighorn Basin.

At the University of Michigan, Gerald R. Smith, Evelyn Peer, Donna Robbins, Karna Steelquist, David Krause, William Bartels, Gregg Gunnell, and Amanda Alexander all helped in preparing manuscripts for the printer. Mrs. Peer and Mr. Krause, in particular, did far more than their share of the work to make this volume a reality. Publication has been partially supported by grants from the Scott Turner Fund of the Department of Geological Sciences at the University of Michigan and from the National Science Foundation (DEB 77-13465).

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THE BIGHORN BASIN—WHY IS IT SO IMPORTANT?

Philip D. Gingerich

Abstract.— The Bighorn Basin of Wyoming is important paleontologically for two reasons. First, it is the only place in the world where the early Cenozoic diversification of mammalian life is recorded through such a long sequence of continental sediments representing virtually continuous deposition. The major groups of modern mammals appeared during this interval, and the Bighorn Basin is the best place to study how this happened. Secondly, many areas of the Bighorn Basin are richly fossiliferous, making it possible to trace evolutionary changes through time in much more detail than is possible elsewhere. Such studies promise to contribute in an important way to our understanding of the evolutionary process itself, both as it affects individual species and as it influences whole faunas. A better knowledge of species-level evolution contributes in turn to biostratigraphy and the refined biochronology necessary to understand the timing of mountain building and other events in the geological history of western North America. Thus the paleontological resources of the Bighorn Basin are of exceptional scientific interest and importance.

INTRODUCTION

One hundred years ago, in 1880, the paleontologist Jacob L. Wortman first crossed the Bridger Mountains and entered the Bighorn Basin of northwestern Wyoming. He obtained a small collection of fossil mammals, and then returned in 1881 to make a much larger collection. The extraordinary richness of this new fossil field has since become world renowned. Indeed it is unique, no other place has been discovered anywhere that has such a thick, continuous, richly fossiliferous sequence of sedimentary rocks spanning the Paleocene-Eocene boundary. Paleontologists have come from Europe and from Asia to see this area because it has such a complete record of the life that lived on land in the 10 million year interval between about 50 and 60 million years ago. Most of the following papers in this volume discuss our present understanding of the early Cenozoic history of the Bighorn Basin in technical terms. In this introductory chapter I want to outline some of the background knowledge necessary to put these in a broader geological and biological perspective.

EARTH HISTORY

Earth history is divided into several major intervals, based in part on the forms of life present in each interval. The earth itself is thought to have originated about 5 billion years ago, judging from the study of radioactive isotopes of chemical elements in rock-forming minerals found on earth and in meteorites. The oldest rocks on earth that have been dated radiometrically are about 4 billion years old, which agrees well with the oldest dated moon rocks as well. The first evidences of life, chemical compounds formed by bacteria and primitive algae, are in rocks dated as being between 3.0 and 3.5 billion years old. These are in what is called the Archean or Archeozoic (literally "primeval life"), the first major interval of

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geological time. The second interval, from about 2.4 billion years ago until 600 million years ago is called the Proterozoic (literally "early life") because such evidence as has been found shows that life was more complex and more abundant in the Proterozoic than during the earlier Archean interval. The granitic rocks exposed in the cores of the Beartooth Mountains and Big Horn Mountains date from this time, although these ranges were not thrust up to form mountains until much later.

Living organisms diversified and became abundant at the beginning of the Paleozoic ("ancient life") era, when shallow seas teeming with marine life covered Wyoming for long periods of time. The Paleozoic lasted from about 600 million until 220 million years ago. Then the Mesozoic ("middle life") era, the so-called "Age of Dinosaurs," began. Wyoming was dry land during several long intervals of the Mesozoic era, and dinosaurs flourished until the end of the Mesozoic. The last dinosaurs became extinct at the end of the Cretaceous period, the final subdivision of the Mesozoic. The stratigraphic section exposed in Polecat Dome on the east side of Polecat Bench includes the end of the Cretaceous and the final disappearance of dinosaurs, which happened 65 million years ago.

CENOZOIC AGE OF MAMMALS

The final major division of the geological time scale, the one we live in today, is the Cenozoic ("recent life") era. The Cenozoic is sometimes called the "Age of Mammals," not because mammals originated in the Cenozoic (primitive mammals first appeared much earlier, in the early Mesozoic), but because this is the time when mammals first diversified and became dominant land animals (Figure 1). The Cenozoic era is divided into six epochs, the Paleocene, Eocene, Oligocene, Miocene, Pliocene, and Pleistocene.

As far as mammalian history is concerned, two of the most important events were the rapid diversification of mammals in the latest Cretaceous and early Paleocene, and the first appearance of most of the major groups of modern mammals (the orders Rodentia, rodents; Chiroptera, bats; Artiodactyla, pigs, deer, etc.; Perissodactyla, horses, rhinos, etc.; modern Primates, lemurs, monkeys, etc., and others) in the Paleocene-to-Eocene transition. The magnitude of these changes is shown schematically in Figure 1. Both changes took place during the long interval of the early Cenozoic when the northern Rocky Mountains, including the Big Horn and Beartooth ranges, were uplifted. Because of this active mountain building nearby, the Bighorn Basin was filled with layer upon layer of latest Cretaceous, Paleocene, and early Eocene sediments eroded from the newly elevated mountains. The ten million year period from 60 million to 50 million years ago is particularly well represented in the Bighorn Basin by a sequence of sediments more than 2,000 meters thick (that is, well over a mile thick). The fossils in successive layers of this sequence tell a story of progressive change in animal life through 10 million years, just as the characters and events on successive pages of an American history book record changes of the past several hundred years.

As Figure 1 shows, the early Cenozoic is a time of great interest for understanding the history of mammals. This period and its mammalian faunas are not known anywhere else in the world in the detail they are known from the geological record preserved on Polecat Bench, in the Clark's Fork Basin, and in the central Bighorn Basin.

EVOLUTIONARY CHANGE THROUGH TIME

Evolution is a dynamic concept involving change. Change requires time, and the length of time necessary to see change in mammalian species is recorded only in the stratigraphic column in ancient sedimentary basins scattered around the world. The Bighorn Basin is among the foremost of these in preserving an exceptionally detailed record of evolutionary change in mammals.

No series of laboratory experiments lasts long enough to study mammalian evolution in its time dimension, and the empirical evidence on which much of theory is based is necessarily gathered by examining layer upon layer of sedimentary rocks and their contained fossils. Fossils are the petrified remains of animals and plants no longer living. Figure 2 shows how one kind of animal, the early primate *Pelycodus,* can be seen to have changed during the four million years or so that it lived in the Bighorn Basin and elsewhere in North America. *Pelycodus* immigrated into North America in the early Eocene, perhaps from Europe, and it then began to change rapidly, eventually changing into another primate genus *Notharctus.*

Evolutionary change in *Pelycodus* has been documented in detail in three areas of the Bighorn Basin: (A) the southern basin, east of Worland, (B) the central basin, west of the town of Basin, and (C) the northern basin, in the Clark's Fork River drainage. All three areas show a similar pattern of change, although they do not overlap completely in time. The

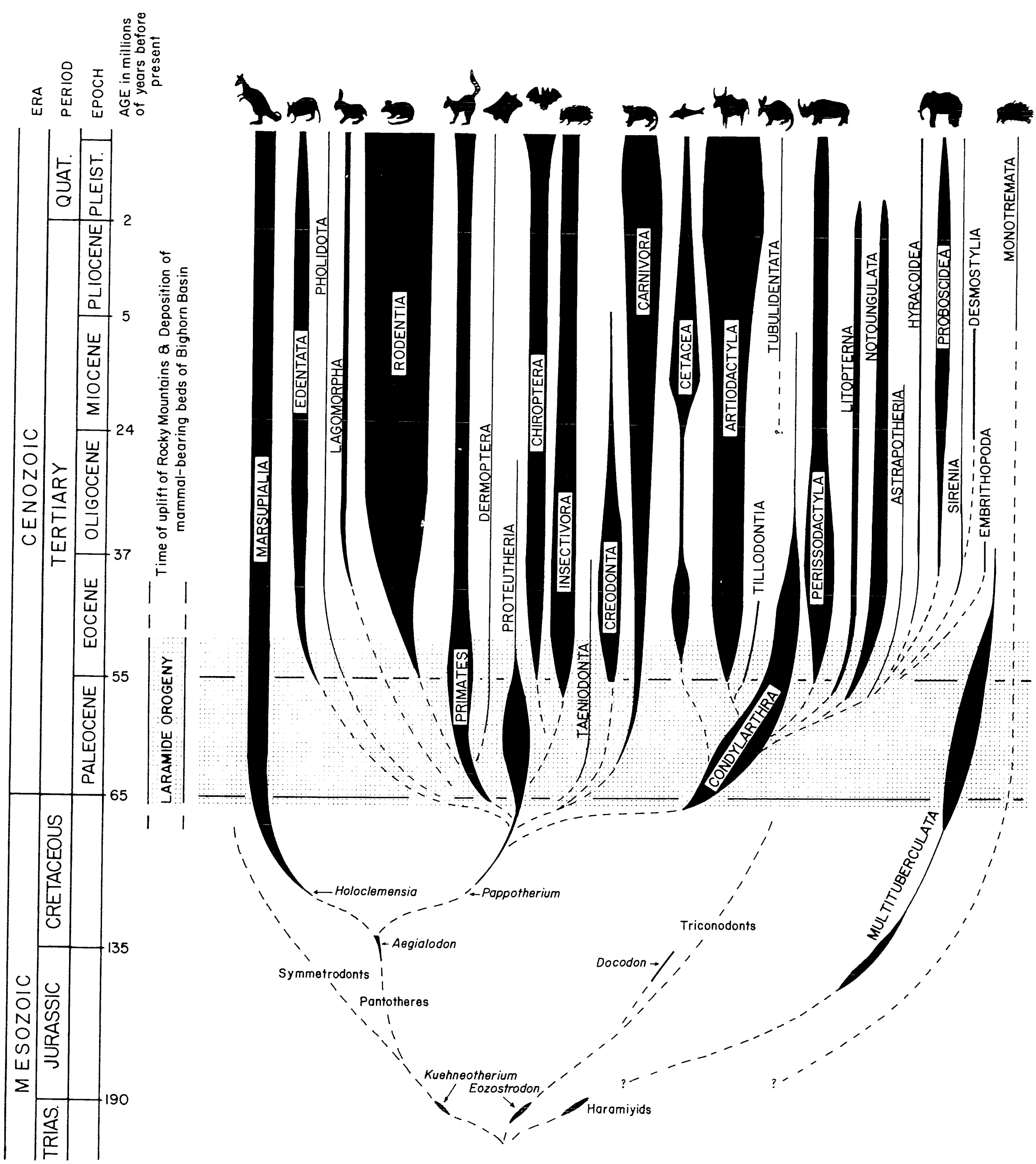

Figure 1. History of diversification of mammals in geological time. Mammals first appear in the fossil record in the Triassic part of the Mesozoic, but they did not undergo a major evolutionary radiation until the time dinosaurs became extinct at the end of the Cretaceous. As this diagram shows, the Paleocene and early Eocene are particularly important for understanding the origin of the major groups of mammals living today because this is when many orders of mammals first appear in the fossil record. The Paleocene and early Eocene are the interval of geological time best known from the Bighorn Basin. A few middle-late Eocene and Oligocene faunas are known from mountainous areas bordering the Bighorn Basin. Figure modified from Gingerich (1977).

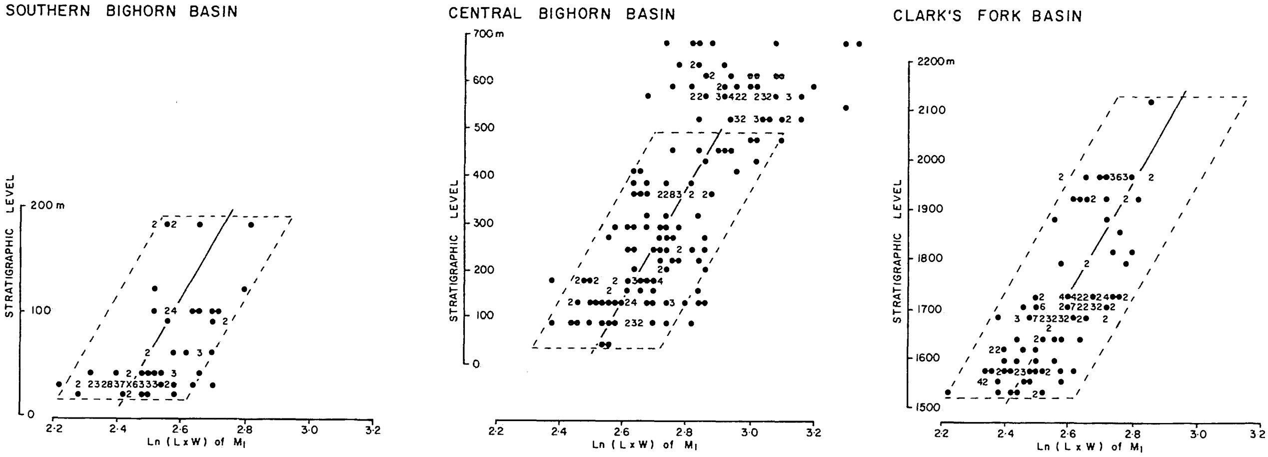

Figure 2. Evolution of the early primate genus *Pelycodus* in three areas of the Bighorn Basin. In each area, *Pelycodus* gradually increases in size in successively higher and younger stratigraphic horizons. *Pelycodus* has one of the densest and most continuous records of evolutionary change through time of any species yet studied. Each closed circle represents one specimen and numerals represent multiple specimens. The vertical axis is stratigraphic level in each of the study areas, and the horizontal axis is a measure of tooth size telling how large the animals were. The three graphs are standardized to have the same slope (principal axis), on the assumption that the rate of evolutionary change during the early and middle Wasatchian was the same in each of the study areas and that a linear model is appropriate. Judging from this comparison, rates of sedimentation in the Clark's Fork Basin and the central Bighorn Basin were approximately equal during the early and middle Wasatchian, while the rate in the southern Bighorn Basin was less than half that in the other two areas. Other evidence indicates that this comparison probably underestimates the rate of sedimentation in the Clark's Fork Basin relative to the central Bighorn Basin. This comparison also shows that earliest Wasatchian faunas are not preserved in the central Bighorn Basin. Stratigraphic levels in the southern Bighorn Basin from Bown (1979), in the central Bighorn Basin from Schankler (this volume), and in the Clark's Fork Basin from Gingerich (1980, and unpublished). All tooth measurements were made by the author.

earliest stages of *Pelycodus* evolution in North America are preserved in the northern and southern parts of the Bighorn Basin, but the later stages are found only in the central basin. *Pelycodus* is only one of more than one hundred kinds of mammals living in the Bighorn Basin in the early Cenozoic and most of the rest have not yet been studied in detail. However, such studies are underway and in the coming years it may be possible to understand not only how individual animals like *Pelycodus* changed but also how changes in *Pelycodus* affected other animals in the fauna, in short, how the whole integrated fauna evolved.

BIOSTRATIGRAPHY AND BIOCHRONOLOGY

A detailed knowledge of how species changed through time in one place permits them to be used to measure time in another place, as is illustrated in Figure 2. This is an application of the classic geological principle of faunal succession and correlation first outlined in England and France almost 200 years ago. The detailed faunal sampling possible in the Bighorn Basin is making this area a standard of reference for the biostratigraphy and biochronology of early Cenozoic sedimentary rocks throughout the Western Interior. Sedimentary rocks are intimately related to such geological events as mountain building and volcanism since these provide the sources of most sediments on the continents. In the thrust belt near LaBarge, in western Wyoming, it has recently proven possible to date the times of movement of two major thrust faults using the biochronology of early Cenozoic mammals worked out in the Bighorn Basin (Dorr and Gingerich, 1980). There are many other potential applications to problems of paleontological and geological correlation and dating.

CONCLUSION

In summary, the early Cenozoic paleontological resources of the Bighorn Basin are important for several reasons. This is the only area in the world where such a complete sequence of late Paleocene and early Eocene sediments is exposed at the surface. It is yielding important information about the origin of the major kinds of mammals dominating today's continental ecosystems, and it is also yielding important evidence about how the evolutionary process works through long periods of time. Furthermore, better understanding of the evolution of species has application in refining the biochronology necessary to date a diverse range of paleontological and geological events.

ACKNOWLEDGMENTS

I thank Professor Jason A. Lillegraven of the University of Wyoming for access to the large collection of *Pelycodus* from the southern Bighorn Basin, Mr. David Schankler for a copy of his measured stratigraphic section in the central Bighorn Basin, and National Science Foundation grant DEB 77-13465 for support in making collections from the Clark's Fork Basin.

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HISTORY OF EARLY CENOZOIC VERTEBRATE PALEONTOLOGY IN THE BIGHORN BASIN

Philip D. Gingerich

Abstract.— The first fossil mammals from the Bighorn Basin were found by Wortman and described by Cope in 1880. These are early Wasatchian in age, and probably came from the southern part of the basin. During Wortman's 1881 expedition he collected mammalian faunas of both middle and late Wasatchian age in the central Bighorn Basin. The Clarkforkian fauna was first documented by Sinclair and Granger in 1911 and 1912 in the northern Bighorn and Clark's Fork basins. Sinclair and Jepsen found Puercan, Torrejonian, and Tiffanian faunas on the flanks of Polecat Bench in 1929. Knowledge of these Paleocene and early Eocene land mammal ages has been augmented considerably during the past fifty years, and recently middle Eocene and Oligocene faunas have been discovered on the margins of the Bighorn Basin as well. Unpublished field records complement published information in illuminating the life and times of paleontologists working in the Bighorn Basin during the past century.

INTRODUCTION

One hundred years of paleontological research on early Cenozoic faunas in the Bighorn Basin have yielded the most complete record of mammalian evolution through the Paleocene and early Eocene known anywhere in the world. In recent years a few scattered middle Eocene and Oligocene fossil localities have also been found on the margin of the Bighorn Basin. The history of paleontological field work in this area of Wyoming is interesting in part because field conditions were so different when the work began a century ago. It is also interesting because the field work involved several of the most important paleontological institutions in the country and many of the principal figures in the development of American vertebrate paleontology.

The history of paleontological research in the Bighorn Basin is important for another reason. By carefully retracing the steps of earlier collectors it is possible to duplicate their collections and determine, in some cases exactly, the stratigraphic level from which important type and referred specimens were collected. The purpose of this chapter is to outline the history of paleontological collecting in the Bighorn Basin, with particular attention to the modern biostratigrahic context of important early collections.

The three North American land mammal ages that are best represented in the Bighorn Basin are the Tiffanian (late Paleocene), the Clarkforkian (transitional Paleocene-Eocene), and the Wasatchian (early Eocene). The Tiffanian can be divided into five reasonably well defined biochrons based on *Plesiadapis*, and these are abbreviated Ti_1-Ti_5 from oldest to youngest (Gingerich, 1976, 1980). The Clarkforkian can similarly be divided into three biochrons Cf_1-Cf_3 based on *Plesiadapis* (Rose, 1979, 1980; present evidence indicates that earliest Cf_1 is actually very latest Tiffanian). The Wasatchian can be divided into five biochrons Wa_1-Wa_5 based on the evolution of

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Pelycodus (Gingerich, 1980). Reference will be made to these subdivisions whenever appropriate to lend precision to the following discussion. In addition, in discussing the history of the Clark's Fork Basin area, it will be convenient to refer to University of Michigan localities, which are prefaced UM.

WORTMAN AND COPE

Jacob L. Wortman made the first paleontological investigation of the early Cenozoic of the Bighorn Basin in 1880, while employed by Edward Drinker Cope. Wortman spent the early part of the 1880 field season collecting in Pliocene deposits along the Snake River in Idaho, and then moved to the Wind River Basin in Wyoming to explore Eocene sediments of Hayden's "Wind River group." Very little has been recorded of how Wortman chanced to cross into the Bighorn Basin, but his headquarters in the Wind River Basin in 1880 is known to have been at Fort Washakie (near the present city of Lander). Fort Washakie was, at that time, the last outfitting post for ranchers and miners entering the Bighorn Basin from the south. It is likely that Wortman learned of the extensive badlands developed in the central Bighorn Basin from men he met at Fort Washakie. In any case, Wortman's preliminary exploration of the Bighorn Basin appears to have been done on his own initiative after finishing his assigned work in the Wind River Basin.

During the 1870's, the Bighorn Basin was virtually enclosed by reserved Indian lands, with Crow Indians settled to the north along the Yellowstone River, Sioux to the east, Arapahoes and Cheyennes in the central part, and Shoshones occupying the southern Bighorn Basin and Wind River Basin. General Custer's last stand against the Sioux and Cheyennes on the Little Bighorn River of southern Montana in 1876 turned public sentiment against the Indians, leading to a severe military retaliation against them and ending their control over the Bighorn Basin. Miners made their first uncontested invasion into the Bighorn Basin in 1877, and cattlemen followed in 1878 and 1879. John W. Chapman's ranch on Pat O'Hara Creek, the modern Two Dot Ranch, was established in 1879, and Count Otto Franc von Lichtenstein brought his first herd of cattle to the Pitchfork Ranch on the upper Greybull River in the same year. Wortman's (1899) description of the Bighorn Basin in 1880 as "a wild, uninhabited region, save for the occasional visits of roving bands of hostile Indians" and his professed fear of "violence at the hands of savage Indians," written nearly twenty years after the fact, cannot be accurate characterizations. They are more logically viewed, in the context of their time, as aberrations of a Victorian "romantic" mentality. Wortman's writing in 1882 indicates that scarcity of water was his major concern.

Figure 1. Jacob L. Wortman as a young man at the American Museum of Natural History. Photograph courtesy of American Museum.

Wortman himself (Figure 1) was originally from Oregon, where he studied under Thomas Condon at the University of Oregon. He met Charles Sternberg while Sternberg was in Oregon during the winter of 1877-78 and Wortman first worked for Cope as a collector during the summer of 1878, accompanying

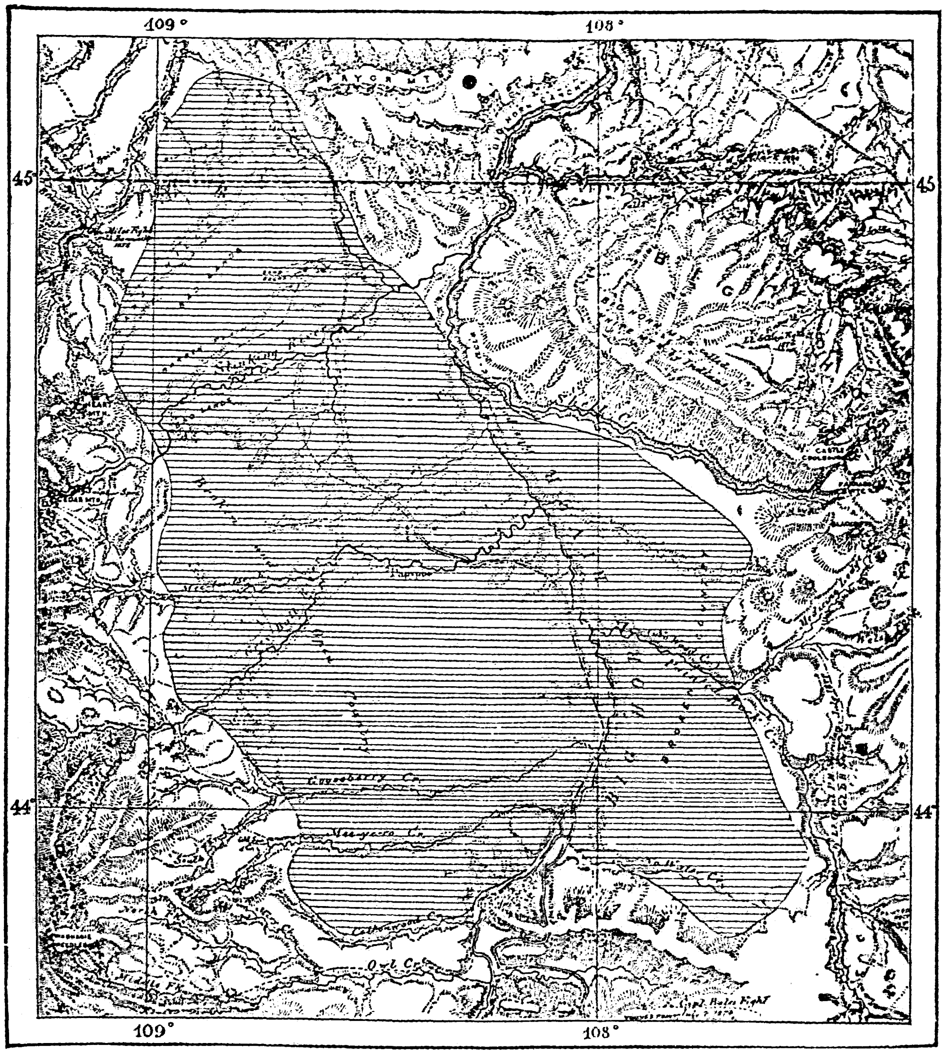

Figure 2. Jacob L. Wortman's map of the Bighorn Basin, based on his work in the basin in 1881. Cross-hatching indicates inferred extent of "Wasatch" deposits. Note one main road crossing the Bridger Mountains from the Wind River Basin in the south, then crossing the Bighorn River near the present town of Worland, the Greybull River near Otto, and the Stinking Water River near Byron, before going up Sage Creek toward Pryor Gap. Reproduced from Wortman (1882).

Sternberg to the John Day beds. In 1879 Wortman took charge of the John Day expedition, before moving to Idaho and Wyoming in 1880.

As a result of his 1880 exploration of the Wind River Basin, Wortman mailed to Cope a collection of some forty-five species of Eocene vertebrates, of which twenty-four were recognized as new. The first report on these was published in September, 1880 (Cope, 1880a). In December, Cope described a second smaller collection, erroneously stating that it had been made by Wortman from beds of the Wind River group (Cope 1880b). This smaller collection was actually the first to be made from the Bighorn Basin. It included the type specimens of *Esthonyx spatularius, Didymictis leptomylus,* and *"Hyopsodus"* [*Haplomylus*] *speirianus.* Cope (1885) later corrected his error and listed these as coming from the Bighorn Basin.

Wortman spent much of the summer of 1881 in the Bighorn Basin, and he was able to make a preliminary map showing the extent of "Wasatch" deposits (Figure 2) in addition to collecting specimens of some sixty-five species of fossil vertebrates, of which Cope recognized twenty-seven as new. Most of these were described early in the following year (Cope, 1882a, b). Wortman's early expeditions into the Bighorn Basin were especially important because they provided the first extensive documentation of early and middle Wasatchian faunas (a collection of middle Wasatchian age had previously been made for O. C. Marsh from the vicinity of Bitter Creek in southern Wyoming, but only a small part of this was ever described).

Unfortunately no detailed locality or stratigraphic records were kept for the earliest collections made by Wortman, but it is possible in retrospect to assign many of these to stratigraphic interval based on circumstantial evidence and the experience of subsequent collecting. Wortman's map of the Bighorn Basin (Figure 2) also gives a clue to the source of his collections. On his first trip from Fort Washakie into the Bighorn Basin he must have crossed the Bridger Mountains via Birdseye Pass. The principal road through the Bighorn Basin in 1880 and 1881, as shown on Wortman's map, generally followed the old Jim Bridger trail. It came down Kirby Creek from the Bridger Mountains and Birdseye Pass, passed to the west of Cedar Mountain near the present site of Kirby, crossed No Water Creek near its mouth, and then followed the east side of the Bighorn River, crossing to the west side of the river near the present site of Worland. From here the road followed within a few miles of the Bighorn River until it reached the vicinity of Elk Creek, where it cut directly across the badlands to ford the Greybull River near the present town of Otto. From here the road passed west of Table Mountain, crossing Dry Creek near Bridger Butte. Then it headed northward down Coon Creek to cross the Shoshone River (formerly called the Stinking Water River) near the present town of Byron. The Jim Bridger trail diverged near Bridger Butte, crossing badlands on a more direct route toward the present town of Garland.

The three mammalian species described from Wortman's 1880 trip into the Bighorn Basin have subsequently only been found in lower Wasatchian deposits (Wa_1 and Wa_2). The first lower Wasatchian deposits that Wortman would have encountered coming into the Bighorn Basin from the south are in the Sand Creek facies of the Willwood Formation in the vicinity of Worland. Bown (1979) has recently studied the mammalian fauna from this area and found it to include abundant *Haplomylus speirianus,* a small species of *Esthonyx* like *E. spatularius,* and a small species of *Didymictis* like *D. leptomylus.* Gazin (1953, p. 23) noted that it seems probable that Wortman obtained all three specimens from about the same locality, inasmuch as a collector of Wortman's experience would have obtained much more material had he extended his examination over any appreciable area. If Wortman had proceeded as far as Elk Creek or the Greybull River it is almost certain that he would have made a much larger collection. Admittedly there is no direct evidence one way or the other, but it seems likely that Wortman's 1880 trip into the Bighorn Basin was little more than a brief trip across the Bridger Mountains to examine the first Wasatchian outcrops he encountered. He probably did not go any farther north than Worland, and probably never crossed to the west side of the Bighorn River.

Direct evidence on the source of the 1881 Bighorn Basin collections is also lacking, but again there is some circumstantial evidence. Wortman (1882) mentions that "the exploration of this region is most arduous and difficult. The great scarcity of water in these badland wastes makes it very inconvenient . . . the broken and mountainous character of the country forbids the use of wagons to such an extent that pack animals are indispensible." He also mentions that "blue" beds seemed to be the most productive for fossils, and that these fossils were often found (as the only known skull of *Tetonius* was) in small limestone nodules, sometimes with a hard layer of ferrous oxide investing them. Considering the need for water and at least initial access by road, it is likely that Wortman spent most of his time during the summer of 1881 collecting in the extensive badlands just south of where the main road through the basin crossed the Greybull River, i.e. in the vicinity of Dorsey Creek south of Otto. Fossils there are often found in nodules with a coating of ferrous oxide weathering out of "blue" beds, as Wortman described. That this area was the source of most of his collections is further corroborated by the account given of his next expedition to the Bighorn Basin ten years later: "Our immediate destination. . . . was the extensive exposures lying to the south of the Gray Bull River in the vicinity of its junction with the Big Horn. . . . On the south side of the Gray Bull from near its mouth to a point twenty miles up the river are to be found the best exposures of the Big Horn Wahsatch" (Wortman, 1892). Scott's intervening expedition of 1884 had also camped on the Greybull River in an unsuccessful attempt to duplicate Wortman's efforts (Scott, 1939; see below).

Wortman's 1881 collection from the Bighorn Basin included a number of new species, such as *Oligotomus* [*Ectocion*] *osbornianus, Anaptomorphus* [*Tetonius*] *homunculus,* and *Pantolestes* [*Cynodontomys*] *nuptus* that have subsequently been found only in the middle Wasatchian (Wa_3), but it also included several new species characteristic of the early part of the late Wasatchian (Wa_4) as well: *Cynodontomys latidens, Mioclaenus* [*Bunophorus*] *etsagicus, Pachynolophus* [*Heptodon*] *posticus,* and *Hyopsodus powellianus* (Cope, 1882a, 1882b, 1885). Thus it is clear that Wortman collected some in both the upper part of Schankler's *Haplomylus-Ectocion* Range Zone and in the *Heptodon* Range Zone (Schankler, this volume). None of the new species described by Cope from these collections is confined to the intervening *Bunophorus* Interval Zone, but the presence of *Hyopsodus lemoinianus* suggests that this interval was probably sampled as well.

SCOTT'S EXPEDITION OF 1884

William Berryman Scott is best known for his work on faunas of the middle Eocene of southwestern Wyoming and Utah and the Oligocene of South Dakota, and for his early expeditions to Patagonia. Scott spent much of the summer of 1884 exploring the Bighorn Basin. He had seen the specimens collected by Wortman, including a nearly complete skeleton of *Phenacodus,* and set out to attempt to duplicate these. As Scott (1939, p. 161) himself admitted: "This was the only one of all the western trips . . . that was a complete failure from the collector's point of view; we obtained practically nothing." The problem seems to have been that, while they knew the collections had come from the vicinity of the Greybull River, they approached this area from the north and attempted to work too far upriver in the vicinity of Meeteetse Creek.

Scott's party traveled as far as Miles City, Montana, on the Northern Pacific railroad, outfitting at Fort Keogh across the Tongue River. On July 1st the expedition set out on horseback from Fort Keogh along the Yellowstone River, arriving at Fort Custer on July 5th. Here they rested for several days, visiting the scene of Custer's last stand, which had taken place only eight years earlier. By July 20th they were in Pryor Gap, and they reached Sage Creek on the 21st. On July 23rd they "had a terrible march of considerably more than 30 miles through the Stinking Water Desert, a hot plain that burns one's face to look at and is utterly without grass and water" (Scott, manuscript autobiography). Robert V. Witter (pers. comm.) identifies this "Stinking Water desert" as Polecat Bench, which Scott's party must have crossed. The freight and stagecoach road from Billings into the Bighorn Basin that they were following paralleled the south side of Polecat Bench before dropping off the end of the bench to cross the "Stinking Water" River at Corbett. Scott's group attempted to collect fossils near Corbett for one day, but had poor success. From Corbett the trail passed east of present-day Cody and then continued southward to Meeteetse. Camp was pitched at a comfortable site near the Greybull River, below the mouth of Meeteetse Creek. Scott's group attempted to collect in this area of poor exposures, some twenty miles west of the productive areas explored by Wortman, and consequently the results were disappointing. The entire collection, consisting of four catalogued specimens of *Coryphodon, Didymictis, Lambdotherium,* and *Hyracotherium* respectively, fit into one cigar box. The only finds worthy of note were the *Didymictis,* a partial skeleton later described by Scott (1887), and the *Lambdotherium,* first record of this genus in the Bighorn Basin (albeit long unpublished; Sinclair and Granger, 1911). The latter presumably came from the head of Fifteen Mile Creek in Buffalo Basin, across the divide on the east side of the Greybull River, because these are the nearest *Lambdotherium*-bearing beds.

WORTMAN AND OSBORN

Wortman was hired by the American Museum of Natural History in 1891 to direct their field program in vertebrate paleontology, and he was immediately sent to the Bighorn Basin and Wind River Basin to make new collections similar to those made ten years earlier for Cope (Osborn, 1926). Fortunately, a reasonably detailed narrative of the 1891 expedition was published along with descriptions of the fossils (Wortman, 1892). By this time the Northern Pacific railroad had reached Red Lodge, Montana, and Wortman traveled from New York to Red Lodge by rail. Here he hired a team and wagon, riding horses, and one assistant to serve as teamster, cook, and collector combined. The expedition set out from Red Lodge for the extensive exposures previously prospected by Wortman south of the Greybull River. They followed the Meeteetse Trail across the Clark's Fork Basin, emerging from the head of Big Sand Coulee where the highway does today, and crossed the Stinking Water River on the new bridge at Corbett. From Corbett they traveled south of the McCullough Peaks down Dry Creek to join the Bridger Trail near Bridger Butte. The Greybull River was impassable due to high water, so Wortman and his assistant passed their time collecting on the divide between Dry Creek and the Greybull River in the vicinity of YU Bench and/or Table Mountain. The greater part of the summer was spent on the south side of the Greybull River in the vicinity of Dorsey

Figure 3. Mode of transport employed by Jacob L. Wortman, Barnum Brown, and Elmer S. Riggs on American Museum of Natural History expedition in the Bighorn Basin in 1896. Driver shown is either Riggs or Brown, in badlands near the Greybull River. Photograph courtesy of American Museum.

Creek and possibly Elk Creek. Prospecting farther from the Greybull was also attempted, the assistant being employed to ferry water from the river, and in this way Wortman managed to prospect in Buffalo Basin south of Sheep Mountain and Tatman Mountain. The final twenty days of the expedition were spent revisiting the Wind River Basin for a brief reconnaissance there.

The 1891 expedition was very successful, perhaps the most extraordinary find being the complete upper and lower dentition of *Palaeonictis,* a creodont previously known only from Europe (Osborn, 1892). Osborn also described *Dissacus* [*Hapalodectes*] *leptognathus* and *Pachyaena gigantea* based on these collections. The *Palaeonictis* and much of the skeleton of an *Oxyaena* were collected by a form of underwater washing invented on the spot by Wortman. He washed in a flat pan as a placer miner would, rather than through screens as one does today, but his results were equally successful. Even so, the *Oxyaena* skeleton collected in 1891 remained incomplete until Cope's collection was purchased by the American Museum in 1895 and W. D. Matthew discovered that many of the missing pieces of the same individual had previously been collected by Wortman in 1881! The complete specimen was described by Wortman (1899).

Wortman made a number of important geological observations during the 1891 expeditions, estimating the thickness of Wasatchian sediments in the Bighorn Basin to be between 2500 and 4000 feet, and describing the apparent unconformity between the Wasatchian and underlying "Cretaceous" sediments near Corbett Bridge. Wortman searched for evidence of "Puerco" deposits between the Cretaceous and Wasatchian, but failed to find any. Wortman correctly inferred that the sediments of the Clark's Fork Basin are continuous with those in the Bighorn Basin, and collected "enough material to settle the age of these beds without question . . . the remains are all mammalian, and the species represented are characteristically those of the Wasatch," not the Cretaceous as previously thought. Assuming Wortman collected near the Meeteetse Trail as he passed through the Clark's Fork Basin, the fossils he collected were almost certainly Clarkforkian and not Wasatchian in age, but none of these remains has ever been described.

Wortman revisited the central Bighorn Basin in 1896 (Figure 3) as part of a more extensive expedition prospecting in the Wind River, Uinta, and San Juan basins. He was accompanied by two fledgling paleontology students, Barnum Brown and Elmer S. Riggs, of the University of Kansas. Both went on to distinguished careers in vertebrate paleontology, Brown at the American Museum and Riggs at the Field Museum in Chicago. One of the few species based on collections obtained in 1896 is *Pachyaena intermedia* Wortman (1899). Matthew and Granger (1915) indicate that Wortman visited the Clark's Fork Basin as well in 1896, but again nothing was ever published of this collection. Many of the leading vertebrate paleontologists of this time, including Wortman and Osborn, are shown in Figure 4.

LOOMIS' EXPEDITION OF 1904

The next scientific party to study the early Cenozoic vertebrate paleontology of the Bighorn Basin was led by Frederick B. Loomis of Amherst College in Massachusetts. In 1904 Loomis and two students went by train to Rapid City, South Dakota. From Rapid City they drove a team and wagon 450 miles across the Powder River Basin and Big Horn Mountains to the vicinity of the Greybull River. As reported in a local Massachusetts newspaper at the time, Loomis initially believed the Wasatchian in the Bighorn Basin to represent a thick series of lake sediments, deposited "about 1.5 million years ago." The total lack of water and grass in the badlands forced Loomis' party to camp along the Greybull River, making daily forays into the badlands eight to ten miles to the south. There each man worked in a different direction from the wagon in order to cover as much ground as possible. According to the newspaper account, Loomis considered the greater part of a *Hyracotherium* skeleton to be one of their most important finds. To insure finding all of the pieces "the earth in the immediate vicinity was scraped up and hauled in sacks to the river, where it was washed through screens and 100 or more further fragments recovered." Thus screen washing, as employed in paleontology today, has apparently had a number of independent origins.

Figure 4. Leading figures in early American vertebrate paleontology, at *Diplodocus* quarry on Sheep Creek, Wyoming, 1899. Man squatting in foreground is J. L. Wortman; others, from left to right, are: W. J. Holland, H. F. Osborn, W. D. Matthew, W. Granger, and R. S. Lull. Osborn, Granger, and Wortman were directly responsible for much early Cenozoic paleontological exploration in the Bighorn Basin. Photograph courtesy of Division of Vertebrate Paleontology, Peabody Museum, Yale University.

After working along the Greybull River and Fifteen Mile Creek for three weeks, Loomis' party left the Bighorn Basin to continue their work in the Wind River Basin. Loomis made a number of contributions to Wasatchian paleontology based upon his Bighorn Basin collections. Perhaps most important was his reinterpretation of the Bighorn Wasatchian deposits as fluvial rather than lacustrine in origin (Loomis, 1907). Judging from both the *Pelycodus* and *Lambdatherium* Loomis collected, his "Tatman Mountain lower level" is in the *Pelycodus trigonodus* Zone (Wa_3) and his "Tatman Mountain higher level" is in the *Pelycodus jarrovii* Zone (Wa_5) of the Wasatchian (*Pelycodus* revised in Gingerich and Simons, 1977).

FISHER AND THE SHOSHONE RECLAMATION PROJECT

In 1906, Cassius A. Fisher published the first extensive treatment of the geology and hydrology of the Bighorn Basin, including a geological map of the entire Bighorn Basin. Impetus for this work was un-

Figure 5. American Museum of Natural History field party in camp in 1910 in the central Bighorn Basin, probably along Dorsey Creek or the Greybull River. Men are, from left to right: William Stein, Walter Granger, William J. Sinclair (of Princeton University), and George Olsen. Photograph courtesy of American Museum.

doubtedly authorization of the Shoshone Reclamation Project by President Roosevelt in 1904. As a result of this ambitious project, some 150 square miles of desert are now productive farmland (Churchill, 1979). Fisher (1906) mapped the present Polecat Bench or Fort Union Formation (Paleocene) as part of the Cretaceous Laramie Group, but he correctly interpreted the Wasatchian deposits as being largely fluvial in origin. His map was used extensively by Sinclair and Granger in their subsequent paleontological explorations of the Bighorn Basin.

SINCLAIR AND GRANGER

One of the most productive phases of research on Cenozoic vertebrate paleontology in the Bighorn Basin began in 1910 when the American Museum of Natural History sent a full expedition into the central basin under the direction of William J. Sinclair and Walter Granger (Figure 5). In 1910 they worked from various camps between the towns of Basin and St. Joe on the south side of the Greybull River. Collections were made from levels near the base of the Wasatchian on Antelope and Elk Creek to the top of Tatman Mountain. Sinclair and Granger concentrated on the interval below Loomis' lower level on Tatman Mountain, and they succeeded in recognizing three "more or less well defined" fossiliferous zones. The lowest, Zone 1, was described as being exposed on Elk Creek Anticline. Zone 2 was higher than Zone 1, and exposed along upper Elk Creek and the lower part of Dorsey Creek. Zone 3 was above Zone 2 and exposed in badlands south of St. Joe, i.e. on upper Dorsey Creek.

In their report on the 1910 expedition, Sinclair and Granger (1911) outlined the stratigraphy of Wasatchian deposits in the Bighorn Basin. They also discussed the origin of the red beds common in these sediments, suggesting that the red beds developed from "blue" beds [gray beds] by concentration and oxidation of iron compounds at the surface during periods of dryer climate than existed during deposition of the blue clays. Sinclair and Granger noticed also that vertebrate fossils are particularly abundant in red clays or at the contact of red and blue strata. These views are not very different from current ideas regarding the origin of both red beds and fossiliferous horizons, although it is clear that Sinclair and Granger attributed the origin of red beds to climatic change rather than normal soil-forming processes in a stable climate. Also, we now know that fossils are usually found in "blue" beds associated with red beds, not actually in the red beds themselves (Bown, 1979; Winkler, this volume).

Sinclair and Granger continued field research in the Bighorn Basin during the summer of 1911. In July they worked in the central basin on Five and Ten Mile Creeks, east of the Bighorn River north of Worland, and then in the upper Fifteen Mile Creek area near Parker Spring. In a letter to W. D. Matthew dated August 2, Granger reports that they obtained "many hundred individuals—and all apparently from the Lysite." Having documented the presence of Lysite equivalent faunas in the Bighorn Basin, Sinclair and Granger then concentrated efforts on finding a distinctive fauna in drab beds of Fisher's "Laramie group" below red-banded Wasatchian beds on the southwest slope of the McCullough Peaks (in Rough Gulch, UM locality SC-196). A similar fauna was found on the bluff north of Ralston (Polecat Bench) and in the head of Big Sand Coulee, and Sinclair and Granger (1912) concluded that if these faunas proved to be older than the typical Wasatchian, the beds should be distinguished as the "Ralston" beds or formation.

Granger collected in the Bighorn Basin in 1912 with William Stein. They arrived late in August, having spent the better part of the summer in New Mexico, and immediately set to work exploring the "Ralston" beds. According to Granger and Stein's field catalogue, September 4th and 5th were spent on the end of Polecat Bench; September 6th, 7th, and 8th were spent in the head of Big Sand Coulee; and September 12th was spent first in Badger Basin on the east side of the Clark's Fork River and then near Sugarloaf Butte on the west side of the Clark's Fork River. After losing several days to a snowstorm, they set up camp on the Hopkins Ranch at the mouth of Pat O'Hara Creek and explored from there. On September 18th a good concentration of Wasatchian mammals was found in red beds three miles southeast of the camp on Pat O'Hara Creek. This locality, almost certainly UM locality SC-40, furnished the largest "Sand Coulee" fauna. Granger appears to have been particularly intrigued by a nice specimen of "*Ptilodus*" he found here—this later became the holotype of *Eucosmodon* [*Neoliotomus*] *ultimus* Granger and Simpson (1928). *Pelycodus ralstoni* Matthew, *Diatryma ajax* Schufeldt, and a number of other new species were first described from specimens found at this locality.

September 19th was spent collecting near camp. Then on September 20th and 21st Stein collected three miles east of camp, near Granger Mountain (UM locality SC-90), and obtained a good collection of "Ralston" mammals, while Granger continued work on the "Sand Coulee" locality. Both then worked the latter through September 25th. September 27th, 28th and 29th were spent collecting five miles southeast of the mouth of Pat O'Hara Creek, probably in the vicinity of UM localities SC-2, SC-54, and SC-87. One curious find here was a pair of phalanges initially identified by Granger in the field and by Matthew and Osborn at the American Museum as belonging to a theropod dinosaur—later they were correctly referred to the giant flightless bird *Diatryma* by Shufeldt (1913). October 2nd was spent on the east side of Polecat Bench, collecting "on Fisher's contact line" between the Laramie and Wasatch (UM locality SC-74). Another early storm ended exploration of the Clark's Fork Basin-Polecat Bench area, "rain, sleet, and snow—over a foot of the latter" is probably all that prevented Granger and Stein from finding the first Tiffanian mammals to the east along Polecat Bench.

This American Museum phase of field work in the Bighorn Basin was essentially completed in 1913 by William Stein and an assistant, Philip L. Turner. Stein was by this time a naturalized German immigrant, ranching on a small scale on Dorsey Creek south of Otto, Wyoming. Turner was a young Easterner who was paid a three month salary totaling $75, out of which he was required to pay his own transportation from New York to Wyoming and back. On a budget like this it is not surprising that Stein and Turner wrote often to Granger complaining that they were short of money.

Stein and Turner spent the early part of the summer of 1913 on Five Mile and Ten Mile Creeks, before heading for Coon and Whistle Creeks east of the McCullough Peaks in August. Here they were not very successful, and soon moved on to the Clark's Fork Basin. They camped for 10 days in the head of Big Sand Coulee, about a mile west of an Irish sheepherder's camp. Unfortunately, no more precise locality data are given. Near this camp, on September 4, Stein found the first specimen of a notoungulate to be discovered outside of South America. It was catalogued as No. 79 "Rodent(?) Jaw (upper beds), Head of Big Sand Coulee." Matthew (1915c) inexplicably described this specimen, the holotype of *Arctostylops steini*, as coming from Gray Bull beds of the Clark's Fork Basin. The only other specimen found that day, the holotype of *Probathyopsis praecursor* Simpson (1929c), was also found by Stein and bears an identical locality record. It was recognized, even by Matthew (letter to Stein, 1913), as coming from the Clarkforkian. All subsequent finds of *Arctostylops steini* and *Probathyopsis praecursor* have been in late Tiffanian or Clarkforkian strata, and Matthew's attribution of *Arctostylops* to a Wasatchian horizon is almost certainly in error.

There was initially some skepticism over whether the notoungulate had really been found in Wyoming and on December 2, 1913, Matthew wrote to Stein about this:

> "Now some of the paleontologists will not be willing to believe in this find if they can help it, and they may suggest that you found the specimen when you were with Loomis in Patagonia and it got mixed in accidentally with your Wasatch collection. It is just possible that you might have picked it up in Patagonia, wrapped it in cotton and tucked it in some out of the way pocket of your coat, and then missed it when you came to turn in your finds at camp there. It might then stay in that pocket when you brought the coat back, and if you were wearing the same coat in the Bighorn Basin, you might find it when you came to turn out your finds at night, and not remembering it, have supposed you had found it in the Wasatch beds. . . ."

Stein replied from Otto on December 8:

> "In regard to the specimen No. 79 it was find by me as stated on label and in record book by Mr. Turner. I even remember the place. I find the two end pieces side by side but the mittle [sic.] part was missing but after looking around a few minute and uttering some very strong word I was able to locate it a few feet below the others in a crack. . . . The little jaw in question is find from Clark's Fork Basin pure and simple and not misplaced specimen from Patagonia by me."

This was sufficient to convince Matthew of the authenticity of the find, and he proceeded to publish it. A few years later American Museum parties found similar notoungulates in Mongolia, corroborating their occurrence outside of South America, and in recent years several additional Clarkforkian specimens have been found in the head of Big Sand Coulee by UM expeditions.

Granger (1914) reviewed and revised the biostratigraphic nomenclature relating to early Cenozoic faunas in the Bighorn Basin. His conclusions are essentially those expressed in Figure 6. The fauna of the Clark Fork beds (= "Ralston" beds) was a completely new one, which Granger correctly distinguished from later faunas by its lack of perissodactyls, artiodactyls, and modern primates. The Sand Coulee fauna was distinguished from the overlying Gray Bull fauna by the absence of "*Systemodon*" and by "the generally more primitive character of such genera as are common to both horizons." The Gray Bull beds were delimited from overlying Lysite beds by the presence of "*Systemodon*" and absence of *Heptodon*. Lysite beds were characterized by the presence of *Heptodon* but not *Lambdatherium*, and finally the Lost Cabin interval was differentiated from lower intervals by the presence of *Lambdatherium*. This sequence has subsequently become widely used in the literature on early mammals as a succession of faunal zones: Clarkforkian, Sandcouleean, Graybullian, etc. It is a measure of the quality of Granger's original field observations and collections that the faunal zones he proposed have withstood nearly seventy years of subsequent research on Bighorn Basin faunas. Other zonation schemes have been proposed to supplement Granger's, and his sequence has been refined, but the basic succession he described remains unchanged.

Many papers have been published on early Eocene faunas based on the American Museum collections from the Bighorn Basin. Principal among these are Sinclair (1914), Matthew (1915a,b,c, 1918), Granger (1915), Granger and Simpson (1928), Simpson (1929c, 1937). Stein made a small collection on Elk Creek and in the Clark's Fork Basin for the American Museum in 1916, but it contained nothing noteworthy.

CASE'S EXPEDITION OF 1924

The first University of Michigan collection of fossil vertebrates from the Bighorn Basin was made in 1924 by Ermine Cowles Case, assisted by A. S. Warthin and W. H. Buettner. They spent several days in July collecting in the lower level of Tatman Mountain badlands as part of a general survey of the Cretaceous and early Tertiary faunas of South Dakota, Wyoming, and Montana. Only one specimen considered worthy of publication was found in the Bighorn Basin. This was the holotype of *Allognathosuchus wartheni*, described by Case (1925). Another notable find, in view of the rarity of birds in early Cenozoic collections, was the distal end of the femur of a large *Paragrus*-like bird (which was, until recently, labelled *Phenacodus*!).

SIEGFRIEDT AND SIMPSON

In November 1926, J. C. F. Siegfriedt, a medical doctor in Bear Creek, Montana, discovered a mammalian molar in gangue from one of the nearby late Paleocene coal mines. Siegfriedt studied the tooth,

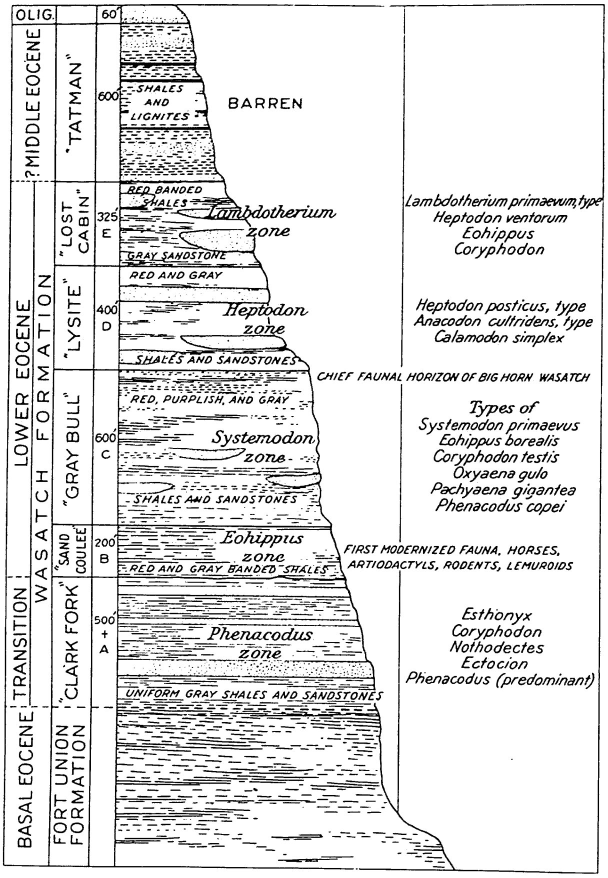

Figure 6. Composite stratigraphic section of Paleocene ("Basal Eocene") and Eocene deposits of the Bighorn and Clark's Fork basins, showing faunal zones as perceived by Granger at the conclusion of American Museum work in the Bighorn Basin in 1918. Figure from Osborn (1929).

concluding that it was human, and further proposed that Bear Creek was the site of the Garden of Eden. This received considerable notice in the local press and within a short time Henry Fairfield Osborn at the American Museum was in contact with Siegfriedt regarding the discovery. Siegfriedt had by this time found more fossils, and he sent the first collection of these to New York in May of 1927. Barnum Brown of the American Museum visited Bear Creek in 1927, as did J. LeRoy Kay of the Carnegie Museum in Pittsburgh. Then Rachel A. Husband (later Nichols) of the American Museum spent the summer of 1928 collecting from the spoil heaps of the Eagle Mine, assisted by the superintendent of the mine, Mr. J. F. Lobdell. George Gaylord Simpson published three papers on the Bear Creek fauna (1928, 1929a, 1929b), bringing it to the attention of the scientific community. As a result of all this activity a 1929 issue of the Carbon County News, published in nearby Red Lodge, echoed Siegfriedt's original claim noting: "it may possibly be found that the ancestors of most mammal life may have originated, not in Asia or Europe, but in North America, and that the Garden of Eden was actually located in the foothills of the Rocky Mountains, with Bear Creek, Montana, figuring as at least the porter's lodge or one of the suburbs." Within a short time Siegfriedt was Mayor of Red Lodge!

In a more serious vein, Simpson (1929b) concluded that the Bear Creek fauna was late Paleocene in age, equivalent to both the Clark Fork fauna of Wyoming and the Tiffany fauna of southern Colorado. Jepsen (1937) first described a rodent, *Paramys atavus*, from the Bear Creek fauna, correctly noting that it was at that time the oldest record of Rodentia known anywhere. Jepsen believed the age of the Bear Creek fauna to be Tiffanian, but more recent work has shown it to be Clarkforkian, probably early Clarkforkian (Cf$_1$; Rose, 1979). Robert V. Witter collected additional fossil vertebrates from the Bear Creek mines for Princeton University in 1948. This collection included two specimens of the champsosaurid *Simoedosaurus* recently described by Sigogneau-Russell and Baird (1978). The most recent collection from Bear Creek was made in 1958 by Peter Robinson, J. T. Gregory, and James Hopson for Yale University.

SINCLAIR AND JEPSEN

Paleontological field work was curtailed during World War I, and the first subsequent expedition to the Bighorn Basin did not take place until 1927. Then William J. Sinclair, accompanied by two students, Glenn L. Jepsen and T. C. von Storch, drove from Rapid City, South Dakota, to the Bighorn Basin, arriving at William Stein's ranch on Dorsey Creek on June 27. On June 29 they moved to the nearby Wardell Ranch. Sinclair and his assistants then spent nearly two months exploring the Dorsey Creek badlands south of the Greybull River, the area previously prospected by Wortman, by Loomis, and by Granger. They were rewarded by several extraordinary finds, among them the *Omorhamphus* [*Diatryma*] described by Sinclair (1928), with its intermingled micromammalian fauna including the holotype of *Parectypodus* [*Ectypodus*] *tardus* (Jepsen, 1930a). A nearly complete skeleton of *Palaeonictis* was also found on this expedition (Sinclair and Jepsen, 1929).

Figure 7. Glenn L. Jepsen (left) and LeMoyne Cook excavating a specimen of *Phenacodus* in the Bighorn Basin during the 1928 Princeton University expedition. Photograph courtesy of Department of Geological and Geophysical Sciences, Princeton University.

In 1928 Jepsen led the Princeton expedition, accompanied by two other students, LeMoyne Cook and Joseph Page (Figure 7). Their first camp was in the Clark's Fork Basin, at the head of the west fork of Big Sand Coulee (Figure 8). This camp was set up on June 27th very near the section corner adjacent to UM locality SC–2, a locality they found to be very productive. This was also, as mentioned above, probably one of Granger and Stein's localities as well. Jepsen and crew remained here until July 13th. Most of the time was probably spent prospecting in the vicinity of the camp, but they also ranged five miles northward on July 10th to the vicinity of UM locality SC–136, and on July 12th they must have hiked some three miles southward to the vicinity of UM locality SC–265 because they recorded finding the section corner near that locality. July 12th is particularly significant because it is the day the holotype and only specimen of *Paleomoropus jepseni* was found. In describing this, Radinsky (1964) quoted the specimen label stating that it was found in "Section 9, T. 55 N., R. 102 W." in "lower Gray Bull beds." Neither of these designations can be true, since there are virtually no exposed Wasatchian sediments in Section 9 and, even if there were, all faunas from this area are upper Graybullian (Wa_3) in age. The original field

Figure 8. Princeton University camp in the Clark's Fork Basin: year is 1928, and the automobile is a Ford Model T. Jepsen (1928) indicates that nearly one hundred specimens were collected at this locality in 1928. This is presumably Jepsen's Camp #1, near UM localities 2 and 54. Photograph courtesy of Department of Geological and Geophysical Sciences, Princeton University.

label says simply "2½ mi. S. Camp #1." Since it is clear that some if not all of the group climbed to the corner between Sections 11, 12, 13, and 14, it is possible that the *Paleomoropus* specimen came from a level as high as UM locality SC–265. Whatever the precise level, the specimen is clearly from the middle Wasatchian, and not the early Wasatchian as described.

Jepsen (1930a) made much of finding *Homogalax* (*Systemodon*) in Sand Coulee beds, but it is clear from his labels and published discussion that he often used Sand Coulee in a geographical sense rather than the stratigraphical sense intended by Granger. A species of *Homogalax* does occur in Sand Coulee beds (Wa_1) but this is a smaller species than that referred to "*Systemodon*", which has not been found in beds older than early Graybullian (Wa_2).

On July 13th, Jepsen moved to his Camp #2 near UM locality SC–80 on the west side of Polecat Bench. From this camp the crew worked along Polecat Bench and in the head of Big Sand Coulee, where they found the holotype of *Probathyopsis successor* at a locality said to be in Gray Bull beds (but now known to be Clarkforkian). On July 27th they moved to Camp #3 near an abandoned coal mine just east of UM localities SC–262, 263, and 264 on the southeast side of Polecat Bench. A specimen of *Plesiadapsis rex* was found by Cook "½ mile southwest of Camp #3," probably in UM locality SC–262. The holotype of *Titanoides gidleyi* Jepsen (1930b) was found one mile southwest of this camp near UM locality SC–261, which is also in the *Plesiadapis rex* Zone (Ti_3). Dinosaur remains were discovered in the lowest beds of Polecat Dome. After a week of prospecting from Camp #3 Jepsen and crew packed their fossils and headed back to Princeton, stopping briefly to collect on Elk Creek in the central Bighorn Basin (where the holotype of *Parectypodus simpsoni* Jepsen, 1930a, was found) and on Cottonwood Creek in the Wind River Basin.

Jepsen's expedition of 1928 proved the feasibility of finding fossils in beds stratigraphically below the typical Clarkforkian documented by Granger in the Clark's Fork Basin. Consequently, Sinclair returned to this area with Jepsen and three undergraduate students, James W. Cooke, Sven Dorf, and Joseph F. Page, in 1929 (Figure 9). Their first camp was set up on June 29th at the west edge of Polecat Bench, near Fossil Hollow (UM locality SC–198), a site Jepsen had visited on his last day in the Polecat Bench area the year before. Sinclair kept a detailed field catalogue that sheds considerable light on the collections made in 1929. The first two weeks were spent prospecting near camp, mostly along the west edge of Polecat Bench. On July 11th the first specimens were collected at what later became the very productive Princeton Quarry. Piecing together several lines of evidence, it appears that discovery of the first specimen from this locality (premolars of *Neoliotomus*) resulted from a fortuitous, if uncomfortable, encounter Page had with a tick. However the actual concentration of jaws and teeth at Princeton Quarry was not recognized until July 22nd, when two days were spent quarrying here.

On July 29th a nice collection of Clarkforkian mammals was made in Sand Coulee, near UM locality SC–136, including the holotype of *Plesiadapis cookei*. The Paint Creek locality (UM locality SC–143), yielding *Neoliotomus conventus* Jepsen (1930a), was discovered on August 2nd in brightly colored strata on the west side of the Clark's Fork Basin. As with the holotype of *Probathyopsis successor*, the Clarkforkian fossils from Paint Creek were incorrectly considered to be Sand Coulee or Graybull in age because they came from red-banded strata. Jepsen (1940) explicitly stated that red beds occur well down in the Clark Fork beds, but he continued to concentrate collecting efforts only on drab sediments, with the result that many rich and important Clarkforkian localities in red-banded strata were not discovered until recently.

The Torrejonian Rock Bench Quarry on the east side of Polecat Bench was discovered on August 6th, when a number of jaws, including the holotype of *Plesiolestes* [*Palaechthon*] *problematicus* Jepsen (1930b), were collected. On August 13th the first Puercan mammal, described as *Eoconodon*, was discovered one half mile east of the coal mine at the 1928 Camp #3. The Mantua Quarry itself was found at the same stratigraphic level on August 14th about a mile to the northwest. The first fossil discovered here was the holotype of *Loxolophus nordicus* Jepsen (1930b). The following day several blocks of matrix were hastily removed from the Mantua Quarry, and Sinclair, Jepsen, and crew headed back to Princeton. In little more than a month of field work this crew had succeeded in finding what became three extremely productive Puercan, Torrejonian, and Tiffanian quarries, and demonstrated their relationship to underlying Cretaceous and overlying Eocene faunas.

The 1928 and 1929 collections formed the basis of Jepsen's doctoral dissertation (Jepsen, 1930b). In addition to the mammals described by Jepsen from the Clark's Fork Basin-Polecat Bench area, these expeditions documented a remarkable diversity of

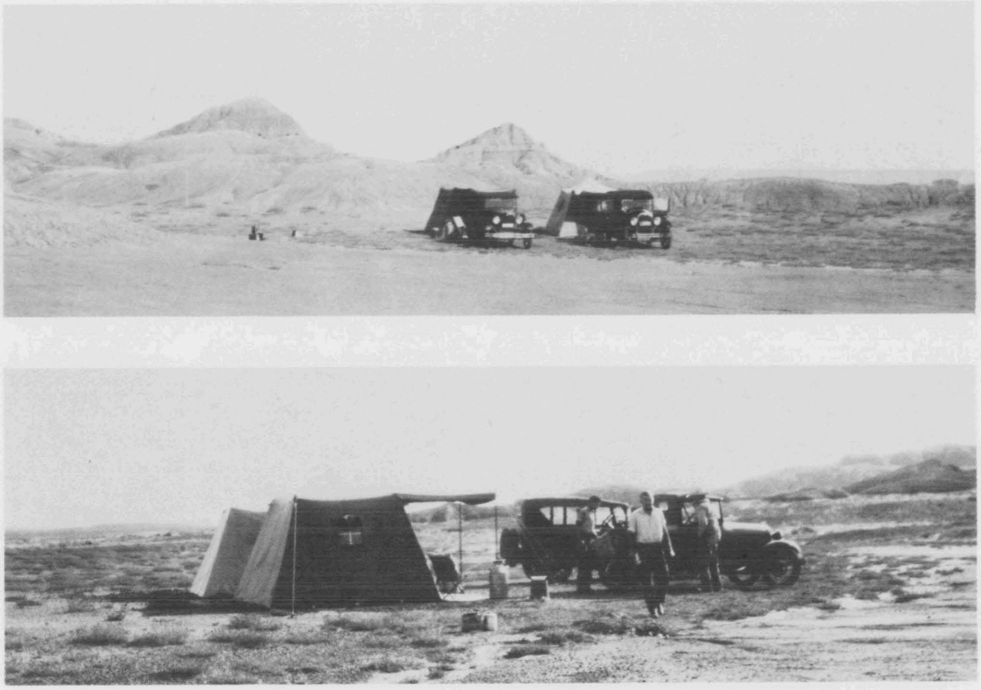

Figure 9. Princeton University camp in the McCullough Peaks in 1929, during a break from prospecting in the Paleocene. *Top:* view looking northwest, showing two Model A Fords, one a touring car and the other a pickup. Note Polecat Bench on the skyline at right. *Bottom:* view looking east. Gentleman at right in hat is William J. Sinclair. Others are students James W. Cooke, Joseph R. Page, or Sven Dorf. Photographs courtesy of Department of Geological and Geophysical Sciences, Princeton University.

land snails in the Clarkforkian and early Wasatchian, differing from the underlying Tiffanian fauna dominated by aquatic forms (Russell, 1931). During the 1930's Jepsen continued to work the Puercan, Torrejonian, and Tiffanian quarries, which yielded a rich collection of fossil vertebrates. Jepsen (1940) described the multituberculates and proposed a new formation, the Polecat Bench Formation, to include, essentially, the Paleocene sediments of the northern Bighorn Basin. This terminology has not been universally accepted because it has never been thoroughly and adequately documented, and the drab early Cenozoic sediments are sometimes still included in the Fort Union Formation.

During the 1930's Jepsen became acquainted with Frederick and Thelma Churchill, a farming couple living near Powell, Wyoming. The Churchill family has continued to play an important role in Bighorn Basin vertebrate paleontology for nearly fifty years. During his lifetime, Frederick discovered many important Paleocene and Eocene fossil localities, among them the late Tiffanian Fritz Quarry and the early Wasatchian Bone Hill locality.

LATER PRINCETON UNIVERSITY EXPEDITIONS

In 1937, Franklyn B. Van Houten began major projects on the Wasatchian stratigraphy and faunas of the Bighorn Basin, which resulted in two important publications (Van Houten, 1944, 1945), and differentiation of the red-banded early Eocene sediments of the basin as the Willwood Formation.

Field work was curtailed during World Was II, but the years following the war were also productive. Robert V. Witter and Albert C. Silberling were employed by Princeton during this period. Silberling was at that time a veteran of some fifty years of paleontological prospecting in the Crazy Mountain Field in Montana, having first accompanied a Princeton party working there in 1901 when he was sixteen years old. Witter was younger and less experienced but proved equally capable as a collector. Together they initiated work in the Foster Gulch area in the large expanse of badlands between the towns of Powell, Lovell, Greybull, and Emblem. Among the most important sites discovered by Witter and Silberling were the Tiffanian Cedar Point (Ti_3), Jepsen (Ti_3), Croc Tooth (Ti_4), and Divide (Ti_4) Quarries, and the late Tiffanian or Clarkforkian Little Dry Creek locality near Greybull. In 1948 Witter succeeded in obtaining a new collection of early Clarkforkian fossil vertebrates from the Foster, Burns, Brophy, and Smith coal mines near Bear Creek, Montana. Minchen Chow, Frank Goto, Marshall Lambert, Ernest Lundelius, William J. Morris, and Elwyn L. Simons also worked with Princeton parties in the Bighorn Basin during the late 1940's and early 1950's.

In 1955, Simons discovered a Torrejonian locality on Cub Creek southeast of Belfry, Montana. This locality yielded several good specimens, among them the holotype of *Stelocyon arctylos* Gingerich (1978). Simons continued exploration of the Bighorn Basin in 1960, assisted by Farish A. Jenkins and Leonard B. Radinsky. They discovered several important sites in the southern Bighorn Basin, among these the Wasatchian Sand Creek-No Water Creek area later worked by Bown (1979), the Puercan (?) Gooseberry Creek locality some 15 miles south of Meeteetse along Highway 120, and the Puercan Leidy Quarry east of Kirby. Simons also found the Sunday locality and a specimen of "Sunday beast" in 1960. Professor Jepsen was away at the time; and according to Simons these were both named to remind Jepsen of how the crew had spent their sabbath. In Jepsen's later years his idea of a day of rest was a day away from the Paleocene, often a "picnic" in more fossiliferous Wasatchian deposits.

During the 1960's Princeton parties working in the Bighorn Basin included Michael Archer, Henry Bunn, Robert Chaffee, Farish Jenkins, Marshall, Brice, and Russell Lambert, David Parris, Wayne Pennington, Robert Rainey, Kenneth Rose, Charles Schaff, Wallace Ulrich, Robert West, Craig Wood, Roger Wood, and a number of others. I first worked for Jepsen in 1967, completing an undergraduate thesis on pollen stratigraphy in the Polecat Bench Formation (Gingerich, 1968). During the summer of 1967 my brother Steven and I, at Jepsen's suggestion, made the first accurate determination of the thickness of the Polecat Bench Formation along the south side of Polecat Bench. After a week spent making a complex series of measurements with plane table and alidade, analyzed by computer at Princeton, we concluded that the thickness of the Polecat Bench Formation was 3,817 feet (1,163 m) from the base of the Mantua lentil to the lowest red bed on the south side of Polecat Bench. Jepsen (1940) had given the thickness of the formation as 3,500 feet (1,067 m), within 10% of our figure. He was pleased and little amused that our figure matched his so closely, since in his calculation he had assumed an average strike and dip and then simply driven his automobile along the south edge of Polecat Bench using its odometer to measure the distance traversed!

Glenn Lowell Jepsen retired from the Princeton faculty in 1971 and passed away in 1974, having devoted nearly two-thirds of his life to research on early Cenozoic faunas of the Bighorn Basin. It is worth noting that most of the contributors to this volume owe their interest in the Clark's Fork and Bighorn basins directly or indirectly to Jepsen.

GILMORE, WILSON, KAY, AND OTHERS

During the summer of 1930, Theodore E. White and Norman Hartweg spent several days in the Bighorn Basin with William Stein collecting for the University of Michigan. They worked "twenty miles west of Basin," where they obtained a small collection consisting mostly of *Hyracotherium, Homogalax,* and *Phenacodus.* Edward L. Troxell of Trinity College (Connecticut) also worked in the Bighorn Basin in 1930, on Elk Creek, where he found a nearly complete skeleton of *Diatryma* (Troxell, 1931). Troxell continued field work in the Bighorn Basin in 1931.

Charles W. Gilmore, George F. Sternberg, and M. V. Walker carried out an extensive survey of the central Bighorn Basin for the U.S. National Museum in 1931, concentrating especially on the south fork of Elk Creek. On their first day of collecting Gilmore's crew located a nearly complete skeleton of *Coryphodon,* only to find out later while visiting Troxell's camp that it was of a specimen Troxell himself was in the process of collecting. Gilmore released all claims, noting in his field book that "some people get all the breaks." Gilmore's party found five fragmentary specimens of *Diatryma* near the mouth of the south fork of Elk Creek, which together with Troxell's eight specimens and the one found by Stein (Matthew and Granger, 1917) all came from a narrow strip not more than two miles wide along the eastern margin of exposures of the Willwood Formation. Walker found a partial skeleton of *Pachyaena* "five miles south of Otto." Then, eight miles northwest of Worland, Sternberg found the skull of a "rare edentate," the taeniodont *Ectoganus* later described by Gazin (1936). Gilmore (1932) published a brief illustrated account of the 1931 expedition. In 1935, Gilmore and Sternberg returned to the Bighorn Basin again for one month of collecting and this time they were rewarded by finding a complete *Coryphodon* skeleton to replace the one taken out from under their noses by Troxell (Gilmore, 1936).

Robert W. Wilson first worked in the Bighorn Basin for a brief time in 1934, with a party of three assistants. They were fortunate in finding a good locality yielding about one hundred jaws in the Dry Creek basin. These specimens were originally deposited at Cal Tech, and have since been transferred to the Los Angeles County Museum. In 1940, Wilson again collected in the Bighorn Basin, for the University of Colorado, being accompanied part of the time by G. E. Lewis of Yale University. Wilson later made a larger collection for the University of Kansas in 1949, mostly on the south fork of Elk Creek. This 1949 collection included the holotype of *Microsyops wilsoni* described by Szalay (1967), the *Pelycodus* mandible with a small supernumerary M_3 following the normal M_3 described by Wilson (1955), and, from the Dry Creek basin locality, a beautiful mandible of *Anacodon* and a highly fragmented nest of bird (?) eggs.

Albert E. Wood made a small collection of mammals from the Clark's Fork Basin in 1948, the most important find being the holotype of *Franimys amherstensis* (Wood, 1962).

In 1952, J. Leroy Kay and John A. Dorr spent thirteen days collecting in the Bighorn Basin for the Carnegie Museum in Pittsburgh. According to Dorr, they headed into the badlands west of Basin on a new seismograph road. The road was so rough and progress so slow that Dorr rode on the fender of the truck while Kay drove. After two miles or so of this, Dorr spotted bone from his perch on the fender. They stopped to prospect and soon found a 1 meter by 2 meter concentration of multituberculate, insectivore, condylarth, perissodactyl, and carnivore teeth, jaws, and skulls in a silty mudstone near the edge of a coarser channel sandstone. This site, Burrough's Pocket, was located at the head of Antelope Creek. Kay and Dorr ultimately removed a 300 kg block of matrix that was shipped back to Carnegie intact for later preparation.

Rohrer and Gazin (1965) published a brief discussion of Graybullian and Lysitean fossil vertebrates and invertebrates collected from 62 localities in connection with a geological mapping project in the vicinity of Tatman Mountain. In 1967, Dwight W. Taylor completed an extensive report on early Cenozoic mollusks, including those of the Bighorn Basin (U.S. Geol. Surv., Open-File report 75-331).

Additional collections of fossil mammals from the Bighorn Basin are housed at the Royal Ontario Museum, the University of Nebraska State Museum, the Raymond Alf Museum, the University of California Museum of Paleontology, Berkeley, the University of California, Riverside, and the University of Alberta. I have no doubt overlooked some smaller collections.

RECENT WORK

Elwyn L. Simons and Leonard Radinsky began the first intensive effort to collect fossil mammals from restricted stratigraphic intervals in the central Bighorn Basin in 1961. The Yale University program was continued through 1976 by Simons, and subsequently by David Schankler and Scott Wing (this volume). All collections are at Yale, except for those made in 1974 by a joint Yale-Michigan team. The latter collections were divided—the primates being housed at Yale, with the remainder of the fauna at the University of Michigan. In 1973, Thomas M. Bown of the University of Wyoming began an intensive survey of the lower Willwood Formation in the Sand Creek-No Water Creek area of the southeastern Bighorn Basin. Results of this study were recently published (Bown, 1979; also, this volume).

Following the summer of joint work with Simons in 1974 in the central Bighorn Basin, I began a University of Michigan project to study the typical Sand Coulee beds in the Clark's Fork Basin. In the process of sampling to find the base of the Wasatchian, we discovered many good localities yielding the formerly rare *Plesiadapis cookei,* a Clarkforkian index fossil, and after the second season of field work, we were able to trace the Clarkforkian-Wasatchian boundary from one side of the Clark's Fork Basin to the other. Kenneth D. Rose (1979) recently completed a monograph on the Clarkforkian mammalian fauna, and related Wasatchian and Tiffanian projects are in progress (Gingerich, Rose, and Krause, this volume). Charles R. Schaff at Harvard University has also continued work on the late Tiffanian faunas in the vicinity of Princeton and Schaff quarries in the Clark's Fork Basin.

A long-term project on the early Cenozoic floras of the Clark's Fork Basin and vicinity is in progress by Leo J. Hickey of the Smithsonian Institution (see report in this volume), and by Erling Dorf of Princeton University. John H. Hanley of the U.S. Geological Survey also initiated a project on early Cenozoic mollusks in the Clark's Fork and Bighorn basins several years ago. All of these studies promise to improve our understanding of early Cenozoic paleoecology greatly.

Post-Wasatchian sediments of the Bighorn Basin have been relatively little studied until recently. In

1962, Elwyn L. Simons received word from Lee Wentworth, a resident of Meeteetse, of fossil mammals occurring near Foster Reservoir on the flank of Carter Montain. Later that summer, James Mead and Peter Parks climbed to the upper levels of Carter Mountain and discovered additional mammal-bearing localities. All of these Carter Mountain localities appear to be Bridgerian in age. Several years ago David C. Parris of Princeton University succeeded in finding teeth of Bridgerian aspect in the Tatman Formation on Tatman Mountain. In 1977, Thomas W. Bown, now of the U.S. Geological Survey, and Jason A. Lillegraven and Jeffrey G. Eaton of the University of Wyoming began work on middle Eocene volcaniclastics along the southwestern margin of the Bighorn Basin (Bown, 1979; Eaton, this volume). Malcolm C. McKenna (this volume) summarizes what is known about Oligocene faunas in the vicinity of the Bighorn Basin and surrounding mountain ranges.

CONCLUSION

The first century of paleontological research in the Bighorn Basin has proven this to be one of the richest areas in the world for study of the early Cenozoic. Yet, in a sense, the work of integrating results of diverse approaches to earth history here has just begun. As the second century begins, we can expect the many complimentary studies now underway to yield a more coherent picture of early Cenozoic faunal and floral coevolution.

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SUMMARY OF LATEST CRETACEOUS AND CENOZOIC SEDIMENTARY, TECTONIC, AND EROSIONAL EVENTS, BIGHORN BASIN, WYOMING

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Abstract.— Principal events in the Cenozoic history of the Bighorn Basin are uplift of the Beartooth, Pryor, and northern Bighorn Mountains in the latest Cretaceous and Paleocene, uplift of the southern Bighorn and Owl Creek Mountains beginning in the Paleocene, extensive volcanic activity in the Absaroka-Yellowstone area during the middle and late Eocene, and regional uplift in the late Oligocene or early Miocene leading to erosional excavation of a considerable thickness of lower Cenozoic sedimentary rocks. Two phases of detachment faulting are contemporaneous with, respectively, volcanic activity in the Absarokas during the middle Eocene, and earthquake activity in the Teton-Yellowstone region during the late Neogene.

INTRODUCTION

The Bighorn Basin of northwest Wyoming is a structural and topograhic basin that is bounded by several positive structural areas that were elevated differentially during the middle and later parts of the Laramide orogeny. In latest Cretaceous time, this elevation resulted in the withdrawal of the Lewis Sea and the onset of continental sedimentation that in turn resulted in the accumulation of nearly 21,000 feet (6,400 m) of fluvial and lacustrine rocks in the deeper basin areas by the end of Eocene time. An unknown thickness of upper Eocene through upper Oligocene (and possibly Miocene) rocks capped this sequence and filled the basin to at least the present 9,000-foot (2,750 m) level of the peripheral Bighorn Mountains. Minor intervals of uplift and erosion recorded by unconformities punctuate this sedimentary record. Principal structural events include (1) initiation of uplift of northern Bighorn, Pryor, and Beartooth Mountains in the Late Cretaceous and Paleocene and continued structural elevation of these positive areas through the Eocene, (2) uplift of the southern Bighorn Mountains and Owl Creek Mountains in the late Paleocene and thrusting of these mountains to the south in the middle early Eocene, (3) large-scale detachment faulting of Paleozoic rocks in the Beartooth Mountains and their gliding as far east as the central part of the northern Bighorn Basin in early middle Eocene time (South Fork, Reef Creek, and Heart Mountain detachment faults), (4) extensive volcanic activity in the Absaroka-Yellowstone National Park region from the early middle Eocene to at least the late Eocene (reduced activity has continued to the present day), (5) regional epeirogenic uplift of the Bighorn area in the late Oligocene or early Miocene that initiated degradational conditions in the basin and resulted in the removal of at lest 5,000 feet (1,520 m) of rock from some parts of the basin and adjacent mountains from the Miocene through the Holocene, and (6) a second episode of major detachment faulting in the late Neogene (this time displacing Eocene volcanic rocks in the southeast Absaroka Range), probably triggered by earthquakes in the Teton-Yellowstone National Park region.

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LATEST CRETACEOUS

Middle and late Laramide structural uplift of mountainous areas surrounding the Bighorn Basin (Bighorn, Owl Creek, Beartooth, and Pryor Mountains) resulted from a combination of vertical tectonism with or without horizontal compression and tensional (gravity) readjustment (Foose, 1971). This deformation may have been associated with the western movement of the North American plate against the Pacific plate (Blackstone, 1971). Laramide deformation reached the Bighorn area from the west by Mesaverde (late Campanian) time, where it is reflected by alternating shale and nearshore or beach sandstone deposits that record fluctuating strandlines. Upper Mesaverde and Meeteetse rocks are dominantly continental in origin and were derived from uplifted areas west of the present Bighorn Basin area. Continental sedimentation continued, with a few minor interruptions, until the late Tertiary.

The Lewis Sea had fully retreated from the Bighorn area by the beginning of Lance deposition in Maestrichtian time. The Lance is characterized by fluvial and palustrine sandstones, mudstones, and shales. Predominance of thick, interconnected sandstone channels in the Lance of the western Bighorn Basin indicates that accumulation of sediment was relatively slow (see, *e.g.,* Allen, 1978) and that rapid structural downwarping along the Bighorn Basin synclinal axis had not yet begun.

In some basin margin areas of the Bighorn Basin, the Lance Formation is overlain by the Paleocene Fort Union Formation (Polecat Bench Formation of Jepsen, 1940) with an angular unconformity. This type of contact is best seen in the eastern, southeastern, and western Bighorn Basin (Hewett, 1926; Bown, 1979) and is less evident in the southern and northern parts of the basin where the unconformity is erosional. These relations suggest there was strong downwarping of an essentially north-south trending basin in latest Cretaceous or early Paleocene time and erosion of folded Mesozoic and Paleozoic rocks, but little downwarping of the northern and southern margins. The Beartooth, northern Bighorn, and Washakie Mountains were elevated enough to be locally exposed to their Precambrian crystalline cores by Paleocene times (Van Houten, 1952; Alpha and Fanshawe, 1954; Keefer, 1965b).

PALEOCENE

The Tertiary Period in the Bighorn Basin area was characterized in the early part by strong basin downwarping, rapid accumulation of fluvial sediments, and rather rapid structural elevation of the basin margins. Paleocene deposition and accumulation was much more rapid in trough areas along the basin synclinal axis than in peripheral areas. In consequence, the Paleocene Fort Union Formation varies in thickness from less than 2,000 feet (600 m) in the southeast Bighorn Basin to more than 10,000 feet (3,050 m) in subsurface axial troughs in the northwest part of the basin (Moore, 1961).

In the central and northern Bighorn Basin, the Fort Union is typified by a dominance of mudstone over sandstone in the upper part, though these relations vary somewhat locally. In the southeast Bighorn Basin on the northern part of the Sand Creek Divide (Bown, 1979, pl. 1), the sandstone/mudstone ratio in the upper part of the Fort Union is commonly as low as 0.05 to 0.15, whereas the ratio in the upper part of the Fort Union near Neiber is as high as 0.6 to 0.75 (Bown, unpublished data). Because low sandstone/mudstone ratios probably are directly proportional to sediment accumulation rates in fluvial sequences (Allen, 1978; M. J. Kraus, L. Middleton, T. M. Bown, unpublished data), it is evident that basin downwarp and sediment accumulation rates fluctuated from place to place at the same time during the Paleocene.

In the southwest Bighorn Basin, the systemic boundary is generally picked by local angular unconformities between fluvial upper Cretaceous Lance sheet sandstones and tabular mudstones, and overlying lenticular, unconnected fluvial sandstones and roundstone conglomerates of the Paleocene Fort Union Formation (Hewett, 1926; Bown, in press). This contact relation indicates that local downwarping and erosion followed Lance deposition, accumulation of Fort Union rocks was rather more rapid than underlying Lance rocks, and major downwarping had begun along the synclinal axis of the Bighorn Basin. Quartzites and weathered volcanic roundstones with no local sources occur in Fort Union conglomerates in the western Bighorn Basin (Hewett, 1926; Lindsey, 1972) and suggest the Washakie Range and Targhee Uplift areas to the west were important sediment source areas. The Washakie Range (Love, 1939) was rapidly being denuded and topography west of the present southern Bighorn Basin margin was low enough to allow eastward transportation of a large amount of coarse sediment that accumulated as conglomeratic bodies in the areas south of Cody and west of Meeteetse (Hewett, 1926; Rea and Barlow, 1975). These bodies grade basinward into a thick sequence of mudstones, sheet and lenticular sandstones, and lignitic shales that were deposited on broad floodbasins and in channels of meandering streams. Lacustrine (probably pond) and "coal swamp" environments prevailed in early Paleocene time in the northern and southern Bighorn Basin and were separated in the central part of the basin and bounded basinward by areas of exclusively alluvial plain deposition (Rea and Barlow, 1975).

Minor incursions of a tongue of the Cannonball Sea, Waltman Lake (Keefer, 1961), or another marine or brackish body are indicated by Fort Union shales containing marine dinoflagellates in the Grass Creek Basin area (J. D. Love, oral comm., 1974) and by thicker shales of marine aspect in Fort Union rocks in the southeast Bighorn Basin (Bown, unpublished data). These deposits suggest that the Owl Creek arch had not begun to rise appreciably by the close of the early part of the Paleocene.

The northern Bighorn Mountains were probably substantially elevated at some time in the Paleocene, as were the Beartooth Mountains at the northwest corner of the basin (Jobling, 1974). The major drainage of the Wind River Basin was eastward in Paleocene times (Love and others, 1963; Keefer, 1965a; Courdin and Hubert, 1969; McGrew, 1971; Rocky Mountain Association of Geologists, 1972), and the major drainage out of the Bighorn Basin was probably southeast and became confluent with that of the Wind River Basin (Love, 1960; Love and others, 1963; Bown, unpublished data). Broad and low anticlinal folds began to form along the present trend of the Owl Creek and southern Bighorn Mountains in the late Paleocene (Keefer, 1965a, 1965b; Love, 1960, 1978).

EOCENE

Fluvial sedimentation was continuous across the Paleocene-Eocene boundary in the axial regions of the northern and central Bighorn Basin and Fort Union Formation was buried by variegated mudstones and lenticular and sheet sandstones of the lower Eocene Willwood Formation. An angular unconformity between Fort Union and lower Willwood rocks is present at Heart Mountain north of Cody, near McCulloch Peaks east of Cody (Sinclair and Granger, 1912), and locally in the southeast Bighorn Basin (Bown, 1979). Southeast of the town of Meeteetse, quartzite pebble and roundstone conglomerates of the upper Willwood Formation truncate Fort Union rocks and older strata (Sinclair and Granger, 1912; Hewett, 1926; Young, 1972; Neasham and Vondra, 1972), and along the southwest margin of the basin adjacent to the Absaroka Range upper Willwood rocks truncate Mesozoic rocks (Bown, in press). These angular relations indicate that local peripheral areas of the Bighorn Basin were differentially elevated and were being eroded at the same time that lower Willwood rocks were accumulating in more central parts of the basin. Remnants of quartzite conglomerate bodies in the lower Willwood Formation on Blue Mesa and similar deposits in the upper Willwood east of Meeteetse indicate relatively low topography immediately west of the present southwestern Bighorn Basin margin and sediment source areas in the more distant Washakie Range and Targhee Uplift. The general absence of conglomerates in lower Willwood rocks of the southeast Bighorn Basin (Bown, 1979) indicates that the southern Bighorn Mountains were not significantly elevated, even though deformation began there in Paleocene time. Conglomerates in lower Willwood rocks on the east side of the Beartooth Mountains (Pierce, 1965; Fleuckinger, 1970; Bredall, 1971) and conglomerates that intertongue with so-called "Wasatch" rocks in the western Powder River Basin (Sharp, 1948; Brown, 1948) show that the Beartooth and northern Bighorn Mountains were already substantially uplifted by the early part of the early Eocene.

Lower Eocene rocks of the Bighorn Basin are largely represented by the Willwood Formation, an alluvial sequence deposited by principally meandering streams on broad, essentially featureless floodbasins. A few carbonaceous shales and lignites formed in ponds, backswamps, or other low-lying areas on the floodbasins (see paper by S. Wing, this volume) and accumulation, though relatively rapid, was punc—tuated by numerous intervals of nondeposition and soil formation (Bown, 1979; Kraus, 1979; Bown and M. J. Kraus, unpublished data). Willwood paleo—drainage in the southern Bighorn Basin was to the southeast in earliest Eocene as in Paleocene times (Bown, unpublished data) and probably passed southeastward over the area of the present day Owl Creek Mountains, joining the eastward-flowing principal drainage of the Wind River Basin (Seeland, 1978). The southern Bighorn Mountains and Owl Creek Mountains were elevated and thrusted southward toward the Wind River Basin in the early middle part of the early Eocene (post-lower Indian Meadows Formation time; see Tourtelot and Nace, 1946; Tourtelot and Thomson, 1948; Keefer and Love, 1963; Love, 1978), and again in the beginning of late early Eocene time (Love, 1978). This elevation reversed the major southeast flowing drainage of the Bighorn Basin to the northwest, where it probably remained throughout the early Eocene (see, *e.g.*, Neasham and Vondra, 1972).

Near the end of Willwood time, depression of the south-central Bighorn Basin area slowed and Willwood rocks overlapped the truncated border fold belt at the western margin of the basin (Bown, in press). Depression of this part of the basin resumed in latest early Eocene and early middle Eocene time, creating the Tatman lake basin and resulting in an unconformity at the top of the border Willwood Formation in the southwest part of the basin (Bown, in press). Bentonites (Rohrer, 1964a, 1964b) and tuffaceous material in uppermost Willwood strata of the southern Bighorn Basin (Van Houten, 1944; Bown, unpublished data) demonstrate that volcanic activity had begun in the Absaroka-Yellowstone National Park region.

In latest early Eocene and early middle Eocene times, at least 900 feet (275 m) and probably much more of green and brown clay shale, brown kerogenic shale, and green and brown sandstone of the Tatman Formation were deposited conformably on Willwood rocks in the Tatman lake basin. Though generally regarded as swamp and lacustrine deposits (*e.g.,* Van Houten, 1944), the Tatman is also largely fluviatile in origin (Sinclair and Granger, 1911; Bown unpublished data). The Tatman intertongues extensively with the upper part of the Willwood Formation in a few areas on the Squaw Buttes Divide (Van Houten, 1944; Rohrer and Smith, 1969; Bown, unpublished data).

Post-Tatman Eocene rocks are not preserved in the central Bighorn Basin but are well developed in the southwest part of the basin adjacent to the Absaroka Range and in the Lysite Mountain area, on the divide separating the southeast Bighorn and northeast Wind River Basins. Because middle and upper Eocene rocks in the southeast Absaroka Range form a high erosional scarp that is not bounded by faults, it is virtually certain that the middle and late Eocene Absaroka volcanic rocks once extended entirely across the Bighorn Basin (McKenna and Love, 1972). Recognition of the significance of these relations is critical to any understanding of the middle Eocene through Quaternary history of the Bighorn Basin.

Tuffaceous fluviolacustrine rocks of Tatman aspect unconformably overlie the Willwood Formation in the southeast Absaroka Range (Hewett, 1926; Rohrer, 1966; Bown, in press) and probably correlate with tuffaceous Tatman-like rocks on Lysite Mountain and not with the non-tuffaceous Tatman Formation of the south-central Bighorn Basin (Bown, in press). In the southeast Absaroka Range, these rocks intertongue with and are overlain by fluvial volcaniclastic rocks of the Aycross Formation (Bown, in press). These relations indicate that the Aycross Formation in part is a basin margin fluvial facies of the tuffaceous upper part of the Tatman Formation that is not preserved in the central Bighorn Basin.

Volcanic activity began in the Absoraka-Yellowstone National Park region in the later part of the early Eocene (Dorf, 1939) and volcanic rocks contributed most of the clastic material deposited in the Bighorn area until late Arikareean times. The fluvial middle Eocene Aycross Formation received sediment from several sources to the west and northwest. Detrital quartz and chert was supplied by the Owl Creek and Washakie Mountains, vein quartz was probably derived from the Washakie Range, and quartzite pebbles and roundstones came from the Targhee area of eastern Idaho, indicating that relief to the west was still low as it was in the Paleocene and early Eocene (Bown, in press). However, most detrital material in the Aycross and younger formations was derived from extrusive and intrusive volcanic igneous sources in the active Absaroka volcanic field. These sources remained very active at least until the close of the Eocene and local areas were moderately active until the end of the Tertiary.

At some time following Willwood deposition and prior to or during earliest depositon of volcaniclastic rocks in the northeast Absaroka Range, large masses of Paleozoic limestones were displaced nearly 50 miles (83 km) eastward of their source (near the northeast corner of Yellowstone National Park) by low-angle gravity faulting (South Fork, Reef Creek, and Heart Mountain detachment faults; Pierce, 1957, 1963, 1973). Because the most easterly dispersed of the Heart Mountain fault klippen lie on a surface developed on truncated Willwood rocks at Heart Mountain and McCulloch Peaks (north and east of the town of Cody), it is uncertain whether a great deal of erosion took place in the northern Bighorn Basin following Willwood deposition, or if secondary post-Eocene movement of the klippen took place. A significant period of post-Willwood Eocene erosion in the northern Bighorn Basin conflicts with the more-or-less continuous sedimentary record of the southern Bighorn Basin.

The lower part of the middle Eocene Aycross Formation was deposited on a surface of considerable relief developed on Paleozoic through lower Eocene rocks in the southeast Absaroka Range. Once deep erosional strike valleys were filled, Aycross alluvial relief lessened and the lithotope was one of broad floodbasins and large meandering streams, similar to those of the Willwood (Bown, in press). Ponds developed in floodbasin swales or in low-lying abandoned distributary channels. At the close of Aycross time (early middle Eocene), volcaniclastic rocks formed a bajada-like prism of sediment that abutted volcanic eruptive centers on the west and draped eastward into the Tatman lake basin (Bown, in press).

The southern Absaroka region was gently uplifted due to increased volcanic activity at the end of Aycross time and upper Aycross rocks were truncated by erosion. The middle and later Eocene Tepee Trail Formation was deposited atop the Aycross and likewise extended eastward into the Bighorn Basin, probably filling the Tatman lake basin and dislocating it to the southeast where dominantly lacaustrine sedimentation continued in the Lysite Mountain area (Love, 1964; Bay, 1969). Following Tepee Trail deposition, the Absaroka volcanic field expanded to the south and east. This expansion is recorded by folding and truncation of Tepee Trail rocks and by a massive influx of coarse volcanic derived sediments, as well as flows, agglomerates, and intrusives of the Wiggins Formation. The top of the Wiggins Formation is nowhere preserved but radiometric dates indicate that the bulk of the formation ranges in age from 47.1 to 43.1 Ma (Love and Keefer, 1975). Eocene volcaniclastic rocks in the Badwater area of the northeast Wind River Basin dates at 41.2 ± 1.4 Ma (Reidal, 1969; Love, 1978) may represent upper Wiggins equivalents not preserved farther west and suggest that volcanic derived sediments had engulfed the Owl Creek and southern Bighorn Mountains before the close of the Eocene (McKenna and Love, 1972).

At some time in the later Eocene and coincident with Wiggins deposition, large-scale deformation resulted in development of the "chaos zone," a widespread, structurally disharmonic unit of rock in the middle part of the Wiggins Formation (J. D. Love, K. Sundell, and J. G. Eaton, oral communs., 1977-79). The "chaos zone" may have resulted from gravity (detachment) faulting or lahar development associated with the renewed intense volcanic activity in middle Wiggins time.

OLIGOCENE

Oligocene rocks are unknown in the central Bighorn Basin but do occur as a few remnants on the Bighorn Mountains (Darton, 1906; McKenna and Love, 1972; Love, 1978), and in the Badwater (Black, 1969) and Teton-Yellowstone National Park areas (Love and others, 1976). Preservation of these remnants unconformably atop Eocene volcaniclastic rocks in the Emerald Lake (Love and others, 1976) and Badwater (Love, 1978) areas indicates that a period of erosion followed Wiggins deposition but that Oligocen sedimentation followed, probably capping much if not all of the Eocene sequence, and overlapping the lower crest of the Bighorn Mountains (Fanshawe, 1952). Oligocene rocks probably also draped eastward off the engulfed Bighorn Mountains into the Powder River Basin where they cap North Pumpkin Butte (Love, 1952; McKenna and Love, 1972).

Arikareean and younger fluvial rocks overlie Oligocene rocks at Emerald Lake south of Yellowstone National Park (Love and others, 1976) and Oligocene (? Whitneyan) rocks occur in the Badwater area of the northeast Wind River Basin (Setoguchi, 1978; see also Love, 1978). Late Arikareean rocks occur at an elevation of 9,000 feet (2,750 m) at Darton's Bluff on the crest of the Bighorn Mountains east of the town of Ten Sleep, Wyoming, where they overlie earlier Oligocene rocks and Precambrian schist (McKenna and Love, 1972; see paper by M. C. McKenna, this volume). These relations indicate that fluvial deposition in the Bighorn-Absaroka area continued into the late Oligocene and that the Bighorn Basin at that time was filled to a level corresponding to the Bighorn Mountain subsummit surface, at about the present 9,000-foot (2,750 m) contour.

The Bighorn subsummit surface is the highest of many eastern Bighorn area erosional surfaces that were formed during pauses in the later Tertiary excavation of the Bighorn Basin sedimentary fill (Mackin, 1937, 1947). Because this surface truncates late Arikareean rocks at Darton's Bluff and because no post-Oligocene and pre-Quaternary rocks are known in the Bighorn area, it is likely that epeirogenic uplift that initiated lower regional base levels and excavation of the Bighorn Basin was an event of late Oligocene or early Miocene age.

MIOCENE AND PLIOCENE

Between the early Miocene and the present day, erosion has removed more than 7,800 feet (2,375 m) of rocks from the Absaroka area and at least 5,000 feet (1,520 m) from the eastern Bighorn Basin area. A high-level erosion surface developed at 11,500 feet (3,500 m) elevation in the eastern Absaroka Range (Breckenridge, 1975) reflects a pause in the early degradational history of that area (because it is nearer depositional centers, the Absaroka subsummit surface is higher than the Bighorn and may also be older.) Numerous lower post-Tertiary erosional surfaces down to the level of the lowest terraces of the Bighorn and Shoshone Rivers (Mackin, 1937) record successively younger stages in the excavation of the basin. At some time in the Miocene or Pliocene, the Wind River-Bighorn River was let down on and superimposed across the folded Owl Creek Mountains, Sheep Mountain Anticline north of the town of Greybull, and the northern Bighorn Mountains from higher levels of basin fill.

Rapid excavation of the sedimentary fill of the Bighorn area resulted in isostatic rebound of the marginal erosional scarp of the Absoraka Range, causing the gentle westerly dip of most of the Absaroka Volcanic Supergroup away from the center of the Bighorn Basin (McKenna and Love, 1972). Volcanism persisted in Miocene and Pliocene times in some areas of the Absaroka-Yellowstone National Park region (*e.g.*, Love, 1960; Hamilton, 1960; Blackstone, 1965; Christiansen and Love, 1978).

QUARTERNARY

Degradation of the Bighorn Basin continued unabated through the Quaternary and typifies the present sedimentary regime. The Fenton Pass Formation (? Pleistocene) was deposited atop the Pliocene or Pleistocene Tatman Mountain erosional surface (Rohrer and Leopold, 1963), and valley fill, terrace, moraine, and glacial outwash deposits accumulated in many places. Lower erosional surfaces (Polecat Bench, Y-U Bench, Emblem Bench, and other Bighorn and Shoshone River terraces; Mackin, 1937) record pauses in the Quaternary dissection of basin fill. Palmquist (1978) has shown that rates of erosion of this fill during the Quaternary were on the order of 0.2 m/1,000 years in the period 2.0 my to 0.6 my before the present and 0.16 m/1,000 years in the period 0.6 my to the present.

The Absaroka Range was extensively glaciated during the Pleistocene (Breckenridge, 1975; T. H. Walsh and J. D. Love, unpublished data) as were the Bighorn and Beartooth Mountains.

At some time in the late Neogene, violent earthquakes associated with faulting and extensive volcanic activity in the Teton-Yellowstone National Park area resulted in massive gravity faulting of Eocene volcaniclastic rocks along the Absaroka Range scarp, adjacent to the southwest Bighorn Basin (Bown, in press; T. M. Bown and J. D. Love, unpublished data). Displaced rocks were distributed east of the Absaroka Range scarp across an area of nearly 1,500 km^2. Stratigraphic, structural, and geomorphic considerations indicate that most of this faulting occurred as recently as 1.9-2.0 my ago, approximately coincident with emplacement of the Huckleberry Ridge Tuff of Yellowstone National Park (Christiansen and Blank, 1972).

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PALEOCENE STRATIGRAPHY AND FLORA OF THE CLARK'S FORK BASIN

Leo J. Hickey

Abstract.— The Fort Union Formation in the Clark's Fork Basin includes Puercan through Clarkforkian sedimentary rocks. Lacustrine, paludal, fluvial, and conglomeratic members of the Fort Union can be mapped both geographically and stratigraphically. The megaflora of the Fort Union is known from nearly 10,000 identified specimens, collected at 66 localities of known stratigraphic level and sedimentary facies, indicating that the Paleocene flora has been relatively stable through time with gradual replacement of archaic Cretaceous forms. Both composition and diversity of the megaflora vary in different sedimentary facies. Four floral zones are recognized in the Fort Union and Willwood formations, corresponding to each of the land-mammal ages of the Paleocene. Tiffanian floras are distinguished from those before and after in being relatively low in diversity and low in equitability or "evenness." Mean annual temperature in the Tiffanian was about 10° C, compared with 13.5° C in the Clarkforkian. The effect of this climatic change was to shift vegetation in the Clark's Fork Basin from deciduous broad-leafed forests in the Tiffanian to forests with a significant broad-leafed evergreen component in the Clarkforkian. Rates of sediment deposition were highest in the Tiffanian, suggesting that the climax of Laramide orogeny in the Clark's Fork Basin area occurred at this time.

INTRODUCTION

An unsurpassed sequence of megafloras spanning the Paleocene Epoch occurs in the Bighorn Basin of Montana and Wyoming. This is only part of a larger floral sequence ranging in age from the Campanian Stage of the Cretaceous to the middle Eocene. The geographic and stratigraphic location of these floras in one of the classic areas of American vertebrate paleontology provides an unequaled opportunity to correlate paleofloristic studies with the mammalian zonation scheme. Conversely, fossil plant studies can provide important climatic and ecological insights for interpreting the record of mammalian evolution in the region.

The results and interpretations presented here are still preliminary. The impulse for reviewing my work at this time was the opportunity to include it along with other paleobiological studies in progress in the basin. Paleobotanical identifications, in particular, are tentative and offered in advance of the completion of monographic work on the flora. However, the present study represents the first time, to my knowledge, that a detailed range chart of megafloras has been assembled for the Paleocene. Detailed facies mapping is not yet complete in the northern part of the Bighorn Basin (here referred to as the Clark's Fork Basin), and additional sections must be measured before adequate stratigraphic control is achieved. What I present here is thus a progress report that should be of value to those whose paleontological or stratigraphic studies of the basin are still in progress.

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This report should also help to elucidate the patterns of change occurring in Paleocene floras. Perhaps most important is the possibility that the Bighorn Basin Paleocene floral sequence can be used as a reference for biostratigraphic correlation in the Rocky Mountain region.

My objectives in this paper will be:

1) to describe the broad-scale sedimentary relationships within the Puercan through Clarkforkian rocks of the basin,

2) to describe the floral sequence found within these rocks,

3) to relate this floral sequence to the vertebrate zonation, to previously described plant sequences, and to the facies of the basin, and, finally,

4) to discuss the relationships and insights that the flora yields into the evolutionary, tectonic, and climatic history of the Bighorn Basin during the Paleocene.

HISTORY

Prior to the present study, the only serious paleobotanical collecting in Paleocene sediments of the Bighorn Basin was by Erling Dorf in the Bearcreek, Montana, area approximately 35 years ago. Otherwise collecting was mainly incidental to the resource reports produced by Woodruff (1909) and Hewett (1928). My collecting in the basin began in 1967, in cooperation with Professor Dorf, and gradually extended throughout the Clark's Fork Basin, roughly within the mapped limits (Figure 1). Throughout my work, I emphasized the recording of the lithologies and sedimentary features of the rocks in which the floras were found and made a concerted effort to recover fossil plants from the proximity of the numerous vertebrate localities in the basin. Much of the collecting and stratigraphic survey is now complete. However, the monographic study of the flora is, as yet, in its initial phases, and, as we shall see below, a serious effort must be made to fill a gap in our knowledge of floras of presumed Torrejonian Age.

STRATIGRAPHY

Cretaceous through Clarkforkian sediments of the Bighorn Basin consist of a lignitic molasse deposited in an actively subsiding tectonic basin during the later phases of the Laramide Orogeny. Carbonaceous mudstone, shale, lenticular sandstone bodies, and lignite are the predominating lithologies of this sequence. Colors are somber, with shades of dark gray, medium tan, and maroon being most common. At varying levels in the uppermost part of the lignitic sequence red beds appear and gradually become more conspicuous upward. Prior to 1940, the name Fort Union Formation was generally applied (Stow, 1938) to the lignitic sediments overlying the Lance, of Late Cretaceous age, and underlying the "Wasatch", generally thought to be of Eocene age. Jepsen (1940), citing confusion in the concept of the Fort Union Formation and the difficulty of correlation to the Bighorn Basin from its type area, renamed the lignitic Paleocene sediments the Polecat Bench Formation. Later, Van Houten (1944) gave the name Willwood Formation to the former "Wasatch" of the Bighorn Basin and drew its contact at the lowest appearance of red banding. In doing this he included the top of Jepsen's Polecat Bench unit in his new formation.

For the purposes of this review and in conformity with the generally recognized application of this time term in the Western Interior United States (Wood et al., 1941; Keroher, 1966), I will include the Puercan through Clarkforkian strata of the basin in the Paleocene Epoch. This does not indicate my judgment concerning the arguments of Rose (1979) and Gingerich (1976) that the Paleocene-Eocene boundary actually falls within the Clarkforkian Stage. I will apply the term Fort Union strata to the lignitic section, and Willwood to that part of the sequence where red banding has become a conspicuous element.

Even in a terrestrial sequence, such as the Fort Union and Willwood Formations, stratigraphic correlation is strongly dependent on tracing individual lithologies or facies laterally. In addition, rock-type exerts a strong control over the composition of megafloral remains. This is inferred to be the result of the inability of such remains to withstand long distance transport (MacGinitie, 1941) and thus probably reflects to some degree, at least, the patchiness of the actual floral communities found in the area of deposition. These factors make it particularly important for the megafloral paleobotanist to understand the stratigraphic framework of the area especially when making biostratigraphic interpretations.

Figure 1 is a lithofacies map of the exposed surface of the lignitic strata of the Clark's Fork Basin. The term "member" will generally be used for these units to distinguish them from smaller-scale lithofacies such as near channel or backswamp deposits. The stratigraphic relationships of these units are shown in the cross-section (Figure 2). The trace of this section is shown as a solid line on Figure 1. Each of the lettered points on this section is located at the intersection of a line (dashed) along which stratigraphic intervals were either measured or recon-

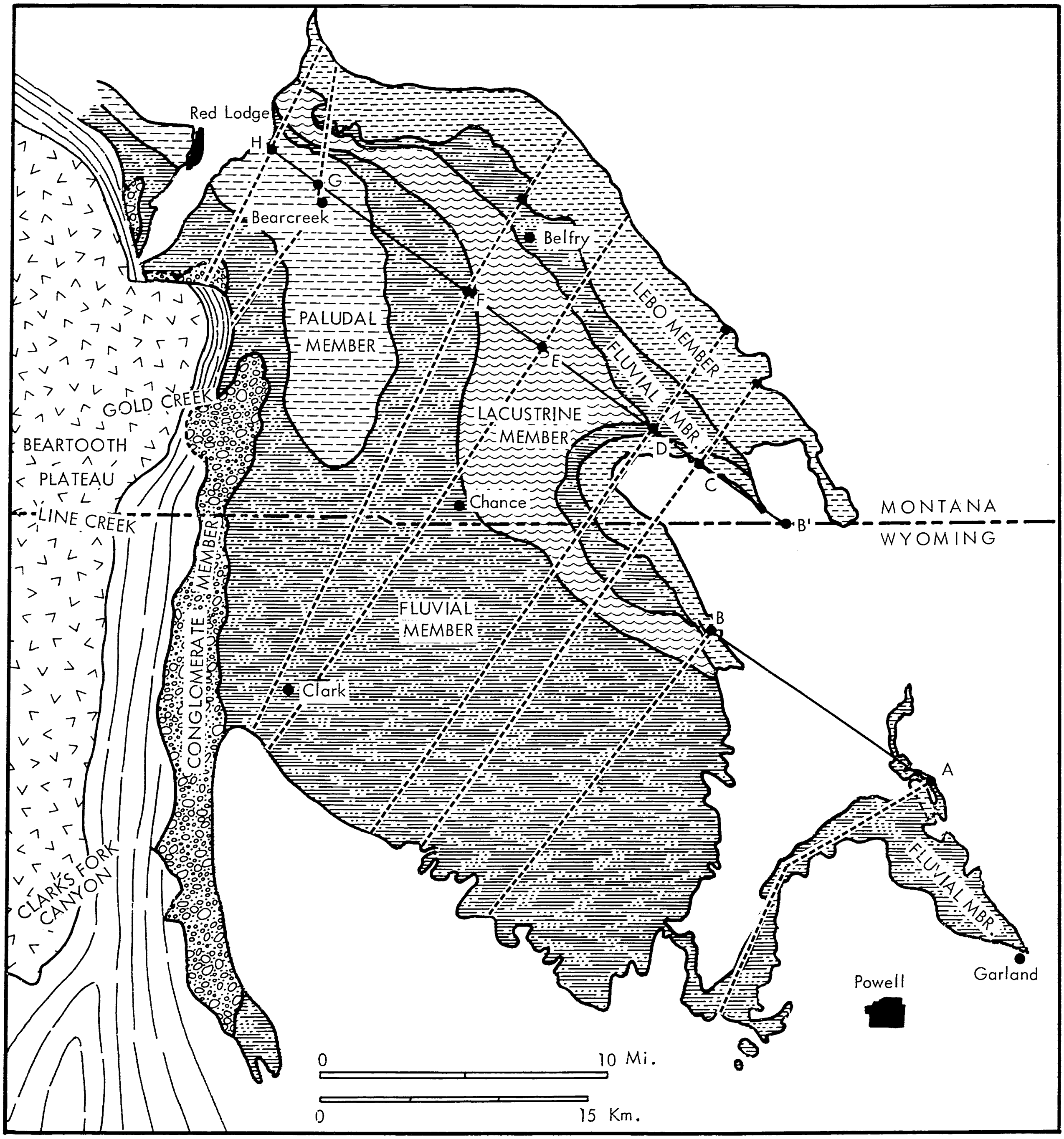

Figure 1. Outcrop map showing the members making up the Fort Union and lower Willwood Formations (Puercan through Clarkforkian Ages) of the Clark's Fork Basin. Lines AB and B'H were followed in constructing the cross section in Figure 2, and these are shown as a solid line. Dashed lines roughly perpendicular to these are lines of measured sections or of observations and trigonometric tabulations used to construct the section at each point.

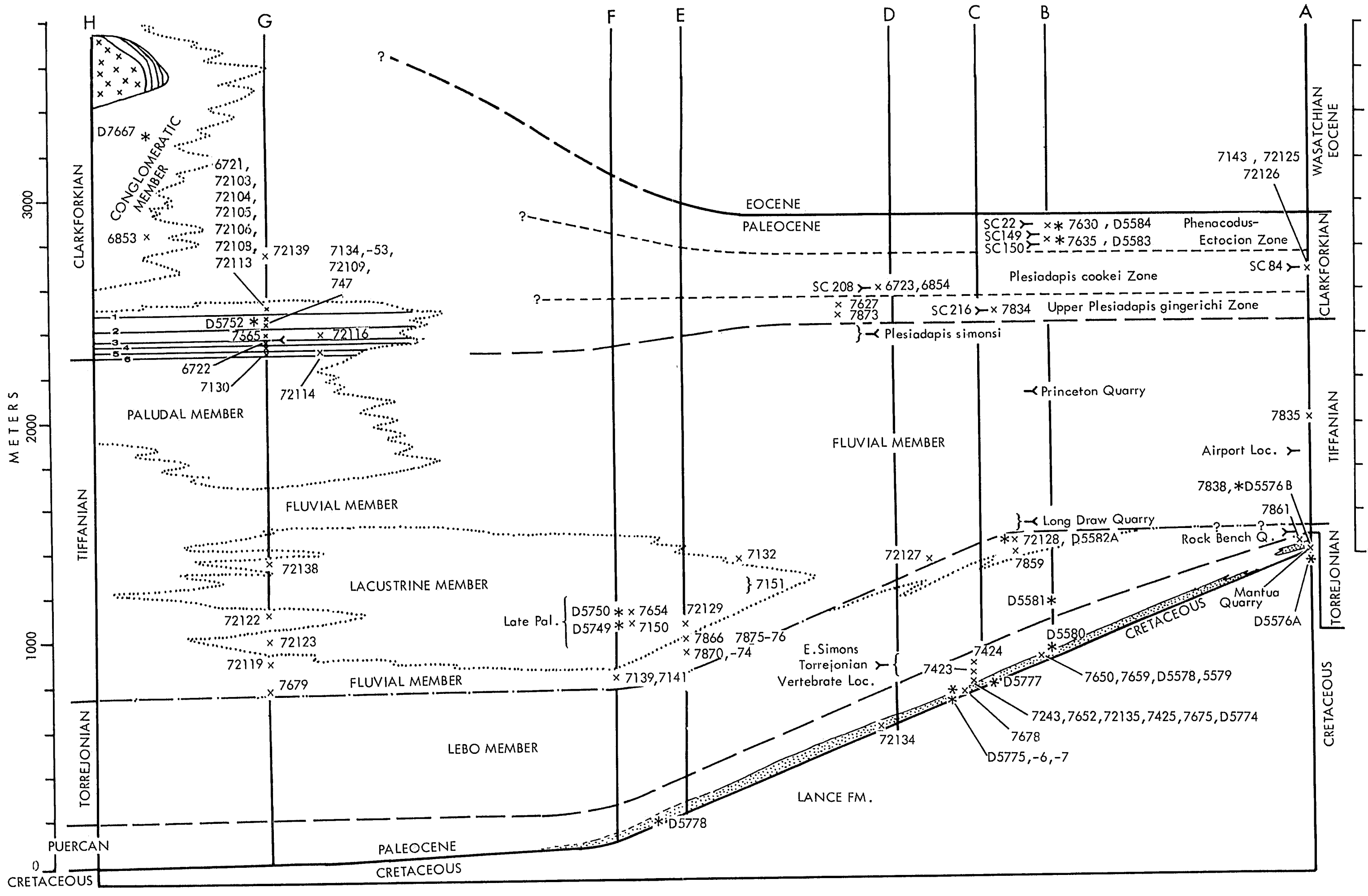

Figure 2. Cross-section of Fort Union and lower Willwood strata in the Clark's Fork Basin, showing relationships of the members, inferred correlations, and the position of megafossil plant sites (*X*), pollen sites (*), and selected mammal localities (brackets).

structed trigonometrically. A hallmark of terrestrial sediments, especially those deposited in a fluvial setting, is their marked vertical and lateral heterogeneity. In the Clark's Fork Basin this inhomogeneity is apparent on two scales; regionally (Figs. 1 & 2) and on the local scale within, and among, closely spaced outcrops. A knowledge of the trends of variation at both scales is necessary, given the influence of local derivation on megafloral remains. Indeed, the utility of biostratigraphic correlation based on megafloras becomes doubtful in the absence of such control. For this reason, I will first describe the facies distribution of the Paleocene sediments in the Clark's Fork Basin. An account of the relationship of lithology and floral composition will be deferred to the section dealing with the floral sequence.

General features of the lignitic sequence.—Throughout the Clark's Fork Basin, lignitic sediment of Puercan through Clarkforkian ages rests conformably on the massive, ledgy, yellowish- or greenish-tan sandstone of the Upper Cretaceous Lance Formation (cf. Stow, 1938). In local areas, Fort Union channel sandstone lenses may cut close to, or slightly below, the top of the Lance, as at the Mantua Quarry on the northeastern margin of Polecat Bench (Point *A*, Figures 1 and 2). The Paleocene section thickens markedly from east to west, increasing from approximately 1,500 m on the northeast side of Polecat Bench (Point *A*) to at least 3,350 m at the toe of the Beartooth Thrust Fault (Point *H*) on the basin axis. This measurement is in approximate agreement with the thickness given in Woodruff (1909) and Moore (1961). In the latter case, 760 m of "Lebo" sediment in the Dry Creek Valley must be added to the figure of 2,743 m shown on Moore's isopach map.

Figure 2 shows that the Paleocene sediments of the basin consist of a somber member at the base and a predominantly fluvial facies forming the bulk of the sequence and constituting a sort of matrix surrounding both a predominantly lacustrine member and a coaly, paludal member which lie in more axial parts of the basin. A conglomeratic member occurs in the upper part of the section along the overthrust margin of the Beartooth Mountains. In all cases the boundaries between these members are gradational and each may include beds whose sedimentary features or lithologic characters are more typical of another. However, recognition of these members is important for stratigraphic correlation and for interpreting the depositional conditions in the basin.

Lebo Member.—The basal part of the Fort Union Formation consists of a predominantly somber sequence of very dark gray to olive gray, carbonaceous shale and mudstone, with subordinate sandstone and lignite. Stow (1938) equated this unit with the type Lebo Member of the Crazy Mountains and correlative beds of southern and eastern Montana. Although I will retain Stow's formal designation in this report, the validity of his correlation remains to be demonstrated.

From the western margin of Polecat Bench to the Clark's Fork River a thin sheet of light gray, cleanly washed, cross-bedded sandstone and inter-bedded siltstone, averaging between 6 and 25 m marks the base of the Lebo Member. This bed is informally named the Hunt Creek sandstone for its occurrence along that creek. In contrast, most of the sandstone units in the lower half of the Lebo Member are highly lenticular, dirty, and rusty brown in color. Siderite and rusty brown concretions are common in the finer beds and fossil plant remains are rare except in the basal 30 m. Beds of laterally extensive sandstone of light gray to yellowish-tan color become common toward the top of the Lebo Member as it grades into a more brightly colored fluvial sequence above. From the axis of the basin to the north side of the Elk Basin Anticline (point *D*, Figures 1 and 2), the lower member thins from approximately 760 to 550 m. Eastward, the appearance of extensive yellowish sandstone lenses and a lightening of the somber color results in a yellowish-tan and somber sequence of less than 300 m on the northeastern side of Polecat Bench (point *A*).

Fluvial member.—The fluvial member covers the greatest area and makes up the thickest portion of the Paleocene sediments of the Clark's Fork Basin. The sequence consists of medium to yellowish gray mudstone with interbeds of carbonaceous shale and lignite and lenses of massive to cross-bedded sandstone. Beds of argillaceous fresh-water limestone weathering yellowish orange also occur in this member. A rough cyclicity in the sequence of lithologies, with frequent interruptions or reversals, is an important property of these sediments. Ideally, such a cycle begins with a thick, lenticular sandstone body having an erosional basal contact, and fines upward through thinly interbedded sandstone and mudstone, increasingly carbonaceous claystone, to shale, and finally to lignite. This crude cyclicity, the lenticularity of the individual lithologic units, graded sandstone units, and numerous features of the bedding are consistent with interpreting this facies as resulting from fluvial processes (Allen, 1964; Blatt, Middleton, and Murray, 1972; Harms et al. 1975). Using criteria such as lithology, bedding, and sedimentary relationships developed from Allen (1964) and others, I have divided these

FACIES ⟶	CHANNEL		CHANNEL MARGIN			FLOOD PLAIN
	CHANNEL	POINT BAR	CREVASSE SPLAY	LEVEE	SWALE	BACKSWAMP
LITHOLOGY	SANDSTONE COARSE TO FINE	SANDSTONE MEDIUM TO FINE	SANDSTONE & SILTSTONE	VERY FINE-GRAINED SANDSTONE & MUDSTONE	SILTSTONE & CLAYSTONE	SHALE, CLAYSTONE AND LIGNITE
FEATURES: BEDS	CROSS- BEDDED TABULAR &	CROSS-BEDDED TABULAR &	CROSS- BEDDED & LAMINATED	CROSS-BEDDED - RIPPLE DRIFT	PARALLEL & MASSIVE	PARALLEL & MASSIVE
	TROUGH	RIPPLE DRIFT	SCOUR & FILL	SCOUR & FILL		
		PARALLEL BELOW	PARALLEL BELOW	PARALLEL BELOW		
SIDERITE NODULES	ABSENT	ABSENT	PRESENT	PRESENT	PRESENT	PRESENT
BASAL CONTACT	SHARP- UNCOMFORMABLE	SHARP - UNCOMFORMABLE TO GRADATIONAL - CONFORMABLE	SHARP- UNCONFORMABLE TO CONFORMABLE	GRADATIONAL- CONFORMABLE	SHARP- CONFORMABLE	SHARP OR GRADATIONAL- CONFORMABLE

⟵ LOW ORGANIC MATTER ⟶ ⟵ HIGH ORGANIC MATTER ⟶

Figure 3. Criteria used to assign a facies designation to fossil plant sites (from Allen, 1964; Harms et al., 1975; Blatt, Middleton, and Murray, 1972; and Visher, 1972).

fluvial deposits into three component facies: (1) the channel facies made up of channel and point-bar deposits, (2) the channel-margin facies made up of crevasse-splay, levee, and swale deposits, and (3) the floodplain facies consisting mainly of backswamp deposits lying at varying distances from the levee. Each of the plant localities in the Fort Union-lower Willwood sequence was assigned to one of these three facies using the criteria outlined in Figure 3. This allowed direct comparison of the floral composition of each facies through the lignitic sequence, thus compensating, to some degree, for the influence of facies on individual floras (Table 1).

Red banding appears in the upper part of the fluvial member and gradually increases in thickness and lateral extent upward in the Willwood. This trend correlates with a gradual decrease in lignitic and carbonaceous beds. Lignitic sedimentation is effectively terminated, in the Clark's Fork Basin, by the sheet sandstone of Kraus (1979; and this volume), which also marks a change to predominantly arkosic sandstone bodies and the loss of the megafossil plant record except for the seeds of *Celtis willistonii* (Cockerell) Berry. In the central Bighorn Basin a relatively rich floral record continues until Bridgerian time (Wing, this volume).

Sandstone bodies in the fluvial sequence are lenticular, fining upward, often downcutting at the base, with trough cross-bedding. They are often massive or show soft sediment deformation in their medial part. A variety of structures including tabular cross-beds, parallel beds, and ripple marks occur near the top of sandstone bodies.

Lacustrine member.—Beds assigned to the lacustrine facies are restricted to one area, lying near the center of the basin. They reach a thickness of nearly 600 m and are more or less well-separated from the underlying Lebo Member and from the paludal member by a predominantly fluvial interval. I have applied the informal name of Belfry lake beds to this sequence because of the good exposures of it lying south and southeast of that town.

This member has a highly unusual aspect for the Fort Union because of its relatively thin, laterally persistant beds with sharp, parallel contacts. Marls and argillaceous limestone beds are common and conspicuous. Lenticular sand bodies with erosional contacts occur in the sequence, especially toward its boundar-

Table 1. Dominant plant species in rank order, segregated by facies for each of the Paleocene stages in the Clark's Fork Basin.

STAGE	FACIES		
	CHANNEL	NEAR CHANNEL	BACKSWAMP
CLARKFORKIAN	*Cercidiphyllum* fruits *Metasequoia* cones *Platanus reynoldsii* *Platanus nobilis* *Carya* fruits	*Persites argutus* *Cercidiphyllum genetrix* *"Viburnum" asperum* *Ampelopsis acerifolia* *"Ficus" artocarpoides* *Ternstroemites aureavallis* *Metasequoia occidentalis* *Averrhoites affinis* *Allantoidiopsis erosa* *Glyptostrobus europaeus* *Carya antiquorum*	*Metasequoia occidentalis* *Cercidiphyllum genetrix* *Glyptostrobus europaeus* *Persites argutus* *Platanus nobilis* *Ginkgo adiantoides* *Equisetum* *Acer* cf. *silberlingii* *Meliosma longifolia* *Platanus reynoldsii* *Ampelopsis acerifolia*
TIFFANIAN	*Cercidiphyllum genetrix* *Platanus reynoldsii* *Glyptostrobus europaeus* *Carya antiquorum* *Metasequoia* cones	*Cercidiphyllum genetrix* *Glyptostrobus europaeus* *Corylus insignis* *Carya antiquorum* *Meliosma longifolia* *Pterocarya glabra*	*Cercidiphyllum genetrix* *Melisoma longifolia* *Glyptostrobus europaeus* *Carya antiquorum* *Porosia verrucosa* *Platanus reynoldsii*
TORREJONIAN		*Eucommia serrata* *"Cinnamomum" sezannense*	
PUERCAN	*Cercidiphyllum genetrix* *Taxodium olrikii* *Platanus reynoldsii* *"Ficus" artocarpoides*	*Metasequoia occidentalis* *Paranymphaea crassifolia* *Glyptostrobus europaeus* *Cercidiphyllum genetrix* *Platanus reynoldsii* *Eucommia serrata* *Onoclea hesperia*	*Metasequoia occidentalis* *Debeya* sp. *Cercidiphyllum genetrix* *Ginkgo adiantoides* *Platanus reynoldsii*

ies, but the majority of sand beds are tabular, with parallel contacts, cross-lamination, and ripple-marked upper contacts. Weathering colors tend to be yellowish gray.

The cyclicity only crudely apparent in the fluvial facies is clearly marked in the Belfry lake beds. From top to bottom an idealized cycle consists of:

1) argillaceous limestone,
2) marl,
3) lignite, upper contact frequently oxidized,
4) mudstone or shale becoming finer grained and more carbonaceous upward,
5) thin parallel interbeds of very fine grained sandstone and siltstone,
6) parallel-bedded sandstone, often ripple-marked,
7) medium to fine grained sandstone, basal contact erosional, base with trough or tabular cross-beds, middle with ball and pillow structure, grading upward to unit 6,
8) underlying cycle terminated by lithology 1, 2, or 3.

Differential erosion of these cycles with their thin, parallel beds produces a distinctive stepped topography with crenulated contour lines. Contacts with the fluvial member are completely gradational, making it impossible to map as a sharp line. As one moves from the fluvial into the lacustrine member, marl and thin, ripple-marked beds of sandstone appear, and these, together with beds of argillaceous limestone, gradually become more abundant.

The bulk of the lacustrine member appears to represent deposition in a series of rapidly shifting delta lobes separated by restricted bodies of relatively deeper water. Shift of a distributory channel as lobes were built above water level is inferred to have caused the pattern of cyclic deposition. Belfry member deposition probably took place in a shallow lake where patches of open water were broken up by marshes, swamp forest, and distributory channels.

Paludal member.—A series of somber, carbonaceous beds containing economic coal seams extends along the axis of the Clark's Fork Basin from the town of Red Lodge to Grove Creek, about 9 miles (14.5 km) to the southeast. The member takes its informal name from its exposures around the town of Bearcreek, Montana. In section, these beds occur above the lacustrine member but appear to be separated from it by a fluvial interval.

Each of the lithologies found in the paludal member also occurs in the fluvial facies. In the aggregate, however, the paludal member is darker in color because of its higher carbon content, finer grained with generally thinner and more localized sandstone beds, and contains the only beds of workable coal in the Tertiary of the Clark's Fork Basin. Because of a generally low erosional resistance, the member weathers to a rounded profile of somber color, with poor exposures, and lacks the stair-step or layered look of the lacustrine member.

The high carbon content of the member, its position on the axis of the basin, together with the presence of thin, extensive lignites and the predominance of fine-grained flood basin and backswamp deposits over channel deposits, indicate that deposition of the Bearcreek member occurred in an extensive swamp with through-flowing streams.

Conglomeratic member.—Thick conglomeratic deposits adjacent to the Beartooth Front have generally been assigned to the Willwood Formation (Foose, Wise, and Garbarini, 1961; Neasham and Vondra, 1972). However, these units interfinger with typical Fort Union sediments and are of late Paleocene age, at least from the Clark's Fork Canyon north to Red Lodge, Montana (this study; Fleuckinger, 1972; Jobling, 1974). Both Fleuckinger and Jobling noted that the earlier conglomeratic deposits consist of Paleozoic and Mesozoic clasts while crystalline clasts appear later and increase in abundance upward in the late-stage conglomerates lying north of the Montana line. The late-stage conglomerate at Gold Creek (Figure 1) gives late Paleocene dates (Fleuckinger, 1972) and contains clasts of Laramide age porphry that forms the youngest series of dikes in the Beartooth Plateau and is intruded on the sole of the Beartooth Thrust Fault (Foose, Wise, and Garbarini, 1961). The Gold Creek conglomerate also appears to breach the upturned Paleozoic section of the range-front and dips gently away from it. Underlying Fort Union sediments all dip toward the front at angles of from 3 to 15 degrees.

The conglomerate member records the major episode of structural deformation of the Beartooth Mountains. It was deposited in alluvial fans under high energy conditions on the upper part of the lignitic floodplain. The localization of the conglomeratic member near the Beartooth Front, and floral dates of late Paleocene obtained from it (this study; Fleuckinger, 1972; Jobling, 1974), are excellent evidence that the range was emplaced and stripped to its crystalline core by that time. Jobling regarded the higher conglomerate north of the Montana line to be post-orogenic and reports a late Paleocene flora from it.

In the central and southern parts of the Clark's Fork Basin, the onset of red-banded deposition probably relates to the climax of the Laramide Orogeny. However, it is not until the sheet sandstone of Kraus (1979; this volume), which marks the base of the Wasatchian Stage in the Sand Coulee area (Gingerich, Rose, and Krause, this volume), that a fundamental shift away from lignitic sedimentation occurs.

MEGAFLORA

The Fort Union and lower Willwood Formations contain a large and important flora whose aspect is that of a typical mid-Northern Latitude Paleocene assemblage. Thus far, collections from over 65 localities have yielded 74 identified species with an additional 20 to 25 as yet unidentified. As mentioned above, work on these identifications is only in its initial stages and much critical comparison must be done to validate their identities. For this summary, works by Brown (1962) and Hickey (1977) were the major sources of nomenclature and identifications. Figures on occurrence and dominance of forms used here were generated from a census of nearly 10,000 specimens from 66 localities. This is not the first study of a flora spanning the Paleocene (Brown, 1964) but it is the first to produce a detailed range chart for the epoch, to pay close attention to lithologic relationships and percentage occurrences of fossil plants, and to be restricted to a relatively local area. Hopefully, the results can be used to develop a standard megafloral sequence for the entire Northern Rocky Mountain area.

Overall dominants of the flora are the dicot *Cercidiphyllum genetrix* (Newberry) Hickey, together with two conifers, *Metasequoia occidentalis*

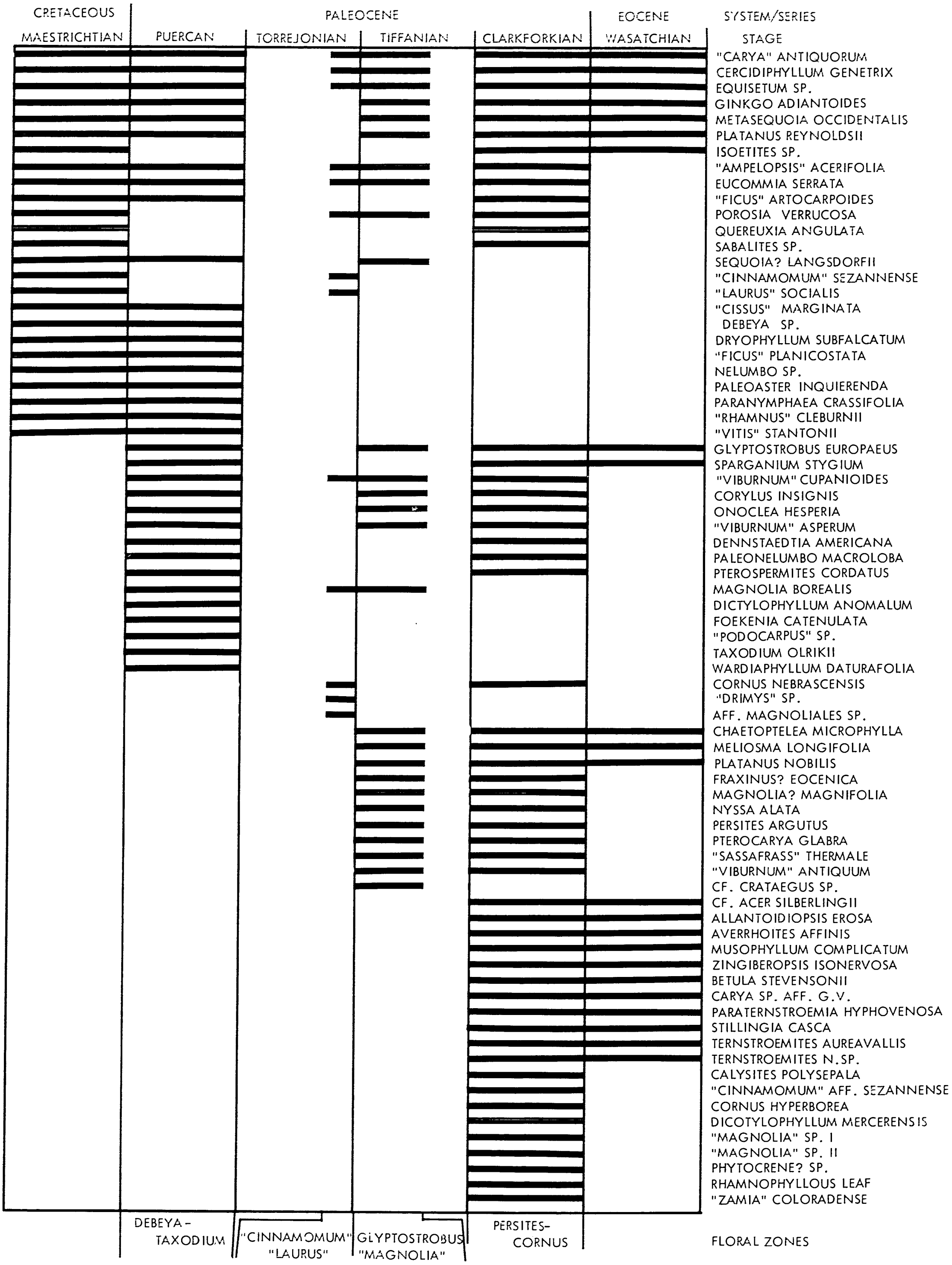

Figure 4. Ranges of the Clark's Fork Basin megaflora through the Paleocene. These are plotted by floral zones and correlated with the provincial stages of the Paleocene.

(Newberry) Chaney and *Glyptostrobus europaeus* (Brongniart) Heer. *Persites argutus* Hickey dominates the sum total of specimens for the entire flora with 17 percent but is found only in the late Paleocene and dominates only the highest floral zone. Important associates are *Ginkgo adiantoides* (Unger) Heer, *Debeya* sp., and *Eucommia serrata* (Newberry) Brown.

Figure 4 is a range chart of the fossil plant taxa found in the Paleocene section. These ranges have been divided into six categories. The lowest and the highest of these represent species with late Cretaceous or early Eocene ranges, respectively. For the Eocene, the principal source of information was Hickey's (1977) work on the Golden Valley Formation in western North Dakota where some forms not found in the Bighorn Basin early Eocene occur (Wing, this volume). The middle four categories constitute the assemblage zones into which the Paleocene flora was divided for this study. This approach was made necessary by regional changes in the thickness of the lignitic strata which made it impossible to express ranges in terms of measured intervals above the top of the Cretaceous. Major breaks in stratigraphic continuity are shown. The approximate correlation of each zone is shown in the figure and discussed below.

Several groupings of species ranges are apparent in this chart. A group of 25 species, or one-third of the total, persist from the Cretaceous. Seven of these range into the Eocene, six range through the Paleocene, and nine are restricted to the lowest floral zone. A group of 11 species appear for the first time in the third floral zone, equated with the Tiffanian Stage. The final floral zone of the Paleocene is, however, the time of greatest introduction of new forms, with approximately 25 percent of the total flora first appearing there. Aside from the second floral zone which appears depauperate because it includes only two localities, a diversity minimum is reached in the third zone. The Paleocene appears to be a relatively stable period with a gradual replacement of the archaic Cretaceous forms, most of which were only distantly related to modern genera. This relatively slow rate of change is in contrast to the Eocene Epoch during which floras of markedly different aspect succeeded one another within short intervals.

Although the chart demonstrates the feasibility of dividing the Paleocene into a number of floral zones, these should be based on a full representation of floras from each of the three major floodplain facies. This was the case for all but the second Paleocene zone.

Looked at as a whole, the Paleocene Series of the Clark's Fork Basin can be characterized by only one species found throughout and not ranging higher or lower, "*Viburnum*" *cupanioides* (Newberry) Brown. An augmented list of species for recognition would include "*Viburnum*" *cupanioides* and one or more of the following common and wide-ranging forms:

Corylus insignis Heer
Onoclea hesperia Brown
"*Viburnum*" *asperum* Newberry
Dennstaedtea americana Knowlton
Paleonelumbo macroloba Knowlton
Pterospermites cordatus Ward
Magnolia borealis Brown
"*Ampelopsis*" *acerifolia* (Newberry) Brown
Eucommia serrata (Newberry) Brown

Debeya-Taxodium *Zone*.—The lowest floral zone is named the *Debeya-Taxodium* Zone. It can be recognized by the presence of any one of *Fockenia catenulata* (Bell) Brown, "*Podocarpus*" sp., *Wardiaphyllum daturaefolium* (Ward) Hickey, or *Taxodium olrikii* (Heer) Brown, together with a group of Cretaceous survivors including *Debeya* sp., *Ficus planicostata* Lesquereux, *Paleoaster inquierenda* Knowlton, *Vitis stantonii* (Knowlton) Brown, and *Rhamnus cleburnii* Lesquereux. Most of these forms are relatively rare, but this zone can also be recognized on the basis of overlap of any one of the characteristic Cretaceous forms *Debeya* sp., *Cissus marginata* (Lesquereux) Brown, *Dryophyllum subfalcatum* Lesquereux, *Ficus planicostata, Paleoaster inquierenda, Vitis stantonii, Rhamnus cleburnii* together with one or more common Paleocene forms such as *Glyptostrobus,* "*Viburnum*" *cupanioides, Corylus insignis, Onoclea hesperia,* or "*Viburnum*" *asperium.*

"Cinnamomum"-"Laurus" *Zone*.—The second floral zone occurs at only two localities, both in an apparent channel margin setting. It is characterized by the unique occurrence of three taxa, "*Cinnamomum*" *sezannense* Watelet, "*Laurus*" *socialis* Lesquereux, and leaves resembling those of the vesselless dicotyledon *Drimys.*

"Magnolia"-Glyptostrobus *Zone*.—The third floral zone is difficult to characterize because its principal features are a low diversity and the presence of many wide-ranging forms. Only a leaf-type resembling those of *Crataegus* is unique to the zone. Otherwise it is distinguished by the overlap of lower Paleocene forms like *Sequoia ? langsdorfii* (Brongniart) Heer and "*Magnolia*" *borealis* with a number of upper Paleocene taxa including *Glyptostrobus, Chaetoptelea* *microphylla* (Newberry) Hickey, *Nyssa alata* (Ward) Brown, and others. The absence of *Cornus* or palms is a particularly striking feature of this zone, though not helpful in defining it when only a few specimens are found.

Persites-Cornus *Zone*.—The highest of the floral zones is characterized by the presence of the overwhelmingly dominant form *Persites argutus*, together with any one of a number of forms including *Acer silberlingii* Brown, *Allantoidiopsis erosa* (Lesquereux) Knowlton and Maxon, *Dicotylophyllum mercerensis* Hickey, and *Cornus hyperborea* Heer.

Although numerous forms found in the upper floral zone range into the Eocene elsewhere, including the central Bighorn Basin (Wing, this volume), only *Celtis* seeds have been found in Wasatchian sediments in the Clark's Fork Basin.

CORRELATION

Correlation of the Early Tertiary sediments of the Bighorn Basin with the standard provincial time-stratigraphic system for western North America is essential if the biologic and structural events taking place in the region are to be evaluated in more than a local framework. Biostratigraphic zones and chronozones that have been established in the Bighorn Basin through the work of Gingerich (1976), Rose (1979), Bown (1979), and Schankler (this volume) have now reached a high level of refinement. However, if mammalian events are to be correlated with data from other organisms, and with climatic and edaphic data from plants, a tentative time-stratigraphic correlation based on stage names for the Paleocene and early Eocene must be adopted. Several different interpretations exist as to the meaning of so-called land mammal "ages" used by Wood et al. (1941) to subdivide the Western Interior Paleogene section. One interpretation, well expressed by Tedford (1969), is that they are actually the equivalent of what would be called assemblage zones or chronozones in standard stratigraphic usage but that the term "land mammal ages" should be retained for them. On the other hand, the Wood Commission did place these terms in the context of standard provincial stages and they have generally been recognized as such since that time (Keroher, 1966; Eysinga, 1975). Apparently, adequate basis exists for regarding each of the current Paleocene stages (except the Dragonian) as being based on a body of rock within a defined geographic area and as characterized by a particular content of fossil mammals. The fact that these definitions are confused, somewhat vague, and probably as yet not inclusive of all Paleocene time is no different from the original status of any time-stratigraphic term now in current use, even at the rank of system. A passage from the Code of Stratigraphic Nomenclature (American Commission of Stratigraphic Nomenclature, 1970) is especially relevant to this problem,

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> "The bases for original definition of the generally adopted geologic systems are remarkably varied and haphazard. The definition of any time-stratigraphic unit should properly depend on a clear original designation of a type sequence of rocks. This has not been true of the original definitions of any of the recognized systems. Almost all systems began as rather local units and many of them have been extended more or less successfully throughout the world on a time-stratigraphic basis, mainly through their fossil content. They have been revised and supplemented by work in the type areas and elsewhere. As a result the rocks included in the several systems as now recognized are only partly, or even indirectly, related to the sections originally designated."
>
> [Art. 29, Remarks (a)]

A stage is commonly based on a succession of biostratigraphic zones. An important characteristic of a stage is that its constituent zones may differ in different areas. Such a classification also permits zones based on many different organisms to be used in recognizing a stage.

Location of Stage Boundaries

In the cross section of the Clark's Fork Basin (Figure 2) tentative stage boundaries have been drawn. These will need to be revised as more data accumulates, but, for now, they represent an important step in building a time-stratigraphic correlation of Puercan through Clarkforkian rocks in the basin.

Since it is the location of boundaries that is of greatest importance in applying time-stratigraphic nomenclature I will describe the criteria used locating them in the section that follows.

Maestrichtian/Puercan boundary.—This boundary is placed at the base of the so-called Mantua lignite, at the base of the Lebo Member on the northeast side of Polecat Bench (point *A*). Lithologically this is the first continuous lignite above the ledgy sandstone beds of the Lance Formation. This level lies above the highest dinosaur remains and is bracketed by a series of pollen localities giving Cretaceous dates below the lignite and early Paleocene dates from, and above, the lignite (Tschudy, in litt. 1977, 1978). This lithologic boundary can be traced westward down the valley of Hunt Creek to the Clark's Fork River and from there up the valley of Dry Creek to the Red Lodge Bench (Figures 1 and 2). This boundary coincides with the base of the *Debeya-Taxodium Zone.*

Puercan/Torrejonian boundary.—This boundary is inferred to fall in the lower third of the Lebo Member but is very difficult to locate. It is provisionally placed between the highest occurrence of the *Debeya-Taxodium* flora (on line *C*, Fig. 2), 100 m above the Cretaceous, and below the estimated 275 m level on Cub Creek where Elwyn Simons found a Torrejonian vertebrate locality (Gingerich, this volume). On line *A*, this level must fall between late Torrejonian fauna at Rock Bench (60 m) and the *Debeya-Taxodium* Zone flora at Grimy Gulch (LJH loc. 7861) (49 m) but this interval seems to be anomalously thin and must be rechecked. The small "*Cinnamomum*"-"*Laurus*" Zone flora found at Serendipity Summit (LJH loc. 72128) and one other locality may fall within the top of the Torrejonian Stage but this is not certain.

Torrejonian/Tiffanian boundary.—This horizon is placed at the top of the Lebo Member and below the lowest occurrences of the "*Magnolia*"-*Glyptostrobus* flora in the western and central parts of the basin. East of line *D* the boundary is difficult to place because of the insertion of sandstone lenses into the top of the Lebo Member and a general lightening of its somber colors. The boundary falls below LJH locality 72127, and is inferred to pass between the level of Serendipity Summit (LJH loc. 72128) and Long Draw Quarry, which yields Tiffanian vertebrates. On the northeast margin of Polecat Bench, the level must pass between the Airport locality and Rock Bench Quarry and I have simply interpolated from the section given in Gingerich (1976) to place the boundary here. The flora occurring in the upper Tiffanian Stage is unknown.

Tiffanian/Clarkforkian boundary.— Vertebrate control of this boundary is excellent through the central and eastern portions of the Clark's Fork Basin where closely associated fossil mammal sites permit the assignment of plant localities belonging to the *Persites-Cornus* flora to precise mammal chronozones. In the west, an early Clarkforkian mammal assemblage occurs in the roof shales of the Red Lodge number 3 coal seam. Here the base of the Clarkforkian is placed at the base of the Red Lodge number 6 coal because fossil plants of the *Persites-Cornus* zone occur to this point.

Clarkforkian/Wasatchian boundary.—This boundary is placed at the base of Kraus's (1979) sheet sandstone in the Sand Coulee area for, although this unit lacks fossil content, it lies at a convenient change in the depositional regime of the central Clark's Fork Basin. Wasatchian mammals are found immediately above this sandstone (Gingerich, Rose, and Krause, this volume) but the only plant fossils to be found are the seeds of *Celtis*. Westward, toward the Beartooth Mountains, this boundary appears to lie above the highest remaining lignitic strata.

FACIES EFFECTS

Megafloral composition at sites in the lignitic strata is strongly influenced by facies (Table 1 and Figure 5). These effects are seen on both a local and a subregional scale. Floras from channel deposits tend to be relatively homogeneous, and to be made up of relatively few, durable plant remains such as leathery leaves and fruits or nuts. These features point to the overriding influence of stream transport. In contrast, assemblages from channel margin sites tend to be the most diverse, highly variable from site to site, and to contain a relatively high percentage of delicate plant remains, like flowers. From these characteristics, I infer that in channel margin deposits taphonomic factors, such as transport, are less important than the composition of the original vegetational community in determining the make-up of a fossil assemblage at a site.

Backswamp deposits tend to show lower diversity than channel margin deposits, to be somewhat more homogeneous from site to site, and, unlike those of the other two facies, to be dominated by conifers. This low energy setting is less affected by transport than any other of the major environments. Backswamp megafloral sites probably indicate the existence of a relatively uniform, conifer-dominated community with generally lower diversity than those growing on channel margin sites. Interestingly, this

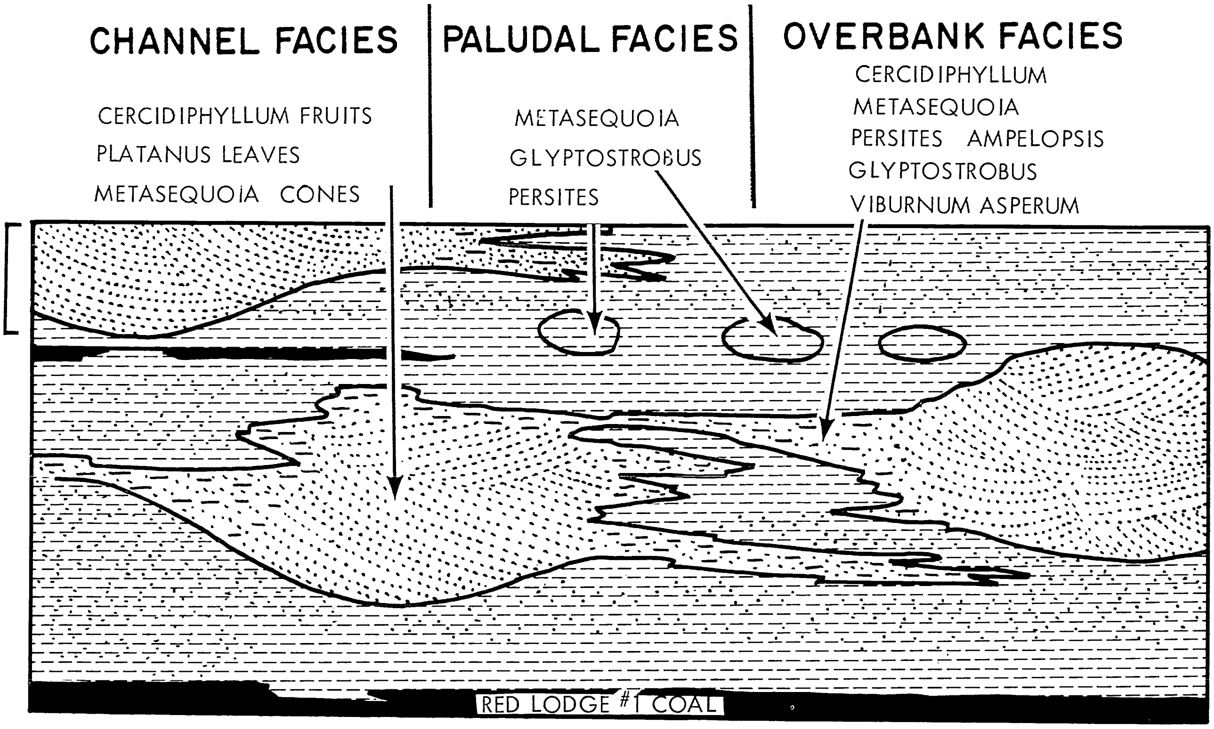

Figure 5. Relationship of facies to megafloral composition at the local scale. The listed forms make up more than 10 percent of the assemblage collected at their respective sites (from the high wall of the Smith Mine open cut west of Bearcreek, Montana).

same pattern is observed on modern floodplains, where the highest diversity is recorded on the better drained, heterogeneous soils of the levee, and lower diversity in the heavier, poorly-drained soils of the low-lying distal reaches of the floodplain (Frye and Quinn, 1979, and references therein). The conclusion marked here, then, is that although transport has some influence on the plant assemblages of the lignitic strata of the Clark's Fork Basin, the observed pattern of variation reflects the heterogeneous mix of forest communities growing on point bars, levees, splays, and in the backswamps of the depositional basin. Figure 5 shows the variation in the dominant megafossils collected in channel, near channel, and swamp sediment above the Red Lodge No. 1 coal at the Smith Mine near Bearcreek, Montana. Table 1 lists the dominant components for the channel, channel margin, and backswamp facies for each of the floral zones of the Fort Union and lower Willwood Formations.

On a regional scale, the floral composition of the members of the lignitic sequence showing the greatest amount of transport, that is, the conglomerate and lacustrine members, contain floras similar in their composition, low diversity, and durability to those found in channel deposits. The paludal member has the highest diversity, probably due to its heterogeneous mixture of channel and channel margin sites as well as extensive backswamps. The diversity of the fluvial member is nearly as high as that of the paludal.

FLORAL TRENDS

Having accounted for the effects of facies on the floras of the Clark's Fork Basin, we can now attempt to account for other trends seen in them. Correlations of floral zones with stages were described above and are as illustrated in Figure 4; no use will be made of the small and poorly correlated *"Cinnamomum"-"Laurus"* flora.

Diversity changes.—Table 2 compares the diversity of the floral units in the Clark's Fork Basin. No sophisticated measure of diversity was attempted

Table 2. Comparison of several measures of floral diversity for each of the floral zones in the Clark's Fork Basin.

FLORAL ZONE	TOTAL SPECIES (Σs)	TOTAL SPECIMENS (Σn)	TOTAL LOCALITIES (Σl)	AVERAGE s / LOCALITY	MAXIMUM s (s_{max}) AT A SINGLE LOCALITY	n AT LOCALITIES WHERE s_{max}
PERSITES-CORNUS	70	5814	31	9.5	25	1562
"MAGNOLIA"-GLYPTOSTROBUS	34	1286	20	9.2	11	79 to 257
"CINNAMOMUM"-"LAURUS"	18	654	2	10	18	652
DEBEYA-TAXODIUM	47	1775	13	12	24	284

for this analysis because the raw species number is a partial function of the number of specimens and localities counted. These figures are also included in the table. The Puercan Flora shows a moderate level of diversity with 47 species from 13 localities. The lowest level of diversity is reached in the Tiffanian with 34 species and rises dramatically into the Clarkforkian. Equitability or "evenness" (Whittaker, 1975), which is a measure of the partitioning of resources in an area, is plotted in Figure 6. This decreases from a high in the Puercan, to a low in the Tiffanian and partially recovers in the Clarkforkian. The low diversity of the Tiffanian Stage appears to be real and not simply a function of the number of species or localities collected. No locality in this stage has yet yielded more than 11 species even though the number of specimens from localities with this maximum species number range from 79 to 257. In contrast, the Puercan reaches totals of 16 to 24 species based on 151 and 284 speciments, respectively. Here, however, a backswamp locality (LJH loc. 7659) numbered only 11 species based on 755 specimens. The Clarkforkian flora reaches a peak number of 25 species at a locality with 1526 specimens.

Leaf margin percentage.—Figure 7 gives the changes in leaf margin percentage for the floras of the Clark's Fork Basin, excluding the *"Cinnamomum"-"Laurus"* flora. Since the time of Bailey and Sinnott (1915) paleobotanists have used this percentage as a rough measure of the temperature under which a flora grew. In brief, tropical floras characteristically have a high percentage of entire-margined leaves among woody dicotyledons. As increasingly temperate floras are considered, the percentage of entire-margined leaves decreases proportionately. Wolfe (1979) has recently refined and carefully documented this hypothesis for modern floras and produced a model that specifies both mean annual temperature and mean annual temperature range from leaf margin percentage. Using this and the Bailey-Axelrod climatic nomogram as modified by Hickey (1977), Puercan and Tiffanian mean annual temperatures appear to have been 10°C with an annual range of approximately 25°C. I infer that the Tiffanian nadir in diversity was caused by a climatic deterioration that was not expressed in the leaf margin percentage and that the climate of that stage was actually cooler than that of the Puercan. However, all measures (diversity, equitability, and percentage of entire-margined leaves) indicate a significant climatic warming into the Clarkforkian.

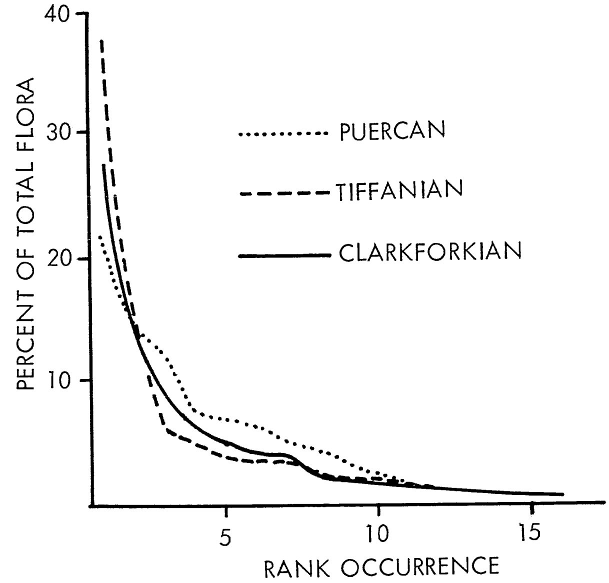

Figure 6. Comparison of equitability (evenness) in the floras of the Puercan, Tiffanian, and Clarkforkian Stages in the Clark's Fork Basin. Note that the horizontal axis is not logrithmic.

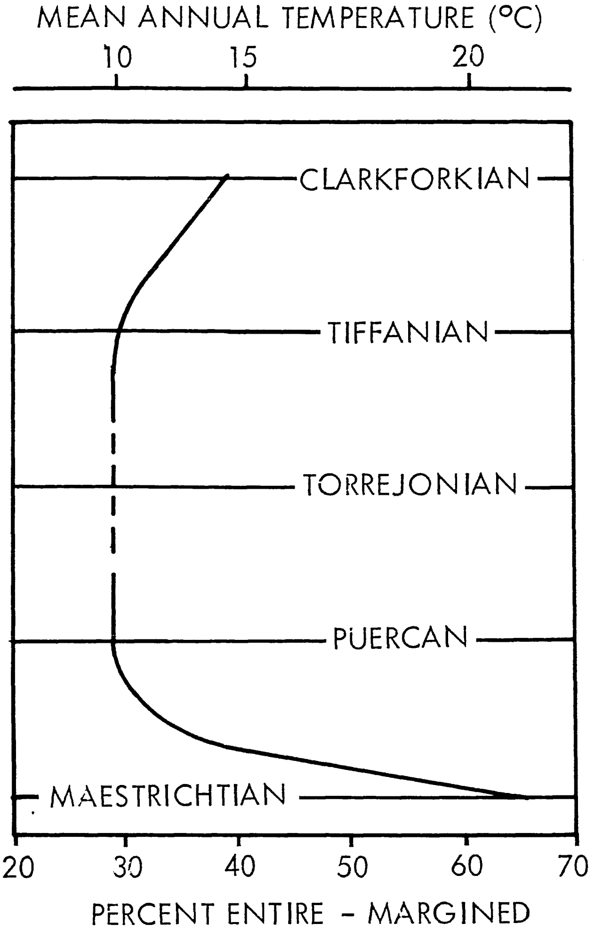

Figure 7. Percentage of entire-margined leaves and inferred mean annual temperatures (after Wolfe, 1979) for the Puercan, Tiffanian, and Clarkforkian floras of the Clark's Fork Basin. For the sake of comparison, leaf margin percentages for the combined Lance, Fox Hills, and Medicine Bow floras of Maestrichtian Age are given from my own tabulations.

SUMMARY AND CONCLUSIONS

Correlations based on fossil content and lithology allowed the construction of Figure 8 which shows the variation in depositional rate from east to west across the Clark's Fork Basin during the Paleocene. Presumably, this is correlated with the intensity of orogenic activity acting on the basin and its surrounding mountains. Even granting the tentative state of the correlations on which it is based, Figure 8 shows that the highest rates occurred on line *G*, lying on the axis of the basin, and decreased toward the east. The sections show a gradual increase in rates of deposition (and presumably intensity of deformation) from very low levels in the Puercan to a climax in Tiffanian time, with a somewhat decreased rate in Clarkforkian time. Very low rates for the Puercan and Torrejonian Stages at Section A on the east side of Polecat Bench are anomalous and may result from deposition on a regional high, diastems in the section, or errors in measurement due to structural complications. In any case, the changes in depositional rates and the composition of the Paleocene section indicate that the climax of the Laramide Orogeny in the Clark's Fork Basin and adjacent Beartooth Range occurred in the Tiffanian Stage and that the range was stripped to its crystalline core and was being thrust by the Clarkforkian.

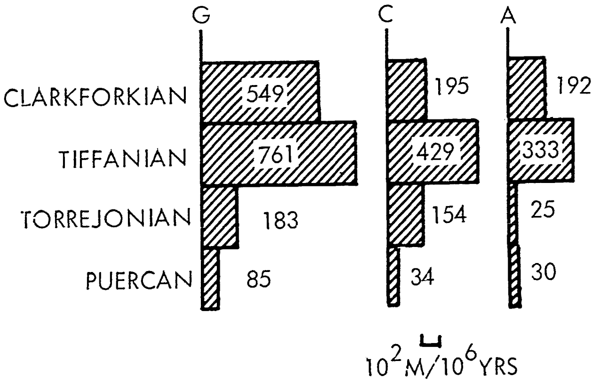

Figure 8. Comparison of rates of deposition at selected points in the Clark's Fork Basin during the Paleocene.

Floras, although generally less diagnostic of time than vertebrate assemblages, are shown to be valuable in extending correlations to areas where vertebrate fossils do not occur. Nevertheless, due to the sensitivity of megafloras to lithologic changes, care must be used in assembling a floral sample from the full spectrum of facies within each biostratigraphic zone. This apparent disadvantage of megafloras turns out to be a useful tool in reconstructing conditions in the local depositional environment or even on a regional level within the basin. On the local level, it was possible to divide the plant assemblages into those which accumulated in channel, near channel, and backswamp environments. Certain broad facies patterns were also evident across the basin, including a gradient from conglomeratic fans to floodplains, to a large swamp, and to a lacustrine area lying roughly on the axis of the basin. Although the data contained in the cross-section in Figure 2 are not sensitive enough to resolve it, the westward displacement of the paludal member may record that a shift occurred in the position of the basin axis from Tiffanian to Clarkforkian time.

A climatic deterioration from the Puercan to the Tiffanian is indicated by a decrease in diversity and floral equitability. A sharp reversal of this trend is suggested by a substantial increase in diversity, in equitability, and in the percentage of entire-margined leaves from the Tiffanian to the Clarkforkian Stages. Using Wolfe's (1979) model, it appears that mean annual temperature increased from 10° C to approximately 13.5° C and the range of mean annual temperature decreased from 25° to 20° C. This would have shifted the vegetation type from a deciduous broad-leafed forest to one lying on the lower (cool) edge of an evergreen broad-leafed forest and raised the mean temperature of the coldest month above 1° C. Corroboration for this inferred temperature change is a shift from a flora with overwhelmingly deciduous affinities in the Tiffanian to one in which evergreen forms comprise 36% of the total. Floristically, this is also corroborated by the appearance of palms, cyads, and forms of theaceous affinity, all of which are intolerant of protracted or hard frosts. Apparently, this trend of climatic warming continued into the Eocene both in the Bighorn Basin (Wing, this volume) and in the northern hemisphere in general (Wolfe and Hopkins, 1967).

The concept of floral zones proposed here appears to be useful for correlation within the northern Bighorn Basin and may well serve as a useful standard for the northern Rocky Mountain region. However, differences in the timing of the appearance of forms do occur, not only in areas outside the basin but also within it, and these must be taken into account in using plants for correlation. A particularly good example is the markedly different distribution of elements of the Clarkforkian flora within the Clark's Fork Basin. Assemblages from the paludal facies on the basin axis contain palms and a number of theaceous forms, including *Ternstroemites aureavallis* Hickey, and a new species of *Ternstroemites* as important associates, yet these do not occur in contemporaneous floras lying in the eastern part of the basin. Here, on the other hand, *Acer silberlingii* is an important associate not found to the west. From the standpoint of regional correlation, *Ternstroemites aureavallis* and *Stillingia casca* Hickey, which both occur in Clarkforkian strata of the Bearcreek area, are index fossils of the Early Eocene in the Williston Basin of North Dakota (Hickey, 1977) and do not occur prior to that time there. Although palms first appear in Clarkforkian time in the Clark's Fork Basin, they are found in Colorado and New Mexico during earlier parts of the Paleocene (Brown, 1962). Thus, floral zones and so-called index plant fossils must be used with care in time correlation. However, as better range charts for megafossil plants are developed in adjacent areas and as these are integrated with zonation schemes from other organisms, the potential for separating migrational patterns from evolutionary trends will be greatly increased. I feel that the level of detailed stratigraphic knowledge of organic change within the Bighorn Basin is rapidly approaching the stage where this will be possible.

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EARLY CENOZOIC MAMMALIAN FAUNAS OF THE CLARK'S FORK BASIN-POLECAT BENCH AREA, NORTHWESTERN WYOMING

Philip D. Gingerich, Kenneth D. Rose,[1] and David W. Krause

Abstract.— A richly fossiliferous stratigraphic section including late Cretaceous, Paleocene, and early Eocene faunas is exposed along Polecat Bench and the southern margin of the Clark's Fork Basin. Lancian, early Puercan, and late Torrejonian faunas are known from three concentrations in 200 m of section on the east side of Polecat Bench: Dumbbell Hill, Mantua Quarry, and Rock Bench Quarry, respectively. Tiffanian faunas occur at 55 localities in about 800 m of section on the east, south, and west sides of Polecat Bench. Large faunal samples are known from Cedar Point Quarry (mid-Tiffanian) in the Foster Gulch area and Princeton Quarry (late Tiffanian) in the Clark's Fork Basin. Clarkforkian faunas occur at 135 localities in about 470 m of section on the south side of Polecat Bench and in the Clark's Fork Basin. Early and middle Wasatchian faunas occur at 105 localities in about 600 m of section in the southwestern part of the Clark's Fork Basin. The Tiffanian-Clarkforkian boundary is marked by the immigration of Rodentia, Tillodontia, *Coryphodon,* and *Haplomylus,* and the Clarkforkian-Wasatchian boundary is defined by the immigration of Artiodactyla, Perissodactyla, adapid and omomyid primates, and hyaenodontid creodonts. Faunal diversity was high in the Torrejonian, relatively low in the Tiffanian and Clarkforkian, and high again in the Wasatchian.

INTRODUCTION

One of the most complete stratigraphic sections spanning the Paleocene-Eocene boundary in continental sediments is in the Clark's Fork Basin-Polecat Bench area of the northern Bighorn Basin. Mammalian faunas from the Clark's Fork Basin were first described by W. J. Sinclair and W. Granger (Sinclair and Granger, 1912; Granger, 1914). They recognized a "Gray Bull" fauna and two new faunas, a "Clark Fork" fauna and a "Sand Coulee" fauna, each older than the typical Bighorn Basin "Wasatch" exposed along the Greybull River. In 1929, Sinclair and G. L. Jepsen discovered three quarries near Polecat Bench in beds stratigraphically below the Clark Fork and Sand Coulee beds. These were, from oldest to youngest, Mantua Quarry, Rock Bench Quarry, and Princeton Quarry. Later, Jepsen discovered latest Cretaceous mammals 120 m below the level of Mantua Quarry. As a result of Granger, Sinclair, and Jepsen's work, all of the latest Cretaceous to early Eocene North American land-mammal ages are represented in one stratigraphic section exposed along the south side of Polecat Bench and the southern margin of the Clark's Fork Basin. These are, from oldest to youngest, the Lancian, Puercan, Torrejonian, Tiffanian, Clarkforkian, and Wasatchian (Granger's "Sand

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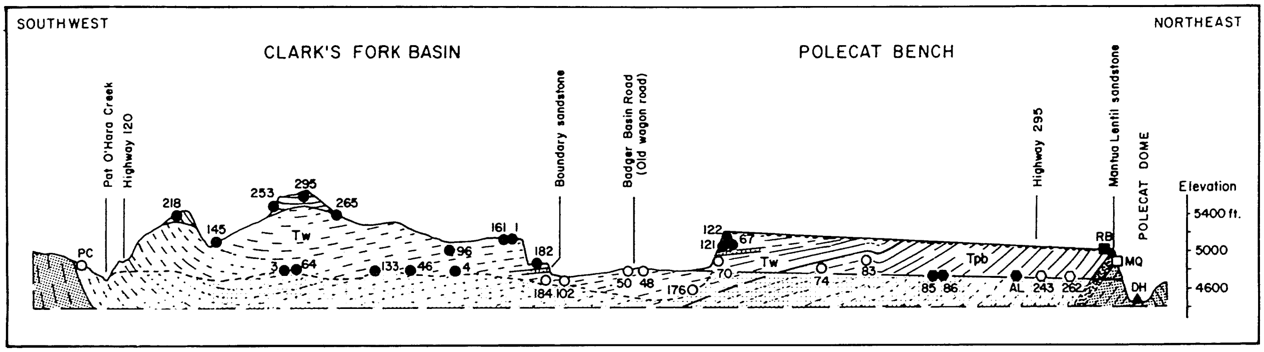


Figure 1. Diagrammatic geological cross-section of the Clark's Fork Basin-Polecat Bench area, showing the stratigraphic relationship of some of the principal fossil localities. Abbreviations, symbols, and horizontal scale as in Figure 2. Vertical scale exaggerated approximately x14.

Coulee beds" are now generally recognized as basal Wasatchian).

The total stratigraphic section exposed at the surface in the Clark's Fork Basin-Polecat Bench area and yielding latest Cretaceous, Paleocene, and early Eocene mammalian fossils is now known to be approximately 2,100 m thick. The combined thickness of the preserved Puercan and Torrejonian sediments on Polecat Bench is only about 80 m, compared with a combined thickness of Tiffanian, Clarkforkian, and Wasatchian sediments of approximately 1,900 m. Thus the Tiffanian-Clarkforkian-Wasatchian sequence spanning the Paleocene-Eocene boundary is particularly well represented.

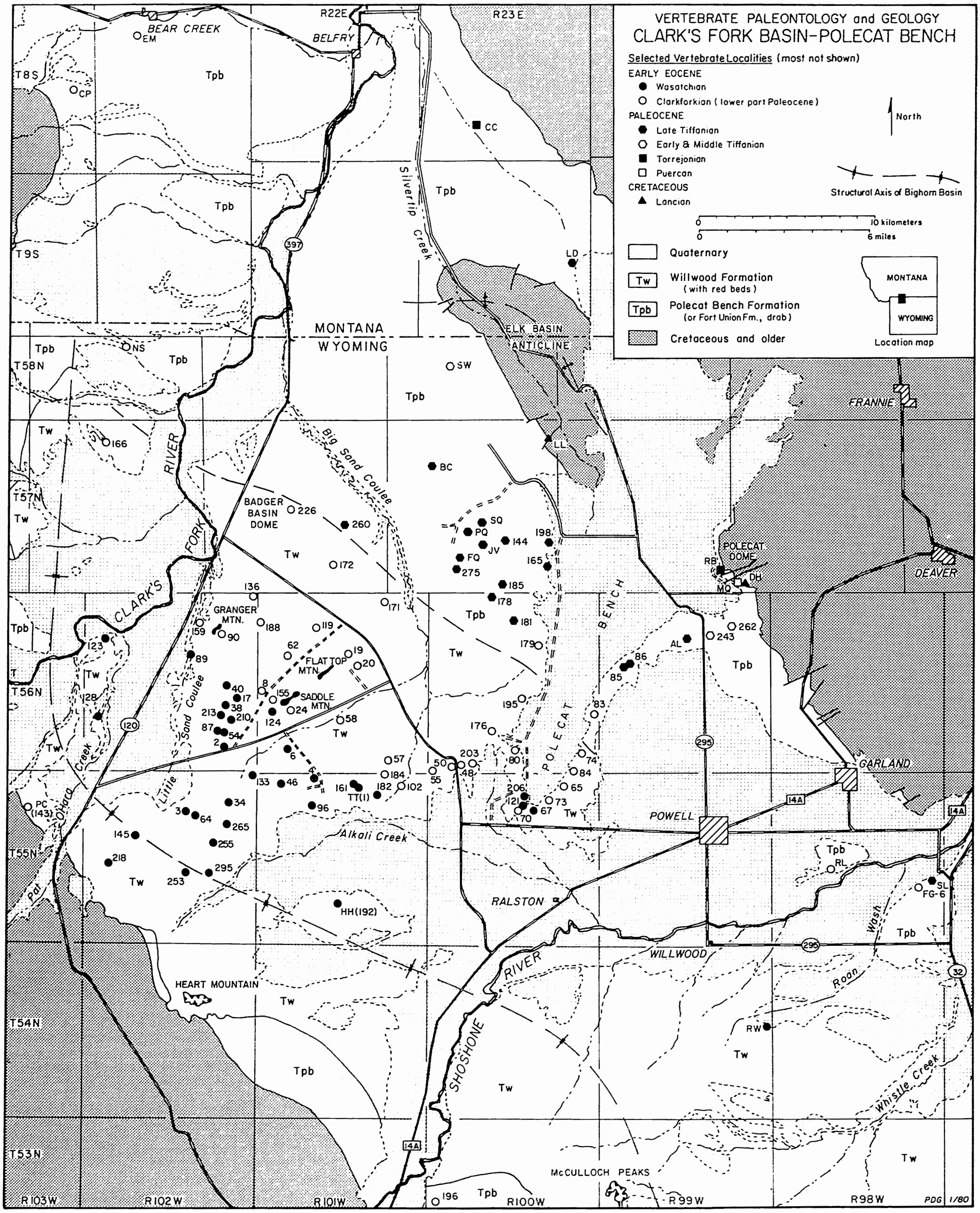
The University of Michigan began field work in the Clark's Fork Basin in 1975 in an attempt to document the poorly known fauna of Granger's Sand Coulee beds. Several very rich Clarkforkian localities with the index fossil *Plesiadapis cookei* were found during the first summer in supposed Sand Coulee beds. During the second summer Clarkforkian and basal Wasatchian localities were mapped, a sandstone unit separating them was located, and this boundary sandstone was traced across the Clark's Fork Basin. Work continues on the Wasatchian faunas of the Clark's Fork Basin, but we have expanded the scope of this project to try to understand faunal change through the entire section exposed on Polecat Bench and in the Clark's Fork Basin.

A map and cross-section of the Clark's Fork Basin-Polecat Bench area are presented in Figures 1 and 2, where some of the more important University of Michigan and Princeton University localities are shown. On the east side of Polecat Bench, Lancian, Puercan, and Torrejonian strata are exposed in the vicinity of Polecat Dome, an anticline representing a southeastward extension of the larger Elk Basin anticline and oil field. The thick sequence of strata above the Torrejonian Rock Bench Quarry (RB) level, representing the Tiffanian, Clarkforkian, and

Figure 2 [Opposite page]. Geological map of the Clark's Fork Basin-Polecat Bench area, showing the geographical distribution of the Polecat Bench and Willwood formations, and the location of some of the principal fossil vertebrate localities. University of Michigan localities in the Sand Coulee area are numbered on the map without the prefatory SC used in the text. Foster Gulch localities to the southeast are prefaced FG. Princeton University localities are abbreviated as follows:

AL, Airport Locality (SC-239, 246)
BC, Brice Canyon (SC-272)
CC, Cub Creek
CP, *Coryphodon proterus* type locality
DH, Dumbbell Hill
EM, Eagle Mine
FQ, Fritz Quarry
HH, Hackberry Hollow (SC-192)
JV, Jepsen Valley Quarry
LD, Long Draw Quarry
LL, *Leptoceratops* Locality
MQ, Mantua Quarry
NS, Noble Site
PC, Paint Creek (SC-143)
PQ, Princeton Quarry (SC-187)
RB, Rock Bench Quarry
RL, Ries Locality (FG-10)
RW, Roan Wash
SL, Sunday Locality (FG-4)
SQ Schaff Quarry
SW, Seaboard Well
TT, Twisty Turn Hollow (SC-1, 161)

SC-144 is the area where the Tiffanian *Hyracotherium* is said to have been found.


VERTEBRATE PALEONTOLOGY and GEOLOGY
CLARK'S FORK BASIN-POLECAT BENCH
Selected Vertebrate Localities (most not shown)
EARLY EOCENE
● Wasatchian
○ Clarkforkian (lower part Paleocene)
PALEOCENE
⬢ Late Tiffanian
⬡ Early & Middle Tiffanian
■ Torrejonian
□ Puercan
CRETACEOUS
▲ Lancian
North
Structural Axis of Bighorn Basin
0 10 kilometers
0 6 miles
Quaternary
Tw Willwood Formation (with red beds)
Tpb Polecat Bench Formation (or Fort Union Fm., drab)
Cretaceous and older
MONTANA
WYOMING
Location map
R22E
R23E
BEAR CREEK
EM
BELFRY
T8S
CP
Tpb
CC
Silver Tip Creek
397
T9S
LD
MONTANA
WYOMING
ELK BASIN ANTICLINE
Tpb
T58N
NS
SW
FRANNIE
Tw
166
RIVER
Big Sand Coulee
LL
BC
T57N
BADGER BASIN DOME
226
260
SQ
PQ
JV
FQ
275
144
198
165
POLECAT DOME
RB
DH
MQ
DEAVER
CLARK'S FORK
136
GRANGER MTN.
159
90
188
119
171
185
178
181
179
BENCH
AL
243
262
123
89
62
FLAT TOP MTN.
19
20
86
85
T56N
128
40
17
38
213
210
87
54
2
8
155
SADDLE MTN.
24
124
58
Sand Coulee
120
195
83
176
POLECAT
295
Little Sand Coulee
6
57
184
50
55
203
48
80
74
84
65
GARLAND
Oiaro Creek
PC (143)
133
46
161
TT(1)
182
102
206
121
170
73
67
POWELL
14A
34
3
64
265
96
Alkali Creek
145
255
T55N
218
253
295
RL
SL
FG-6
Pat
HH(192)
RALSTON
Wash
WILLWOOD
RIVER
Roan
32
HEART MOUNTAIN
T54N
RW
SHOSHONE
Whistle Creek
T53N
McCULLOCH PEAKS
196
R103W
R102W
R101W
R100W
R99W
R98W
PDG 1/80

early-middle Wasatchian, is best exposed along the south side of Polecat Bench and the southern margin of the Clark's Fork Basin. Here the sediments are part of a monocline dipping gently to the southwest, with dips of up to 10-12°. Some 20 mi (32 km) southwest of Polecat Dome, in the structural axis of the Clark's Fork Basin, beds are flat-lying. West of the basin axis they dip steeply to the northeast. The Clark's Fork Basin is asymmetrical, with the structural axis running very near the western margin. Stratigraphically, the basin is also asymmetrical, and along the western margin Clarkforkian and Wasatchian age sediments rest directly on the Cretaceous. Intervening Paleocene sediments were probably never deposited along this western margin.

In the following sections of the paper we summarize what is known about Lancian, Puercan, Torrejonian, Tiffanian, Clarkforkian, and Wasatchian faunas of the Clark's Fork Basin-Polecat Bench area.

Abbreviations referring to specific localities are given in parentheses. These are explained in the captions to Figures 1 and 2.

LANCIAN FAUNA (LATE CRETACEOUS)

Mammalian fossils from "Lance equivalent" strata in the northern Bighorn Basin have not yet been described in detail. Jepsen (1931) first reported the discovery of an isolated mammalian tooth east of Red Lodge, Montana, in association with dinosaur bones, teeth, and egg shell fragments. Later, mammalian teeth were recovered by Princeton University field parties from a locality known as "Dumbbell Hill" (DH), on the east side of Polecat Bench. This collection was described by J. Dyer in 1948 in an unpublished senior thesis at Princeton University. Dyer's collection and a subsequent collection made by D. C. Parris of Princeton in 1971 include the taxa listed in Table 1. These confirm the Lancian age generally ascribed to "Lance equivalent" strata in this area. Ostrom (1978) described a partial skeleton of the ceratopsian dinosaur *Leptoceratops gracilis* from a locality (LL) 8.5 mi (14 km) northwest of Dumbbell Hill.

Table 1. Mammalian fauna of the Dumbell Hill locality, late Cretaceous. Identifications by R. E. Sloan and W. A. Clemens (see Clemens et al., 1979).

MULTITUBERCULATA
- *Cimolomys gracilis*
- *Mesodma formosa*
- Cf. *Cimexomys* sp.
- *Cimolodon nitidus*

MARSUPIALIA
- *Alphadon* cf. *A. marshi*

PROTEUTHERIA
- ?Leptictoid insectivore

PUERCAN FAUNA (EARLY PALEOCENE)

The Mantua lentil is a massive sandstone about 40 meters thick at the base of the Polecat Bench Formation, directly overlying Lancian strata. A sample of over one hundred mammalian specimens, including skulls and jaws, was obtained from Mantua Quarry at the base of the sandstone by Jepsen and Princeton University field parties. The mammalian fauna has been described by Jepsen (1930, 1940) and Van Valen (1978), with additional citations of taxa by Russell (1967) and Sloan (1969). A faunal list is given in Table 2. Dinosaur bones and teeth occur in "Lance equivalent" strata only 6 ft (1.83 m) below the thin coal bed that directly underlies Mantua lentil (Jepsen, 1940).

Table 2. Mammalian fauna of Mantua Quarry (Jepsen, 1930, 1940; Van Valen, 1978).

MULTITUBERCULATA
- *Mesodma ambigua*
- *Stygimys gratus*

PROTEUTHERIA
- *Procerberus* sp.

CONDYLARTHRA
- *Oxyprimus galadrielae*
- *Oxyprimus putorius*
- *Ragnarok nordicum*
- *Eoconodon copanus*
- *Maiorana noctiluca*
- *Mimatuta minuial*
- *Earendil undomiel*
- *Oxyacodon josephi*

The collections from Mantua Quarry and from Leidy Quarry (in the southern part of the Bighorn Basin) represent a distinctive fauna, and Van Valen (1978) proposed a pre-Puercan land-mammal age, the Mantuan, to recognize their individuality. In our opinion the evidence is insufficient for recognition of a distinct stage or land-mammal age (see Savage, 1962; Tedford, 1970), and we therefore provisionally regard these faunas as earliest Puercan in age. Puercan mammals are unknown from elsewhere in the Bighorn Basin.

TORREJONIAN FAUNA (MIDDLE PALEOCENE)

Torrejonian mammals are known from only two localities in the Clark's Fork Basin-Polecat Bench area: Rock Bench Quarry, and "Simons' 1955 locality" on Cub Creek. Both localities have yielded late Torrejonian mammals.

Rock Bench Quarry (RB) is one of the most productive and significant sites of middle Paleocene (Torrejonian) age anywhere in North America. While some of the lower vertebrates from the quarry have been described (e.g., Gilmore, 1942; Boreske, 1974; Krause, this volume; Bartels, this volume), the site is best known for its variety and abundance of fossil mammals. Jepsen (1930, 1940) and Russell (1967) presented the principal accounts of the mammalian fauna. Their faunal lists have since been expanded by Rose (1979).

Fossil vertebrates in the quarry are concentrated in a thin clay-gall conglomerate at the base of a thick channel sandstone. Since this is a water-laid deposit, we may assume that some hydraulic sorting has occurred. Remains of small and very small mammals predominate in the sample; however, many of the larger species of the time are also represented (for example, arctocyonid and phenacodontid condylarths, mesonychids, pantodonts, and taeniodonts). Hence size-sorting does not appear to be a serious bias in the sample. Sedimentary conditions at Rock Bench Quarry suggest rapid deposition of the bone-producing bed. The Rock Bench sample, then, should give us a reasonably accurate picture of mammalian life in northern Wyoming during the latter part of the middle Paleocene.

The composition of the mammalian fauna, based on minimum numbers of individuals, is depicted in Figure 3A. Dominating the fauna are several archaic groups: condylarths (particularly hyopsodontids and arctocyonids), multituberculates, and plesiadapiform primates. The assemblage is very similar to that of Gidley Quarry, a late Torrejonian locality in the Crazy Mountain Field, Montana (Simpson, 1937a). The most significant features of the composition of the Rock Bench fauna are its very high species richness (57 species)—the highest of any single Paleocene site yet analyzed—and its relatively even distribution of species abundance. The two most common species, the multituberculate *Ptilodus wyomingensis* and the primate *Plesiolestes problematicus,* each account for only about 10% of the fauna. These and other factors suggest that the sample from Rock Bench Quarry represents a diverse subtropical forest community.

Simons' locality on Cub Creek (CC), 5 mi (8 km) southeast of Belfry, Montana, appears to be temporally equivalent to Rock Bench Quarry, but it represents a very different depositional setting. Fossils here are found on the surface, weathering out of a Lebo-like greenish sandy shale. Only *Pronothodectes jepi* and *Stelocyon arctylos* have been described from this locality (Gingerich, 1976, 1978).

TIFFANIAN FAUNAS (LATE PALEOCENE)

Tiffanian mammals have been recovered from a total of 55 localities in the Clark's Fork Basin-Polecat Bench area. Abundant specimens of plesiadapid primates from here and elsewhere in the Rocky Mountain Interior permit the Tiffanian to be subdivided into five zones or biochrons, which are, from oldest to youngest, the *Plesiadapis praecursor, P. anceps, P. rex, P. churchilli,* and *P. simonsi* zones (Gingerich, 1976). The very latest Tiffanian belongs to a sixth zone based on a new species of *Plesiadapis* that is predominantly Clarkforkian in age (Rose, 1980). No mammalian taxa have been described from the *P. praecursor* Zone in the Clark's Fork Basin-Polecat Bench area and only a single dentary of *P. anceps* has been reported from the next highest zone (Gingerich, 1976). This specimen was recovered from locality SC-263 (just east of locality SC-262 in Figure 2) on the south side of Polecat Bench, approximately 115 m above the level of Rock Bench Quarry (175 m above the Cretaceous-Tertiary boundary at the base of our measured section).

Mammals from the *P. rex* Zone are known from several localities (e.g. SC-262, 243) on the south side of Polecat Bench between levels 280 m and 425 m. The most productive *P. rex* Zone locality is Cedar Point Quarry located in the Foster Gulch area approximately 20 mi (32 km) southeast of Polecat Bench. Cedar Point Quarry was found by Robert Witter and Albert Silberling, while working for Jepsen in the late 1940s. Since then, more than 2000 mammalian fossils have been collected at the site, making it one of the richest late Paleocene localities in the world. Although certain elements of the fauna have been studied (e.g. pantodonts, Simons, 1960; phenacodontids, West, 1976; apatemyids, West, 1973; carpolestids, Rose, 1975; plesiadapids, Gingerich, 1976), no summary of the total mammalian as-

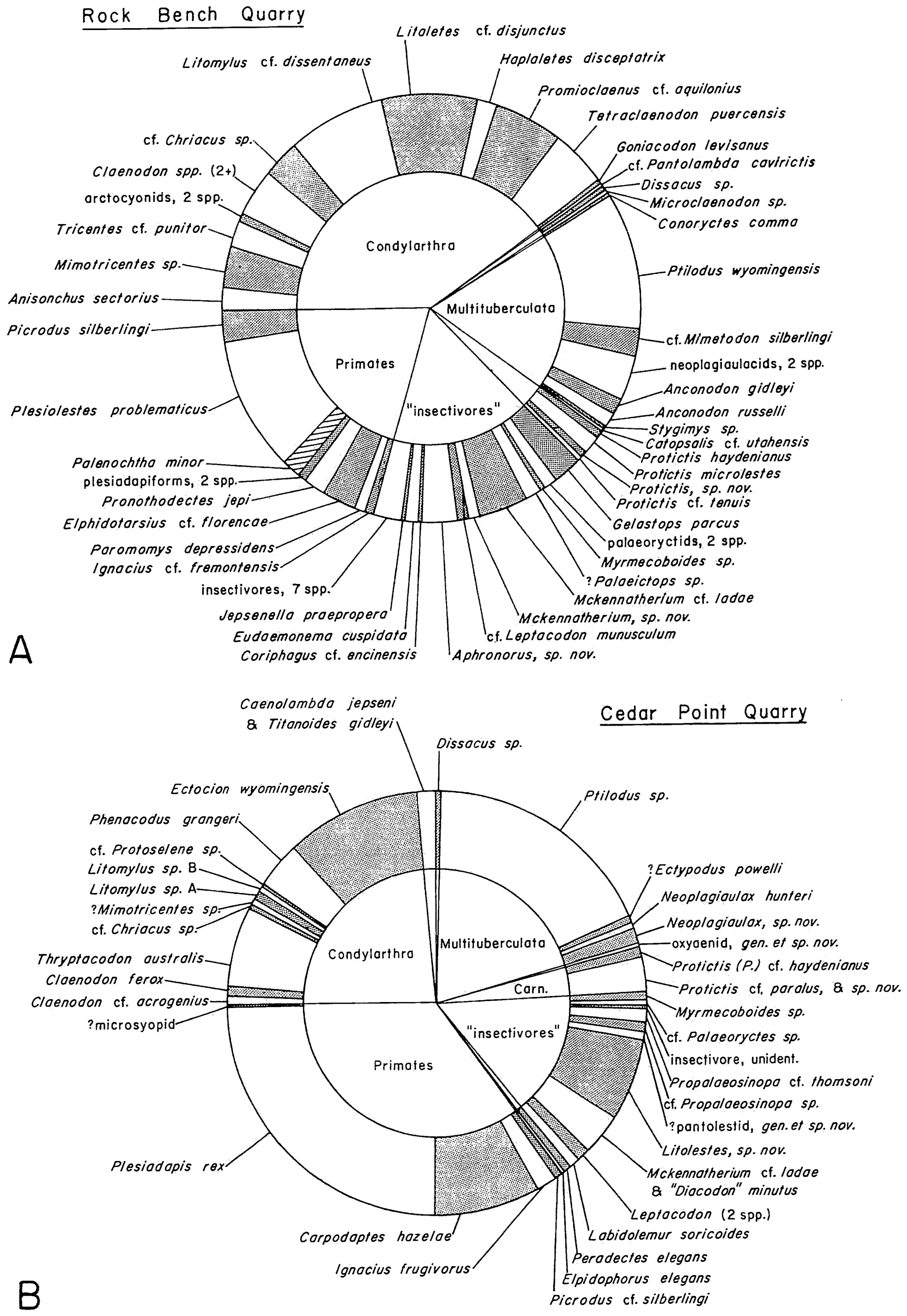


Figure 3. Pie diagrams comparing the mammalian fauna from the late Torrejonian Rock Bench Quarry (A) with that from the mid-Tiffanian Cedar Point Quarry (B). Rock Bench diagram is based on 1687 specimens representing a minimum of 496 individuals and a total of 57 species. Cedar Point diagram is based on 1988 specimens representing a minimum of 503 individuals and a total of 38 species. Note the greater species richness and equitability (evenness) of the Torrejonian Rock Bench Quarry sample compared to those of the Cedar Point Quarry sample. Both of these quarry samples are found in similar clay-gall conglomerate beds at the base of massive channel sandstones. Figures and calculations from Rose (1979).

semblage was available until recently (Rose, 1979; Figure 3B).

As at Rock Bench, fossils at Cedar Point occur in a thin clay-gall conglomerate at the base of a channel sandstone. Deposition was probably rapid, and size-sorting probably occurred but does not appear to have been a serious factor. The assemblage at Cedar Point Quarry shows dramatic differences from that at Rock Bench—contrasts that cannot be attributed merely to evolutionary changes within lineages. Species richness is only two-thirds as great as that at Rock Bench Quarry, and two of the 38 species at Cedar Point Quarry far outrank all others in relative abundance (the primate *Plesiadapis rex* accounts for 25% of the mammalian population, and the multituberculate *Ptilodus* sp. is 18%). Diversity among multituberculates, primates, and arctocyonids, and the relative abundance of hyopsodontids show marked declines compared to the Rock Bench assemblage (see Table 3).

Mammals of the *P. churchilli* Zone are known principally from the Airport Locality (AL) and other localities on Polecat Bench between the 495 m and 550 m levels. Long Draw Quarry (LD) is north of Elk Basin. Croc Tooth Quarry, Divide Quarry, and Lower Sand Draw, all in the Foster Gulch area southeast of Polecat Bench, also correlate with this interval. None of these quarries have yet been exploited to their full potential.

Numerous localities, including several quarries, have yielded mammalian fossils assigned to the *P. simonsi* Zone, which includes levels from about 650 m to 850 m in the Polecat Bench section. The best known of these localities is Princeton Quarry (PQ). Princeton Quarry, cited as "Silver Coulee Quarry" by some authors, was the first (and most productive) of several late Tiffanian quarries to be found on the west side of Polecat Bench. Within a few miles of Princeton Quarry are Fritz (FQ), Schaff (SQ), and Jepsen Valley (JV) quarries (all at about the same level as Princeton Quarry), and UM locality SC-165 (stratigraphically somewhat higher).

The concentration of fossil vertebrates at Princeton Quarry occurs in a "fine grained gray-green sandstone" (Jepsen, 1940), in contrast to the coarse channel sandstones at Rock Bench and Cedar Point quarries. Although there is little evidence of water transport of the bones (well-preserved and articulated specimens have been found), the larger mammals of the time are rare or absent in the quarry, suggesting that the sample is biased toward small animals.

The principal discussions of the Princeton Quarry mammalian fauna were presented by Jepsen (1930, 1940), Jepsen and Woodburne (1969), and Rose (1979). Reptiles and amphibians from the quarry and sites at equivalent levels have been described by Gilmore (1942), Estes (1975), Krause (this volume), and Bartels (this volume). The Princeton Quarry assemblage is dominated by small mammals, chiefly multituberculates, insectivores, primates, and a hyopsodontid (*Phenacodaptes,* the most common element in the fauna), suggesting that the quarry sample does not provide an accurate picture of the whole late Tiffanian mammalian community (see Table 4). About ten species of relatively large mammals occur in close proximity to the quarry (but not at the quarry itself—see Table 4). Nonetheless, the Princeton Quarry fauna probably does offer a very good census of small mammals of the time.

Table 3. Comparison of the Rock Bench, Cedar Point, and Princeton Quarry mammalian assemblages (Rose, 1979).*

	ROCK BENCH (Torr.)	CEDAR POINT (M. Tiff.)	PRINCETON (L. Tiff.)
Sample size/MNI	1687/497	1988/503	546/185
Number of species	57	38	36
Multituberculata	18% (8)	20% (4)	13% (8)
Primates (all)	20% (8)	36% (4)	26% (4)
Plesiadapidae	2% (1)	25% (1)	10% (1)
Arctocyonidae	13% (8)	8% (5)	5% (3)
Phenacodontidae	4% (1)	14% (2)	4% (2)
Hyopsodontidae	22% (4)	1% (3)	15% (1)

*MNI = Minimum number of individuals necessary to account for all specimens of teeth and jaws. Percentage of the fauna represented by each taxon is based on MNI. Number of species present in each group is shown in parentheses.

Other noteworthy localities that have produced mammalian fossils of the *P. simonsi* Zone are Michigan and Princeton localities SC-85, SC-86, SC-198 (Fossil Hollow), SC-144 (Horse Pasture), and Brice Canyon (BC) in the vicinity of Polecat Bench. The Sunday localities (SL) and Middle Sand Draw in the Foster Gulch area are also in this zone.

CLARKFORKIAN FAUNAS (PALEOCENE-EOCENE)

The Clark's Fork Basin is the type area of the Clarkforkian Land-Mammal Age, and it remains the

Table 4. Mammalian fauna of Princeton Quarry* (Rose, 1979).

	Total/MNI	Frequency (MNI)
MULTITUBERCULATA		
Neoliotomus conventus	4/1	.005
Microcosmodon conus	7/4	.022
Pentacosmodon pronus	2/1	.005
Prochetodon cavus	12/3	.016
Neoplagiaulax hazeni	4/1	.005
Mimetodon churchilli	2/1	.005
Parectypodus laytoni	9/5	.027
Ectypodus powelli	10/8	.043
MARSUPIALIA		
Peradectes elegans	4/3	.016
?*Peratherium* sp.	1/1	.005
PROTEUTHERIA		
Cf. *Palaeoryctes* sp.	11/4	.022
Prodiacodon cf. *concordiarcensis*	2/1	.005
?*Palaeictops* sp.	3/3	.016
Unuchinia sp.	3/2	.011
LIPOTYPHLA		
Leptacodon packi	8/5	.027
Litolestes ignotus	25/14	.076
"*Diacodon*" *minutus*	43/17	.092
Adapisoricid or nyctithere, unident.	11/6	.032
Apternodus-like sp. A	1/1	.005
Apternodus-like sp. B	1/1	.005
PRIMATES		
Micromomys silvercouleei	1/1	.005
Plesiadapis fodinatus	112/19	.103
Carpolestes dubius	48/13	.070
Phenacolemur pagei	51/17	.092
CONDYLARTHRA		
Cf. *Tricentes* sp.	14/5	.027
Thryptacodon sp.	3/2	.011
Claenodon sp.	1/1	.005
Phenacodus sp.	3/1	.005
Ectocion osbornianus	15/5	.027
Phenacodaptes sabulosus	103/27	.146
Dissacus cf. *navajovius*	5/2	.011
CARNIVORA		
Didymictis, sp. nov.?	5/1	.005
Cf. *Viverravus*, sp. nov.	12/4	.022
Viverravine, sp. A	2/2	.011
Viverravine, sp. B	1/1	.005
PALAEANODONTA		
Propalaeanodon schaffi	2/2	.011
Totals	541/185	.996

**NOTE:* The following additional taxa have been found in the vicinity of Princeton Quarry, but not at the quarry itself:

CONDYLARTHRA
- *Anacodon? nexus*
- *Phenacodus* cf. *vortmani*

PANTODONTA
- *Haplolambda quinni*
- *Leptolambda schmidti*
- *Titanoides primaevus*
- Gen. and sp. nov.

DINOCERATA
- *Probathyopsis* sp.

TAENIODONTA
- Cf. *Lampadophorus* sp.

NOTOUNGULATA
- *Arctostylops* cf. *steini*

CREODONTA
- Cf. *Oxyaena* sp.
- ?*Dipsalodon matthewi*
- *Dipsalodon* sp. nov.

only area where the entire Clarkforkian sequence is preserved and is richly fossiliferous. Based on the studies of Matthew and Granger (1915-1918), Jepsen (1930, 1940), and Simpson (1973b), the Clarkforkian was proposed as a North American Provincial Age by H. Wood et al. (1941). Collections of Clarkforkian age were meager, however, and for years doubts about the validity of the Clarkforkian persisted (e.g. R. Wood, 1967; A. Wood, 1977). Our work in the Clark's Fork Basin during the last five field seasons has provided evidence affirming the validity of the Clarkforkian and permitting this age to be precisely defined (Gingerich and Rose, 1977; Rose, 1978, 1979, 1980).

Clarkforkian faunas occur in an interval about 470 m thick in the uppermost Polecat Bench Formation and lower Willwood Formation. The formational boundary is time-transgressive and does not coincide with any faunal boundary. In Badger Basin west of Polecat Bench, most of the earliest Clarkforkian sites appear to be in Willwood sediments, whereas on the south side of Polecat Bench, Willwood sedimentation did not begin until the middle Clarkforkian. The University of Michigan presently has 135 Clarkforkian vertebrate localities in the Clark's Fork Basin and along Polecat Bench, most of them in the Willwood Formation.

We define the lower boundary of the Clarkforkian by the first occurrence of Rodentia *(Paramys),* Tillodontia *(Esthonyx),* the pantodont *Coryphodon,* and the condylarth *Haplomylus,* all of which first appear at essentially the same time within our present powers of resolution (Rose, 1979, 1980). Wood et al. (1941) believed that the first appearance of *Ectocion, Oxyaena, Esthonyx,* and cf. *Coryphodon* characterized the Clarkforkian, but the first two genera are now known from Tiffanian sediments. They also listed the first occurrence of Rodentia in the Tiffanian, but this was undoubtedly based on specimens of *Paramys atavus* from Bear Creek (EM), now known to be of Clarkforkian age. The end of the Clarkforkian—that is, the beginning of the Wasatchian—may be defined in the Bighorn Basin by the first appearance of Artiodactyla *(Diacodexis),* Perissodactyla *(Hyracotherium),* adapid and omomyid primates *(Pelycodus, Tetonoides),* and hyaenodontid creodonts *(Arfia),* which first appeared at the same time as immigrants. These taxa mark the beginning of Wasatchian time throughout the northern Western Interior, but *Hyracotherium* is known from two possible Clarkforkian sites in the southern part of North America (Morris, 1968; Schiebout, 1974; an intensive collecting effort in the late Tiffanian around

Figure 4. Clarkforkian-Wasatchian boundary in the Willwood Formation on the south side of Saddle Mountain in the Clark's Fork Basin. Dashed line shows the base of the boundary sandstone ("Clark Fork sheet sandstone" of Kraus, this volume), which forms the large, nearly flat dip slope at the left of the photograph and in the foreground. Sediments above this boundary sandstone are Wasatchian in age. Two Clarkforkian localities, SC-24 and SC-25, are shown below the boundary sandstone. View looking to northeast.

Princeton Quarry and SC-144 has failed to corroborate the present of *Hyracotherium* in late Tiffanian faunas as reported by Jepsen and Woodburne, 1969, and we suspect locality information with the single specimen in question to be in error). The abundant condylarth *Hyopsodus* is another good indicator of Wasatchian age, but it is also known (very rarely) from the late Clarkforkian (Rose, 1979).

Through much of the Clark's Fork Basin, the Clarkforkian-Wasatchian boundary coincides with a widespread sheet sandstone complex (Figure 4, see also Kraus, this volume). Faunas found just below the sandstone are Clarkforkian, while those from immediately above it are Wasatchian. At the southern end of Polecat Bench (Figure 5) this sandstone thins and disappears, and Wasatchian mammals occur at localities SC-67 and SC-121 above Clarkforkian mammals at SC-70, SC-71, and SC-107 with no evidence of a stratigraphic or sedimentological discontinuity.

In addition to defining the boundaries of the Clarkforkian, it is possible to characterize this land-mammal age in terms of the most common mammalian fossils found and by taxa that appear to be confined to the Clarkforkian. In the past, the common primate *Plesiadapis cookei* has been regarded as a Clarkforkian index fossil, and this remains so, although we now know that it is restricted to the middle Clarkforkian. Other taxa that are at present known only from the Clarkforkian include the primate *Carpolestes nigridens,* the condylarths *Aletodon gunnelli, Apheliscus nitidus,* and a new species of *Haplomylus,* the tillodonts *Esthonyx xenicus* and *E. ancylion,* the multituberculate *Microcosmodon rosei,* and the rodent *Paramys atavus.* Particularly characteristic of Clarkforkian faunas, although not restricted to that age, are the condylarths *Phenacodus primaevus, P. vortmani,* and *Ectocion osbornianus,* the uintathere *Probathyopsis praecursor,* the carnivore *Didymictis proteus,* the multituberculate *Neoliotomus conventus,* and several species of oxyaenid creodonts (see Rose, 1979, and Krause, 1980, for additional discussion). The composition of the middle Clarkforkian fauna is depicted in Figure 6A.

Seventy species of mammals have been recorded from the Clarkforkian of the Clark's Fork Basin (Rose, 1979), and they reveal that this was truly a time of transition in mammalian faunas. Clarkforkian faunas are dominated by archaic mammals of Paleocene aspect, but they also include (for the first time) several forms that are characteristic of Wasatchian faunas. Among the latter are miacine carnivores and the genera *Plagiomene, Microsyops, Niptomomys, Palaeonictis,* and *Palaeanodon,* as well as the four taxa that define the beginning of the Clarkforkian.

Three faunal zones can be recognized in the Clark's Fork Basin, corresponding approximately to early, middle, and late Clarkforkian. They are based primarily on the stratigraphic ranges of species of *Plesiadapis.* Species of the primate *Phenacolemur* and the tillodont *Esthonyx* are also particularly useful

Figure 5. Clarkforkian-Wasatchian boundary at the south end of Polecat Bench. Dashed line shows the base of the boundary sandstone. Bright red-banded sediments just above this sandstone (SC–121) and higher (SC–122) yield a Wasatchian fauna. Drab beds below the boundary sandstone here (SC–70, SC–71) yield a Clarkforkian fauna. Entire sequence is in the Willwood Formation. View looking to north.

in recognizing the zones. The lowest zone, which corresponds to the upper part of the range of a new species of *Plesiadapis* (not yet described), occurs in Badger Basin (e.g., locality SC-226) and along Polecat Bench (SC-179 on the west side, SC-83 on the southeast side). Middle Clarkforkian sites (*Plesiadapis cookei* Zone) occur in the center of the Clark's Fork Basin (e.g. SC-19, SC-62, SC-136, SC-183), and along Polecat Bench (e.g. SC-74, SC-110, SC-195) south of early Clarkforkian sites. Two quarries have been located in this zone: SC-188, the most productive Clarkforkian microsite, and SC-195, which has yielded several well-preserved skulls and partially articulated mammalian skeletons. The original Clarkforkian locality discovered by Sinclair and Granger, locality SC-196 in Rough Gulch west of the McCullough Peaks, belongs to this zone (Gingerich, (1976). A large collection of middle Clarkforkian mammals has also been obtained from the Paint Creek locality (SC-143). Late Clarkforkian sites (*Phenacodus-Ectocion* Zone) occur in a northwest-southeast band west of middle Clarkforkian sites in the Clark's Fork Basin and at the southern end of Polecat Bench. Some of the most productive localities are around Granger Mountain (SC-90) and in the head of Big Sand Coulee (vicinity of SC-102).

The question of the age of the Clarkforkian has been controversial, and it has been complicated by several factors, not the least of which has been a general misconception that faunal, formational, and temporal boundaries coincide in the Clark's Fork Basin. Evidence now available suggests that the Clarkforkian straddles the Paleocene-Eocene boundary, with the early Clarkforkian best considered latest Paleocene and the middle and late Clarkforkian best considered earliest Eocene (see Rose, 1979, 1980, for detailed discussion).

WASATCHIAN FAUNAS (EARLY EOCENE)

Wasatchian faunas are known from 105 localities in the southwestern part of the Clark's Fork Basin. These localities occur in a stratigraphic section 600 m thick representing the early and middle Wasatchian. The Clark's Fork Basin is the type locality for the "Sand Coulee beds" of Granger (1914) and the "Sandcouleean" subdivision of the Wasatchian Land-Mammal Age. Wasatchian strata yielding a typical Graybullian mammalian fauna occur in the Clark's Fork Basin immediately above "Sand Coulee beds," but Lysitean and Lostcabinian faunas are not present in the Clark's Fork Basin.

Granger (1914) distinguished the Sand Coulee beds from underlying Clark Fork beds by the presence of *Eohippus* [*Hyracotherium*], Artiodactyla, Rodentia, and Primates. He distinguished Sand Coulee beds from overlying Gray Bull beds by the absence of *"Systemodon"* [large *Homogalax*], presence of a multituberculate [*Neoliotomus ultimus*], and by "the generally more primitive character of such genera as are common to both horizons." Granger listed several areas of red-banded exposures in the Clark's Fork Basin as yielding a Sand Coulee fauna, but practically all of the species later described from this interval, including *Neoliotomus ultimus,* were collected three

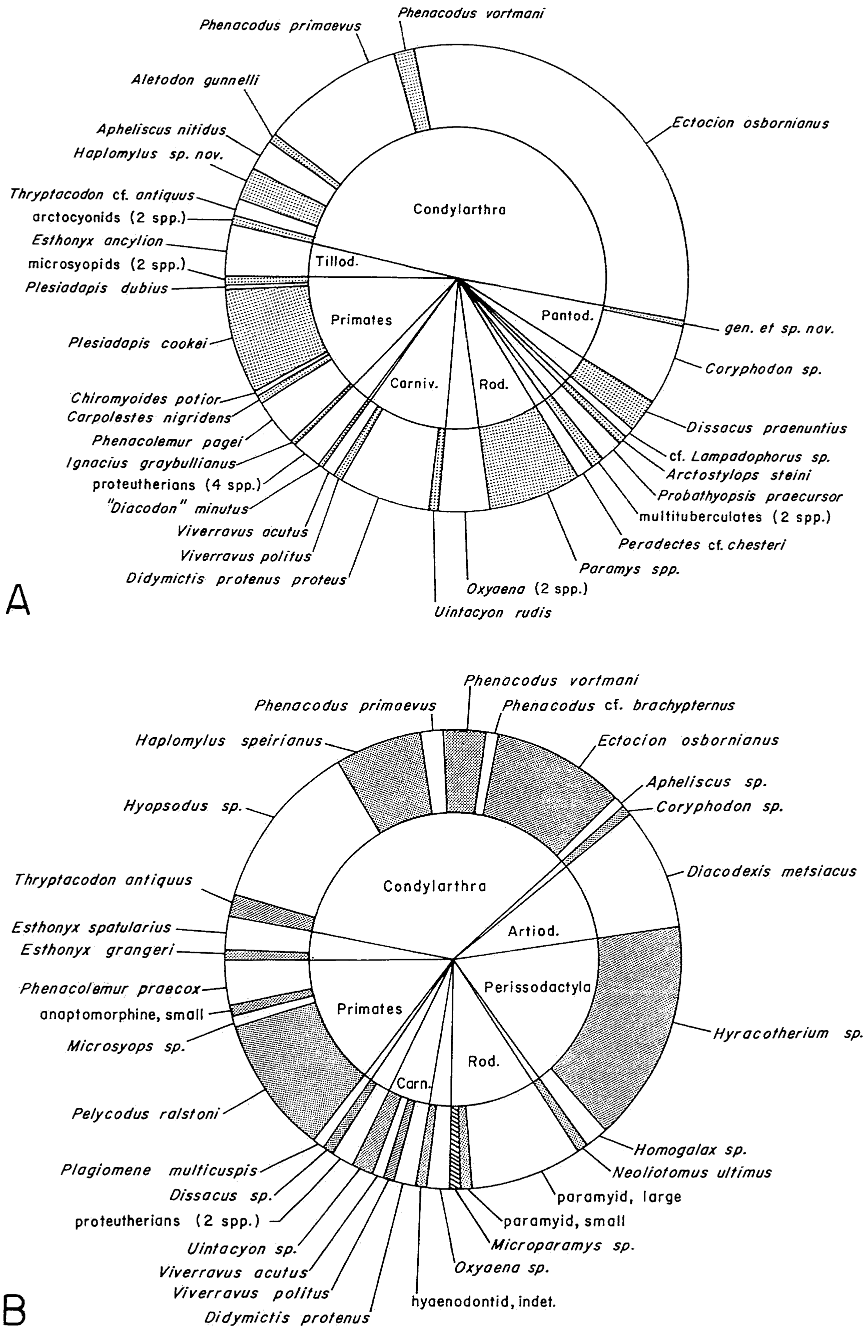


Figure 6. Pie diagrams comparing the mammalian faunas from selected localities in the *Plesiadapsis cookei* zone of the Clarkforkian (A) with one well-sampled locality in the Wasatchian (B). Both samples are based on surface collections only (with no extensive quarrying or screen-washing). The Clarkforkian diagram is based on 793 specimens from 20 localities representing a minimum of 338 individuals and a total of 39 species. The Wasatchian diagram is based on 398 specimens representing a minimum of 129 individuals and a total of 32 species, all from one locality (SC–4). Note the greater equitability (evenness) of the Wasatchian sample, where no species dominates the fauna like *Ectocion osbornianus* does in the Clarkforkian. Figures and calculations from Rose (1979).

miles southeast of the mouth of Pat O'Hara Creek (in the vicinity of SC-40). A new small species of *Homogalax* (not the larger *"Systemodon"*) does occur in the basal Wasatchian at locality SC-40 and elsewhere (in fact Granger collected some fragmentary specimens of this himself). In our collections, *Neoliotomus ultimus* occurs only in the lower 160 m of the Wasatchian section. *Pelycodus ralstoni, Esthonyx spatularius, Esthonyx grangeri, Didymictis leptomylus,* a new small species of *Arfia,* and the new small species of *Homogalax* are among the more primitive species characteristic of the Sand Coulee beds.

We are not yet in a position to restrict or extend Granger's definition of the Sand Coulee subdivision of the Wasatchian, but this interval does appear to contain a fauna more primitive than that of the typical *"Systemodon"*-bearing Graybull beds. Sand Coulee faunas occur on the southwest end of Polecat Bench (Figure 5), and along a northwest-trending belt including localities SC-182, SC-4, SC-6, SC-40, SC-89, and SC-123 at the mouth of Pat O'Hara Creek. The Roan Wash locality (RW) southeast of the settlement at Willwood is also in this interval. The relative abundance of mammalian taxa from one of these localities (SC-4) is depicted in Figure 6B.

Large *Homogalax ("Systemodon")* does occur in the Clark's Fork Basin Wasatchian section, beginning 180 m above the base of the Wasatchian, and extending to the highest levels exposed, some 600 m above the base of the Wasatchian. *Tetonius* has a similar distribution. Thus the uppermost 420 m of the Clark's Fork Basin section appears to be faunally equivalent to typical "Gray Bull beds" exposed in the central Bighorn Basin.

Five sequential species of the adapid primate *Pelycodus* can be recognized in the Wasatchian, and these provide a useful zonation (Gingerich, 1980). The species are, from oldest to youngest, *P. ralstoni, P. mckennai, P. trigonodus, P. abditus,* and *P. jarrovii. Pelycodus ralstoni* is confined to the lowest 130 m of the Clark's Fork Basin Wasatchian. Its descendant *P. mckennai* is found from 135 m to 425 m above the base of the Wasatchian. *P. trigonodus* is derived from *P. mckennai,* and it occurs from 430 m to the highest levels at about 600 m above the base of the Wasatchian. These three species are sequential parts of a chronocline. Boundaries between the successive species are arbitrary but *Pelycodus* does change significantly through time in both size and morphology, making it useful in biochronolgy. *Pelycodus abditus,* which occurs in the very highest Gray Bull and Lysite equivalent beds of the central Bighorn Basin and the Lysite of the Wind River Basin, has not been found in the Clark's Fork Basin.

Judging from faunal comparisons, the highest stratigraphic levels in the Wasatchian of the Clark's Fork Basin (localities SC-253, 295) are equivalent to the "middle Gray Bull" of authors in the central Bighorn Basin (upper *Haplomylus-Ectocion* Range-Zone of Schankler, this volume). *Bunophorus etsagicus* of Schankler's overlying *Bunophorus* Interval-Zone has not been found in the Clark's Fork Basin. Locality SC-128 on Pat O'Hara Creek and the Hackberry Hollow locality (HH, SC-192) in the Eaglenest Basin south of Alkali Creek correlate faunally with levels approximately 400 m above the base of the Wasatchian. Higher stratigraphic levels may occur at the top of the McCullough Peaks, but this has not yet been investigated.

FAUNAL DIVERSITY

Rose (1979) has analyzed mammalian faunal diversity in the Torrejonian, Tiffanian, Clarkforkian, and Wasatchian in the Clark's Fork Basin-Polecat Bench area. As noted above in the discussion relating to Tiffanian faunas, the Rock Bench Quarry (Torrejonian) and Cedar Point Quarry (Tiffanian) are very similar lithologically and appear to represent the same depositional setting, yet these localities differ markedly in species richness and equitability. Cedar Point Quarry contains 38 species, compared with 57 present at Rock Bench Quarry (Table 3). *Plesiadapis* and *Ptilodus* dominate the fauna at Cedar Point (Figure 3B), whereas numbers of taxa are relatively evenly distributed in the Rock Bench fauna (Figure 3A).

It is more difficult to compare Clarkforkian and Wasatchian faunal assemblages directly with those at Rock Bench Quarry and Cedar Point Quarry because they come from different depositional environments and they were collected in different ways. Nevertheless, some generalizations can be made regarding species richness and equitability in the Clarkforkian and Wasatchian. Middle Clarkforkian faunas typically include about 39 species (Figure 6A) and this number increases only slightly in the late Clarkforkian (Rose, 1979). Equitability in the middle and late Clarkforkian resembles that in the Tiffanian because of the dominance of *Ectocion* in Clarkforkian faunas (Figure 6A). Early Wasatchian faunas typically include about 50 species if they have been sampled by a combination of surface collecting and screen-washing techniques (Rose, 1979). These faunas usually display a much higher level of equitability, with no species comprising more than about 15-16% of the fauna.

Faunal diversity is a measure of both species richness and faunal equitability or evenness that can be calculated in a number of ways depending on how these two factors are combined. As the figures cited here would suggest, mammalian faunal diversity was high in the Torrejonian, relatively low in the Tiffanian and Clarkforkian, and high again in the Wasatchian (see Rose, 1979, for a full analysis and documentation). Such low diversity as that observed in Tiffanian and Clarkforkian mammalian faunas is often associated with stress or unpredictability in the environment (Hutchinson, 1961; Goulden, 1969). Paleobotanical evidence indicates that temperatures and climatic equability were lower in the Tiffanian and Clarkforkian than at any other time during the Paleocene or early Eocene (Hickey, 1977, and this volume; Wolfe, 1978). These differences are also reflected in the diversity of mammalian faunal assemblages. Thus there is a substantial evidence that a change in climate and/or ecology took place between the late Torrejonian and middle Tiffanian and again in the Clarkforkian and early Wasatchian.

FUTURE WORK

The Clarkforkian-Wasatchian boundary is now one of the best documented episodes of faunal turnover in Cenozoic mammals, but much remains to be learned about faunal evolution in the early Cenozoic. Other episodes of turnover remain to be documented, and most of the intervening periods of relative faunal stability are not yet thoroughly studied. The relatively thin Puercan and Torrejonian sections exposed on Polecat Bench preclude extensive analysis of faunal evolution in these intervals in the northern Bighorn Basin. However thick Tiffanian sections, exposed on the flanks of Polecat Bench and along strike to the southeast in the Foster Gulch area, invite a more intensive analysis of the Tiffanian than has been attempted to date. There is some indication of a significant episode of faunal turnover between the middle and late Tiffanian that requires study. The Tiffanian-Clarkforkian turnover is not as fully documented as we would like because fossils are rare in this stratigraphic interval (although the major features of this turnover are now clear, Rose, 1979). Finally, preliminary indications are that a significant episode of faunal turnover occurred about 180 m above the base of the Wasatchian in the Clark's Fork Basin, and this remains to be analyzed thoroughly. Continued interdisciplinary study of faunas, floras, sedimentology, and stratigraphy in the Clark's Fork Basin-Polecat Bench area promises to contribute to a better understanding of evolution across the Paleocene-Eocene boundary.

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APPENDIX

ROAD LOG -- POLECAT BENCH & CLARK'S FORK BASIN AREA

Mileage		
Cumul.	Increm.	
0.0	0.0	Begin at Post Office in Powell, Wyoming. Drive one block west and turn right (north) onto Wyoming Highway 295 leading out of Powell toward Elk Basin. As you leave Powell, the long low bluff stretching from due west to northeast along the skyline is Polecat Bench. It is capped by a river gravel deposited during the Pleistocene before the surrounding softer sediments were eroded away. Now Polecat Bench stands above the Shoshone and Clark's Fork river basins on both sides because it is protected by the gravel cap. Latest Cretaceous sediments outcrop on the east side of Polecat Bench out of view to the northeast. Most of the southwesterly dipping strata visible from the highway are in the drab Polecat Bench Formation, which includes a remarkably complete sequence of Paleocene faunas (Puercan, Torrejonian, Tiffanian, and early Clarkforkian). Near the southwest end of Polecat Bench red beds first appear, and these are the lowest part of the Willwood Formation of early Eocene age (Clarkforkian and Wasatchian).
6.6	6.6	University of Michigan locality SC-243 is 0.2 miles east of the highway at this point. It is (was) a large anthill developed on a bed of clay gall conglomerate that contained several hundred teeth, including a good sample of *Plesiadapis rex* (middle Tiffanian).
6.9	0.3	Approximately 0.5 miles west of the highway is the Princeton Airport Locality, yielding *Plesiadapis churchilli* (early late Tiffanian). The transitional interval between the middle and late Tiffanian is in a magnetozone of normal polarity interpreted as magnetic anomaly 26 (Butler, Lindsay, and Gingerich, this volume).
8.0	1.1	Top of Polecat Bench. Road leading to Powell Airport branches to left. Continue straight ahead.
8.5	0.5	Turn off of Wyoming Highway 295 onto the graded road heading east (right turn). This road leads to the small oil field in Polecat Dome, a southeastern extension of the much larger Elk Basin oil field.
10.2	1.7	Fence and cattle guard. This is where the track leading to Rock Bench Quarry leaves the Polecat Dome road. Proceed straight ahead to Polecat Dome.
10.9	0.7	Begin descent into Polecat Dome. Lignite bed exposed on right side of road as you descend into Polecat Dome is the Mantua lignite thought to mark the Cretaceous-Tertiary boundary. Dinosaur remains have been found within a short distance below this, and Mantua Quarry yielding early Paleocene (Puercan) mammals is just above the level of this lignite.
11.4	0.5	STOP 1: Park near the storage tanks and oil well. Talus from the Mantua Quarry, discovered in 1929 by Sinclair and Jepsen's expedition, is visible below the heavy sandstone (the Mantua Lentil sandstone) about 0.5 miles directly to the west across Polecat Dome. Dumbbell Hill, a Lancian mammal-bearing locality, is the small dumbbell-shaped hill at the bottom of Polecat Dome. Rock Bench Quarry is out of sight about one mile west-northwest of here, on the north flank of the graben north of Mantua Quarry. Turn around and return up the road we just came down.
11.9	0.5	Again note the Mantua lignite, this time on your left, as we emerge onto the top of Polecat Bench.
12.6	0.7	Fence and cattle guard we crossed earlier. Cross the guard and turn right (north), driving along the track on the west side of the fence.
13.8	1.2	Head of valley with small stock tank. Turn right off of track, driving across Polecat Bench on the north side of the valley.
14.1	0.3	STOP 2: Edge of Polecat Bench above Rock Bench Quarry, discovered in 1929 by Sinclair and Jepsen. Take a few minutes to walk down to

		the quarry and examine the lithology of the sandstone and the clay gall conglomerate at its base. The bone-producing layer here, as at many of the other fossil quarries in the Polecat Bench Formation, is the clay gall conglomerate. Return to vehicles and backtrack to the graded road.
15.6	1.5	Graded road at cattle guard. Turn right.
17.3	1.7	Wyoming Highway 295. Turn right (north) and proceed toward Elk Basin.
19.6	2.3	Junction with road to South Elk Basin oil field. Turn left (west) and drive through oil field.
22.6	3.0	Road curves to north. Badlands on your left are all late Tiffanian. This is the area where the alleged late Tiffanian *Hyracotherium* described by Jepsen is said to have been found.
26.1	3.5	Junction with road to Husky cracking plant. Turn left and descend into Sand Coulee. Stay on main graded road.
27.3	1.2	Turn south just before cracking plant.
28.2	0.9	STOP 3: Princeton Quarry is about 0.2 miles east of the road at this point. Horizon is still productive although the quarry itself, discovered by Sinclair and Jepsen in 1929, is worked out. Spend 20 minutes examining lithologies and prospecting for fossils. Note that the productive bed here is a soft gray mudstone. Charles Schaff found a very nice palate of *Arctostylops* here several years ago. This is UM locality SC-187.
33.8	5.6	Backtrack to curve in road near South Elk Basin oil field. Drive south on the track along the west edge of Polecat Bench.
34.3	0.5	STOP 4: Fossil Hollow (SC-198). Valley to right is an old Princeton locality first visited by Jepsen on his last day in the field in 1928. He and Sinclair worked here at the beginning of the 1929 field season.
35.8	1.5	Late Tiffanian locality SC-165, including a good concentration of small jaws, is in the valley on the right. Continue to south.
37.8	2.0	Junction with power line track. SC-179 of early Clarkforkian age is at the base of Polecat Bench to the west of this point. Continue to south.
39.7	1.9	Track joins from northeast. Continue toward southwest. Krause Quarry (SC-110/195, middle Clarkforkian *Plesiadapis cookei* Zone) is just west of here, near the base of Polecat Bench. This quarry has yielded a number of very well preserved skulls, including those of *Dissacus* and *Oxyaena*.
41.7	2.0	Track drops over the edge of Polecat Bench here. Do not follow this but turn right and drive out on the point to the west ("Miles" triangulation point).
42.2	0.5	STOP 5: Panoramic view of the Clark's Fork Basin. Heart Mountain and Ralston Flats are to the southwest. The Absaroka and Beartooth mountains are to the west. Yellowstone Park is on the plateau behind these mountains. Area just below is drained by Big Sand Coulee. Here we are standing on the Clarkforkian-Wasatchian boundary sandstone. SC-176 at the base of the escarpment below is where the holotype skull of *Esthonyx ancylion* was found. This locality is in the late Clarkforkian *Phenacodus-Ectocion* Zone. American Museum of Natural History Clarkforkian localities in the head of Big Sand Coulee on "both sides of the wagon road where it drops down to the Big Sand Coulee" are 1-2 miles southwest of here, also in the *Phenacodus-Ectocion* Zone. Backtrack southeast along the edge of the bench.
42.7	0.5	Junction of several tracks. Continue driving to southwest along the edge of Polecat Bench.
44.7	2.0	Pipeline road off southwest end of Polecat Bench. As you descend, earliest Wasatchian ("Sand Coulee") localities SC-206 and SC-69 are in the bright red beds on your left.
46.7	2.0	Lane Nine. Turn left on paved road

		toward Powell, Wyoming.
47.6	0.9	Junction with Road 16. Turn left (north) on dirt track.
48.3	0.7	STOP 6: Clarkforkian-Wasatchian boundary on southwest end of Polecat Bench (Figure 5). Localities SC-70 and SC-71 are in the drab beds immediately below the boundary here, and SC-121 is just above the boundary in the bright red beds. This is one of Granger's type areas of the "Sand Coulee" fauna. Backtrack to Lane Nine.
49.0	0.7	Lane Nine. Turn right (west).
51.0	2.0	Junction with Badger Basin highway. Turn right (north).
53.4	2.4	Descend into the Clark's Fork Basin in the head of Big Sand Coulee. Badlands on both sides of highway are late Clarkforkian.
53.7	0.3	Old wagon road travelled by Wortman in 1891 and Granger and Stein in 1912 is visible on the right.
57.1	3.4	Little Sand Coulee Road diverges on the left. Continue straight ahead on the Badger Basin highway.
58.4	1.3	Locality SC-116 yielding a middle Clarkforkian fauna, including *Arctostylops steini* is on the left. On the right, about two miles to the northeast, are a number of early Clarkforkian localities.
59.8	1.4	Husky Refinery. Turn left on oil field road.
60.8	1.0	Type locality of *Franimys amherstensis* is in middle Clarkforkian beds along strike 0.5 miles to the northwest of here.
62.0	1.2	Locality SC-62 is on the right. *Plesiadapis cookei* has been found on the north side of this locality, in the lowest beds, but not higher.
63.5	1.5	STOP 7: Clarkforkian-Wasatchian boundary sandstone. Thick sheet sandstone above peppermint-striped beds marks the Clarkforkian-Wasatchian boundary. Peppermint-striped beds yield a *Phenacodus-Ectocion* Zone late Clarkforkian fauna.
65.0	1.5	Leave main track and take side track to the west.
65.4	0.4	STOP 8: Locality SC-210. This early Wasatchian site has been intensively analyzed taphonomically (see Winkler, this volume). All fossils seem to be weathering out of one of the five orange-gray or red-gray paleosol couplets. Return to main track.
65.8	0.4	Main track. Turn right and continue to the southwest.
66.2	0.4	Gate. Wasatchian locality SC-7 is just to the west of this gate.
66.9	0.7	Little Sand Coulee Road. Wasatchian locality SC-2 is just to the west. Jepsen camped here in 1928 and made a moderately large collection of mammalian fossils. In recent years this locality and others in the vicinity have yielded a large fauna including *Pelycodus mckennai*. Beds along the west end of the escarpment two miles south of here yield *Pelycodus trigonodus*. Turn left (east) on Little Sand Coulee Road.
68.9	2.0	STOP 9: Saddle Mountain is on our left. Note extent of Clarkforkian-Wasatchian boundary sheet sandstone forming dip slope in the foreground (see Figure 4).
72.2	3.3	Turn left on track, driving north.
73.0	0.8	STOP 10: Locality SC-20. This is one of the localities that has yielded numerous specimens of *Plesiadapis cookei*. In addition, Leo Hickey has a good fossil plant locality nearby (Hickey, this volume). Return to Little Sand Coulee Road.
73.8	0.8	Little Sand Coulee Road. Turn left (east).
75.2	1.4	Badger Basin Highway. Turn right, climbing out of the Clark's Fork Basin at the head of Big Sand Coulee.
81.3	6.1	Lane Nine. Turn left (east) toward Powell. Polecat Bench is on our left.
88.8	7.5	Road Ten. Turn right (south).
89.4	0.6	U.S. Highway 14 (Alt.). Turn left (east).
90.4	1.0	Enter Powell. Turn right (south)

		across the railroad tracks, joining Wyoming Highway 295, and proceed south to Willwood corner.
94.2	3.8	Willwood corner. Turn left (east) and continue on Wyoming 295. Badlands on the right are Wasatchian in age.
100.0	5.8	Cross Roan Wash and the old Jim Bridger Trail.
101.0	1.0	Cross under powerline. A new middle Clarkforkian quarry in a clay gall conglomerate (FG-6) is located 1.7 miles north of here. One mile east of FG-6 is the Princeton Sunday Locality of late Tiffanian age.
102.7	1.7	Junction with Wyoming Highway 32. Turn right (south) onto Wyoming 32. The vast area of badlands extending 10 - 12 miles east of Wyoming 32 is a southeastern extension of Tiffanian, Clarkforkian, and Wasatchian beds exposed on Polecat Bench. This area includes Cedar Point Quarry, Croc Tooth Quarry, Foster Gulch Well, Bone Hill, and other very productive late Paleocene and early Eocene localities. This area was formerly prospected by Princeton University parties in the late 1940's and late 1960's. Intensive work by University of Michigan parties was initiated in 1979.
109.5	6.8	Cross Coon Creek. Yale-Michigan localities 415 and 418 are on the left.
112.7	3.2	Yale-Michigan locality 417 is on the right.
117.7	5.0	Cross Dry Creek.
118.3	0.6	Intersection with U.S. Highway 14. Turn right (west).
118.9	0.6	Junction with Burlington-Otto road. Turn left.
122.9	4.0	Burlington, Wyoming. The peak straight ahead is Sheep Mountain, and the longer, flat-topped mountain to the west of it is Tatman Mountain capped by the middle Eocene Tatman Formation.
132.9	10.0	Otto, Wyoming. This is one of the oldest towns in the Bighorn Basin. Formerly located closer to the Greybull River, this is the area where the Jim Bridger Trail and the first wagon road through the Bighorn Basin crossed the Greybull River. The badlands to the south of here along Dorsey Creek were first collected by Wortman in 1881 and have subsequently been extensively prospected by many other expeditions. There are several extremely productive Yale-Michigan localities in this area, YM-421 being the richest.
144.9	12.0	Arrive in Basin, Wyoming. Continue with Central Bighorn Basin road log (Schankler, this volume).

EARLY TERTIARY AMPHIBIANS FROM THE BIGHORN BASIN, WYOMING

David W. Krause

Abstract.— The early Tertiary record of amphibians from the Bighorn Basin consists of seven salamander and three frog species, comprising only a small fraction of the known faunal diversity. No amphibian fossils have been recovered from horizons earlier than late Torrejonian or later than late Clarkforkian. Most of the salamander species are elongate, aquatic, paedomorphic forms known also from the Late Cretaceous of the Rocky Mountain Interior. Anurans are poorly represented in early Tertiary deposits of the Bighorn Basin.

The record of fossil vertebrates from early Tertiary deposits of the Bighorn Basin is strongly dominated by mammals. Amphibian remains, and those of other lower vertebrates, have been discovered primarily as the fortuitous result of intensive searches for mammalian fossils and are therefore relatively few in number. Furthermore, surface collections from the Bighorn Basin have only rarely yielded remains of *small* lower vertebrates; samples consist largely of crocodile, champsosaur, and turtle specimens. Quarrying operations and the recently-employed technique of screen-washing large quantities of fossiliferous matrix have significantly increased the known diversity of early Tertiary amphibians.

Despite over 80 years of collecting fossil vertebrates in the Bighorn Basin, no Paleogene amphibians were described from the area until Auffenberg (1961) noted the occurrence of *Opisthotriton* sp. in the Bear Creek local fauna, now considered to be early Clarkforkian in age (Gingerich, 1976; Rose, 1979). Gilmore (1942, p. 166) listed the presence of "at least two kinds of amphibia" from Princeton Quarry (late Tiffanian) but these were not described until Estes' (1975) treatment of the entire lower vertebrate fauna from the quarry. At present, a total of seven salamander and three frog species are known from the Bighorn Basin (Table 1—most of the localities that have yielded amphibian fossils are shown in Figure 1 of Gingerich et al., this volume). They range in age from late Torrejonian to late Clarkforkian. No amphibian taxa have been described from later Paleogene horizons in the basin even though large collections of fossil vertebrates, particularly mammals, have been recovered from these levels. Also, no amphibian taxa have been reported from the central or southern parts of the basin except for Bown's (1979, p. 133) statement that "amphibians . . . are represented by rare jaws and vertebrae" in the Sand Creek—No Water Creek area.

Over one-half of the salamander species *(Lisserpeton bairdi, Scapherpeton tectum, Opisthotriton kayi,* and *Habrosaurus dilatus)* known from early Tertiary horizons in the Bighorn Basin are conspecific with Late Cretaceous forms and apparently cross the Cretaceous-Tertiary boundary with little or no change. The earliest geologic record of *Amphiuma* and one of the earliest records of *Cryptobranchus* occur in the Bighorn Basin. Both of these genera have survived to the present but are now restricted to the southern and eastern United States. Of all the salamander genera

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Table 1. Record of early Tertiary amphibians from the Bighorn Basin, Wyoming

Taxon	TORREJONIAN	TIFFANIAN			CLARKFORKIAN		
		Early	Middle	Late	Early	Middle	Late
Order CAUDATA							
Family Scapherpetontidae							
Scapherpeton tectum	X[1]			X[2,3]			
Lisserpeton bairdi	X[1]		X[4]				
Piceoerpeton willwoodense			X[5]	X[6]	X[7]	X[8]	X[9]
Family Cryptobranchidae							
Cryptobranchus sp.					X[10]		
Family Batrachosauroididae							
Opisthotriton kayi	X[1]			X[2,11]	X[12]	X[13]	
Family Sirenidae							
Habrosaurus dilatus	X[1]						
Family Amphiumidae							
Amphiuma jepseni				X[2,14]			
Order ANURA							
Family Rhinophrynidae							
Eorhinophrynus sp.				X[2,15]			
Family Discoglossidae							
Undescribed genus and species				X[2]			
Anura *incertae sedis*				X[2]			

NOTES: 1. Rock Bench Quarry; Estes (pers. comm., 1980)
2. Princeton Quarry; Estes (1975)
3. Schaff Quarry; Estes (1975)
4. Cedar Point Quarry; Estes (pers. comm., 1980)
5. Cedar Point Quarry; Naylor and Krause (in press)
6. Fossil Hollow and Univ. of Michigan loc. SC-273; Naylor and Krause (in press)
7. Univ. of Michigan loc. SC-171; Naylor and Krause (in press)
8. Univ. of Michigan loc. FG-6; Naylor and Krause (in press)
9. Near Univ. of Michigan locs. SC-50, 55, and 56; Meszoely (1967)
10. Univ. of Michigan loc. SC-227; Naylor (in press)
11. Univ. of Michigan loc. SC-270; specimen UM 73575
12. Bear Creek local fauna; Auffenberg (1961)
13. Univ. of Michigan loc. FG-6; specimen UM 74126
14. Princeton Quarry; Estes (1969)
15. Fritz Quarry; Estes (1975)

known from the Bighorn Basin, only *Piceoerpeton* is confined to the early Tertiary. *Piceoerpeton* is of further interest in that late Paleocene occurrences of the genus exhibit growth zones in several parts of the skeleton, thereby indicating a markedly seasonal climate (Naylor and Krause, in press). The salamander taxa represented are primarily aquatic, paedomorphic forms recovered in lowland floodplain associations. Upland species of Caudata remain unsampled both in the Bighorn Basin and elsewhere in the Rocky Mountain Interior.

The early Tertiary anuran fauna is very poorly known. In contrast to the condition in the late Tertiary, salamanders tend to be more abundant than frogs (Estes, 1970). Only nine anuran specimens have been found, all from the late Tiffanian, and they have been assigned to three taxa. Only those of *Eorhinophrynus* have been identified below the familial level; they provide the earliest geologic record of the genus.

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EARLY CENOZOIC REPTILES AND BIRDS FROM THE BIGHORN BASIN, WYOMING

William S. Bartels

Abstract.— Vertebrate faunas recovered from the Polecat Bench and Willwood Formations contain abundant and diverse reptilian faunas. These Bighorn Basin deposits have yielded important early Cenozoic records of lizards, champsosaurs, amphisbaenians, turtles, and crocodilians. Snakes and small lizards are very rare elements, while turtles and crocodilians constitute a large portion of the recovered vertebrate assemblage. Birds are also very rare in the Polecat Bench and Willwood Formations. The more common Wasatchian forms include the gigantic "terror crane" *Diatryma* and several more conventional cranes and rails.

INTRODUCTION

A century of extensive field research on fossil mammals in the Bighorn Basin has, as would be expected, provided much information on early Cenozoic history of the other tetrapod classes as well.

Historically, the most common method of fossil collecting in the Bighorn Basin, surface prospecting, has both helped and hindered the study of Paleocene and Eocene reptilian and avian faunas. The large-sized reptilian groups, being highly visible, fare particularly well when surface collecting is employed, but often these remains, though plentiful, are very fragmentary and of limited systematic utility. Less commonly employed quarrying operations have provided some relatively complete material, but many large reptilian taxa remain poorly known. Small reptiles (and other tetrapods) are often missed entirely by the surface collector, and these constitute a decidedly small percentage of existing early Cenozoic fossil vertebrate collections. Screen-washing of fossiliferous matrix has added much to our record of small tetrapods, and continued use of this technique will eventually remove the bias in favor of larger taxa.

Avian remains, despite their adequate size and visibility for surface collecting, face a different obstacle. Birds, owing to their ecology and hollow, often delicate bones, are not very good candidates for preservation in the fossil record. Furthermore, few of the fossilized elements can later survive the process of weathering to the surface for collection by the paleontologist. Most bird specimens in the University of Michigan collection have been fortuitously preserved and collected in concretions. With these conditions in mind, it is not surprising that birds are the rarest elements in Paleogene vertebrate faunas (approximately 0.1% of catalogued specimens in the University of Michigan collection from the Bighorn Basin Tertiary).

The information included here comes both from the few published records of reptiles and birds, and from undescribed specimens in the University of Michigan (UM), Princeton University (PU), and Yale Peabody Museum collections.

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Table 1. Distribution of Bighorn Basin Lepidosauria

	TORREJONIAN	TIFFANIAN			CLARKFORKIAN			WASATCHIAN		
		Early	Middle	Late	Early	Middle	Late	Early	Middle	Late
AMPHISBAENIA										
Oligodontosauridae										
Oligodontosaurus				X^{1}						
Rhineuridae										
Spathorhynchus								X^{2}		
rhineurid, unidentified								X^{2}		
rhineurid, unidentified				X^{3}						
CHORISTODERA										
Champsosauridae										
Champsosaurus	X^{4}		X^{5}	X^{2}	X^{2}	X^{2}	X^{2}			
Simoedosaurus				X^{6}	X^{6}					
SQUAMATA										
Anguidae										
Glyptosaurinae										
Glyptosaurini										
Paraglyptosaurus								X^{7,8}		
Cf. *Paraglyptosaurus*									64201^{9}	
Eoglyptosaurus								X^{10}		
Melanosaurini										
Cf. *Arpadosaurus*								67543^{2}		
Cf. *Melanosaurus*						66709^{2}	65083^{2}	67531^{2}		
Xestops					?74127^{2}	73787^{2}		X^{11}		
glyptosaurine, unidentified									66058^{9}	
Anguidae, incertae sedis										
Cf. *Machaerosaurus*				66412^{12}		73570^{2}				
Odaxosaurus	X^{13}		X^{5}	X^{1,3,14}						
Parasaniwidae										
Provaranosaurus				X^{1}		?73498^{2}				
Varanidae?										
Saniwa								X^{15}		
Xenosauridae										
Exostinus				X^{1,14}		73565^{2}				

NOTES: Undescribed squamate specimens indicated by University of Michigan catalogue numbers

1. Princeton Quarry, Gilmore (1942), Estes (1975)
2. Clark's Fork Basin, undesc. University of Michigan specimens
3. Fritz Quarry, Estes (1975)
4. Rock Bench Quarry, undesc. Princeton University specimens
5. Cedar Point Quarry, undesc. University of Michigan specimens
6. Clark's Fork Basin, Sigogneau-Russell and Baird (1978)
7. Lower Greybull River valley, Sullivan (1979)
8. Sand Coulee (Clark's Fork Basin), Sullivan (1979)
9. Central Bighorn Basin, undesc. University of Michigan specimens
10. Bighorn Basin, Sullivan (1979)
11. Elk Creek, central Bighorn Basin, Gilmore (1938)
12. Divide Quarry, undesc. University of Michigan specimens
13. Rock Bench Quarry, Gilmore (1942), Estes (1975)
14. Schaff Quarry, Estes (1975)
15. Clark's Fork Basin, Gilmore (1928)

REPTILIAN FAUNAS

Reptilian faunas of the Bighorn Basin remain to this date largely undescribed. However, fairly extensive collections of all Tertiary reptilian groups (except snakes) do exist. Work on many of these assemblages is just beginning, and our understanding of early Paleogene herpetofaunas should soon be greatly improved.

Bighorn Basin lizard faunas are dominated by glyptosaurine anguids (Table 1), heavily armored relatives of the Recent alligator lizard (*Gerrhonotus*) and limbless lizard (*Anguis*). The most common Paleocene genus is *Odaxosaurus*, an early anguid already well-represented in the Late Cretaceous. By the early Eocene there is a high diversity of both glyptosaurs and melanosaurs (Sullivan, 1979). The latter tribe is first represented by *Xestops* in the early Clarkforkian, and later by abundant *Arpadosaurus*/*Melanosaurus* forms in the late Clarkforkian and early Wasatchian. The glyptosaurs are less common, and occur only in Wasatchian deposits.

A small anguid of uncertain affinity, cf. *Machaerosaurus*, has been identified from the late Tiffanian Divide Quarry, and from middle Clarkforkian screen-washed concentrate.

Scincomorph lizards, common during the Late Cretaceous (Estes, 1964), and iguanids have never been reported from the basin, and are absent from the University of Michigan collections.

The low lizard diversity seen in the late Torrejonian through early Clarkforkian and middle Wasatchian (Table 1), is probably due in large part to poor sampling. Additional undescribed specimens from these two intervals may be found in the Princeton University and Yale Peabody Museum collections, respectively.

Ophidian remains are exceedingly rare in the Bighorn Basin Tertiary. A few undescribed henophidian snake vertebrae are present in the Yale Peabody Museum (T. M. Bown, pers. comm., 1979), Princeton University, and University of Michigan collections.

The Bighorn Basin provides important early records of the problematical Amphisbaenia, limbless lepidosaurians of unknown relationship. Originally described as a lizard (Gilmore, 1942), *Oligodontosaurus wyomingensis* from the late Tiffanian Princeton Quarry local fauna, represents the oldest diagnostic amphisbaenian (Estes, 1965). Estes (1975, p. 378) erected a new monotypic family for *Oligodontosaurus*, and suggested that it represents "a structural organization closer to the lacertilian ancestors of amphisbaenians than is seen in the other amphisbaenian families."

Another late Tiffanian amphisbaenian specimen (PU 18627) from Fritz Quarry indicates the first presence of the modern family Rhineuridae in the fossil record (Estes, 1975, p. 380). Two other rhineurids have been recovered from an early Wasatchian horizon. The first of these is represented by a skull (UM 68490), and is the earliest certain record of *Spathorhynchus*, the large primitive genus reported from the Bridger and White River Formations (Berman, 1973, 1977). A second, fairly large skull (UM 73403) possesses reduced dorsal sculpturing and enlarged, possibly open orbits, indicating a more derived condition than that seen in *Spathorhynchus*. Based on the skull and vertebral morphology of these forms, early Eocene amphisbaenians were probably already limbless at this comparatively early stage in their evolution.

Champsosaurs, large crocodile-like eosuchians, inhabited the Western Interior of North America from the Late Cretaceous through the Paleocene. Their remains, usually consisting of isolated vertebral centra, are moderately common throughout the Bighorn Basin Paleocene. Specimens have been recovered from the Puercan Mantua Quarry (PU 17076), late Torrejonian Rock Bench Quarry (PU 17077), and most Tiffanian and Clarkforkian horizons in the Big Horn Basin (see Table 1). *Simoedosaurus* is the only genus actually described from the basin (Sigogneau-Russell and Baird, 1978). First identified in Europe, this short-faced form is represented with certainty by only four specimens from the latest Tiffanian and earliest Clarkforkian of the Clark's Fork Basin. The common gavial-like species, *Champsosaurus gigas* (Erickson, 1972), is known from fragmentary specimens in the University of Michigan and Princeton University museums. *Champsosaurus* disappeared abruptly at the end of the Clarkforkian, and is thus of limited biostratigraphic utility. The sudden extinction of champsosaurs, which crossed the Mesozoic-Cenozoic boundary without adverse effect, remains something of a mystery.

The Bighorn Basin provides one of the best areas in North America for the study of early Tertiary crocodilians. Alligator and crocodile remains are relatively abundant throughout the region, in all parts of the stratigraphic section.

The crocodilid *Leidyosuchus* is a common Paleocene element that first appears in the Mantua Quarry (PU, unnumbered). A very fragmentary skull (PU 17121) from the late Torrejonian Rock Bench Quarry may be referable to *Leidyosuchus*. A more complete skull (UM 63119) from Cedar Point Quarry represents a middle Tiffanian form similar to either *L. riggsi* (Schmidt, 1938) or *L. formidablis* (Erickson, 1976). Isolated teeth and postcranial elements from various Tiffanian localities suggest that this genus reached body lengths in excess of four meters. The habitus of the larger species was probably similar to that of the somewhat larger Nile crocodile, an omnivorous dweller of major rivers and lakes (Cott, 1961).

Leidyosuchus-like teeth persist throughout the University of Michigan sections (late Tiffanian to middle Wasatchian), but the Wasatchian remains are exceedingly rare. This seems to be due in part to taphonomic processes. There is a marked change from the large stream and lake regime of the Polecat Bench Formation, to the low topography, small stream and floodplain systems of the younger Willwood Formation. This change presumably discouraged inhabitation by and/or preservation of large crocodilids, while at the same time greatly expanding the environments suitable for small alligatorids.

By far the most common crocodilian elements of the Bighorn Basin Tertiary are *Allognathosuchus* and *Ceratosuchus*. These alligators are relatively small (1.5 to 3.0 meters in total body length) and broad-snouted. They are found almost exclusively in overbank deposits (usually dark grey mudstones).

The most abundant and diverse genus is the familiar pseudoheterodont *Allognathosuchus*, which ranges throughout the early Paleogene of the Western Interior (Mook, 1921, 1961; Simpson, 1930). The first certain Bighorn Basin record of the genus, a fragmentary maxilla (PU 17120), is from Rock Bench

Quarry (late Torrejonian). Two middle Tiffanian species are discernible in the Cedar Point Quarry local fauna. *Allognathosuchus* continues through the Tiffanian, where isolated remains indicate the possible presence of a third, very large species (paralleling the "gigantism" seen in *Leidyosuchus* and *Champsosaurus* at the same time). This alligatorid remains only moderately abundant until the middle Clarkforkian (Willwood Formation), then rapidly increases in numbers to peak sometime during the early Wasatchian. It appears that during the Wasatchian at least two species of *Allognathosuchus* existed at any given time, in a system probably similar to parts of the Amazon Basin where several caiman (*Caiman, Melanosuchus, Paleosuchus*) species may live in the same watershed.

The only described species of *Allognathosuchus* from the Bighorn Basin is *A. wartheni* (Case, 1925), from the "lower levels" (probably late early Wasatchian) of Tatman Mountain.

Schmidt (1938) first described *Ceratosuchus* from the Plateau Valley beds (Clarkforkian?) of Colorado. It appears with moderate abundance in late Clarkforkian deposits of Sand Coulee. The genus is characterized by enlarged horn-like squamosals, but is otherwise a fairly primitive alligatorid. *Ceratosuchus* has not been identified with certainty from horizons other than those mentioned, but this may well be due to misidentification. The dentition of *Ceratosuchus* is only slightly less heterodont than that of *Allognathosuchus*, leading, in the absence of the diagnostic squamosals, to assignment to the more common form.

A single specimen of the "European" caiman *Diplocynodon* has been recovered from a channel sand just below the base of the Wasatchian in Sand Coulee (Clark's Fork Basin). The specimen (UM 69867) closely resembles the type of *D. stuckeri* (Mook, 1960) from the Bridger Formation. *Diplocynodon* was a narrow-snouted, fairly large animal with stout armor and acute, conical teeth. A few isolated teeth probably assignable to the genus are known from Sand Coulee localities of definite Wasatchian age. The scarcity of *Diplocynodon* remains in the Willwood Formation may well be due to the same factors that resulted in low diversities of *Leidyosuchus* in the same horizons (see above). A small dentary (PU 14491) from Mantua Quarry (Puercan) is probably referable to *Diplocynodon*.

The only other crocodilian described from the Bighorn Basin Tertiary is *Orthogenysuchus olseni* (Mook, 1924) from the North Fork of Ten Mile Creek. Known only from the type skull, *Orthogenysuchus* was a broad-snouted eusuchian of moderate size and uncertain affinity. It may be related to *Pristichampsus* (W. Langston, Jr., pers. comm., 1979), a ziphodont crocodilid from the Washakie and Bridger Eocene (Langston, 1975). The presence of a ziphodont crocodilid (cf. *Pristichampsus*) in the Bighorn Basin Tertiary is confirmed by a single tooth (PU 17074) from the Puercan Mantua Lentil.

The testudine faunas of the Polecat Bench Formation and Clarkforkian portion of the Willwood Formation (in the Clark's Fork Basin) are reviewed here. Wasatchian turtles of the Willwood are discussed by J. Howard Hutchison in a following chapter.

Despite their moderate abundance, few turtles have been described from the Polecat Bench Formation. Many important specimens have been collected from Mantua (Puercan), Rock Bench (late Torrejonian), Cedar Point (middle Tiffanian), and Princeton Quarry (late Tiffanian) levels, but only four taxa have been reported. Turtles first appear in the Bighorn Basin Tertiary at Mantua Quarry, where an undescribed trionychid skull (PU 16785), and shell fragments of the baenid *Compsemys* (PU, unnumbered) have been recovered.

Gaffney (1972) studied the baenids from Rock Bench Quarry, where turtles first comprise a significant portion of the herpetofauna. At this level *Palatobaena bairdi* is known from a single maxilla collected near Rock Bench Quarry. The same locality has produced complete lower jaws and skull fragments of the eubaenid *Plesiobaena putorius*. A second late Torrejonian eubaenid is indicated by a partial skull (PU 16838) similar to the Late Cretaceous genus *Eubaena* (Gaffney, 1972, p. 269).

Two forms of trionychids are known from Rock Bench. These undescribed specimens are tentatively assigned to the wastebasket "*Trionyx*" (PU 17109) and the modestly sculptured *Axestemys* (PU 17600). The taxonomy of fossil and Recent "softshell" turtles is poorly understood (see Gaffney, 1979), so precise identification of these forms awaits a revision of the family.

By the middle Tiffanian the baenids had changed little. Cedar Point Quarry has provided the type skulls of *Palatobaena bairdi* and *Plesiobaena putorius*, but there is no evidence of the second eubaenid. Indeterminate baenid taxa are represented by the shell form genus "*Baena*", and the complete lower jaws (UM 74528) of a form that may be referable to *Plesiobaena*.

The most common turtles in the Cedar Point Quarry local fauna are trionychids. Recently excavated specimens in the University of Michigan collections suggest the presence of *Plastomenus* and "*Trionyx*". University of Michigan parties have not yet found any emydid turtle specimens in Cedar Point Quarry. Emydids of this age would add greatly to our understanding of the origin of this important family.

Recent collections from various late Tiffanian localities in the Clark's Fork Basin (including the Princeton Quarry area) have provided many new late Paleocene turtle specimens. Trionychids continue to be the most abundant and diverse group, again represented by *Plastomenus* and "*Trionyx*". Shell fragments of the form genus "*Baena*" are present, but unfortunately no diagnostic cranial material has been recovered (see Gaffney, 1972).

Two undescribed genera of emydid turtles occur in late Tiffanian deposits of the Bighorn Basin. Estes (1975, p. 376) briefly described three specimens of the European emydid *Ptychogaster* from Princeton Quarry and the Reiss Locality. This generic assignment is now questioned (J. H. Hutchison, pers. comm., 1980), and it seems that this North American macrocephalic emydid evolved convergently with the European genus. Fragments of this peculiar turtle have also been found at University of Michigan localities near Princeton Quarry. A "normal" emydid, closely resembling the Eocene genus *Echmatemys*, is fairly abundant in late Tiffanian horizons of the Clark's Fork Basin.

Middle and late Clarkforkian deposits of the Willwood Formation contain abundant, but not very diverse turtle faunas. Several trionychid taxa continue to be very abundant, particularly in the dark gray mudstones where they are often closely associated with alligatorids. Macrocephalic and *Echmatemys*-like emydids are more frequently encountered than in the Tiffanian, and rival the trionychids in abundance. Baenids and chelydrids are represented by very rare, generically indeterminate shell fragments.

Clarkforkian Willwood turtle faunas are considerably less diverse than their Wasatchian counterparts, due largely to early Eocene immigrations and a less diverse emydid component. Dermatemydids, kinosternids, and testudinids first appear in the Bighorn Basin during the Wasatchian, presumably as the result of an immigration from an undetermined source (Hutchison, this volume). Emydids on the other hand appear to have evolved *in situ*, with diversification beginning sometime in the Tiffanian (or earlier?). This radiation produced two Clarkforkian genera, but by the late Wasatchian four or five genera had evolved (Hutchison, this volume).

AVIAN FAUNAS

The birds constitute a minor portion of the vertebrate fauna recovered from the Bighorn Basin Tertiary. Avian remains have not been reported from the Polecat Bench Formation (several fragmentary Princeton University specimens do exist, however), and diagnostic elements are exceedingly rare in Willwood collections. Only ten species, belonging to three orders, have been identified.

The most spectacular and well-known genus is *Diatryma*, the seven foot (2 m) "terror crane" of the Early Tertiary of North America and Europe. Often placed in a separate order (Diatrymiformes) along with related European genera, *Diatryma* is closely related to the rails and cranes (Gruiformes), and may actually be a highly specialized member of that order (Brodkorb, 1967). First described from the Wasatchian of New Mexico (Cope, 1876), and later reported from the Clarkforkian of the Bighorn Basin (Shufeldt, 1913), *Diatryma* was poorly known until 1916 when William Stein discovered a nearly complete skeleton in early Wasatchian beds along Elk Creek (Matthew and Granger, 1917).

Two species of *Diatryma* are known from the Bighorn Basin. *D. ajax* has been reported from the Clarkforkian and Wasatchian of Clark's Fork Basin, and *D. gigantea* (=*D. steini*) represented by Stein's skeleton and a specimen from the early Wasatchian of the Dorsey Creek area in the central basin. The Dorsey Creek specimen is a partial skeleton of a juvenile that was originally described as *Omorhamphus* (Sinclair, 1928).

The skull of *Diatryma* was enormous. The compressed beak was 23 cm long and 16 cm high. The neck was correspondingly long and powerful, and the body was robust. *Diatryma*'s wings were vestigial, but the hind limbs were long (up to 1.3 m) and sturdy, with large feet equipped with four sharp claws. *Diatryma* represented a fascinating avian attempt to fill the terrestrial niche left open by the Mesozoic bipedal carnosaurs. Despite their great size, running ability, and powerful beak and talons, diatrymiforms disappeared by the late Eocene, presumably competitively excluded by the proliferation of carnivorous mammals.

The Gruiformes (Ralliformes) are by far the most diverse and abundant Wasatchian bird group. One rail and six crane species have been described from the Bighorn Basin. The Geranoididae is an Eocene family of primitive cranes that reached their maximum diversity during the Wasatchian. *Geranoides jepseni* is known from poorly preserved portions of the left tibiotarsus and tarsometatarsus found in Willwood deposits along South Elk Creek (Wetmore, 1933). A related species, *Palaeophasianus meleagroides* is also known from the Elk Creek region of the central basin (Shufeldt, 1913). A second, much larger, crane from the Dorsey Creek area was tentatively placed in the genus *Palaeophasianus* as *P. incompletus* by Cracraft (1969). *Geranoides* and *Palaeophasianus* are somewhat similar to the limpkins (Aramidae) and a possible relationship has been suggested (Cracraft, 1969, p. 30).

The oldest described Bighorn Basin crane is *Eogeranoides campivagus* from the late Clarkforkian beds of Foster Gulch. The type specimen (PU 16179) includes the left tibiotarsus and tarsometatarsus, and indicates that *Eogeranoides* was an early offshoot of the Geranoididae, most closely related to *Paragrus* (Cracraft, 1969, p. 27).

Two birds originally described from the head of Elk Creek are referred to the genus *Paragrus. P. prentici* is known only from the type locality (Loomis, 1906), but *P. schufeldti* has also been reported from the early Wasatchian of Foster Gulch (Cracraft, 1969). Two undescribed University of Michigan specimens (UM 9356 and 64050) indicate that *Paragrus* survived into the middle or late Wasatchian in the central basin.

Palaeorallus troxelli is the only true rail (Rallinae) described from the Western Interior Eocene. It is a primitive, medium-sized but moderately robust rail, discovered in Wasatchian deposits northwest of Tatman Mountain (Wetmore, 1931).

The only other described avian order in the Bighorn Basin Tertiary is the Order Strigiformes. *Eostrix mimica* is one of the earliest known owls, preceded in the fossil record only by *Ogygoptynx* from the Tiffanian of Colorado. *Eostrix* was a small, primitive raptor described by Wetmore (1938) from the early or middle Wasatchian of Ten Mile Creek northwest of Worland.

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TAPHONOMY AND FAUNAL SAMPLING IN THE EARLY WASATCHIAN OF THE CLARK'S FORK BASIN, WYOMING

Dale A. Winkler

Abstract.— Intensive study of a previously unsampled early Wasatchian fossil locality in the Clark's Fork Basin indicates that fossils are particularly abundant in the dark gray beds of orange-gray or red-gray couplets representing paleosols. Quantitative comparison of faunal samples collected on the surface with those derived from screen-washed bulk sediment samples indicates that some small taxa (especially insectivores and multituberculates) are seriously underrepresented in surface collections.

INTRODUCTION

With increasing study of early Cenozoic mammalian evolutionary patterns and dynamics in the northern Bighorn Basin (e.g. Gingerich and Simons, 1977; Gingerich and Gunnell, 1979; Rose, 1979), it is becoming increasingly important to understand the death-to-burial history of the fossil assemblages being studied and something of the paleoecology of the mammals themselves. Recent taphonomical studies of Neogene faunal assemblages have demonstrated the great value that analyzing depositional processes and careful sampling of fossil remains have in paleoecological reconstruction (Voorhies, 1969; Behrensmeyer, 1975; Hunt, 1978). During the 1978 field season I carried out a similar study of an early Eocene faunal assemblage in the Clark's Fork Basin of northwestern Wyoming. This paper presents some preliminary results of a more complete analysis to be presented later.

FAUNAL SAMPLING AND TAPHONOMY

To begin this taphonomical analysis, it was necessary to locate an area of outcrop containing fossil material that had not been previously collected. A suitable study area was found in early Wasatchian sediments of the Willwood Formation, and this locality was designated SC-210. The "U"-shaped outcrop at SC-210 occupies an area of approximately 260 x 210 meters. Abundant fossil remains, including mammals, lizards and other reptiles, snails, hackberry seeds, and wood fragments, were present on the surface. Before any collections were made, the surface was examined and all identifiable vertebrate dental and postcranial remains that were encountered were marked with surveyor's flags. This allowed a visual examination of fossil abundance and the relationship between fossil material and lithology (flagging also, incidentally, allowed measurement of fossil movement by slope wash).

The surface was very carefully collected through three stratigraphic intervals to document this fossil-sediment relationship. This was done using a twenty-five square meter quadrat net. All fossil material was located to the nearest square meter, and all dental remains were plotted to the nearest five centimeters.

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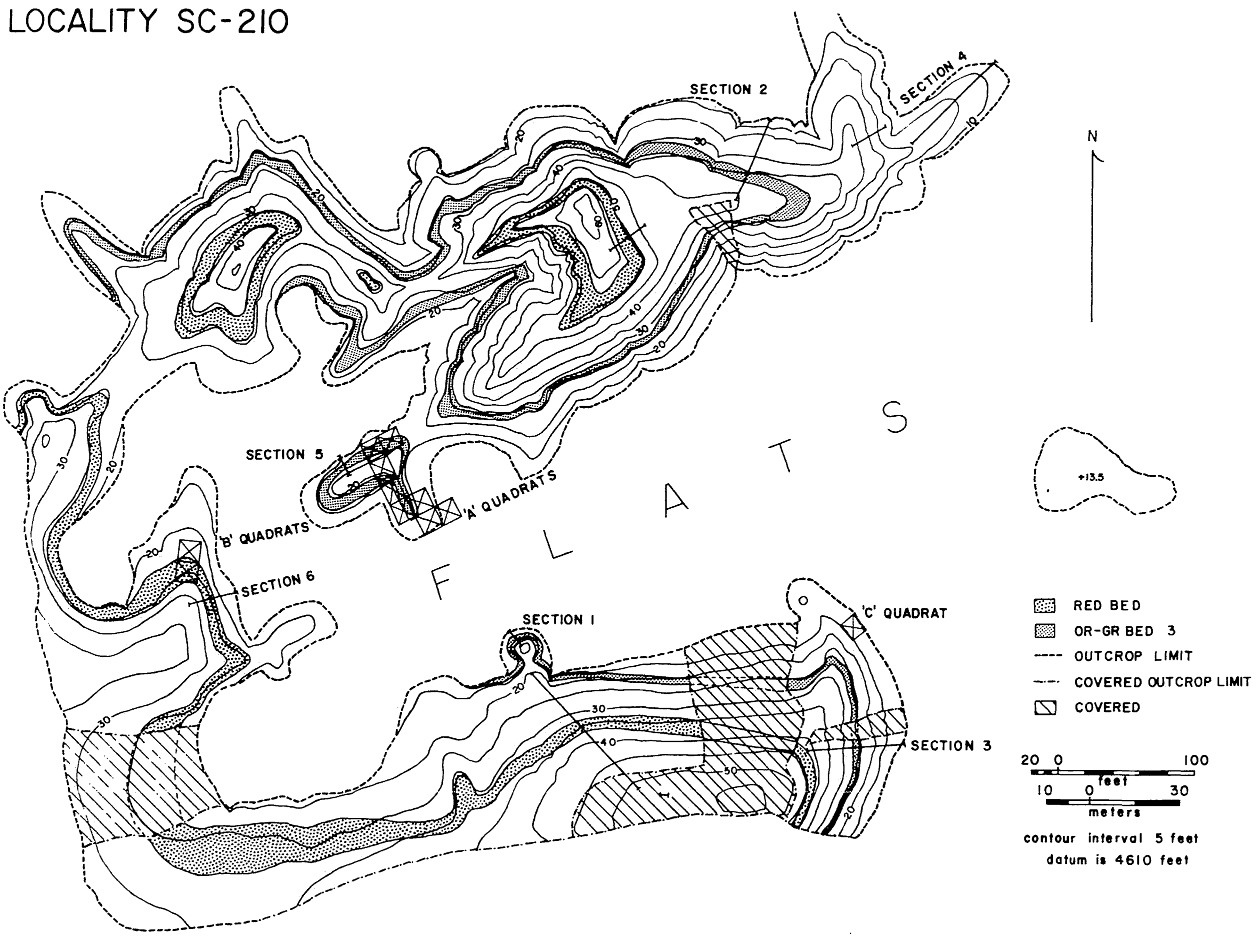

Figure 1. Topographic map of locality SC-210. Two of the prominent paleosols that contain fossil vertebrates are shown (Red Bed, Orange-Gray Bed 3). Sections 1 through 6, and quadrat series 'A', 'B', and 'C' are also shown.

Quadrat sampling is very time-consuming; however it is by far the most effective means of preserving positional information from fossils exposed at the surface. Fossil abundance was particularly high over dark gray mudstones that appear always to overlie mudstones weathering orange or red in color. Bown (1979) found the same relationship in the Sand Creek facies of the Willwood Formation in the southern Bighorn Basin. Quadrat analysis showed that fossil abundance decreased markedly downslope from these dark gray mudstones. This decrease is interpreted as resulting from rapid movement, with destruction and/or reburial of specimens in alluvium after they are exposed at the surface. Fossils were not found in sandstones. The gray-and-orange, -red, or -purple colored mudstone couplets have been interpreted as two horizons of paleosols (Neasham and Vondra, 1972; Bown, 1979).

Fossil collections were linked to lithology by six stratigraphic sections measured within SC-210. Both quadrat and section location were plotted on a topographic map that was made using a plane table and alidade. The position of these sections and of the three quadrat areas ('A', 'B', and 'C') are shown in Figure 1. The stratigraphic sections were measured on unweathered profiles made by trenching. Fossil specimens were found in situ in these section trenches as well as by careful quarrying in areas that had abundant remains on the surface. This procedure also demonstrated that fossils occur only within the dark gray mudstones, as was previously inferred from the surface distributions. Bone and teeth found by

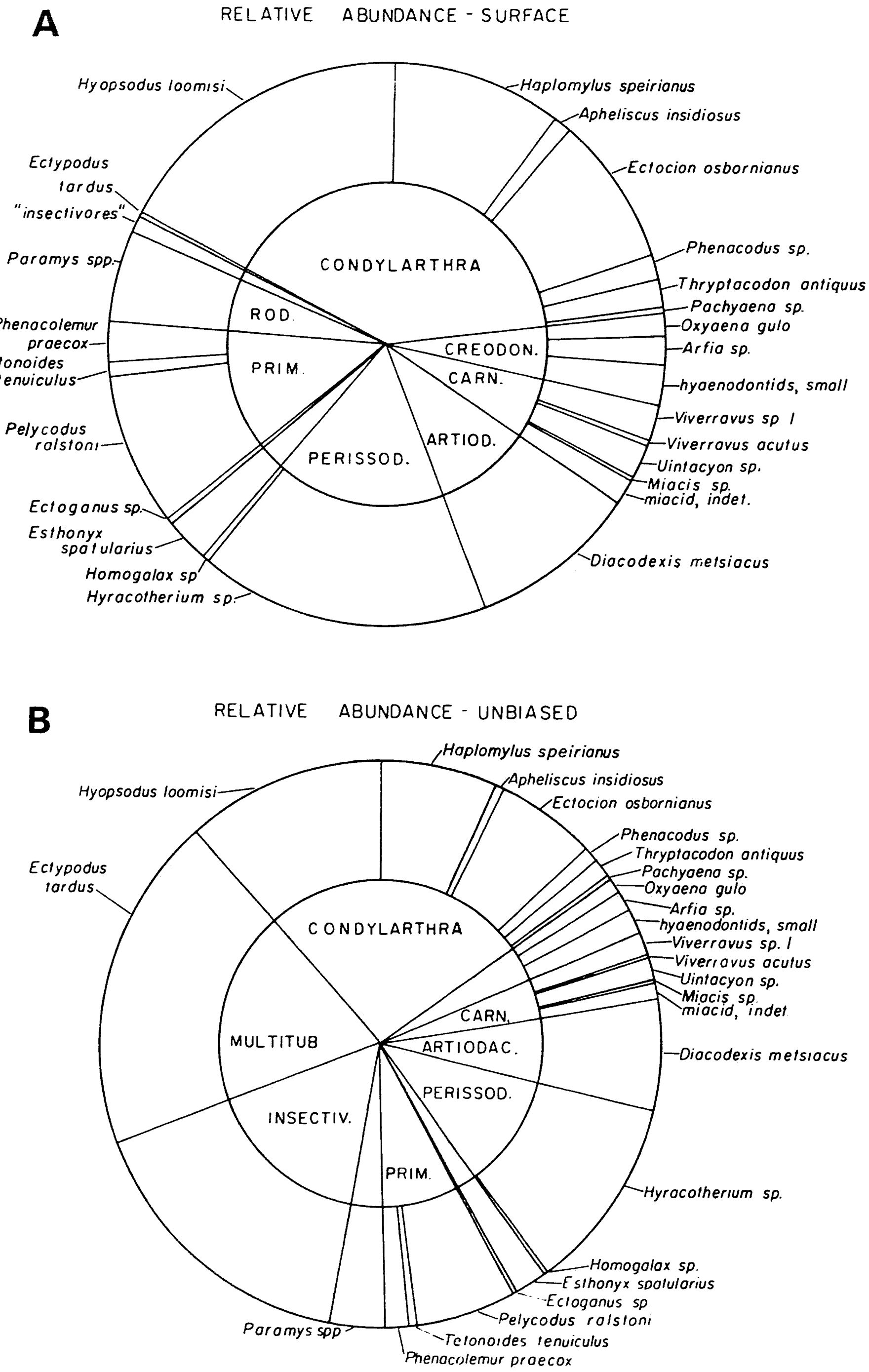

Figure 2. (A) Relative abundance of all mammalian taxa represented by teeth in surface collections from SC-210. The percent abundances are based on a minimum number of 300 individuals. (B) Relative abundance of mammalian taxa after calculating the expected numbers of very small taxa that would be found in an unbiased surface collection, based upon screen-washed samples.

quarrying were fresh and unabraded, but highly fragmented. The very fragile condition of many bone fragments and their unabraded surfaces strongly imply that no appreciable transport of bone occurred before burial. The distribution of preserved skeletal elements indicates that bones of different transport properties were not sorted by currents before burial (Voorhies, 1969; Dodson, 1973). In fact, dental and vertebral elements are among the most common parts preserved, but these are at opposite ends of the transport spectrum (Voorhies, 1969).

The surface outcrop at SC-210 was subdivided into sixty-five units on the basis of breaks in topography and prominent stratigraphic horizons. The units were divided so that collections from them most often represented deposits from only one of the seven dark mudstones present in the locality. Six of these mudstones contained fossil material, but the seventh contained little or none. Each of the units was systematically surveyed to give as complete sampling of the surface of the locality as practicable. Minimum numbers of individuals were computed, using teeth only, for all mammals found in surface collections from the locality. Figure 2A shows the relative abundance of mammals for the entire SC-210 locality. This relative abundance is based on a minimum number of 300 individuals. Figure 2A suggests that the dominant taxa in this fauna were animals of medium-to-large body size. These include *Hyopsodus, Hyracotherium, Diacodexis, Haplomylus, Ectocion,* and *Pelycodus*. Small and very large forms are rare in surface collections.

Once the primary fossil-producing beds were identified, bulk samples from four different dark gray mudstones were screen-washed to obtain all fossil concentrate. This was done to examine the true proportions of taxa and skeletal elements originally preserved in the assemblage. The results showed that the surface collections were clearly biased against taxa of very small body size. Also, modern surface weathering increases the proportion of teeth to other skeletal parts by more rapid destruction of post-cranial bones.

To make an estimate of the unbiased numbers of small insectivores and the multituberculate *Ectypodus tardus* that should have been found in surface collections, the proportions of each of these two groups relative to four of the common taxa listed above *(Hyopsodus, Diacodexis, Haplomylus,* and *Pelycodus)* were calculated for all the screened samples together. This proportion was then related to the actual number of individuals of the four common taxa found in surface collections, so that the expected number of individuals of insectivores and *Ectypodus,* if the surface sample was unbiased, could be calculated. The relative abundances of all taxa were then recalculated using the expected numbers of very small taxa and this is shown in Figure 2B. The unbiased diagram shows that small taxa clearly dominate the assemblage at SC-210. *Ectypodus* comprises nearly nineteen per cent of the mammalian fauna.

It is possible that this proportion of small mammals is unusally high due to washing samples from areas with concentrations of small forms. Bown (1979) has also shown a bias of surface collections against small forms; however his calculated bias was not nearly as large as that found here. Insectivores and multituberculates in the Sand Creek Facies (Bown, 1979) did not constitute nearly as much of the fauna as at SC-210. McKenna (1960) obtained a high proportion of very small insectivores and multituberculates in screen washed samples from Four Mile Wasatchian localities. In no case was *Ectypodus* the dominant element in the Four Mile localities, instead "*Paramys* sp. A" showed the same overdominance pattern in several localities that *Ectypodus* does in SC-210 (McKenna, 1960). These large differences in species dominance might be expected for faunas that are widely separated geographically and also differ by vast amounts of "ecological" time. Although these fossil assemblages preserve only small instants of constantly changing living faunas, the dominant species in the assemblages probably constitute major parts of the early Wasatchian fauna in the areas sampled.

CONCLUSIONS

Locality SC-210 represents at least seven major episodes of soil formation. Bone assemblages accumulated on six of these paleosols. Although the fragmentary condition of bone from this locality probably indicates some carnivore influence on the death assemblage, little or no post-mortem bias or transport was caused by depositing currents, and many animals were probably buried where they died.

Fossil-sediment relationships can tell much of the paleoecology and post-mortem history of fossil taxa. This purpose is best served by careful sampling of fossils and recording detailed positional data. Much can be learned from examining the surface distribution of fossils in badlands localities such as SC-210, however small mammals are clearly underrepresented in surface collections. The most effective means of reconstructing the ecology of ancient mammals is through an intensive program of screen-washing of bulk sediment.

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GENESIS OF A FLUVIAL SHEET SANDSTONE, WILLWOOD FORMATION, NORTHWEST WYOMING

Mary J. Kraus

Abstract.— The Clark Fork sheet sandstone is a 12-31 m thick, laterally extensive sandstone marking the boundary between Clarkforkian and Wasatchian sediments in the Clark's Fork Basin. Analyses of sedimentary facies indicate that the Clark Fork sheet sandstone was deposited by a meandering stream system, and paleocurrent directions indicate that it flowed nearly due north. This sheet sandstone indicates extensive reworking and selective preservation of coarser sediments, resulting from decreased basin subsidence and decreased rates of sediment accumulation in the Clark's Fork Basin at the end of the Clarkforkian and beginning of the Wasatchian.

INTRODUCTION

Meandering or braided stream systems are responsible for most alluvial plain sedimentation occurring in intermontane basins and other areas bordering highlands. In general, braided streams are characterized by relatively steep gradients, shallow, wide channels, and highly variable water and sediment discharge. Meandering streams tend to have more gentle stream gradients, smaller channel width to depth ratios, and more uniform discharge than do braided rivers. As a result of differences in stream behavior, sedimentary deposits left by braided and meandering streams are dissimilar. Deposits of meandering streams are generally finer and contain more overbank sediments than deposits of braided streams. Differences in primary sedimentary structures and in vertical sequences of these structures also occur.

Recent papers in fluvial sedimentology, including Campbell (1976), Allen (1974, 1978, 1979), Friend *et al.* (1979), and Bridge and Leeder (1979), have focused attention on alluvial architecture and its relation to stream morphology and other internal and external constraints. The term alluvial architecture (Allen, 1978) refers to the geometry and internal organization of channel deposits and overbank deposits in an alluvial sequence. The Willwood Formation is of interest in this regard because sandstone geometry varies with time and place. Most Willwood sandstones are lenticular channels with width to depth ratios between 2:1 and 20:1 (Bown, 1979). Channel depths are usually 5 to 10 m and sand bodies are enveloped and separated by thick overbank deposits. Sheet sandstones are both less common and considerably larger than lenticular channel sandstones. Sheets have relatively great lateral extents, as much as several km, and thicknesses of 30 m have been measured. Sheet sandstones are absent in the Willwood Formation of the southeast Bighorn Basin (Bown, 1979) and, in the central Bighorn Basin, they are relatively thin and occur high in the Willwood section. However, sheet sandstones of various sizes are common in the lower portion of the Willwood Formation in the northwest Bighorn Basin. This paper describes the external geometry and internal structure of one laterally

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Figure 1. Exposure of Clark Fork sheet sandstone (arrows) in the Clark's Fork Basin, Sec. 20, T. 56 N., R. 101 W., Park County, Wyoming. View to north.

extensive sheet, herein called the Clark Fork sheet sandstone, in the lower part of the Willwood Formation in the Clark's Fork Basin (Figure 1). The depositional environment and genesis of this sheet sandstone, as well as factors affecting Willwood alluvial architecture and its modification over time are examined.

DESCRIPTION OF THE CLARK FORK SHEET SANDSTONE

The Clark Fork sheet sandstone (Figure 2) crops out over nearly 12 km in the Clark's Fork Basin and ranges from 12 to 31 m in thickness, averaging about 21 m. This sand body forms a lithic boundary between rocks containing mammals of Clarkforkian and Wasatchian ages (Rose, 1978, 1979; Gingerich, Rose, and Krause, this volume). No age diagnostic mammalian fossils are known from the sandstone or from small lenticular mudstone bodies present in it.

In the lower portion of the Willwood Formation in the Clark's Fork Basin (rocks of Clarkforkian age), sheet sandstones are thin (9 m maximum thickness) and laterally impersistent, in comparison to the Clark Fork sheet sandstone and younger sand units. Sheet sandstones in the upper part of the Clark's Fork Basin Willwood section (above the Clark Fork sheet sandstone) are thicker and more laterally extensive than those lower in the section. However, none is as thick or persistent as the Clark Fork sheet sandstone.

The base of the Clark Fork sheet sandstone is a sharply defined erosional surface with varying relief. Beds underlying the sand are invariably grey mudstones containing pedogenic calcium carbonate nodules (Bown, 1979). The sheet sandstone is a multistory, multilateral sand body in that it is not a single, discrete sand unit, but rather it consists of numerous channel deposits that coalesce, both laterally and vertically. Many individual channels can be recognized in the sand body (Figure 3), but most are only partially preserved because younger channels have scoured into them. The largest channel observed is approximately 6 to 7.5 m deep and 55 m wide. Though the Clark Fork sheet sandstone consists primarily of sandy channel deposits, volumetrically insignificant lenticular mudstone bodies also occur in the sand body.

Fossil freshwater gastropods and pelecypods are locally common in other Willwood channel sandstones of the Clark's Fork Basin, yet they are rare in the sheet sandstone. Vertebrate fossils are slightly more common than invertebrate fossils, although mammalian remains are extremely rare. Plant remains, from fragments of wood to logs, are the most abundant organic remains in the sheet sands.

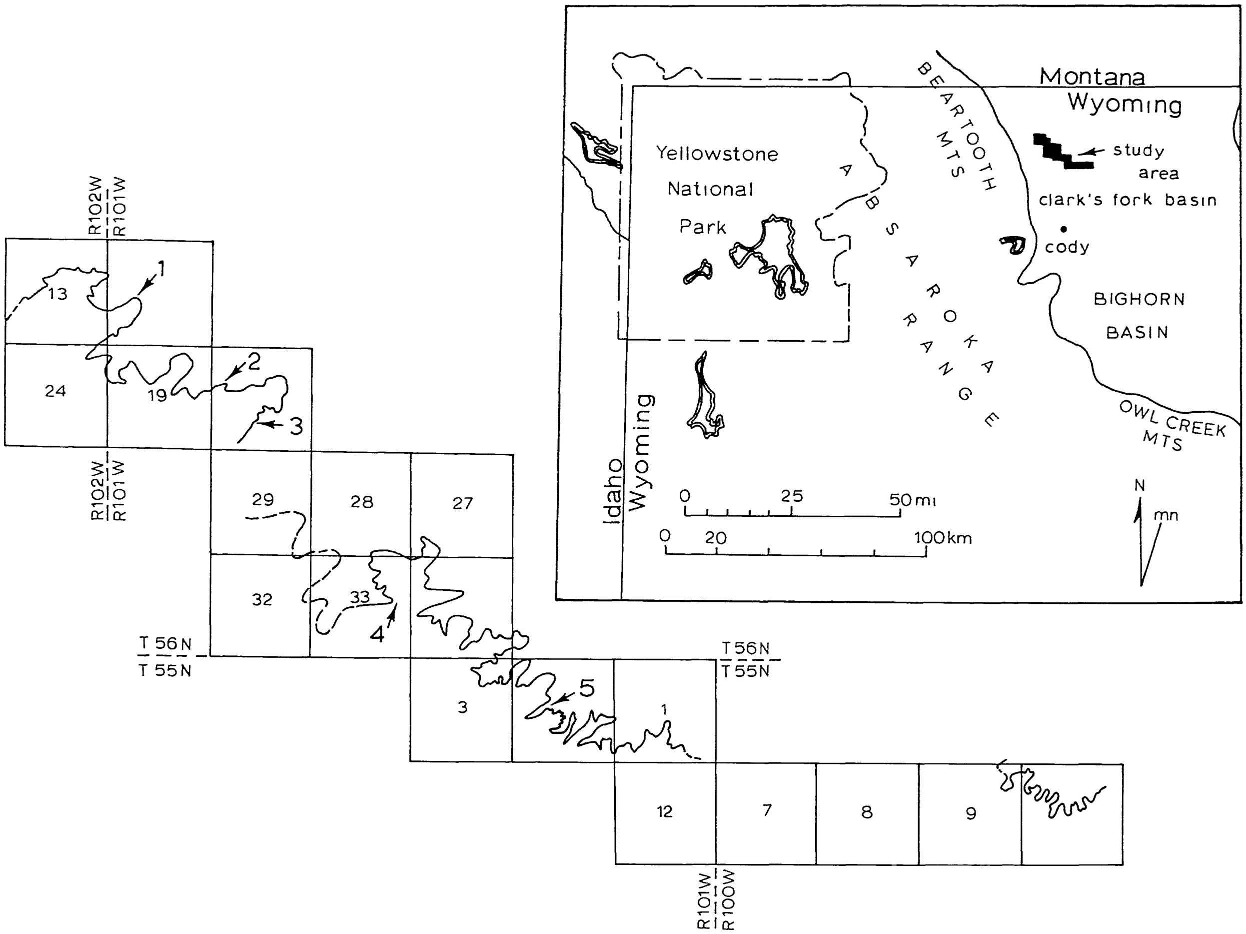

Figure 2. Distribution of Clark Fork sheet sandstone in Clark's Fork Basin of northwestern Wyoming. Numbers indicate measured stratigraphic sections of Kraus (1979; see also Fig. 4).

SEDIMENTOLOGY

Sedimentary Structures

Primary sedimentary structures recognized in the Clark Fork sheet sandstone include scour surfaces and fill, large and small scale trough cross-bedding, low angle stratification, and penecontemporaneous deformation structures. Five depositional facies were distinguished on the basis of sedimentary structures and sediment textures:

1) Scour Fill Facies: Scour surfaces vary in geometry from broad asymmetric scoops to very irregular surfaces. These are generally filled with a poorly sorted mixture of pebbles and coarse sand. The pebbles consist primarily of water abraded calcium carbonate nodules and mudstone intraclasts. This facies makes up 8% of the total thickness of 5 measured stratigraphic sections in the Clark Fork sheet sandstone.

2) Large Scale Trough Cross-Stratified Sandstone Facies: Large scale trough cross-stratification is volumetrically one of the most abundant sedimentary structures, and forms 43% of total section thickness in the sheet sandstone. Cross-stratified sets are generally composed of moderately sorted, medium to fine sand. Average set size ranges from 20 to 30 cm in thickness and rarely exceeds 45 cm. Sets are grouped in cosets

Figure 3. Multiple channels in Clark Fork sheet sandstone showing truncation of older channel deposits by younger channels. Dashed lines separate the different channels. SW¼, NE¼, Sec. 20, T. 56 N., R. 101 W., Park County, Wyoming. View to northeast.

with set size generally decreasing upward within a coset. Set boundaries vary from gently trough shaped to nearly planar. Penecontemporaneous deformation structures, especially convolute laminae, are abundant in this facies.

3) Small Scale Trough Cross-Stratified Sandstone Facies: Small scale cross-stratification is not common in the sheet sandstone, and it comprises only 4% of total section thickness. Sets range from 1 to 5 cm in thickness and are grouped into cosets of 4 to 6 sets. Set boundaries vary from trough shaped to nearly planar. Internal strata are curved and composed of fine to very fine sand. In some cases, sets consist of interstratified mud and fine sand.

4) Low Angle Stratified Sandstone Facies: A volumetrically important depositional facies (42% by thickness) is low angle stratified sandstone. This facies consists of sets of low angle strata that are developed on planar or very slightly curved surfaces. The laterally continuous strata have original dips between 6° and 12° and flatten to nearly horizontal at the base of each set. Sets lie above each other discordantly. Set size varies from 60 to 80 cm in thickness and grain size is fine sand. Parting lineation is usually present on exposed upper surfaces of strata. Scour and fill structures and penecontemporaneous deformation structures are common in this facies.

5) Mudstone Facies: Grey mudstone lenses occur within the Clark Fork sheet sandstone and form 3% by thickness of the measured sections. Sedimentary structures are undetectable. Most mudstone lenses are 0.5 m to 3 m thick and usually less than 20 m wide.

A representative measured stratigraphic section, showing the typical ordering of these 5 depositional facies in the Clark Fork sheet sandstone, is illustrated in Figure 4.

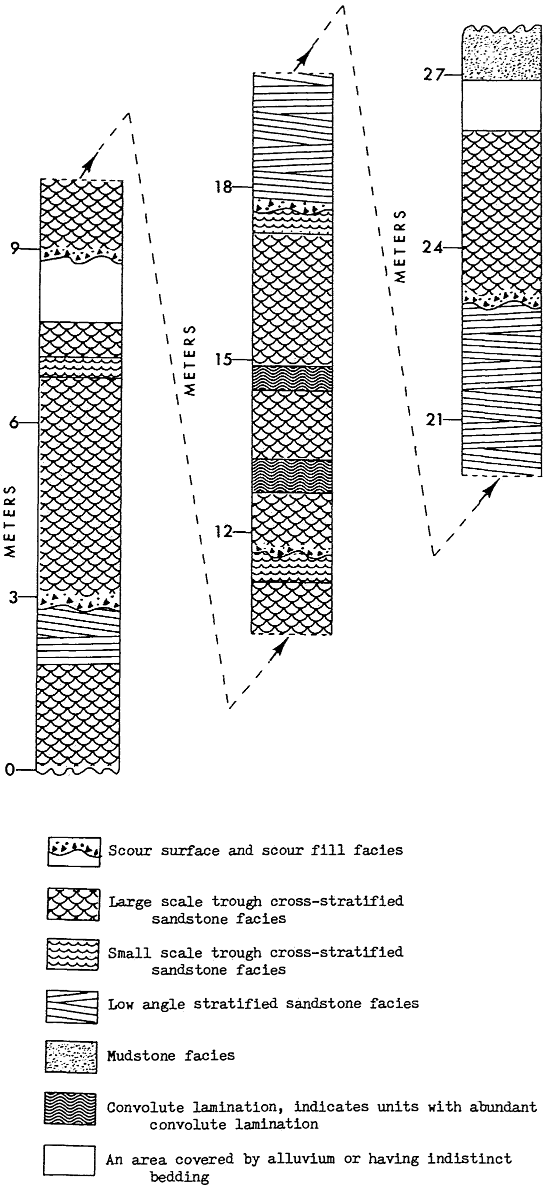

Figure 4. Representative measured section (Section 2) of Clark Fork sheet sandstone (location shown on map in Fig. 2). For other measured sections, see Kraus (1979).

Markov Analysis

Markov chain analysis is a useful tool in studying alluvial deposits (*e.g.,* Gingerich, 1969; Miall, 1973). It allows an ideal facies model or facies sequence to be distilled from observed depositional facies sequences. Figure 5 demonstrates the facies model determined for the Clark Fork sheet sandstone from the combined data of 5 measured sections. Solution of a 5 x 5 matrix for these facies yields a chi-square value of 36.87 with 15 degrees of freedom. For this value, the probability of random ordering of facies is less than 1 in 200.

Depositional Environment

Depositional facies recognized in the sheet sandstone and the ordering of facies determined by Markov analysis indicate that the Clark Fork sheet sandstone was deposited by a meandering stream system. The facies model generally resembles fining upwards sequences described by Allen (1964, 1965), Visher (1965), and others for meandering stream deposits. A fining upwards sequence records the sequential development of a channel system, channel abandonment, and eventual channel fill and burial beneath floodplain deposits. Complete fining upwards sequences are not common in the sheet sandstone because of its multistory character (superimposed channel deposits). Coarser lower members of the sequence, that is, scour fill facies (8% of total section thickness) and large scale trough cross-stratified sandstone facies (43% of total section thickness), are more commonly preserved than the finer upper members. Mudstones and small scale trough cross-stratified sandstones are commonly truncated by younger channels. Wolman and Leopold (1957), Bridge (1975), and Jackson (1976) have observed that complete fining upwards sequences are rarely preserved when a channel meanders freely across its floodplain. This is because meander migration erodes older deposits.

Additional evidence supporting a meandering stream interpretation for the Clark Fork sheet sandstone and other Willwood sheets includes: 1) high mudstone to sandstone ratios for the Willwood section as a whole in the Clark's Fork Basin (Jackson, 1978); 2) clay plugs, which record the neck or chute cut-off of a meander loop and the subsequent infilling of the abandoned channel with fine material (Allen, 1965); 3) abundant mudstone intraclasts in coarser facies (Jackson, 1978); and 4) channel width to depth ratios which are less than 40:1 (Miall, 1977).

Paleocurrent Analysis

Paleocurrent measurements obtained from large scale trough cross-strata indicate that the stream system which deposited the sheet sandstone flowed

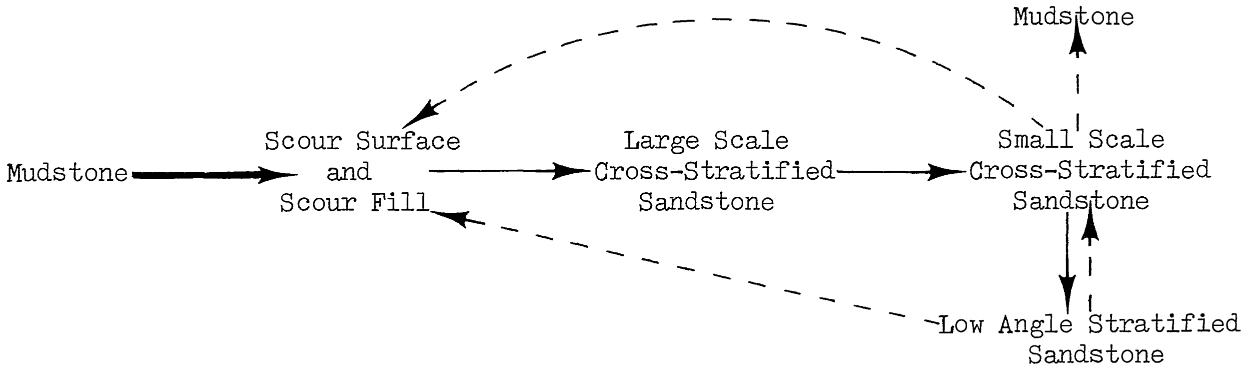

Figure 5. Preferred non-random depositional facies sequence for the Clark Fork sheet sandstone. Heavy solid lines show transitions that have observed-minus-random transition probabilities greater than 0.5, light solid lines show probabilities between 0.15 and 0.3, and dotted lines indicate probabilities between 0.04 and 0.15. Diagram derived from data in Appendix B of Kraus (1979).

nearly due north. This agrees closely with Neasham's (1970) azimuth of 4° for Willwood streams in the Clark's Fork Basin and his average azimuth of 355° for Willwood streams in the central and northern Bighorn Basin. Love and Reed (1968), Young (1972), and Bown (1979) demonstrated southeast trending paleocurrents for upper Paleocene rocks of the Polecat Bench Formation in the southeast Bighorn Basin. Bown (1979) suggested that a reversal from southeast to north for the major Bighorn Basin paleodrainage occurred sometime between the Paleocene and middle early Eocene. This reversal was related to the rise of the Owl Creek Mountains which border the southern Bighorn Basin (Keefer, 1965; Bown, 1979). Evidence of this study suggests that major Willwood streams in the Clark's Fork area flowed northward earlier than streams in the southern part of the basin.

Genesis of the Clark Fork Sheet Sandstone

The mechanisms responsible for continental sheet sandstone formation are not completely understood, and the interpretations of these bodies in the literature are varied. Campbell (1976) determined that the Westwater Canyon Member of the Morrison Formation, a very extensive sheet sandstone in New Mexico, was deposited by coalescing braided streams. Conaghan and Jones (1975) demonstrated that the sheetlike Hawkesbury Sandstone of Australia was formed by low sinuosity streams. McCormick and Picard (1969) concluded that the Gartra Formation, a thin sheet sandstone in northeast Utah and northwest Colorado, was deposited by low gradient, probably meandering streams, though they failed to explain how or why the sheet geometry developed.

Floodplain construction is governed by a complex of external and internal variables, including stream morphology, lithology and climate of the source area, tectonic activity, climatic conditions in the depositional area, total sediment load, and amount of suspended load. Early fluvial facies models (*e.g.*, Allen, 1965; Walker, 1976) related sandstone geometry primarily to stream morphology. It was thought that braided and low sinuosity streams deposited sheet sandstones, while meandering streams formed lenticular or tabular sand bodies separated laterally and vertically by fine overbank deposits. Recently attention has been focused on the relation of alluvial architecture to other controls on floodplain sediments. For example, Friend *et al.* (1979) suggested that different sandstone geometries in middle Tertiary deposits in the Ebro Basin of northeast Spain reflect differing stream flow strengths, bank strengths, and climatic and tectonic conditions. Simulation modeling by Allen (1978) demonstrates that the alluvial architecture of meandering stream deposits depends on channel size, frequency of avulsion, and rate of basin subsidence. Sand body density in an alluvial sequence is inversely proportional to the rate of basin subsidence. Floodplain deposits with a high degree of sand body interconnectedness and a relatively small proportion of fine overbank deposits develop if the rate of basin subsidence is low. Some of Allen's conclusions were foreshadowed by Yeakel (1962) and Smith (1970) who suggested that slow basin subsidence would result in a meandering stream migrating back and forth across its floodplain, continually reworking older sediments. Fine overbank deposits are removed from the system, leaving a floodplain sequence dominated by sandy channel sediments. Wolman and Leopold (1957) observed such floodplain sediments along modern, stable meandering streams in North Carolina and Maryland.

The Clark Fork sheet sandstone was deposited by meandering streams. In light of Allen's (1978) model, attributes of the sheet, including its lateral continuity, multistory character, and the paucity of associated overbank sediments, reflect decreased subsidence of the northern Bighorn Basin and relatively slow rates of sediment accumulation. Decreased subsidence allowed the stream system to repeatedly rework previously deposited material, selectively removing fine overbank sediments. There is abundant evidence to show reworking of older deposits in the Clark Fork sheet sandstone. Fining upwards sequences are typically truncated by scour surfaces. Mudstone intraclasts and rounded calcium carbonate paleosol nodules that were derived from surrounding overbank sediments are abundant clasts in channel lag deposits. The thickness and degree of sand body interconnectedness of the sheet sandstone developed not because fine overbank deposits did not form, but because these sediments were not preserved. Consequently, the Clark Fork sheet sandstone represents an alluvial accumulation dominated by sandy channel deposits associated with minor overbank deposits.

SUMMARY

It seems probable that Willwood alluvial architecture in the Clark's Fork Basin was modified through time in response to tectonic controls (specifically basin subsidence rates), rather than in response to changes in channel morphology, climate, or lithologic controls. In that section of the Willwood Formation that is of Clarkforkian age, sandstone bodies are principally lenticular channel sandstones, deposited by meandering streams. Thick overbank deposits envelope and separate the sand bodies and reflect fairly rapid rates of basin subsidence and sediment accumulation. In the upper part of the Clarkforkian sequence and in overlying rocks of Wasatchian age, sheet sandstones appear. Channel morphology did not change, and there is no evidence to suggest the development of different climates or new source areas. Sheet development resulted from decreased rates of basin subsidence and decreased rates of sediment accumulation in the Clark's Fork Basin during this time. This allowed reworking of floodplain deposits and the consequent selective preservation of sandy, channel deposits.

ACKNOWLEDGMENTS

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MAGNETIC POLARITY STRATIGRAPHY AND PALEOCENE-EOCENE BIOSTRATIGRAPHY OF POLECAT BENCH, NORTHWESTERN WYOMING

Robert F. Butler,[1] Everett H. Lindsay,[1] and Philip D. Gingerich[2]

Abstract.— Late Paleocene and early Eocene mammalian faunas are well represented in a 1500 m sequence of continental sediments exposed on the south side of Polecat Bench. This part of the Polecat Bench section includes faunas representing four of the five Tiffanian *Plesiadapis* zones, all three Clarkforkian zones, and the basal Wasatchian *Pelycodus ralstoni* zone. The entire sequence is of reversed polarity except for two normal polarity zones, one in the transition from the middle to late Tiffanian and the other in the transition from the Tiffanian to Clarkforkian. By comparison with the Cenozoic magnetic polarity time scale, these are interpreted as magnetic anomalies 26 and 25. The Paleocene-Eocene boundary in North American mammalian faunas is placed between the early and middle Clarkforkian, which our work indicates is just above anomaly 25 on the magnetic polarity time scale.

INTRODUCTION

Magnetostratigraphic studies of terrestrial sedimentary sequences containing important vertebrate faunas are of considerable importance in establishing the geochronology of land mammal ages. Early and middle Paleocene land mammal ages (Puercan and Torrejonian) are best known from continental sediments of the Nacimiento Formation in the San Juan Basin of New Mexico. The paleomagnetic stratigraphy of these beds has been studied recently (Butler et al., 1977; Lindsay, Jacobs, and Butler, 1978; Taylor and Butler, 1980; Lindsay, Butler, and Johnson, 1980; see also Tomida and Butler, 1980). Faunas of late Paleocene and early Eocene land mammal ages (Tiffanian, Clarkforkian, and Wasatchian) are best documented in the Clark's Fork and Bighorn basins. Here we present a preliminary report on the paleomagnetic stratigraphy of late Paleocene and early Eocene land mammal ages in the northern Bighorn Basin, with particular reference to mammalian faunas in the stratigraphic section exposed on the south side of Polecat Bench. A more extensive report on this work in the Clark's Fork Basin-Polecat Bench area is in preparation.

BIOSTRATIGRAPHY

The Tiffanian Land-Mammal Age can be subdivided into five zones or biochrons in the Clark's Fork Basin-Polecat Bench area, based on the evolution of the archaic primate genus *Plesiadapis* (Gingerich, 1976). These are, in sequence, the *P. praecursor, P. anceps, P. rex, P. churchilli,* and *P. simonsi* zones, which we abbreviate Ti_1-Ti_5, respectively. The very latest Tiffanian and Clarkforkian can be subdivided into three zones, based on large *Plesiadapis* or its absence. These are, in sequence, the *P.* sp. nov., *P. cookei,* and *Phenacodus-Ectocion* zones (Rose, 1980), which we abbreviate Cf_1-Cf_3, respectively. Similarly, the Wasatchian of the Clark's Fork and Bighorn basins can be subdivided into five *Pelycodus* zones or

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biochrons (Gingerich, 1980), only the first of which, the *Pelycodus ralstoni* zone (Wa_1), is present on Polecat Bench.

Tiffanian, Clarkforkian, and Wasatchian faunas occur through a 1500 m thick sequence of sediments in the Polecat Bench and Willwood formations on Polecat Bench (from approximately 100 m to 1600 m above the base of the Polecat Bench Formation; see Gingerich, Rose, and Krause, this volume). This sequence includes faunas of Tiffanian zones Ti_2-Ti_5, Clarkforkian zones Cf_1-Cf_3, and early Wasatchian zone Wa_1; that is, a complete sequence of late Paleocene and early Eocene faunas from zones Ti_2 through Wa_1.

The Paleocene-Eocene boundary in North America was previously placed between the Tiffanian and Clarkforkian land mammal ages, based on correlation of North American mammalian faunas with those of the Paris Basin in Europe using *Plesiadapis* (Gingerich, 1976). Recent work indicates the presence of a new species of *Plesiadapis* in North America temporally and phyletically intermediate between previously known *P. simonsi* and *P. cookei.* This latest Tiffanian-early Clarkforkian species is most similar to latest Thanetian *Plesiadapis* in Europe, indicating that the Paleocene-Eocene boundary recognized between the Thanetian and Sparnacian in Europe should be placed between the early and middle Clarkforkian in North America (Rose, 1980). In terms of the zonation used here, the Paleocene-Eocene boundary falls between biochrons Cf_1 and Cf_2.

MAGNETIC POLARITY STRATIGRAPHY

At least three oriented block samples were collected at each of 190 sites in the Polecat Bench section. Collection and sample preparation techniques are described in Lindsay, Butler, and Johnson (1980). Each paleomagnetic site was chosen to sample the finest lithology and least weathered outcrop available, and sites were spaced 20 ft (6 m) apart whenever suitable lithologies were present. Most sites were in dark claystone or fine siltstone, and red beds in the Willwood Formation were avoided. Measurements of remanent magnetization were made using a cryogenic magnetometer (Superconducting Technology, C-102) with noise level of approximately 1×10^{-7} gauss·cm^3. A Schonstedt GSD-1 single-axis demagnetizer was used for performing alternating-field (AF) demagnetization. Double demagnetizations were done for most AF treatments and no diverging directions or erratic behavior were observed.

Intensities of natural remanent magnetization (NRM) are low in both the Polecat Bench and Willwood formations. Mean NRM intensities following AF demagnetization in 300 oe peak field are 3×10^{-7} gauss in the Polecat Bench Formation and 6.5×10^{-7} gauss in the Willwood Formation. The AF demagnetization behaviors observed for these samples are quite similar to those observed for samples from the San Juan Basin (Lindsay, Butler, and Johnson, 1980). The carrier of the primary NRM has the characteristics of detrital magnetite or titanomagnetite, and there seems little doubt that the primary NRM is a depositional remanence acquired penecontemporaneous with deposition.

Site mean directions were calculated and a test for randomness was also performed. Statistical parameters of all sites were examined to establish which sites contained a grouping of sample NRM vectors exceeding that expected if the vectors were sampled from a random population ($p \leqslant 0.05$). Passage of this test requires $R \geqslant 2.62$ for $N = 3$ and is a rather stringent test for such weakly magnetized rocks. In the Polecat Bench section, 90 of the 128 sites in the Polecat Bench Formation passed this test, while 28 of the 40 sites in the Willwood Formation passed the test. No data were rejected as a result of this statistical analysis. However, we are more confident of polarity assignments for sites passing the test than for others. Accordingly, sites whose clustering is significantly different from random at the 95% confidence level are given more weight in our interpretation of the polarity zonation.

INTERPRETATION

Site mean virtual geomagnetic pole (VGP) latitudes following AF demagnetization are plotted for the Polecat Bench section in Figure 1. Also illustrated are positions of the principal fossil localities and the range of each of the Tiffanian, Clarkforkian, and Wasatchian mammalian biochrons, together with the interpreted magnetic polarity column. Negative VGP latitude indicates reversed polarity and positive VGP latitude indicates normal polarity. We have not designated polarity zones in the lower 100 m of this section because we do not believe that the results in this interval can be interpreted reliably. Lithologies in this stratigraphic interval are dominated by sandstones, and weathering of the outcrop is quite deep in this area. Also, we do not observe a coherent pattern of results distributed into stratigraphic intervals of positive and negative VGP latitudes. Above the 100 m level, we do observe coherent patterns of VGP latitudes that clearly define the polarity zonation.

Most of the 1500 m thick stratigraphic sequence

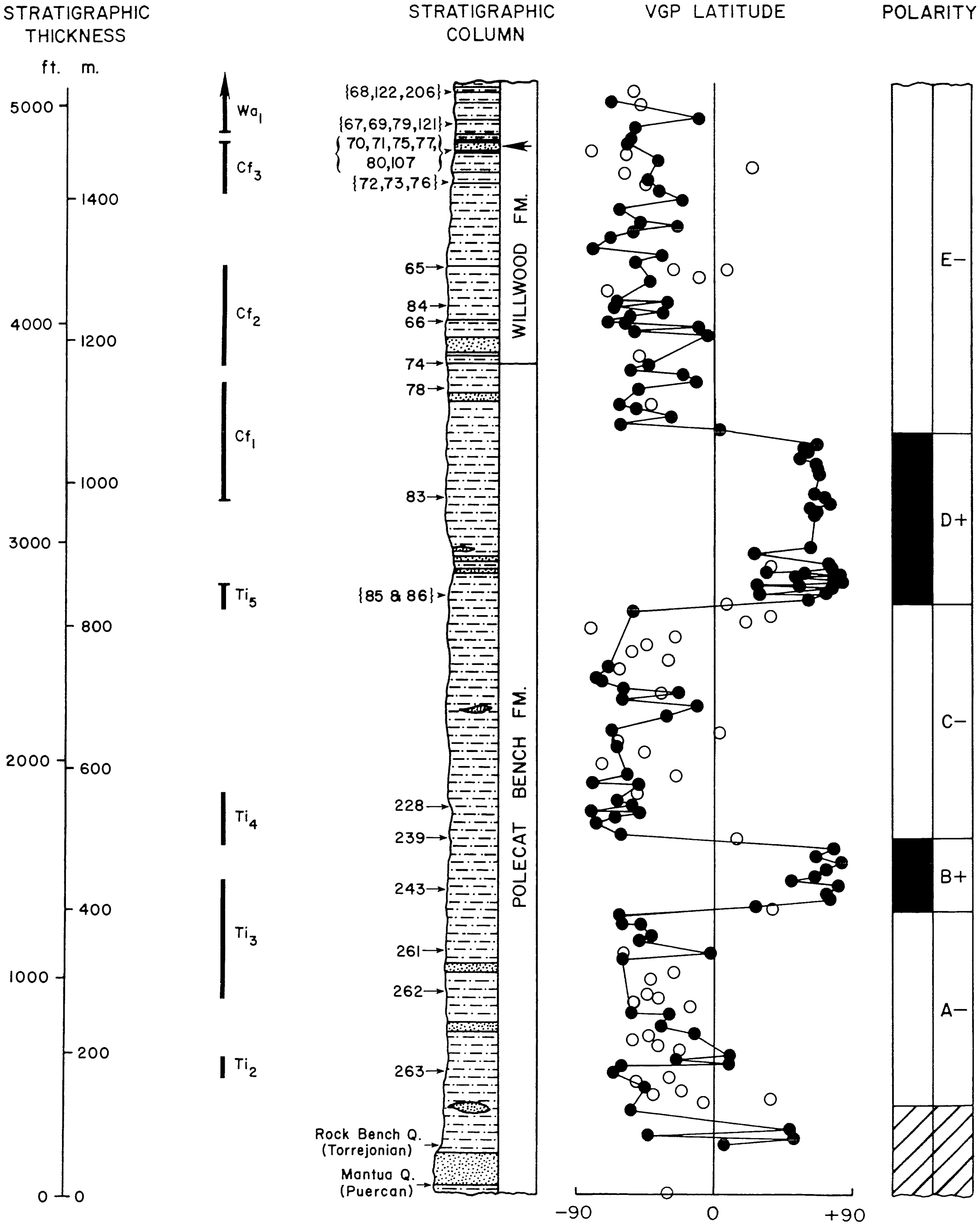

Figure 1. Stratigraphic section on the south side of Polecat Bench, showing the position of each of the principal University of Michigan fossil locations (numbered) in the drab Polecat Bench and red-banded Willwood formations. Biochrons abbreviated Ti_{2-5}, Cf_{1-3}, and Wa_1 are explained and discussed in the text. Mean virtual geomagnetic pole (VGP) latitudes for each site in the Polecat Bench section are illustrated together with our interpreted polarity column. Normal polarity zones B+ and D+ are interpreted as magnetic anomalies 26 and 25, respectively. The Paleocene-Eocene boundary between biochrons Cf_1 and Cf_2 is just above the top of anomaly 25.

above the 100 m level in the Polecat Bench section is of reversed magnetic polarity. There are two significant normal polarity zones in this sequence, one from level 400 m to 500 m, and the other from level 820 m to 1070 m. As shown in Figure 1, the first normal polarity zone (B+) occurs at the transition between the *Plesiadapis rex* (Ti$_3$) and *P. churchilli* (Ti$_4$) zones, which is also the transition from middle to late Tiffanian. The second normal polarity zone (D+) occurs at the transition from the latest Tiffanian *Plesiadapis simonsi* Zone (Ti$_5$) to the early Clarkforkian *Plesiadapis* sp. nov. zone (Cf$_1$). Most of the early Clarkforkian falls within this second normal polarity zone.

The pattern of reversals observed in the Polecat Bench section is one of a relatively long early and middle Tiffanian reversed interval (A-), a relatively short normal interval (B+), a short late Tiffanian reversed interval (C-), a moderate early Clarkforkian normal interval (D+), then a long reversed interval (E-) extending through the middle and late Clarkforkian and early Wasatchian (our results indicate that all of the early Wasatchian in the Clark's Fork Basin to the west of Polecat Bench is also of reversed magnetic polarity). This signature matches that of anomalies 25 and 26 on recently published magnetic polarity time scales (Tarling and Mitchell, 1976; La Brecque, Kent, and Cande, 1977; Hardenbol and Berggren, 1978; and others). Furthermore, anomaly 26 corresponds to the *Planorotalites pseudomenardii* (P4) planktonic foraminiferal zone, which is mid-Thanetian in age (Berggren et al., 1978), corroborating our interpretation here.

In Europe, the Paleocene-Eocene boundary is usually drawn between the Thanetian and Sparnacian ages (Gingerich, 1975; Berggren et al., 1978). By comparison with mammalian faunas of the Paris Basin, the Paleocene-Eocene boundary in North America appears to correspond to the early Clarkforkian-middle Clarkforkian boundary (Rose, 1980). The transition from the early to middle Clarkforkian occurs between localities SC-78 and SC-74, which is just above magnetic polarity zone D+ (Figure 1). In other words, the Paleocene-Eocene boundary appears to fall just above anomaly 25 in the Polecat Bench section. The Paleocene-Eocene boundary on Polecat Bench corresponds closely to the Polecat Bench-Willwood formational boundary, but this correspondence appears to be largely accidental since the formational boundary is clearly time transgressive in other areas of the Clark's Fork and Bighorn basins.

Magnetic stratigraphy and its correlation with mammalian biostratigraphy during most of the Eocene has not yet been studied, and a number of questions in the Paleocene remain to be clarified. For example, we are not yet able to make an unambiguous paleomagnetic and biostratigraphic correlation between the San Juan Basin and the Polecat Bench area. However, it is becoming increasingly clear that magnetostratigraphy can and will make a very important contribution to understanding the geochronology of the Paleocene-Eocene transition and other important events of Cenozoic faunal evolution.

ACKNOWLEDGMENTS

We thank Larry Flynn, Louis Taylor, Yuki Tomida, and Dick Haskin for assistance in the field and in the paleomagnetic laboratory. Some paleomagnetic equipment was furnished by a Cottrell Research Grant from the Research Corporation at the University of Arizona. This research was supported by National Science Foundation grants DES 75-13516 and EAR 78-03326 to the University of Arizona and DEB 77-13465 to the University of Michigan.

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FAUNAL ZONATION OF THE WILLWOOD FORMATION IN THE CENTRAL BIGHORN BASIN, WYOMING

David M. Schankler

Abstract.— A new biostratigraphic zonation of the Willwood Formation is proposed, based on mammalian faunas from 240 fossil localities in a 773 m thick stratigraphic section in the central Bighorn Basin. Three biohorizons, A, B, and C, associated with exceptionally high rates of faunal immigration and "extinction" are documented. These biohorizons separate the Lower and Upper *Haplomylus-Ectocion* Range Zones, the *Haplomylus-Ectocion* Range Zone and *Bunophorus* Interval Zone, and the *Bunophorus* Interval Zone and *Heptodon* Range Zone, respectively. Immigration and "extinction" in the first two biohorizons (A and B) appear to be related to changing climatic or ecological conditions, whereas turnover at the third biohorizon (C) has characteristics suggesting breakdown of a physical barrier to immigration. Ideally, biostratigraphic correlation should be based on immigration-"extinction" events in whole faunas as well as morphological characteristics of individual species.

INTRODUCTION

In the thirty five years after Wortman's first expedition into the central Bighorn Basin, extensive collections of early Eocene mammals were secured by parties from Princeton University, Amherst College, and the American Museum of Natural History. These specimens provided much of the data for the major reviews of the Bighorn Basin early Eocene fauna by Sinclair, Matthew, and Granger (Sinclair, 1914; Matthew, 1915, 1918; Granger, 1915). Stratigraphic information gathered by the expeditions of Sinclair and Granger (1911, 1912), coupled with this faunal data, produced the faunal zonation of Granger (1914) that has stood until today. For the better part of a century the detail of this zonation was sufficient for most paleontological needs. However, recent interest in constructing species lineages (Gingerich, 1974, 1976; Gingerich and Simons, 1977; Gingerich and Gunnell, 1979) has necessitated a finer division of the record and a faunal zonation that more accurately reflects the nature of changing faunal composition. For the early collections, however, "a great deal of the potentially important data inherent in the specimens brought back from this classic early Eocene collecting ground have been lost because exact locality and horizon records were not kept" (Radinsky, 1963).

Renewed investigation of the faunas from the central Bighorn Basin, using specimens collected by Yale University parties under the direction of Elwyn L. Simons, has begun to remedy this situation. Starting in 1961 and continuing to the present, over 15,000 specimens have been collected from more than 300 localities in the area southwest of the town of Basin, Wyoming. Individually, most of these localities are of limited areal extent and pertain to a restricted stratigraphic interval. Together they cover a 250 square mile (650 km^2) area along the drainages of

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Antelope, Dorsey, Elk, and Fifteen Mile Creeks, and represent a time interval that spans most of the Wasatchian Land-Mammal Age. The geographic position of each locality is plotted on reference topographic maps housed at Yale University. All localities are in the Willwood Formation as defined by Van Houten (1944).

Two stratigraphic sections have previously been measured through the Willwood Formation, one by Meyer and Radinsky in 1965 (unpublished) and the other by Neasham and Vondra in 1969 (unpublished). Neither of these sections includes the richest localities found during the past ten years, greatly limiting the utility of the large fossil collections from the central Bighorn Basin. During the summers of 1976 through 1978 a third stratigraphic section was measured by Schankler and Wing from the contact with the underlying Fort Union Formation on Antelope Creek to the contact with the overlying Tatman Formation on Bobcat Ridge. A total of 240 fossil localities were tied directly into this new section in the field. The Schankler-Wing section, hereafter referred to as the Elk Creek Section, provides the basis for a new analysis of faunal zonation in the Willwood Formation of the central Bighorn Basin. The new zonation presented here is based on the relatively precise temporal ranges of the entire fauna and it promises to be both utilitarian and heuristic.

Abbreviations used in the text and figure captions are: UW, University of Wyoming, Laramie; and YPM, Yale Peabody Museum, New Haven.

HISTORY OF INVESTIGATION

When fossils from the Bighorn Basin were first discovered, they were thought to come from a faunally undifferentiated unit, the *Coryphodon* Zone. Following the first published report of *Lambdotherium* from the Buffalo Basin (Loomis, 1907), it was recognized that the Bighorn Wasatch is in part faunally equivalent to the Wind River Formation. This eventually led to a threefold division of the Bighorn Wasatch: the Bighorn Knight, the Bighorn Lysite, and the Bighorn Lost Cabin. A further study of the rather sparse fossil collection from the type Knight Formation of southwestern Wyoming led Granger (1914) to believe that the Knight was a closer equivalent to the fauna from the Lysite "Formation" of the Wind River Basin, and he proposed the name Gray Bull beds as a substitute for Bighorn Knight. This zonation of the Bighorn Wasatch was based on the temporal distribution of three genera of perissodactyls. The Gray Bull beds were defined as those sediments containing the genus *"Systemodon" (Homogalax),* the Lysite was defined by the presence of *Heptodon* and the absence of both *"Systemodon"* and *Lambdotherium,* and the Lost Cabin was defined by the presence of both *Heptodon* and *Lambdotherium.* The Gray Bull beds were also informally subdivided into three units (lower, middle, and upper), presumably corresponding to the three faunal horizons of Sinclair and Granger (1911). The faunal characteristics of this subdivision were never discussed in any detail.

Van Houten (1944) reviewed the stratigraphy and distribution of the Bighorn Wasatch and proposed the replacement name of Willwood Formation for the red-banded sediments that overlie the Fort Union Formation and are overlain by the Tatman Formation. Van Houten (1944) and Neasham (1967) provide excellent summaries of the nomenclatural history of the stratigraphic and faunal zonation of the Willwood. It was also at this time that problems with the zonation of the Willwood Formation began to become apparent. Van Houten (1945) noted that the upper Gray Bull was faunally more similar to the Bighorn Lysite than it was to the middle Gray Bull. Guthrie (1967), while reviewing the fauna from the type Lysite in the Wind River Basin, pointed out that the Lysite member of the Wind River Formation was equivalent to only the upper portion of the sediments referred to as Lysitian in the Bighorn Basin. This was based on the presence of *Heptodon* and absence of *Hyopsodus powellianus* in the lower part of the Bighorn Lysite, both species being present in the faunas from the type Lysite and the upper part of the Bighorn Lysite. It is also probable that the fossiliferous zone of the Bighorn Lost Cabin does not correspond to the Lost Cabin fauna of the Wind River Formation as defined by Guthrie (1971), although both are included in the Lostcabinian or *Lambdotherium* Zone as presently understood.

Bown (1979), in discussing the faunal correlation of the No Water fauna, notes the inadequacy of the present nomenclatural system and in particular points out the difficulty associated with using the range zone of *Homogalax* to define the Gray Bull, since the No Water fauna appears to be "Graybullian" in age and yet contains no specimens of that genus. Gingerich (pers. comm.) reports that the specimen (UW 8201) referred to *Hyracotherium* sp. by Bown (1979) is most likely a specimen of *Homogalax.* The important point, however, is that the virtual absence of this genus from the No Water fauna raises serious doubts as to its utility for defining the Gray Bull. Further Bown (1979) and Rohrer and Gazin (1965) record the overlap of *Homogalax* and *Heptodon* at localities in the central Bighorn Basin (YPM 45 and Bed "A," respectively). Perhaps overlooked was the earlier statement by Radinsky (1963) that *Homogalax* persisted for at least 20 meters above the first appearance of *Heptodon*. *Homogalax* has also been reported from the faunas of the type Lysite and Lost Cabin of the Wind River Basin (Guthrie, 1971), and is presently known to exist well above the first occurrence of *Heptodon* in the Bighorn Basin (Bown and Gingerich, pers. comm.; Schankler, pers. obs.).

In the absence of precise documentation of the traditional divisions of the Wasatchian, Gingerich (1980) abandoned the previous nomenclatural framework entirely and divided the Wasatchian part of the Willwood Formation into five biochrons or lineage-zones based on the notharctine primate *Pelycodus*. There are a number of problems associated with this zonation. First, the transitions between the five species of *Pelycodus* are usually arbitrary. Specifically, the boundary between *P. mckennai* and *P. trigonodus* cannot at present be well defined (see Gingerich and Simons, 1977, fig. 10; Gingerich, 1980, Fig. 4). Also the datum point for the first appearance of *P. jarrovii* is unclear, as evidence suggests that this species is not an anagenetic descendent of *P. abditus* and that the two species overlapped temporally (Schankler, unpubl. data). Second, data exist showing that isochronous populations of the same species within the Bighorn Basin differ in size (cf. *Haplyomylus*, Bown, 1979; Schankler, unpubl. data; *Esthonyx spatularius, Viverravus politus*/ *Viverravus* sp. 3, Schankler, unpubl. data). For these two reasons the Gingerich zonation of the Willwood does not appear to be very useful biostratigraphically, either within the basin or across basins. A third criticism is the lack of heuristic value of this zonation, in that it does not reflect the overall changes in the fauna that are documented in this paper.

Bown and Schankler (1980), utilizing data presented in part of this paper, divided the Willwood Formation into five biostratigraphic zones that corresponded closely to the intent of previous divisions and retained the pre-existing names. This was done in an attempt to preserve nomenclatural stability. On the basis of the present analysis an alternative zonation of the Willwood that emphasizes major patterns of faunal turnover in the Wasatchian of the central Bighorn Basin is proposed. The new zonation is compared to other recent zonations in Figure 1.

GEOLOGY OF THE ELK CREEK SECTION

The Willwood Formation of the central Bighorn Basin is a molasse facies of sandstones, variegated mudstones, and carbonaceous shales. The sandstones and mudstones are fluviatile in origin, while the carbonaceous shales represent a backswamp, marsh, or pond environment. Excellent accounts of the stratigraphy and sedimentology are provided by Neasham (1970), Neasham and Vondra (1972), and Bown (1975, 1979). The taphonomy and pedogenic origin of "red" beds are discussed by Bown and Kraus (1980), and the distribution and paleobotanical content of the carbonaceous shales is dealt with by Wing (this volume).

The thickness of the Willwood Formation varies in different parts of the Bighorn Basin. This is the result of four factors: truncation of the upper part of the formation because of erosion, truncation of the lower part of the formation because of an unconformable contact with the underlying Fort Union Formation, different rates of deposition, and time-transgressive onset of deposition. The difference in thickness between sections measured on the eastern and western flanks of the central basin is the result of the second factor (Neasham and Vondra, 1972). The difference in thickness between the Elk Creek Section and the Willwood section in the Clark's Fork Basin, measured by Gingerich, Rose, and Krause, is the result of the first, second and third factors. The time-transgressive aspect of the Willwood is most clearly demonstrated between the sections measured by Bown east of Worland and the Gingerich, Rose, and Krause section. Both sections begin at a conformable contact with the underlying Fort Union Formation, but sediments of Clarkforkian age are completely absent from the Bown Willwood sections (Bown, 1979; Rose, 1979).

The Schankler-Wing section is the third section to be measured through the Willwood of the central Bighorn Basin in recent years. All three sections started from the same geographic locality, but the Neasham-Vondra section places the Willwood-Fort Union contact 30 m below that for the Meyer-Radinsky and Schankler-Wing sections. This is because there is some disagreement about whether the Willwood-Fort Union contact is unconformable in this region (cf. Sinclair and Granger, 1911; Van Houten, 1944; Neasham and Vondra, 1972; Bown, 1975). The Neasham section also terminated with the Willwood-Tatman contact on Sheep Mountain, whereas the other two sections ended with the contact on Bobcat Ridge. The Neasham and Meyer sections

<table>
<tr><th>Wood et al.
1941</th><th colspan="2">Van Houten
1945</th><th colspan="2">Gingerich
1976</th><th colspan="2">Gingerich and Simons
1977</th><th>Gingerich
1980</th><th colspan="2">Bown and Schankler
1980</th><th colspan="2">This Paper</th></tr>
<tr><td>Lost Cabin equivalent</td><td colspan="2">Lost Cabin Faunal Zone</td><td colspan="2">Lost Cabin</td><td colspan="2" rowspan="3">Lost Cabin</td><td rowspan="3">*Pelycodus jarrovii* Biochron</td><td colspan="2">Lost Cabin Biostratigraphic Zone</td><td rowspan="4">*Heptodon* Range-Zone</td><td>Upper</td></tr>
<tr><td rowspan="3">Lysite equivalent</td><td colspan="2" rowspan="3">Lysite Faunal Zone</td><td colspan="2" rowspan="4">Lysite</td><td colspan="2" rowspan="3">Lysite Biostratigraphic Zone</td><td>Middle</td></tr>
<tr><td rowspan="2">Lower</td></tr>
<tr><td colspan="2" rowspan="2">Lysite</td><td rowspan="2">*Pelycodus abditus* Biochron</td></tr>
<tr><td rowspan="5">Gray Bull member</td><td rowspan="5">Gray Bull Faunal Zone</td><td rowspan="2">Upper</td><td rowspan="5">Gray Bull Biostratigraphic Zone</td><td rowspan="2">Upper</td><td colspan="2" rowspan="2">*Bunophorus* Interval-Zone</td></tr>
<tr><td rowspan="4">Gray Bull</td><td rowspan="2">Upper</td><td rowspan="4">Gray Bull</td><td rowspan="2">Upper</td><td rowspan="2">*Pelycodus trigonodus* Biochron</td></tr>
<tr><td rowspan="2">Middle</td><td rowspan="2">Middle</td><td rowspan="3">*Haplomylus-Ectocion* Range-Zone</td><td rowspan="2">Upper</td></tr>
<tr><td rowspan="2">Lower</td><td rowspan="2">Lower</td><td rowspan="2">*Pelycodus mckennai* Biochron</td></tr>
<tr><td>Lower</td><td>Lower</td><td>Lower</td></tr>
</table>

Figure 1. Summary of recent faunal zonations of the Willwood Formation. All earlier zonations have been standardized against the Elk Creek Section.

have never been published in full, but the inclusion of Yale fossil localities allows for a direct comparison. Standardized at the first YPM locality (YPM 95), the Schankler-Wing section measures 773 m, the Neasham-Vondra section measures 640 m, and the Meyer-Radinsky section measures 550 m. These differences in thickness are not caused by the factors mentioned in the previous paragraph, but are the result of measurement error and differences in correlating beds. Although the Schankler and Neasham sections differ by more than 130 m, this discrepancy is localized in the area between the western limb of the Elk Creek Anticline and the Dorsey Creek Road. Below and above this the sections are in virtual agreement. Neasham notes at least three faults in this area, and only a tentative correlation between the separate sections that make up the composite section. During the present study these faults were also noted, as well as at least three more in the western limb of the anticline. For this reason we left the valley of Elk Creek at this point and went north into the valley of Dorsey Creek, where the structural difficulties do not *appear* to exist. A section was also measured down the valley of Elk Creek through the same place that Neasham traced the beds for his section and a comparable thickness was obtained. This section was abandoned however, because of the imprecision encountered in trying to match beds across the faults. The discrepancies between the Schankler-Wing section and the Meyer-Radinsky section are more systematic and will be discussed elsewhere (Schankler, Ph.D. thesis, in prep.).

As indicated above, 240 Yale fossil localities were mapped into the Schankler-Wing section and this constitutes the Elk Creek Section as presented in Figure 2. The localities were grouped into ten-meter intervals, the maximum resolution thought possible. In many cases this is probably a liberal estimate of

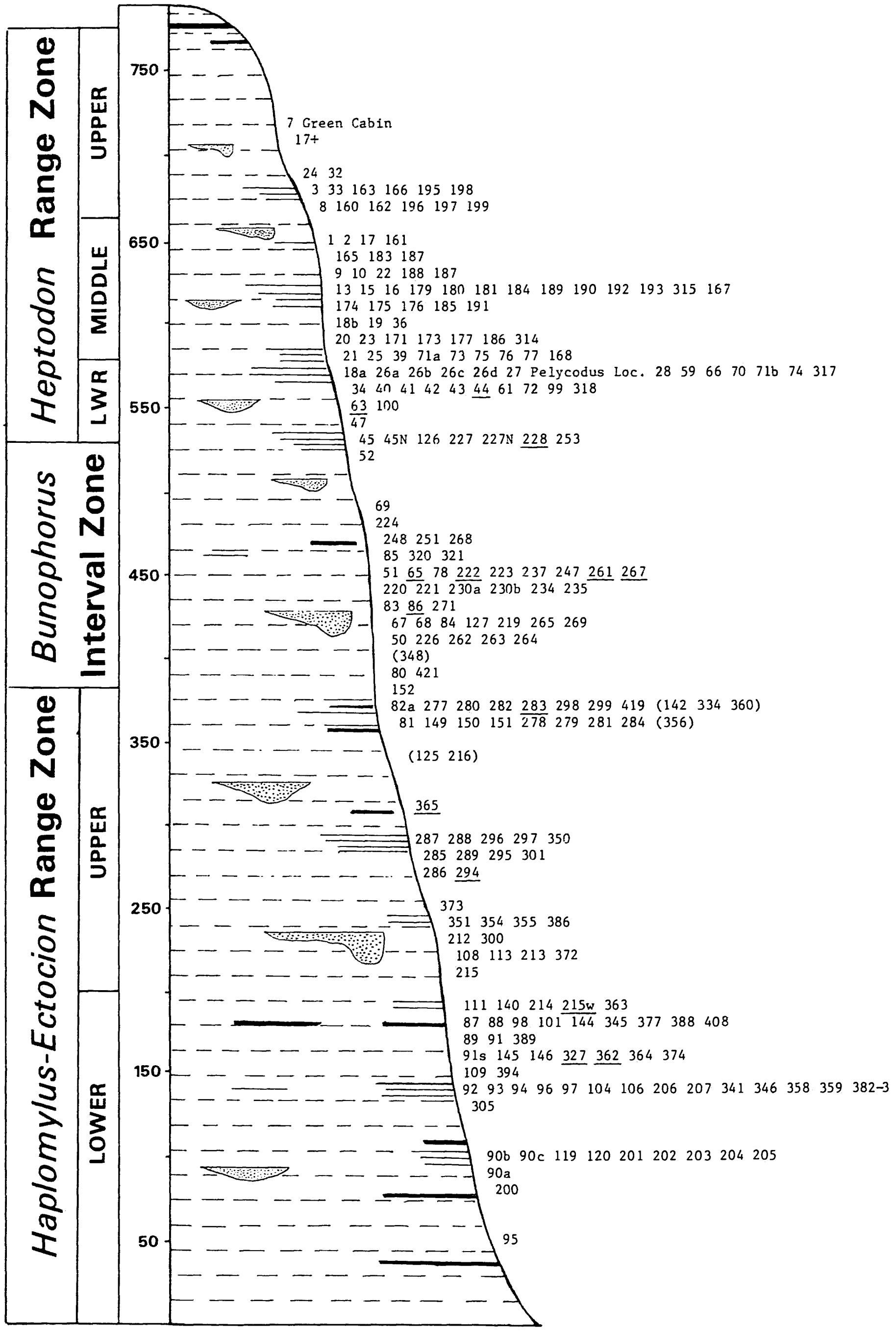


Figure 2. Composite diagram of the Elk Creek Section, showing YPM fossil localities grouped into ten-meter intervals. Underlined localities were located in the field, although beds were not directly traceable to these localities. Localities in parentheses were placed into the section on the basis of field and faunal studies.

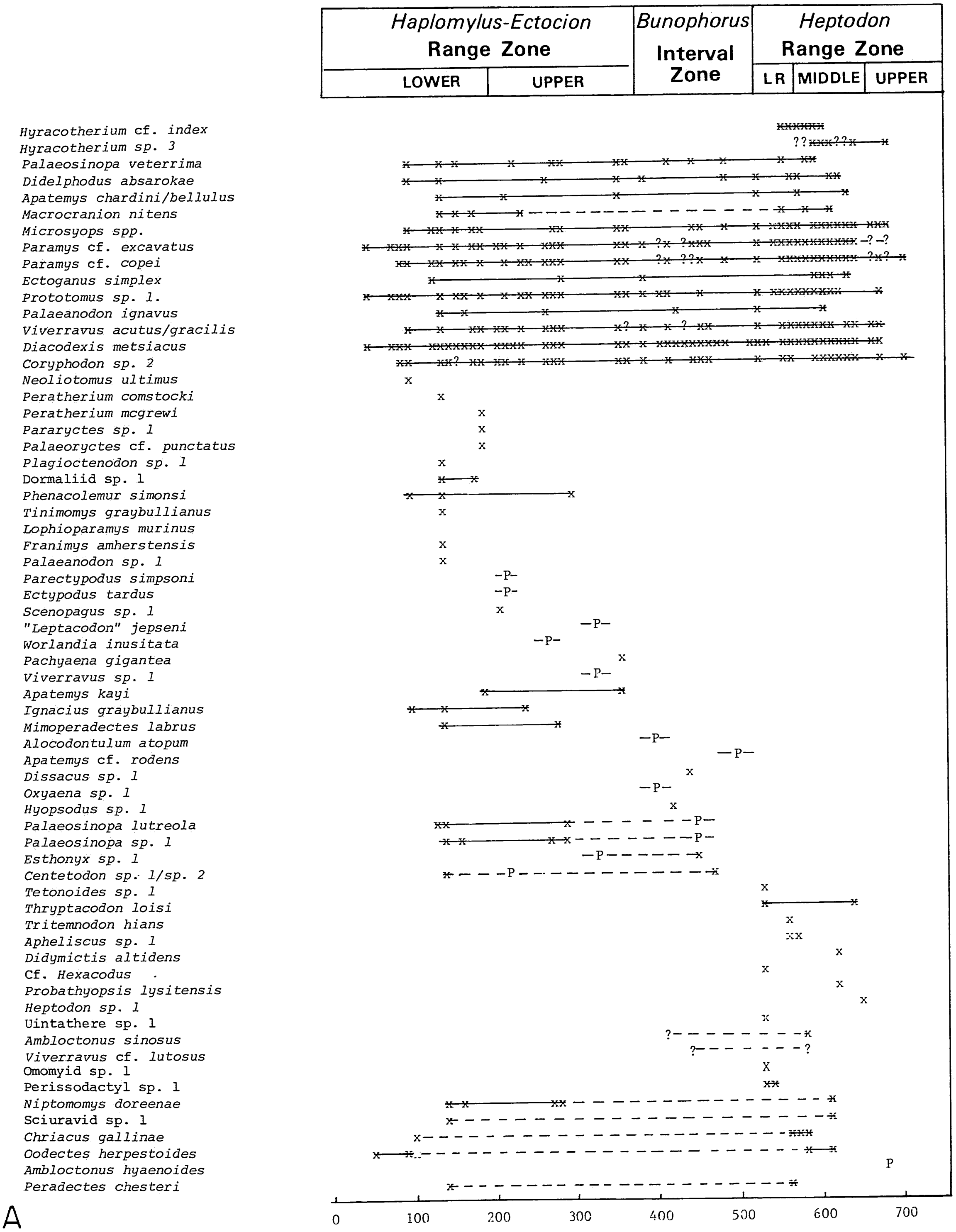
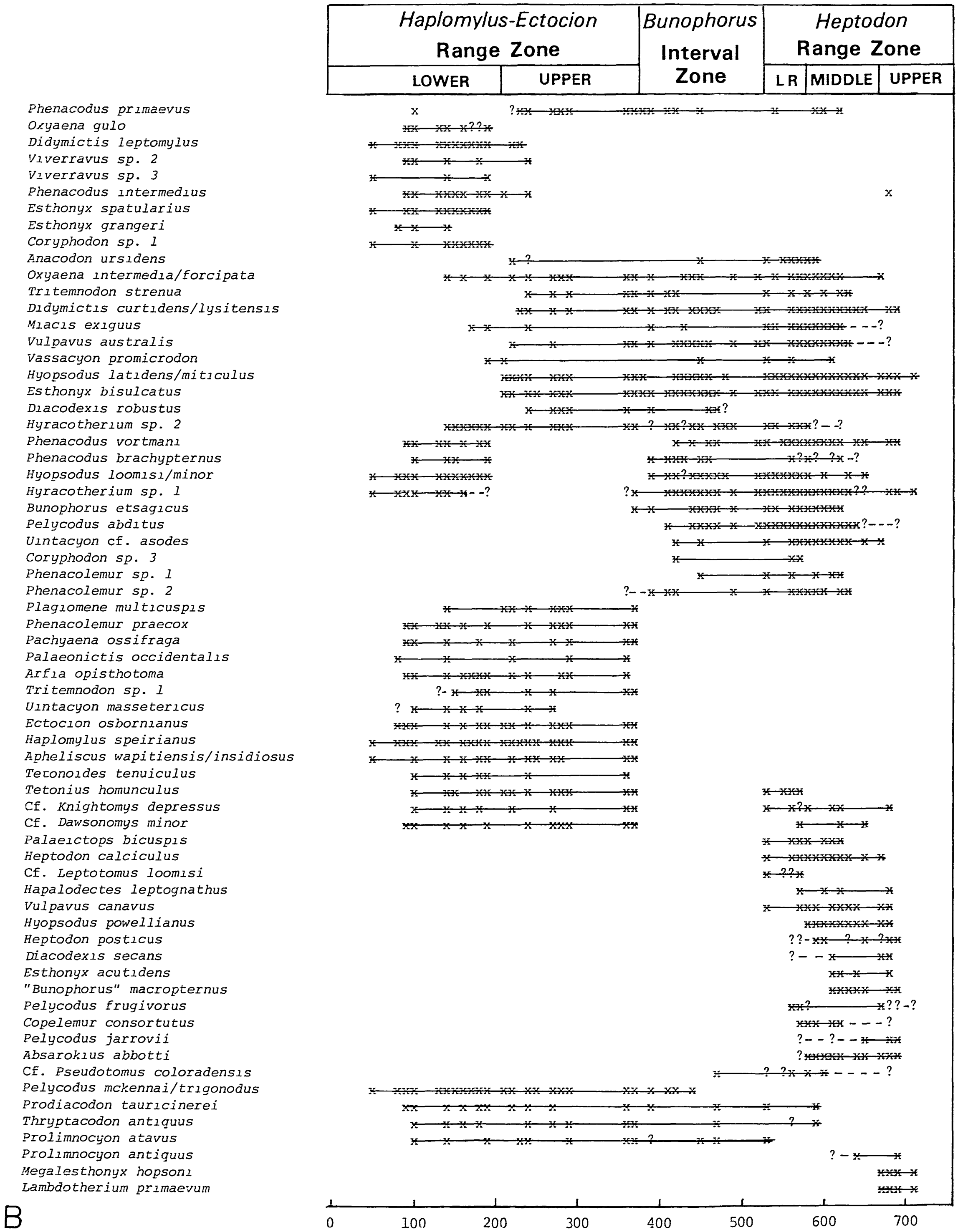


Figure 3. Temporal range diagram for mammalian species of the Elk Creek Section fauna. (A) Species found throughout the section or species too poorly known stratigraphically to show any definite pattern. (B) Species with stratigraphic ranges showing



definite patterns and forming the basis for the zonation at the top of the figure. An *x* represents the occurrence of at least one specimen of a species at that level, *?* represents a taxonomic uncertainty, and *P* represents a stratigraphic uncertainty.

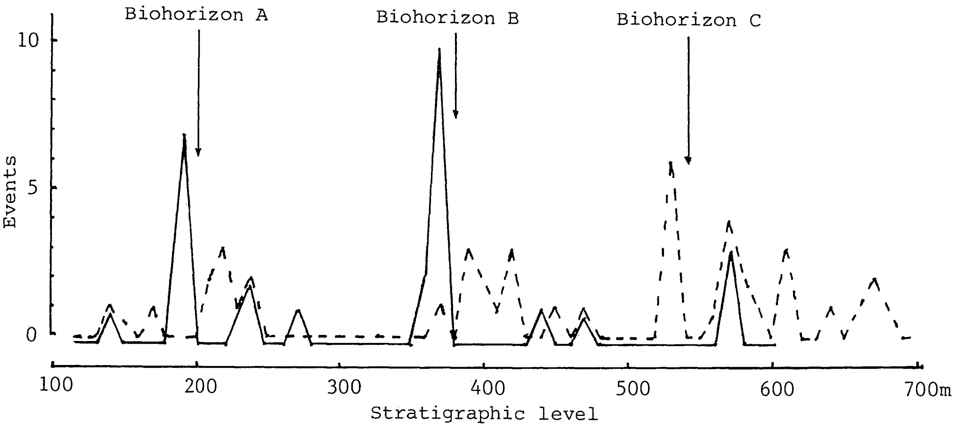


Figure 4. Frequency of "extinctions" (solid line) and immigrations (dashed line) by stratigraphic position. Ordinate is the number of "extinction" or immigration events at the meter level indicated on the abscissa.

our resolution because of errors in measurement and bed correlation, and variation in the stratigraphic interval represented by the lag deposit that formed the locality.

FAUNAL ZONATION

The Elk Creek Section fauna contains approximately 77 genera and 140 species of mammals. The temporal distribution of each species is recorded in Figure 3. Each "x" indicates the occurrence of at least one specimen of that species at that level. The figure is derived largely from a study of the specimens from the Yale Peabody Museum that were found at localities tied to the measured section. Where appropriate, data have been used from the collections at the Harvard University Museum of Comparative Zoology, the University of Michigan and University of Wyoming Museums of Paleontology, the Royal Ontario Museum, the American Museum of Natural History, and the U.S.Geological Survey in Denver. Of the 140 species in the fauna, over half are of limited biostratigraphic value, either because their ranges are indeterminate because of small sample size, or because their ranges extend through the entire section. The temporal ranges of the remaining 68 species have been used to divide the Willwood Formation of the Elk Creek Section into three faunal zones. In stratigraphic sequence they are the *Haplomylus-Ectocion* Range-Zone (50-380 m), the *Bunophorus* Interval-Zone (380-530 m), and the *Heptodon* Range-Zone (530-773 m). Statements about temporal distributions of species and genera refer only to the Wasatchian part of the Willwood as preserved in the Elk Creek Section. The boundary between the Clarkforkian and the Wasatchian has recently been discussed in detail by Rose (1979).

Of the 43 species that occur at the 100 m level or below, only 13 are also known from the 670 m level or higher. Similarly, of the 37 species that are present at the 670 m level or above, only 11 are known from the 100 m level or below. This represents a species turnover of about 70%. As can be seen from Figure 4 this turnover was episodic. The peaks of "extinction" at the 190 and 370 m levels and the onset of immigration at the 210, 390 and 530 m levels have been used to define three biohorizons (Hedberg, 1976) within the Elk Creek Section. Biohorizons A, B, and C are located at the 200, 380, and 530 m levels, respectively. In the following discussion the word "extinction" subsumes true extinction, local extinction, and emigration, but not pseudo-extinction. All first appearances of new species are immigration events, except the first appearance of a species that is the anagenetic descendent of a species already present in the fauna. Immigration also includes the reappearance of a species that has previously emigrated from the region.

Haplomylus-Ectocion Range-Zone

Biohorizon B represents the most significant break in the faunal succession preserved in the Elk Creek Section. Thirteen species became "extinct" just prior to this boundary, including *Plagiomene multicuspis, Pachyaena ossifraga, Palaeonictis occidentalis, Arfia opisthotoma, Ectocion osbornianus, Haplomylus speirianus, Apheliscus wapitiensis/insidiosus, Teton-*

oides tenuiculus, Phenacolemur praecox, Tritemnodon sp. 1, *Tetonius homunculus,* cf. *Knightomys depressus,* and cf. *Dawsonomys minor.* The first six of these are also generic "extinctions," while two other genera, *Apheliscus* and *Tetonoides,* are known from only one or two specimens above this level. For the last three species Biohorizon B represents a documented emigration event, as these species reappear at the onset of or during the *Heptodon* Range-Zone, but are significantly absent (in a statistical sense) from the *Bunophorus* Interval-Zone. Immigrations and species abundance shifts also occur at Biohorizon B. The immigrations are discussed below and the abundance shifts are left for a future paper. The *Haplomylus-Ectocion* Range-Zone is defined on the concurrent ranges of the 13 species that became "extinct" at Biohorizon B. Biohorizon B marks the upper limit of this zone, and the lower limit is coincident with the Clarkforkian-Wasatchian boundary and occurs below the 50 meter level of the Elk Creek Section. Its exact position is indeterminate because of the unfossiliferous nature of the lowest 50 meters of the Elk Creek Section.

The *Haplomylus-Ectocion* Range-Zone is subdivided into a lower and an upper unit, with the boundary between these two units at the 200 meter level (i.e. Biohorizon A). Biohorizon A is characterized by the "extinction" of eight species: *Oxyaena gulo, Viverravus* sp. 3, *Esthonyx spatularius, Coryphodon* sp. 1, *Phenacodus vortmani, Phenacodus brachypternus, Hyopsodus loomisi/minor* and *Hyracotherium* sp. 1. There are no generic "extinctions" and four of the species (*Phenacodus vortmani, Phenacodus brachypternus, Hyopsodus loomisi/minor,* and *Hyracotherium* sp. 1) reappear at or near the onset of the *Bunophorus* Interval-Zone. In addition to the "extinctions," Biohorizon A precedes the immigration of seven species: *Anacodon ursidens, Didymictis curtidens/lysitensis, Tritemnodon strenuus, Vulpavus australis, Hyopsodus latidens/miticulus, Esthonyx bisulcatus,* and *Diacodexis robustus.* Although the number of turnover events that occur at Biohorizons A and B are approximately equal, they are qualitatively different. Many of the events that occur at Biohorizon B are at the generic level, while seven of the species that became "extinct" at Biohorizon A are merely replaced by congeners of larger size. These replacements are not isochronous and considerable overlap occurs, but it does represent the major difference between the Lower and Upper *Haplomylus-Ectocion* Range-Zones.

The Lower *Haplomylus-Ectocion* Range-Zone is defined on the concurrent ranges of the 13 species that became "extinct" at Biohorizon B and the eight species that became "extinct" at Biohorizon A. Other characteristic elements of the zone include *Viverravus* sp. 2, *Neoliotomus ultimus, Didymictis leptomylus,* and *Phenacodus intermedius.* Only *Neoliotomus ultimus* is restricted to the zone, the other three species range over Biohorizon A into the Upper *Haplomylus-Ectocion* Zone. The Upper *Haplomylus-Ectocion* Range-Zone is defined on the concurrent ranges of the thirteen species that became "extinct" at Biohorizon B and the seven species that immigrated into the region at Biohorizon A. No species (except those represented by unique specimens) are restricted to this zone, and all species that first appear at Biohorizon A are also known from higher zones. Although not restricted to this zone, three species (*Plagiomene multicuspis, Phenacodus primaevus,* and *Diacodexis robustus*) are most abundant during this zone.

Bunophorus Interval-Zone

The *Bunophorus* Interval-Zone has a lower boundary at Biohorizon B and an upper boundary at Biohorizon C. Nine species immigrate into the region at or near Biohorizon C. Four of these (*Phenacodus vortmani, Phenacodus brachypternus, Hyopsodus loomisi/minor,* and *Hyracotherium* sp. 1) represent the reappearance of species that emigrated from the region at Biohorizon A. Four species have congeners in the *Haplomylus-Ectocion* Zone that differ in either size (*Pelycodus abditus, Uintacyon* cf. *asodes,* and *Phenacolemur* sp. 2) or morphology (*Coryphodon* sp. 3). *Bunophorus etsagicus,* which has a first appearance slightly below Biohorizon B, is the sole new genus. All nine species continued into the *Heptodon* Range-Zone and no species became "extinct" at Biohorizon C. For this reason the *Bunophorus* Interval-Zone cannot be defined on concurrent range zones and is instead characterized by the absence of those species that became "extinct" at Biohorizon B and those that first appeared at Biohorizon C.

The *Bunophorus* Interval-Zone is equivalent to the Upper Gray Bull of most previous workers, and while it has elements in common with both the Lower and Upper *Haplomylus-Ectocion* Zone (equivalents of the Lower and Middle Gray Bull), only three species are common to all three zones. As can be seen in Figure 3, a much greater number of species are common to the *Bunophorus* Interval-Zone and the *Heptodon* Range-Zone. No species except those represented by unique specimens are restricted to the *Bunophorus* Interval-Zone; this is in direct contrast to the paleobotanical evidence, where it appears that at least six taxa are known only from this zone (Wing, pers. comm.).

Heptodon Range-Zone

The *Heptodon* Range-Zone has a lower limit at Biohorizon C. Six species immigrate into the region at this level, of which two were previously present. The upper limit of this zone is presumably coincident with the Willwood-Tatman contact. The concurrent ranges of *Heptodon* and *Vulpavus canavus* define this zone. Other characteristic elements of this faunal zone include *Palaeictops bicuspis*, cf. *Knightomys depressus, Microsyops,* and a large paramyid, possibly representing *Leptotomus loomisi* or *Pseudotomus coloradensis* or both. The *Heptodon* Range-Zone is a period of continued immigration of new species. No obvious breaks occur in the faunal composition, but it has been subdivided into three units (lower, middle, and upper) because of the dominant role that single new species come to have in the fauna, and also to facilitate comparison with the faunas from the Wind River Basin.

The boundary between the Lower and Middle *Heptodon* Range-Zones is marked by the first appearance of *Hyopsodus powellianus* at the 580 m level, although the species does not become extremely abundant until the 590 or 600 m levels. The boundary between the Middle and Upper *Heptodon* Range-Zones is placed at the first appearance of *Lambdotherium* at the 670 m level. It should be noted that two specimens of *Lambdotherium* are known from levels below 670 m. Both specimens were found in the collection and their presence was not noted in the field. The date or locality of discovery of both specimens raises the possibility of pocket or slope contamination. In any event, *Lambdotherium* first appears as a dominant element of the fauna (7% abundance) at the 670 m level.

Characteristic elements of the Lower *Heptodon* Range-Zone include *Chriacus gallinae, Anacodon ursidens,* and *Tetonius homunculus.* Faunal elements characteristic of the Middle *Heptodon* Range-Zone include *Hyopsodus powellianus, "Bunophorus" macropternus, Copelemur consortutus,* and *Absarokius abbotti.* The Upper *Heptodon* Range-Zone is equivalent to the *Lambdotherium* Zone or Bighorn Lost Cabin of all previous workers except Gingerich and Simons (1977) and Gingerich (1980). Species known only form this zone include *Megalesthonyx hopsoni, Lambdotherium primaevum, Lambdotherium popoagicum,* and *Ambloctonus hyaenoides.* The last two species are represented by single specimens. Characteristic species that are also known from earlier zones include *Esthonyx acutidens, Diacodexis secans,* and *Prolimnocyon antiquus.* It is also interesting that *Phenacodus intermedius* returns as the large species of *Phenacodus.* This is also true for the Lost Cabin fauna from the Wind River Formation described by Guthrie (1971). *Lambdotherium* is known from within 10 m of the Willwood-Tatman contact in the Elk Creek Section, but the most fossiliferous beds occur at the base of this zone, and the upper part of this zone is not well defined.

FAUNAL CORRELATION

The near synchrony of immigration-"extinction" events at Biohorizons A and B suggests changing climatic or ecological conditions as a causative factor, whereas the period of immigration beginning at Biohorizon C with little or no apparent "extinction" raises the possibility that the breakdown of a physical barrier to immigration was responsible. The degree to which these events can be translated geochronologically or even biostratigraphically to other basins of the Rocky Mountain system is not yet clear. It is also not yet clear to what degree species evolving in semi-isolated basins exhibit the same morphological and size characteristics synchronously. The most reliable course for biostratigraphic correlation would be to use both sets of data for the entire fauna. In many cases the taxonomic proclivities of various authors coupled with the absence or irretrievability of measurement data makes precise correlation of faunas difficult at this time. This is particularly true of the faunas from the San Juan and Washakie Basins. Two examples of faunal correlation, one within the Bighorn Basin and one between the Bighorn and Wind River Basins are, however, presented.

Work on the faunas from the Wasatchian part of the Willwood Formation in the Clark's Fork Basin is still in progress. The information published to date (Gingerich and Gunnell, 1979; Gingerich, 1980) indicates a correlation between Biohorizon A and the 1750-1775 m level of the Gingerich, Rose, and Krause section in the Clark's Fork Basin. This is based on the abundance shift in *Tetonoides,* and the size shift in *Esthonyx* and possibly *Homogalax.* The Clarkforkian-Wasatchian boundary is placed at the 1525 m level (Gingerich, 1980) and *Haplomylus* is known to occur at least until the 2100 m level (Gingerich, pers. comm.). Thus at least 575 m of section should fall within the *Haplomylus-Ectocion* Zone, of which 325-m would be equivalent to the Upper *Haplomylus*-

Ectocion Zone and 250 m equivalent to the Lower *Haplomylus-Ectocion* Zone. In the Elk Creek Section the Upper *Haplomylus-Ectocion* Zone is 180 m thick. The ratio of sedimentation rates between the Clark's Fork Basin section and the Elk Creek Section for this subzone is then 1.8:1. If this ratio of sedimentation rates is constant for the entire *Haplomylus-Ectocion* Zone, then the Lower *Haplomylus-Ectocion* Zone in the Elk Creek Section should be 140 m thick, placing the Clarkforkian-Wasatchian boundary at the 50-60 m interval. Since YPM 95 (located at the 50 m level) is definitely a Wasatchian locality this raises four possibilities: the disappearance of *Haplomylus* was time transgressive, the events that occur at Biohorizon A were time-transgressive, the correlation between Biohorizon A and the 1775 m level of the Clark's Fork Basin section was incorrect, or the sedimentation rate ratio was not constant. There is some evidence that the disappearance of *Haplomylus* from the basin was ecological controlled and not synchronous (Bakker, pers. comm.), but the ultimate correlation awaits further information on the faunal ranges from the Clark's Fork Basin.

Guthrie (1967) pointed out that the fauna from the Lysite member of the Wind River formation was equivalent only to the faunas from the upper portion of the sediments referred to the Bighorn Lysite. In correlating the type Lysite fauna to the Elk Creek Section the following taxa are most relevant: *Anacodon* is absent from the type Lysite fauna and last occurs in the Elk Creek Section fauna at the 590 m level; *Hyopsodus powellianus* first occurs in the Elk Creek Section fauna at the 580 m level but does not obtain the abundance level seen in the type Lysite fauna until the 590 or 600 m level; *Diacodexis secans, Esthonyx acutidens, Didymictis altidens,* and *Prolimnocyon antiquus* do not occur in the type Lysite fauna (although they do occur in the type Lost Cabin fauna) and do not occur below the 610 m level in the Elk Creek Section. The size ranges of *Hyopsodus miticulus, Hyopsodus powellianus, Diacodexis metsiacus,* and *Esthonyx bisulcatus* from the type Lysite fauna are co-equal with those from the Elk Creek Section at the 590 to 620 m interval.

The type Lysite fauna comes from a stratigraphic interval of 60 m, located at the base of the Lysite Member of the Wind River Formation. The lowest 30 m of this interval (basal cliff to upper cliff of Guthrie, 1967) is the most fossiliferous and would seem to correlate most closely with the interval between 590 and 620 m levels of the Elk Creek Section (i.e. the lower half of the Middle *Heptodon* Range-Zone). The absence from the type Lysite fauna of those species that occur in the upper half of the Middle *Heptodon* Range-Zone is probably because the sample size from the correlative part of the Lysite member is too small to pick up these relatively rare species.

Further confirmation of this correlation comes from two lines of evidence. First, a comparison of the higher-order taxonomic abundance structure revealed the highest similarity between the type Lysite fauna and the faunas from the 590 and 600 m levels of the Elk Creek Section. Second, the Lysite Member of the Wind River Formation is 105 m thick (Granger, 1910). Guthrie (1967) states that the first occurrence of *Lambdotherium* occurs in the upper 45 meters of the Lysite Member. If we take the mid-point of 22 m, *Lambdotherium* first occurs approximately 80 m above the base of the Lysite member. Since the base of the Lysite member has been correlated with the 590 m level of the Elk Creek Section, *Lambdotherium* should first occur within the Elk Creek Section at about the 670 m level, which it does (Figure 3). This evidence also suggests that sedimentation rates are approximately equal.

The Lost Cabin fauna described by Guthrie (1971) comes from an interval less than 10 m thick at the base of the Lost Cabin member of the Wind River Formation. Based on the presence of *Lambdotherium* this interval should lie somewhere within the Upper *Heptodon* Range-Zone, but this is a relatively poorly understood zone of the Elk Creek Section since most of the fossiliferous beds lie within 20 m of the first occurrence of *Lambdotherium*. The size ranges of the species that occur in both the type Lost Cabin fauna, as described by Guthrie (1971), and the Upper *Heptodon* Range-Zone do not for the most part agree. The species dominance relationships of the Upper *Heptodon* Range-Zone are intermediate between those of the Middle *Heptodon* Range-Zone and the type Lost Cabin fauna (i.e. *Esthonyx bisulcatus* is the only species of *Esthonyx* in the lower *Heptodon* Range-Zone; *E. acutidens* first appears in the Middle *Heptodon* Range-Zone where it is less frequent than *E. bisulcatus; E. acutidens* becomes the dominant species of *Esthonyx* in the Upper *Heptodon* Range-Zone; *E. acutidens* is the only species of *Esthonyx* in the type Lost Cabin fauna). Similar patterns pertain to *Didymictis* and *Diacodexis.* Although not yet complete, the faunal evidence suggests that the sediments containing the type Lost Cabin fauna correlate with a level of the Elk Creek Section higher than the 690 m level. The stratigraphic relationships within the Wind River Basin support this conclusion. As mentioned above, the Lysite member is 105 m thick. There is an additional 30 m transition zone between the Lysite and Lost Cabin members of the Wind River Formation (Guthrie, 1967). Since the evidence suggests that sedimentation rates are approximately equal, if we correlate the base of the Lysite member with the 590 m level of the Elk Creek Section, then the stratigraphic interval containing the Lost Cabin fauna would be equivalent to the 725 m level of the Elk Creek Section.

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APPENDIX

ROAD LOG -- CENTRAL BIGHORN BASIN

Mileage		
Cumul.	Increm.	
0.0	0.0	Assemble in front of the Bighorn County Library in Basin, Wyoming. Drive west on Wyoming Highway 130.
0.4	0.4	Continue on Highway 130, taking the left fork toward Otto.
2.7	2.3	Turn left on dirt road at the power line and drive south.
3.9	1.2	STOP 1: Look south at the panoramic view of the unconformable contact between the Willwood Formation and the underlying Fort Union Formation as depicted in both Sinclair and Granger (1911) and Van Houten (1944). To the left of the fault fossil plant localities indicate a Tiffanian age for this part of the Fort Union (L. Hickey, S. Wing, pers. comm.). The dip of the Fort Union in this area is about 35°, carbonaceous shales are common, and there is an absence of red beds. On the right side of the fault the down-warped Willwood Formation occurs with an initial dip of greater than 15°, decreasing rapidly basinward to less than 2° at the western end of the bluff. The measured section of this report begins at the contact between the Fort Union and Willwood Formations. This may or may not coincide with the base of the Wasatchian Land-Mammal Age. Note also the lateral persistence of carbonaceous shales in this part of the Willwood.
5.2	1.3	Turn left and travel up the north side of Antelope Creek.
5.9	0.7	STOP 2: A closer look at the contact. To the right of the contact the lowest fossil locality of the Elk Creek Section (YPM 95) can be seen outcropping in association with a thin red bed. This locality is relatively poor, containing only 13 species. It stands at the 50 m level of the measured section.
6.6	0.7	Return to the power line road and head south. Due west of this point and .75 miles distant lies one of the first fossiliferous localities of the Elk Creek Section. YPM 119 contains 32 species and stands at the 100 m level. This level also includes a number of localities to the south, and the entire level contains approximately 40 species. A complete lower jaw of *Neoliotomus ultimus* was found at YPM 119 and that species is only known from this level
6.7	0.1	Cross Antelope Creek. To the east is YPM 200. A number of specimens of *Esthonyx grangeri* were found here. Isolated teeth of this species record its persistance to at least the 140 m level.
7.3	0.6	The relatively poor localities YPM 201-205 are located around these hills. The presence of *Phenacodus primaevus* at locality YPM 201 indicates that this species co-existed with the smaller *P. intermedius* at the 100 m level.
8.5	1.2	STOP 3: On the right side of the road can be seen a red-purple bed that is associated with localities at the 140 m level of the section. This level extends to the north and south, outcropping over a lateral distance of seven miles. While not as specimen rich as some of the *Heptodon* Range-Zone levels, it is the most diverse, containing 56 species including 13 species of marsupials, proteutherians, and insectivores.
9.9	1.4	The extensive flats in the distance on the right form YPM 104, another locality at the 140 m level that will be visited later.
10.4	0.5	Cross Elk Creek.
10.9	0.5	YPM 92, another locality at the 140 m level, occurs around the base of the small hills by the side of the road. A specimen of *Viverravus* only slightly smaller than contemporaneous *Didymictis leptomylus* was found at this locality.
12.2	1.3	At the substation turn right and head west.
12.7	0.5	STOP 4: YPM 363, also known as Teakettle Hill, is just off the road on the right. This locality stands at the 190 m level and marks the highest level in the Lower *Haplomylus-Ectocion* Range-Zone. Inch for inch this is one of the

		richest fossil localities in the central basin, but it is species poor. It is heavily dominated by the condylarth *Hyopsodus loomisi*, which makes up about 35% of the fauna. To the southeast are a number of localities along the drainage of the South Fork of Elk Creek. They are all from the Lower *Haplomylus-Ectocion* Range-Zone. Return to substation.
13.2	0.5	Turn left at the substation and retrace route north along the power line road.
15.2	2.0	Two-tenths of a mile after crossing Elk Creek turn left.
15.8	0.6	STOP 5: YPM 104, as mentioned earlier, is an extension of the 140 m level. Bown (pers. comm.) reports that the fossiliferous zone of this locality is a Class A gray mudstone. Over 36 species are known from this locality, more than any other locality in the central basin.
17.6	1.8	To the south across Elk Creek is YPM 214, which stands at the same level as Teakettle Hill and has the same characteristic high frequency of *Hyopsodus loomisi*.
18.5	0.9	YPM 215 to the south across Elk Creek is the first locality in the Upper *Haplomylus-Ectocion* Range Zone. We are also entering the eastern limb of the Elk Creek Anticline and YPM 215w, which lies just to the west of YPM 215, is a Lower *Haplomylus-Ectocion* Range-Zone locality. Also of note is the pump in the middle of nowhere. It works!
19.6	1.1	STOP 6: Climbing the hill to the north of the road and looking north there is a small fault. The displacement is on the order of 45 m. Looking south one can see the arching beds of the Elk Creek Anticline on the south side of Elk Creek. This is probably the bed referred to as Horizon 1 by Sinclair and Granger (1911). Return east on the Elk Creek Road.
20.0	0.4	Turn left. Note carbonaceous shales on hillsides.
21.3	1.3	Turn left on dirt "road" and climb the hill.
21.5	0.2	STOP 7: Looking southwest from the crest of the hill the western limb of the Elk Creek Anticline is well exposed on the opposite side of the valley. To the northwest is YPM 315, also known as *Phenacolemur* Ridge. This is the first really productive locality of the Upper *Haplomylus-Ectocion* Range-Zone and stands at the 240 m level. The beds at the mouth of this valley are in the Lower *Haplomylus-Ectocion* Range-Zone. Return down the hill.
21.6	0.1	Turn left on the "main" road.
22.8	1.2	Turn left and proceed west. Continuing north at the intersection would bring us to Dorsey Creek and a series of localities that stand between the 270 and 290 m levels. These are probably equivalent to the localities referred to as "east of Wardell's" or "southeast of Otto" by earlier workers. A right turn at the intersection and a drive of 1.8 miles would bring us near YPM 290, unusual for its high representation (8%) of the dermopteran *Plagiomene multicuspis*.
25.6	2.8	Dorsey Creek Fence.
26.6	1.0	STOP 8: YPM 149 is one of many localities outcropping between Dorsey and Elk Creeks in this area. They stand at the 360 and 370 m levels and represent the highest levels of the Upper *Haplomylus-Ectocion* Range-Zone. This fossiliferous level also extends to the west at least as far as Wardell's Reservoir and most likely coincides with Horizon 2 of Sinclair and Granger (1911). A partial skeleton, including a complete mandible and maxilla, of the mesonychid *Pachyaena gigantea* was found at YPM 149.
34.3	7.7	STOP 9: YPM 67, 68, and 84 are located in this small valley. They are from the 429 m level and thus very low in the *Bunophorus* Interval-Zone. This level is heavily represented by the isectolophid tapir *Homogalax* and, through a misunderstanding that occurred over 15 years ago, was erroneously thought to contain the helaletid *Heptodon*. This is the reason that the Gray

		Bull-Lysite boundary as shown in Gingerich (1976) occurs at the same level as YPM 67. *Heptodon* is not found for another 110 m of section. Climb the hill to the Dorsey Creek Road.
34.4	0.1	Turn right on the Dorsey Creek Road.
35.0	0.6	Cross Dorsey Creek.
36.9	1.9	STOP 10: Looking east across YPM 320, the richest locality in the *Bunophorus* Interval-Zone, one can see the change in the character of the carbonaceous shales in this part of the section. In the lower part of the section the shales are more areally widespread, whereas this shale is clearly delimited laterally and probably represents the filling of an abandoned channel (Wing, this volume). Identifiable plant remains have been found in this shale and are presently being studied by S. Wing. Return south on the Dorsey Creek Road.
38.8	1.9	Recross Dorsey Creek.
39.4	0.6	Locality 67 crest.
40.9	1.5	YPM 69 is on the right. It is the highest locality that is definitely in the *Bunophorus* Interval-Zone.
42.8	1.9	YPM 230a is on the right. Fragmentary remains of the mesonychid *Dissacus* from this locality record the highest level of this genus in the Willwood.
43.2	0.4	Cross Elk Creek.
43.9	0.7	Intersection with the Elk Creek Road. Numerous *Bunophorus* Interval-Zone localities are found on both sides of Elk Creek and on up toward the Elk Creek Rim. None of these localities are particularly fossiliferous and more extensive collecting needs to be carried out in this area, since the *Bunophorus* Interval-Zone is one of the least understood faunal zones in the Willwood.
45.3	1.4	At the top of the Elk Creek Rim turn right.
45.8	0.5	STOP 11: A quarter of a mile off the road on the right is YPM 277N. This locality stands at the 530 m level and, with the first occurrence of *Heptodon*, represents the beginning of the *Heptodon* Range-Zone. This locality is located at the same level as the YPM 45 complex, one of the richest localities in the Willwood. Although no locality included in Bed "A" of Rohrer and Gazin (1965) was included in the Elk Creek Section, it is believed on the basis of geographic location and topography to fall within 10 m of this level, probably on the high side. The notion that the co-occurrence of *Heptodon* and *Homogalax* in Bed "A" necessitated the presence of the "Gray Bull-Lysite" boundary is incorrect, since *Homogalax* is found at least 60 m above the first appearance of *Heptodon*. Like the 190 m level, the 530 m level is heavily dominated by the genus *Hyopsodus*. The two species *H. minor* and *H. miticulus* account for at least 44% of the fauna.
46.3	0.5	Having returned to the Elk Creek Rim, continue east.
47.4	1.1	Turn right.
52.4	5.0	Junction with the Fifteenmile Creek Road. A left turn here will bring one to the north end of the YPM 45 complex. This locality will be visited later.
54.6	2.2	Cross Dry Cottonwood Creek.
57.4	2.8	Intersection with the Platte Pipeline Road. Turn right.
61.6	4.2	Turn left on dirt road and head south toward Mueller's cabin.
62.1	0.5	Turn left prior to crossing Fifteenmile Creek.
62.7	0.6	STOP 12: YPM 28, also known as Windy Gap, has flats occurring at two levels, at the base of the purple bed and above the purple bed below the red-orange bed. The lower bed is relatively unproductive, whereas the upper bed is highly fossiliferous. Specimens of *Pelycodus* as large as *P. jarrovii* from the Upper *Heptodon* Range-Zone have been found at this locality. To the south and east of this locality are a series of localities from the 610 and 620 m levels. These levels are the most fossiliferous in the Elk Creek Section. Return to the Platte Pipeline Road.

63.8	1.1	Intersection with the pipeline road. Turn left.
65.3	1.5	STOP 13: YPM 39, 75, 76, and 77 from the 580 m level are located on both sides of the road. This level contains the first record of *Hyopsodus powellianus*, although other evidence suggests that the fauna from the type Lysite of the Wind River Basin is a closer equivalent of the faunas from the 590 to 610 m levels (see text). A fragment of a single tooth diagnostic of the genus *Lambdotherium* is also known from this level. It is possible that this specimen represents a pocket contaminate, but it might also signify an early, mostly unsuccessful incursion of that genus into the central basin.
69.8	4.5	Dead Indian Hill on the left has around its base beds from the highest level of the Middle *Heptodon* Range-Zone.
73.1	3.3	STOP 14: YPM 3 from the 680 m level has *Lambdotherium* as a common element of the fauna. This places this level within the Upper *Heptodon* Range-Zone. The species of *Lambdotherium* that occurs most frequently in the central Bighorn Basin, *L. primaevum*, is significantly larger than the species *L. popoagicum* from the fauna of the Lost Cabin member of the Wind River Formation, although the latter species is known from a single locality (YPM 195) in the Elk Creek Section. The fossiliferous levels of the Upper *Heptodon* Range-Zone are thought to be earlier than the Lost Cabin fauna described by Guthrie (1967, see text). Return to intersection with Fifteenmile Creek Road.
87.6	14.5	Intersection with Fifteenmile Creek Road. Begin Bown section.

TURTLE STRATIGRAPHY OF THE WILLWOOD FORMATION, WYOMING: PRELIMINARY RESULTS

J. H. Hutchison

Abstract.— The Wasatchian portion of the Willwood Formation contains at least twelve genera of turtles, including the earliest North American records of testudinids and kinosternids. The first occurrences of *Echmatemys, Baptemys,* and *Hadrianus* indicate immigrational events of particular biostratigraphic significance.

INTRODUCTION

The Willwood Formation of northwestern Wyoming contains the most complete and continuous record of late Paleocene-early Eocene terrestrial mammals known. Aside from a few isolated records reported by Gilmore (1919), Rohrer and Gazin (1965), Gaffney (1972) and recently by Bown (1979), nothing is known of the taxonomic diversity and stratigraphic distribution of turtles in the Willwood Formation. My own brief field work in the last two years was limited mostly to the Lysitian and Graybullian parts of the Willwood Formation but the presence of at least 12 genera of turtles is indicated by these collections. The small Yale turtle collection from this formation is also included here. The only comparable stratigraphic collection of Wasatchian turtles is from the Main Body Member of the Wasatch Formation of the Bitter Creek area on the northwestern rim of the Washakie Basin, south-central Wyoming (see Figure 1; also Savage, Waters, and Hutchison, 1972). Comparison of these two lithologically and ecologically distinct sections provides the first opportunity to assess the correlative value of Wasatchian turtle assemblages. In the brief following synopsis of the Willwood turtles, the numbered taxa correspond to the numbered stratigraphic ranges in Figure 1.

WILLWOOD TURTLES

1-3) Three genera of baenid turtles are known from Wasatchian deposits; (1) *Baena* Leidy, (2) *Chisternon* Leidy and (3) *Palatobaena* Gaffney. Baenids are relatively rare but, because the bones of the skull and shell coosify in adults, baenids are disproportionately represented in collections by more complete skulls and shells. *Palatobaena* is known in the Wasatchian only from the Bitter Creek area (Archibald and Hutchison, 1979). *Chisternon* is present in the Lost Cabin Member of the Wind River Formation and in the top of the Main Body of the Wasatch Formation in the Bitter Creek area. Gaffney (1972) reported a skull and jaws of *Baena arenosa* Leidy from the Graybullian section of the Willwood Formation, but additional referred material consists only of a partial shell and shell fragments. *Baena* is an aquatic turtle usually associated with local channel sandstones. *Baena (sensu stricto)* is unknown prior to the Graybullian; it ranges into the Uintan and exhibits Cope's rule of increasing size with time.

4-5) The family Trionychidae is represented in the Willwood Formation by two genera; (4) *Trionyx* Geoffroy *sensu lato* (see Gaffney 1979) and (5) *Plastomenus* Cope. Both genera are known elsewhere earlier and later than Wasatchian and it is doubtful that either genus will have stratigraphic significance within the Willwood Formation. Data from other areas suggest that *Plastomenus* may be ecologically

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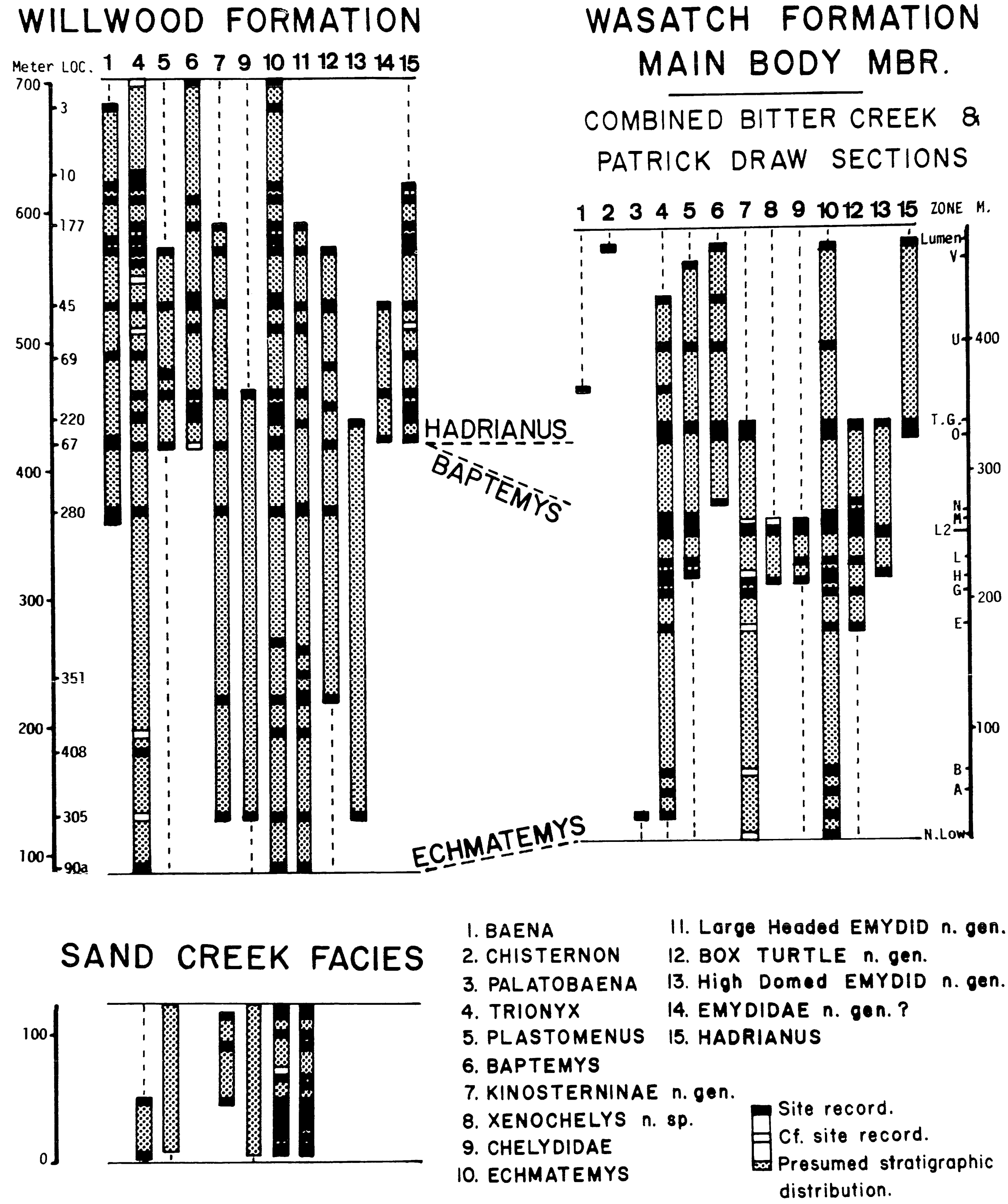

Figure 1. Comparison of the stratigraphic distribution of turtles in the Willwood Formation and Main Body of the Wasatch Formation (Bitter Creek area). The two sections are aligned by the lowest occurrence of *Hadrianus*. Vertical dashed lines indicate predicted occurrences. Stratigraphic base for the Willwood Formation after Schankler (this volume), Sand Creek Facies section of the Willwood Formation after Bown (1979), and Wasatch Formation sections after D. E. Savage and B. T. Waters (pers. comm.).

more restricted than *Trionyx,* although both genera are highly aquatic turtles. *Trionyx* is the largest aquatic turtle in the Willwood Formation and may exceed 50 cm in carapace length.

6) The dermatemydid genus *Baptemys* Leidy is a relatively common aquatic turtle in the late Graybullian through Lostcabinian deposits of Wyoming. This turtle is unknown anywhere earlier than late Graybullian. Its abrupt appearance in the ecologically distinct Bitter Creek area and Willwood Formation supports the hypothesis that its appearance is an immigrational event of widespread regional significance. *Baptemys* is common in the type Lysite and Lost Cabin beds and it is also present in the Golden Valley Formation fauna reported by West (1973) as Graybullian. The first appearance of *Baptemys* and *Hadrianus* (see below) in the Bighorn Basin is isochronous based on present samples and is nearly so in the Bitter Creek sections. Wasatchian specimens of this genus have distinctly tricarinate carapaces and are generally referable to *B. tricarinata* Hay but the taxonomy of this species needs revision. *Baptemys* continues into the Bridgerian and exhibits Cope's rule coupled with a reduction of the carapacial carina, increasing shell thickness and increasing plastral width. Jaw morphology indicates an herbivorous diet.

7-8) Two genera of kinosternid (mud and musk) turtles make their appearance in the Wasatchian. Kinosternids occur in the Four Mile, San Jose, Bitter Creek, Lysite, Lost Cabin, La Barge, Fowkes and Bridger faunas and mark the earliest records of the family. Only one genus (7), undescribed, is known thus far from the Willwood Formation. It is a small species, less than 12 cm in shell length, characterized by a small narrow plastron. I originally (Savage, Waters, and Hutchison, 1972) referred the Bitter Creek specimens of this taxon to the Staurotypinae but new material indicates that this form is cladistically a very primitive member of the Kinosterninae. Early species (undescribed) of (8) *Xenochelys* Hay also occur in the Bitter Creek, Lost Cabin, Bridger and Fowkes faunas. The two genera occur together in several local faunas. The fossil species were probably molluscivorous. Modern representatives of this family prefer quiet bodies of water with soft bottoms and abundant vegetation.

9) The family Chelydridae is represented by rare shell fragments and is presently too poorly known to identify below family level. The family is also encountered in Clarkforkian and Bridgerian deposits in Wyoming.

10-14) At least five genera (four undescribed) of emydid turtles are present in the Wasatchian of Wyoming. Emydids are the most commonly encountered turtles in the Willwood Formation and in Wasatchian deposits in general. The early diversity of the group points to a major undocumented (Paleocene?) radiation of the Emydidae, most branches of which do not lead to modern taxa.

10) The emydid genus *Echmatemys* Hay is an aquatic turtle unknown earlier than early Graybullian and becomes extinct near the end of the Eocene. Wasatchian specimens of this genus are distinctive in having the costal bones thickened just below the vertebral-pleural sulci (Hay, 1908, Gilmore, 1919). Gilmore (1919) identified a partial shell from the Willwood Formation as belonging to *E. megaulax* (Cope). However, the type of this species is not diagnostically distinct in published accounts from *E. testudinea* (Cope). While all the *Echmatemys* in the Willwood Formation are referable to the "Megaulax Group," the lower representatives may be specifically distinct from specimens in the upper beds. *Echmatemys* appears to exhibit Cope's rule through the Eocene. This genus is the most commonly encountered turtle in the Eocene rocks of Wyoming.

11) An undescribed large-headed emydid (= emydine n. gen. in Bown, 1979) ranges upward into the Lysitian of the Willwood Formation and occurs at least as early as Tiffanian elsewhere (Bison Basin). While the latest records are Lysitian, Wasatchian representatives of this genus are unknown outside the Bighorn Basin despite good samplings from the Wind River and Wasatch Formations. This taxon has an unusually broad and short skull which is indicated on the shell by very broad gutter-shaped epiplastral lips and a large head notch in the carapace. The posterior lobe of the plastron was kinetic.

12) Perhaps the most unusual emydid turtle from the Willwood Formation is an undescribed box turtle first discovered in the Bitter Creek area. Unrelated to extant or other known box turtles, this form was terrestrial and reached a size of 35 cm or more in shell length. This genus is the earliest known example of a fully developed box turtle morphology. There is a single transverse plastral hinge separating fully kinetic anterior and posterior lobes. The genus is unique among emydid turtles in having well developed, elongate costiform processes on the nuchal bone. Earliest records of the genus occur in the Clarkforkian of the Bitter Creek section but it is unknown thus far in post-Lysitian deposits. Its relative abundance in the Bighorn Basin is in accord with the well-drained nature of the Willwood Formation depositional environment (Bown, 1979).

13) A small (about 12 cm shell length), apparently high-domed, undescribed emydid occurs rarely in the Willwood and Bitter Creek sections. This species was

apparently also macrocephalic judging from the shell structure.

14) At least one other emydid, probably a new genus, occurs in the Willwood Formation but its morphology and stratigraphic distribution are poorly understood at present. It does not appear to be referable to a known North American genus.

15) The genus *Hadrianus* Cope is the oldest recognized testudinid and the lowest records in the Willwood and Bitter Creek sections document the earliest records of the family. *Hadrianus* (synonymized with *Geochelone* Fitzinger by Auffenberg, 1971, on purely plesimorphic character states) is a terrestrial turtle and attains a carapace length of at least 61 cm. The bones have a distinctive surface texturing which usually allows identification of even small fragments. As in the case of *Baptemys*, the abrupt appearance of *Hadrianus* seems to represent an immigrational event of regional significance. Identifiable specimens of *Hadrianus* in the Willwood Formation are referable to the San Juan Basin species *H. majusculus* Hay. Like other tortoises, *Hadrianus* was probably an herbivore.

SUMMARY

In summary, preliminary sampling of the turtle faunas of the Willwood Formation indicate the presence of at least 12 genera and 7 families of turtles.

- Baenidae
    - *Baena arenosa*
- Trionychidae
    - *Trionyx (s.l.)*
    - *Plastomenus*
- Dermatemydidae
    - *Baptemys tricarinata*
- Kinosternidae
    - Kinosterninae n. gen.
- Chelydridae
- Emydidae
    - *Echmatemys*
    - N. gen. (Large-headed turtle)
    - N. gen. (Box turtle)
    - N. gen. (High-domed turtle)
    - N. gen. ?
- Testudinidae
    - *Hadrianus majusculus*

This diversity is similar to that in the Bitter Creek area of the Washakie Basin (Savage, Waters, and Hutchison, 1972). A congruent sequence of the earliest occurrences of *Echmatemys, Baptemys* and *Hadrianus* in both sections supports an hypothesis that these taxa represent immigrational events of regional utility. Maximum turtle diversity in the Willwood Formation is achieved in the late Graybullian and Lysitian parts of the section and appears to decrease subsequently. Preliminary results suggest that turtles in conjunction with mammals would be useful in refining and subdividing the biostratigraphic sequence of the Willwood Formation.

ACKNOWLEDGMENTS

I wish to thank Tom Bown and Scott Wing for field work guidance and David Schankler for a preliminary draft of his Willwood stratigraphic section. D. E. Savage and B. T. Waters kindly released measurement data on the Bitter Creek sections. Dennis Bramble reviewed the manuscript and provided material support. The University of California Museum of Paleontology, Berkeley, and a fellowship at the University of Utah supplied field funds and research time.

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ADDENDUM

After the manuscript was accepted, T. M. Bown provided additional specimens which included a skull fragment of the baenid *Chisternon* cf. *C. undatum* Leidy, the first record of this genus from the Willwood Formation.

FOSSIL FLORAS AND PLANT-BEARING BEDS OF THE CENTRAL BIGHORN BASIN

Scott L. Wing

Abstract.— Carbonaceous plant-bearing beds of the lower part of the Willwood Formation (lower Gray Bull faunal zone) in the central Bighorn Basin are characteristically tabular and laterally extensive. Those of the middle part of the formation (middle to upper Gray Bull and lower Lysite) are predominantly lenticular and local in extent. No plant-bearing beds are known from most of the Lysite faunal zone. Carbonaceous beds of the upper part of the Willwood Formation (Lost Cabin faunal zone) and the overlying Tatman Formation are tabular and laterally extensive like those of the lower Willwood. Both the lithology and fossil floras of the tabular carbonaceous beds suggest extensive marshy backswamp facies, whereas the lenticular carbonaceous beds appear to represent more restricted pond facies. Ecological factors affecting the distribution of Willwood floras probably also had an important effect on early Eocene faunas of the central Bighorn Basin.

INTRODUCTION

In contrast to its long history as a classic area for mammalian fossils, the central Bighorn Basin has largely been neglected by paleobotanists. Published mention of fossil plants from the Willwood Formation of the central Basin is confined to brief notes by Hewett (1926) and Van Houten (1948, p. 2102). This dearth of information probably results from the rather unpromising appearance of the Willwood's red-banded sediments. However, the Willwood of the central Basin does have a small proportion of fine-grained, carbonaceous layers that contain fossil plants in varying degrees of abundance and preservation. These carbonaceous layers have been noted by vertebrate paleontologists for some time, but have been largely ignored by them. By 1978 the increasing amount of paleoecological information on the Willwood, emphasizing both faunal and sedimentological perspectives, made an investigation of Willwood fossil floras an attractive project.

Study of the Willwood floras offers several unique opportunities. Work by Schankler (Ph.D. thesis in prep., also this volume) on mammalian faunal composition from the area, and by Bown (1979) and Bown and Kraus (in press) on taphonomy, soil formation, and depositional environments, provides a background of knowledge which makes information on the flora more valuable in our attempt to reconstruct the setting for early Eocene mammal evolution. Also, the stratigraphic section that David Schankler and I measured through the Willwood in this area allows a study of floral change through time on a scale which has seldom been attempted by paleobotanists.

Two-and-one-half months of collecting in the last two summers have yielded two or three thousand specimens from 15 distinct stratigraphic levels in the Fort Union, Willwood and Tatman Formations. Six of these levels in the Willwood and one in the basal Tatman have proven most productive, and this study is based largely on them.

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In addition to fossil leaves, fruits, seeds, flowers, and pollen, carbonaceous layers have produced abundant aquatic gastropods, pelecypods, some non-ganoid fish scales, and fragmentary insect remains. Previous discussion of Willwood carbonaceous layers is largely confined to the work of Bown (1979). He states that they comprise about 2.5% of the thickness of the Sand Creek facies, and that they generally are thicker than the colored overbank mud units. He hypothesizes (p. 37):

> [Their] . . . origin [was] through the slow infilling of topographic lows on a broad distal floodbasin with some vegetational ground litter. These lows were eventually filled by fine sediment that was deposited largely from suspension, probably during overbank flows.
>
> The thicker and less laterally extensive carbonaceous shales that are overlain and truncated by apron-channel fills probably were deposited in ponds on the distal floodbasin.

He also notes (p. 23) that, "Poorly preserved leaf and twig impressions are locally abundant."

Carbonaceous shales are also common in parts of the Clark's Fork Basin, but largely restricted to Paleocene and lowest Eocene beds (P. D. Gingerich, pers. comm.). Leo Hickey reports (pers. comm., also this volume) that the youngest fossil leaf locality from this areas is LJH 7634, at the bottom of the *Phenacodus-Ectocion* zone. Above this level in the northern Bighorn Basin the only plant megafossils are *Celtis* seeds found in the overbank mudstones.

The following abbreviations are used here: LJH, Leo J. Hickey locality; WCS, Willwood carbonaceous shale or stratum; YPM, Yale Peabody Museum. The terms Gray Bull, Lysite, and Lost Cabin are used in this paper to denote local faunal zonation seen in Willwood rocks of the central Bighorn Basin, and are not meant to imply exact chronological or biostratigraphic correlation with other basins or other parts of the Bighorn Basin. See Bown (1979) and Schankler (this volume) for discussion of these faunal zone terms.

VERTICAL DISTRIBUTION OF PLANT-BEARING BEDS

Our knowledge of the vertical distribution of carbonaceous beds in the central Bighorn Basin is based largely on the Schankler-Wing stratigraphic section measured in 1976 and 1977, although roughly half of the plant-bearing deposits were not located until the following two field seasons. This section begins at the unconformable contact between the Willwood and Fort Union Formations on Antelope Creek, and continues west and south, roughly following the Elk Creek and upper Fifteen Mile Creek drainages. On the basis of mammalian fossils from known levels in our section, Schankler (pers. comm.; and this volume) has described five faunal zones in the Willwood of the central Bighorn Basin.

The bottom 190-200 m of the section fall in the lower Gray Bull zone, from 200 m to about 380 m falls in the middle Gray Bull zone, from 380-510 m includes the upper Gray Bull, from 510-660 m includes beds of the Lysite zone, and from 660 m to about 780 m is in the Lost Cabin faunal zone. At its top in this area, the Willwood grades conformably into the middle Eocene Tatman Formation.

In contrast to Wasatchian deposits in the northern and southern part of the basin, the Elk Creek-Fifteen Mile Creek region has carbonaceous layers scattered throughout the section from top to bottom, though there is a 150 m thick section in the upper Lysite and lower Lost Cabin faunal zones that lacks carbonaceous layers. In discussing the plant-bearing deposits it is useful to make a distinction between tabular, laterally extensive carbonaceous beds, and those which are lenticular and local. Although these types may intergrade to some extent, nearly all of the more than 30 plant-bearing layers belong clearly in one category or the other. The stratigraphic distribution of these two distinct bed geometrics forms an interesting and perhaps revealing pattern, especially when it is considered on the scale of the whole formation (see Figure 1).

In the bottom 125 m of our section there are at least nine plant-bearing layers, accounting for about 10% of stratal thickness. Carbonaceous layers in the lower part of the Willwood are characteristically of the tabular and laterally extensive variety; one of them was traced laterally for two miles (3.2 km). Above the 125 m level, tabular zones become less common, there being only four of them between 125 m and 355 m. The tabular layers become increasingly rare and finally disappear above 355 m, but at about 290 m lenticular carbonaceous deposits begin to appear.

Between 290 m and 320 m in the section (middle Gray Bull faunal zone) there are four lenticular, plant-bearing beds, all of them less than 350 m across. One of these layers, near YPM locality 365, shows clear evidence of cut-and-fill deposition and is possibly the filled-in channel of an oxbow cut-off. These local, lenticular deposits continue to occur as one moves up section: four of them are known from within the upper Gray Bull faunal zone. Strati-

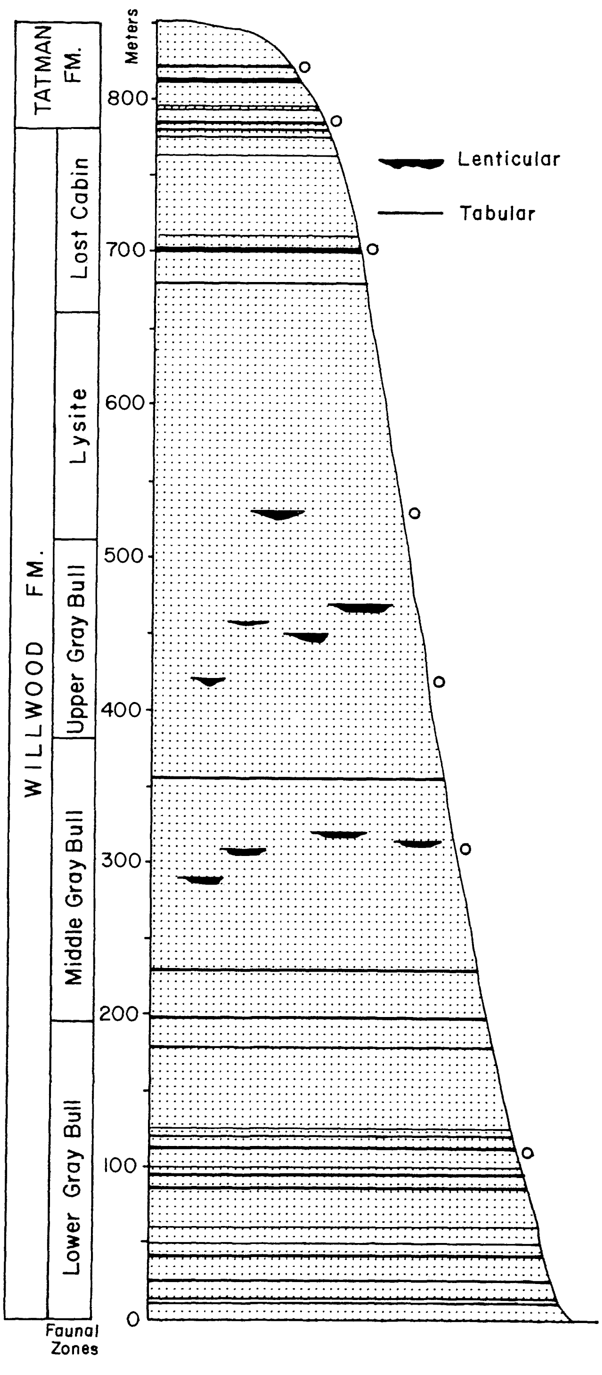

Figure 1. Composite section through the Willwood formation in the Elk Creek-Fifteen Mile Creek drainages, showing vertical distribution of the two types of carbonaceous deposits. Circles indicate levels for which there are major collections of plant fossils. Faunal zones are according to Schankler (this volume).

graphically, these deposits are all between 420 m and 470 m in the section, but they are distributed over a wide geographic area. One carbonaceous layer, near YPM locality 320 is a particularly clear example of the lenticular geometry of these deposits. Only a single plant-bearing deposit is known from the Lysite faunal zone, and it occurs quite low, at 530 m. Like the carbonaceous deposits of the upper Gray Bull zone, this bed is local, but its geometry is difficult to determine. Both the lithology of the site and the type of preservation of the plant fossils found there are unique in the central Bighorn Basin.

In the Lost Cabin faunal zone shale once again becomes a major rock type in the Willwood Formation. Laterally extensive, tabular layers of carbonaceous shale, much like those seen near the bottom of the Willwood, are known from Tatman Mountain, Bobcat Ridge, and the north and south sides of the upper Fifteen Mile Creek drainage. From the 680 m level through the top of the Willwood Formation and into the Tatman Formation there are many thick layers of carbonaceous shale. At least five major layers occur in the top 100 m of the Willwood and account for 4-6% of stratal thickness. Several of these layers have been traced for over two miles (3.2 km) along the south side of the Fifteen Mile Creek drainage, and one layer (at 700 m in the section) is more than 2 m thick. Up section into the Tatman Formation, the carbonaceous shale units become even thicker (individual layers up to 4 m) and continue to be laterally extensive. Lacustrine limestone appears at about 790 m.

In summary, the plant-bearing beds in the Willwood Formation of the central Bighorn Basin exhibit a change in their geometry as they are followed up section. In the lowest 290 m of our section, they are exclusively tabular and laterally extensive. Above 290 m but below 355 m both tabular and lenticular geometries are found. Above 530 m but below 680 m, no carbonaceous zones are known. Above 680 m carbonaceous layers are once again found to be tabular and laterally extensive.

Although the correlation is far from precise, changes in the geometry of carbonaceous layers correspond generally to the faunal zonation proposed by Schankler (this volume). The middle Gray Bull-upper Gray Bull boundary is 25 m above the beginning of a 325 m hiatus in the deposition of tabular, laterally extensive, carbonaceous layers. The upper Gray Bull-Lysite boundary is 20 m below the highest known lenticular carbonaceous deposit. The Lysite-Lost Cabin boundary is 20 meters below the lowest recurrence of tabular, laterally extensive layers.

Only the lower Gray Bull-middle Gray Bull boundary lacks association with a change in the geometry of the carbonaceous deposits. So far the correlation is only suggestive, but it is important to note that changes in the mammalian fauna appear to be accompanied by subtle changes in the characteristics of the carbonaceous layers. This correlation between shifts in lithology and fauna suggests that changes in local ecology may act directly to produce some of the transitions we see within the mammalian fauna.

DEPOSITIONAL ENVIRONMENTS

The two kinds of plant-bearing deposits in this part of the Willwood Formation can be distinguished by differences in lithology as well as by the differences in geometry already described. Tabular layers are characterized by lateral variation in grain size, bedding type, organic content, and color. They also frequently have slickensided surfaces. Lenticular layers are notable for thinning at the margin of the deposit and for strong vertical zonation.

Most of the detailed observation on tabular carbonaceous zones comes from one such layer, designated WCS-7, which outcrops extensively along the south fork of Elk Creek, near the Basin-Manderson highway. Within this single layer, grain size varies from a fine silt to medium sand, as bedding changes laterally from fissile, finely-laminated shale to blocky sandstone. This lateral variation in lithology suggests that the layer was not deposited under uniform conditions. The fine-grained, well-laminated areas are dark in color because of the large quantity of organic material they contain; leaves in such areas are so densely packed that their outlines are obscured. Bioturbation, slickensided surfaces, and large amounts of jarosite and gypsum are further characteristics of these heavily organic layers. More sandy areas of the bed have a lighter color (less organic material), and fewer but more completely preserved leaf fossils. The most sandy regions of WCS-7 contain leaf fossils only in thin, infrequent, silty interlayers.

Although observations on sedimentary features and the spatial relationship of different facies are probably not complete enough to demonstrate a particular environment of deposition for these rocks, the data are consistent with parts of Allen's (1964) model for fluviatile deposition. Allen considered fine grain size, bioturbation, and lamination as characteristics of his backswamp facies. Bown (1979) and Hickey (1977 and pers. comm.) have noted the high organic content of backswamp sediments in Tertiary deposits of the West. It is probable that the fine-grained, laminated, highly organic sediments of WCS-7 and other similar carbonaceous zones were deposited under backswamp conditions. More sandy, less well-bedded parts of WCS-7 are attributed to one of the near channel depositional environments, but present data do not permit discrimination between point bar, crevasse splay, or levee environments.

A preliminary examination of the plants from WCS-7 supports the hypothesis that this layer represents an environmental gradient from backswamp to near channel environments. *Equisetum, Glyptostrobus,* several ferns, and to some extent *Averrhoites,* are common forms in the backswamp facies. In the coarser rocks *Glyptostrobus* is rarer, as are *Equisetum* and *Averrhoites,* but *Platanus* and *Cercidiphyllum* are more common.

Vertical zonation of sediments is also present within these tabular beds, and involves variation in the same features seen in the lateral changes. Frequently, dark, fine-grained, fissile shale is overlain by coarser sediment. This coarsening upwards may represent overbank deposition of fine sands in levees or crevasse splays, or it may indicate shifting of the channel into what had previously been an area of backswamp.

Lenticular deposits are local, thick, and have well-developed vertical zonation of grain size and organic content. One of these deposits, near YPM locality 365, was extensively quarried for leaves, and observations were made on its stratigraphy (Figure 2). The very fine-grained clay, the abundance of aquatic gastropods and pelecypods, and the clear vertical zonation probably indicate deposition in standing water. This idea is corroborated by the abundant presence of *Salvinia preauriculata,* a floating fern that requires open water.

Floral remains from the deposit near YPM locality 365 include few conifers, ferns, or horsetails, but have abundant fossils of *Cerciciphyllum,* and of a member of the walnut family (probably *Carya* or *Juglans*). The low abundance of backswamp taxa argues for well-drained soils along the pond's margin.

Adding these conclusions about depositional environments to our knowledge of the vertical occurrence of different bed types, we can reconstruct a scenario for changing floodplain environments. In early Gray Bull time, Willwood floodplains were characterized by fairly frequent intervals during which low, marshy backswamp covered extensive areas, while mesophytic plants were restricted to slightly higher or better drained locations near stream channels. During the later part of early Gray Bull and middle Gray Bull time, intervals of widespread backswamp became

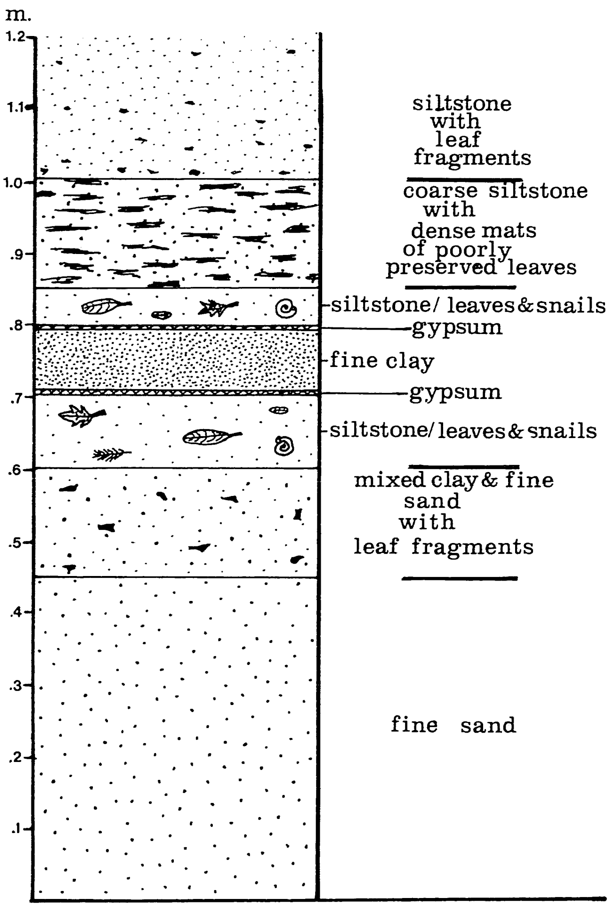

Figure 2. Section through Lightning Bolt Quarry, near YPM locality 365.

rarer, but the floodplain was dotted with small ponds resulting from local channel cuts. By late Gray Bull time, backswamps were no longer a part of the regional floodplain environment, though local ponds persisted through late Gray Bull and into Lysite time. Middle and upper Lysite zone sediments contain no evidence of either backswamp or local pond deposits. Shortly after the beginning of the Lost Cabin faunal period, backswamps once again became an important part of the floodplain environment, and these were increasingly dominant during the formation of middle Eocene Lake Tatman.

TEMPORAL CHANGES IN THE FLORA

Study of the floras from the central Bighorn Basin is still in its preliminary stages, and therefore identification of many of the taxa is as yet tentative. There are also difficulties with comparing floras that differ both in stratigraphic level and depositional environment. The preceding description of bed types and their stratigraphic distribution reveals that equivalent environments are not available at all levels, particularly in the middle part of the Willwood Formation where tabular backswamp layers are absent. Because of these two difficulties the following discussion of floral change represents work in progress which is certainly subject to future refinement. Nevertheless, I feel that the large-scale patterns will probably hold true.

Several generalizations can be made about Wasatchian floras from the central Bighorn Basin. First, species are lost from the flora slowly, there being a strong element of continuity between Clarkforkian floras of the northern Bighorn Basin (Hickey, this volume) and lower Gray Bull floras from the central basin. Second, there is an increase in total diversity of the flora from the bottom to the top of the Willwood, with a large jump near the beginning of Lost Cabin time. Most of these new Lost Cabin species are members of higher level taxa characteristic of subtropical to tropical environments, for example Magnoliidae and Dilleniidae. Third, the lowest diversity in the formation is recorded in the pond facies of the middle Gray Bull through Lysite faunal zones. The diversity and composition of the flora are greatly influenced by environment of deposition, however this does not necessarily imply that low diversity in the middle of the formation is an artifact of facies differences. If backswamps were absent from the central Basin during late Gray Bull and Lysite time, then the absence of backswamp-living plants could have produced a real decrease in floral diversity.

Floras from lower Gray Bull beds on Antelope and Elk Creeks contain the fern *Allantoidiopsis,* conifers *Glyptostrobus* and *Metasequoia,* the monocot *Zingiberopsis,* two species of *Platanus* (sycamore), *Cercidiphyllum, Averrhoites,* and *Equisetum,* all common members of upper Fort Union Formation floras (Hickey, this volume). *Metasequoia, Glyptostrobus, Zingiberopsis, Cercidiphyllum,* and *Averrhoites* are dominant forms in the lower Willwood as well. However, *Hemitelia* and *Lygodium* (both ferns), are first recorded in the Bighorn Basin from lower Willwood beds. This agrees with the stratigraphic distribution of these two genera described by Hickey (1977) in the Golden Valley Formation. There they were recovered from the upper member (Camels Butte), a probable Gray Bull equivalent, but not from the lower member (Bear Den), a probable Clark Fork equivalent. Curiously, some taxa that are present both in Clarkforkian sediments of the Bighorn Basin (Hickey, this volume and pers. comm.) and in the Camels Butte member of the Golden Valley Formation are absent from the lowest Willwood collections. These taxa include: *Persites argutus, Ternstroemites aureavallis, Porosia verrucosa, Nelumbo aureavallis, "Viburnum" antiquum,* and *Meliosma longifolia* (the last known from a single specimen). Of these taxa, *Persites* and *"Viburnum"* are present in only low abundance in the Golden Valley, and thus their absence from the lower Willwood Formation may be a result of sampling error. *Nelumbo* and *Porosia* are floating aquatics, and their absence from the lower Willwood may be a result of facies control (no open standing water). The absence of *Ternstroemites* and extreme rarity of *Meliosma* are more difficult to explain. These two genera are found in great abundance both in Eocene Golden Valley sediments (*Meliosma* and *Ternstroemites* are second and fifth, respectively, in rank order abundance), and in upper Fort Union sediments of the Bighorn Basin (Hickey, this volume). Their absence from the Willwood may indicate they were becoming extinct locally.

The flora sampled from the middle Gray Bull faunal zone has winged seeds of *Acer* (maple), and leaves of *Gingko,* here in their lowest occurrence in the Willwood. Both are known from the Fort Union Formation in the Bighorn Basin (Hickey, this volume). A new type of juglandaceous leaf (walnut family), *?Prunus* (cherries, almonds), *Sequoia,* and an entire-margined dicot of unknown affinities are also first known from this level, probably their first occurrences in the Bighorn Basin. *Salvinia preauriculata,* considered an Eocene index fossil (Hickey, 1977), is abundant at this locality. *Cercidiphyllum* is present and abundant, just as in the Lower Gray Bull, but *Averrhoites* and *Equisetum,* though present, are rare.

Fossils in the upper Gray Bull zone also come from lenticular deposits, and predictably, *Salvinia* occurs in abundance. Another floating aquatic (possibly *Lemna,* duckweed) is also common. Several forms known from the lower levels are also found in the upper Gray Bull, but only *Cercidiphyllum* occurs in abundance. At least six new kinds of dicot leaves first appear at this level, most of which bear little resemblence to forms from either older Paleocene or younger middle Eocene floras. One particularly distinctive form with violoid teeth is numerically the dominant taxon at this level, but it is unknown from any other level of the formation. The upper Gray Bull flora may prove to be the most "time endemic" component of the Willwood flora, containing several distinct forms not known from any other levels.

As remarked above, the plant-bearing bed in the Lysite zone has a lithology unlike that of the other plant fossil beds in the central Bighorn Basin. The matrix from which these fossils come is a fine, light gray, blocky siltstone which contains little organic matter except along infrequent bedding planes. However, the lithology and small areal extent of the site are comparable to LJH 7634 from the Sand Coulee area. It is interesting to note that both beds occur immediately below a lengthy hiatus in the deposition of carbonaceous layers, and that both are characterized by a high abundance of *Platanus nobilis* leaves and *Platanus* fruiting heads. The Lysite locality also contains abundant *Salvinia, Zingiberopsis,* legume (bean) pods, and leaves of the genus *"Dalbergia." "Dalbergia"* is also common in middle Eocene floras of the Wind River Basin and the Tepee Trail Formation.

With the return of backswamp layers in the Lost Cabin faunal zone, a great many new taxa enter the flora. Between 20 and 25 new forms make their first appearance in the Willwood at the 700 m level, which is the first thick and extensive carbonaceous layer in the upper part of the formation. Among these are *Dombeya, Osmunda* (a fern), the middle Eocene species of *Lamanonia,* several magnoliids and dilleniids, and two or three unidentified monocots. In addition, some of the forms common in the backswamps of the lower levels of the formation are still present, though in low abundance. *Averrhoites, Zingiberopsis,* and *Allantoidiopsis* are each known from a few specimens at these upper levels. *Hemitelia* and *Lygodium,* also first seen at lower levels, are found in even greater abundance at the 700 and 785 m levels. Among the conifers, the cooler-adapted *Metasequoia* and *Glyptostrobus* are absent, but the more warm-climate *Sequoia* is present. The result of this influx of new taxa without widespread extinction of older forms is a large increase in number of taxa. There are no fewer than 30 distinct forms known from the 700 m level; this is nearly half the number known from the entire formation.

SUMMARY

Both the fossil plants of the Willwood Formation and the sedimentary units that contain them give evidence of a major change in regional environments during Wasatchian time. In the bottom 125 m of the Willwood the percent of stratal thickness taken up by carbonaceous layers is comparable to that in the underlying Fort Union. These backswamp deposits, in their extent, frequency, and in the fossil plants they contain strongly resemble their late Paleocene analogues.

Above 125 m, tabular carbonaceous shales become steadily less important until they cease altogether above 355 m. The driving forces behind this change, whether climatic or geomorphological, are not currently known. However, a middle early Eocene shift of paleodrainage from southeast to northwest (Bown, this volume) may have been involved. One of the biotic consequences of this change in depositional regime was the regional elimination of the backswamp plant community, although clearly some of its species survived in other habitats.

Conditions unfavorable to the formation of backswamps persisted all through the upper Gray Bull and Lysite faunal periods and into the lower Lost Cabin (from 330 to 680 m in the Schankler-Wing section). Floral information for this intervening period is derived from localized floodplain pond deposits. With few exceptions, the backswamp taxa of the lower Willwood are not well represented in these samples.

The backswamp environment returned to the central Bighorn Basin shortly after the beginning of the Lost Cabin faunal period. Again the reasons for this change are not clear, though basin subsidence is a likely cause (Bown, this volume). With the recurrence of backswamps came a changed backswamp flora. These backswamp floras were considerably more diverse than those of the Paleocene (Hickey, pers. comm., this volume) or earliest Eocene, containing many new species as well as retaining some of the old ones. The transition from middle Gray Bull to Lost Cabin effected a more rapid and complete change on the backswamp flora than did the transition from Paleocene to Eocene.

The relationship between floral composition and environment of deposition is clearly a close one. The correlation mentioned earlier between change in bed geometry and faunal zonation suggests that ecological factors such as the ones that so clearly affect floras may also influence the mammalian fauna. With a better understanding of these ecological factors it may be possible to study their effect on faunal change and evolution.

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THE WILLWOOD FORMATION (LOWER EOCENE) OF THE SOUTHERN BIGHORN BASIN, WYOMING, AND ITS MAMMALIAN FAUNA

Thomas M. Bown

Abstract.— Two facies of the Willwood Formation have been recognized in the southern Bighorn Basin. The Sand Creek facies is typified by a predominance of purple and gray mudstones, whereas orange and red mudstones predominate in the Elk Creek facies. These and other differences characteristic of the two facies are attributed to climatic differences in depositional environments within the Bighorn Basin. Faunal lists are given for both the Sand Creek and Elk Creek facies.

INTRODUCTION

The Willword Formation is a fluvial deposit that is exposed over approximately 3,000 km² in the axial region of the southern and southeastern Bighorn Basin (south of the Greybull River; Figure 1). For most of this outcrop area, basal Willwood beds conformably overlie the Paleocene Fort Union Formation (Polecat Bench Formation of Jepsen, 1940) but along the southwest margin of the basin upper Willwood rocks overlie the Upper Cretaceous Lance Formation and the Paleocene Fort Union Formation with a striking angular unconformity (Figure 2). This relationship is best seen at Hole-in-the-Ground, southeast of the town of Meeteetse, but it is also observable at several points along Wyoming State Highway 120, between Gooseberry Creek and Meeteetse. Bown (1979) also reported a minor unconformity between Willwood and Fort Union rocks east of Worland.

In areas where there is no unconformity with underlying rocks, the base of the Willwood is recognized by the first persistent occurrence of red, purple, and (or) orange mudstones in association with (1) calcium carbonate and (or) iron oxyhydrate nodules and concretions, and (2) lenticular gray sandstones with wide aprons of sand extending laterally from the channel troughs. However, in the Blue Mesa area (Bown, 1979, pl. 1, Figure 2 in this paper), upper Fort Union and conformable lower Willwood mudstones and sandstones intertongue with thin beds of quartzite pebble and roundstone conglomerate. These conglomerates are similar to those in the upper part of the Willwood Formation near Meeteetse where the Willwood is unconformable on older rocks (Hewett, 1926; Young, 1972; Neasham and Vondra, 1972).

The Willwood Formation in the southern Bighorn Basin consists chiefly of varicolored mudstone (50-80%), sandstone (20-25%), conglomerate (0-30%), and shale (about 2%). The mudstones are composed of quartz and feldspar silt and smectite-rich mixed-layer illite-smectite clays with subordinate amounts of kaolinite and pigmenting iron and manganese oxyhydrate minerals (Bown, 1979; Kraus, 1979). Most of the mudstones are non-calcareous or weakly calcareous. The sandstones are largely quartzarenites, lithic subarkoses, and feldspathic litharenites (Bown, 1979; Kraus, 1979). Metaquartzite conglomerates with pebble and roundstone clasts of quartzite (35-75%), carbonate (3-10%), sandstone (1-25%), and

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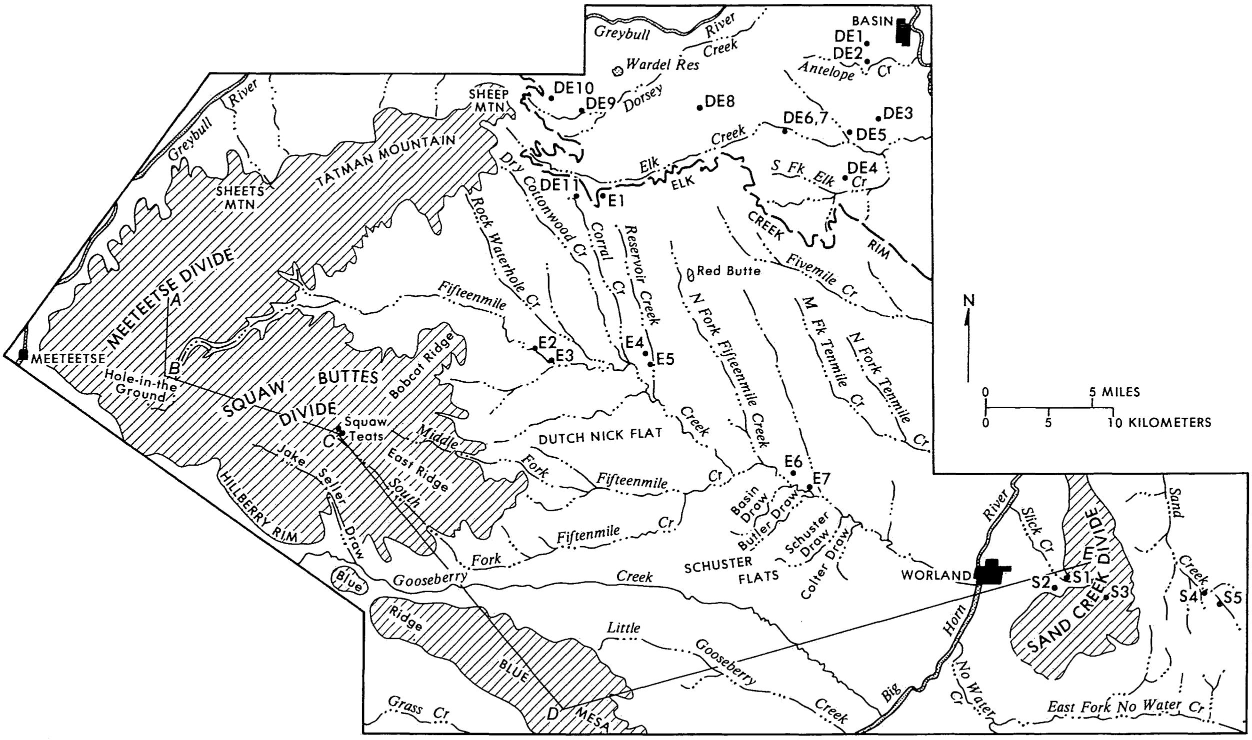

Figure 1. Sketch map of the south-central and southeast Bighorn Basin, showing major physiographic features, drainages, and field conference stops. E1-E7, Elk Creek facies stops; S1-S4, Sand Creek facies stops; DE1-DE11, Dorsey Creek-Elk Creek stops (Schankler road log, this volume). A-B-C-D-E shows line of cross-section in Figure 2.

other lithologies (0-25%) are locally common (Young, 1972). Carbonaceous shales and gray paper shale are rare.

A complete Willwood section is preserved in the southern and central Bighorn Basin where the formation is at least 750 m (2360 ft) thick. The lower part of the formation is best exposed in the drainages of Slick and Sand Creeks, east of the town of Worland, and along the lower drainages of Tenmile and Fifteenmile Creeks and their tributaries, north of Schuster Flats and west of Worland (Figure 1). The upper part of the formation is best exposed in the upper drainages of Gooseberry and Fifteenmile Creeks and their tributaries, adjacent to Dutch Nick Flat, on the Squaw Buttes Divide and Tatman Mountain, and in the Buffalo Basin, between the towns of Worland and Meeteetse (Figure 1).

The Willwood Formation is conformably overlain by the lower and middle Eocene Tatman Formation in the south-central Bighorn Basin (Sinclair and Granger, 1912; Rohrer and Smith, 1969). The Tatman consists of green and brown clay shale, brown kerogenic shale, carbonaceous shale, lignite, and green and brown feldspathic quartz sandstone. The Tatman is preserved as two erosional outliers, one on the Squaw Buttes divide (about 290 m) and the other on the Tatman Mountain table (about 220 m). At least five tongues of red or purplish-red Willwood mudstones up to 15 m in thickness interfinger with the lower 240 m of the Tatman Formation on the Squaw Buttes divide (Bown, unpublished data). The top of the Tatman Formation is not preserved in the southern Bighorn Basin, though younger rocks occur above it. Squaw Teats on the Squaw Buttes divide are capped by detachment fault klippen probably derived from the Tepee Trail Formation of the southeast Absaroka Range (Rohrer, 1966; Rohrer and Smith, 1969; Bown, in press). About 15 m of andesitic conglomerate and sandstone atop Tatman strata on Tatman Mountain were assigned to the Pleistocene (?) Fenton Pass Formation by Rohrer and Leopold (1963). Tuff-bearing so-called Tatman rocks that lie between the Willwood and Aycross Formations along the southeast margin of the Absaroka Range

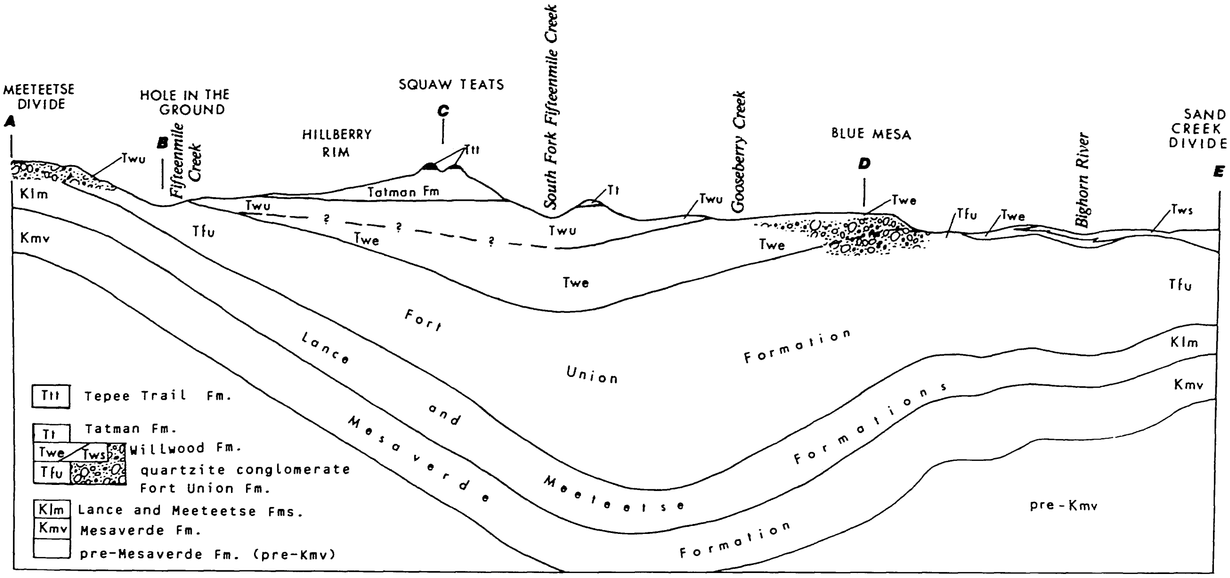

Figure 2. Diagrammatic cross-section (not to scale) of Willwood and older rocks in the southern and southeast Bighorn Basin. Line of section A-B-C-D-E shown on map in Figure 1.

are probably younger than the non-tuffaceous Tatman rocks of the southern Bighorn Basin (Bown, in press). It is uncertain whether Tatman rocks were ever deposited in the northern Bighorn Basin.

SAND CREEK FACIES AND ELK CREEK FACIES

Bown (1979) distinguished two facies in the lower part of the Willwood Formation of the southern Bighorn Basin. The Sand Creek facies is exposed east of the Bighorn River in the southeast axial part of the Bighorn Basin and in the lower part of the drainage of Fifteenmile Creek, west of the Bighorn River. Because of the complex intertonguing of the Sand Creek and Elk Creek facies, the facies contact is very difficult to map. In general, rocks typical of the Sand Creek facies persist about 8 km west of the Bighorn River in the drainages of Gooseberry and Fifteenmile Creeks, and about 1 km west of the Bighorn River in the drainage of Tenmile Creek (Figure 1). Rocks of the Sand Creek facies intertongue with the Elk Creek facies along the axis of Neiber Syncline, east of the Bighorn River (Bown, 1979).

The Sand Creek facies is typified by relatively thin mean thicknesses of colored mudstones, a predominance of purple and gray mudstones (22% and 21%, respectively), paler mudstone colors, paucity of calcium carbonate cement in sandstones, absence of calcium carbonate nodules, abundance of iron and manganese oxyhydrate nodules and concretions, and dominance of sandstones of shoestring and apron-channel cross-sectional geometries (Bown, 1979). The Elk Creek facies, on the other hand, is characterized by relatively thick deep-colored mudstone bands, predominance or orange and red mudstones (41%) , abundance of calcium carbonate cement in sandstones, abundance of calcium carbonate nodules, relative paucity of iron and manganese oxyhydrate nodules and concretions, and dominantly apron-channel sandstones (Bown, 1979).

Van Houten (1948, p. 2083) believed that red coloration of Willwood mudstones was derived from primary hematite that was in turn derived either from "older red formations exposed at the basins' margins or from red soil developed on the surrounding uplands." A paleosol origin for Willwood mudstone coloration was first postulated by Neasham (1967) and several lines of evidence argue against the interpretation that red pigmenting hematite is reworked from older rocks or upland soils (Bown, 1979). The most compelling of this evidence is fourfold: (1) the Permian-Triassic redbeds of the

Bighorn area were probably not exposed in some Willwood sediment source areas during the early Eocene, (2) the well-documented cyclic alternation of Willwood mudstone coloration (Neasham and Vondra 1972; Bown, 1979) would require the cumbersome interpretation of cyclic access to source areas with detrital hematite, (3) some mechanism must be postulated to explain the cyclic hydration of detrital hematite in orange and mottled mudstones but not in red mudstones, and (4) the geochemistry of Willwood mudstones and associated sedimentary structures such as nodules and concretions, the absence of bedding, and the strong bioturbation of the mudstones are completely compatible with the results of pedogenic processes at work today in a variety of warm temperate to subtropical climatic regimes. The presence of abundant bioturbation and root and insect burrow casts strengthens the paleosol hypothesis, as does the evidence of Willwood vertebrate taphonomy. Evidence for the very early diagenetic formation of Willwood coloration, nodule formation, and calcium carbonate cementation is most compatible with soil-forming processes and has been documented by Bown (1979), Kraus (1979), and Bown and Kraus (unpublished data).

Bown (1979) related mudstone coloration to the early diagenetic translocation of iron and manganese minerals during periods of early Eocene soil formation. Bown and Kraus (unpublished data) have related calcium carbonate cement in Willwood sandstones to pedogenesis as well. The greater incidence of red mudstones, calcium carbonate nodules and concretions, and calcium carbonate cement in the Elk Creek facies indicates that soil conditions were drier during deposition of that unit than during deposition of the Sand Creek facies. The paucity or absence of calcium carbonate as cement or nodules, the paucity of red mudstones, and the presence of numerous iron and manganese nodules in the Sand Creek facies are, conversely, related to moister soil conditions. The geochemistry and sedimentology of Willwood mudstones indicates that Willwood paleosols are most closely related to red-yellow tropical soils and tropical and subtropical podzols (Bown and Kraus, unpublished data).

Bown (1979) postulated that the Elk Creek facies was deposited under climatic conditions typified by relatively spaced yearly rainfall (*i.e.*, monsoons), whereas rainfall was more equally distributed during the year in the area of the Sand Creek facies. Because the Sand Creek facies intertongues with the lower part of the Elk Creek facies, moister conditions in the southeast Bighorn Basin were probably related to the proximity of this area to the then-rising southern Bighorn Mountains.

The Elk Creek facies and younger Willwood rocks in the central and southern Bighorn Basin show a gradual up-section increase in the thickness and proportion of red mudstones. This phenomenon is probably related to increasingly spaced rainfall during the middle and later early Eocene, reflecting the development of a basinward rain shadow as the Bighorn Basin became progressively surrounded by elevated areas.

WILLWOOD VERTEBRATE TAPHONOMY

In the lower 200 m of the Willwood Formation throughout most of the Bighorn Basin, most of the major *in situ* concentrations of vertebrate fossils occur in tabular gray mudstones that generally overlie orange, purple, or mottled-purple-and-orange mudstones (Bown, 1975, 1979). The fossil remains are principally those of mammals and mammalian fossils are dominated by fragmentary upper and lower jaws (about 22%) and isolated teeth (about 65%). Postcranial bones (about 13%) are generally very fragmentary and consist principally of broken distal ends of long bones, vertebrae, astragali, calcanea, and phalanges (Bown and Kraus, unpublished data). Articulated material, associated skeletal and gnathic remains, and complete long bones are extremely rare.

The postcrania show various stages of weathering and disturbance that occurred after death and prior to burial. These include disarticulation, cracking and flaking, and tooth marks on bones. Coprolites often occur associated with bones and teeth.

Bown and Kraus (unpublished data) believe that these bone-bearing beds reflect gradual accumulation of vertebrate remains on the surfaces of early Eocene alluvial soils. Some of the most richly fossiliferous gray mudstones, termed Class A gray mudstones because of their coincidence with suspected A horizons of paleosols, possibly represent accumulation of bones and teeth in and on the surfaces of leached A horizons of podzolic soils. A paleosol lag origin for these fossiliferous beds rather than concentration by hydraulic transport is supported by the following evidence: (1) association of the bones and teeth with bioturbated mudstone containing root casts and insect burrow casts, (2) association of the fossils with nodules and concretions similar to those developing in some present-day soils, (3) presence of numerous cracked, partly rotted, gnawed, broken, and dis-

Table 1. List of mammals from the Sand Creek and Elk Creek facies of the Willwood Formation. List for Elk Creek facies records mammals identified by Bown in unpublished collections at the Yale Peabody Museum, the University of Wyoming Geological Museum, and the U. S. Geological Survey (Denver) and is not a comprehensive list for the Willwood Formation elsewhere in the Bighorn Basin. (*) denotes published types in these collections, (**) denotes new taxa in press with types in these collections, (+) denotes representation in U. S. Geological Survey collections in Denver. SCF = No Water fauna, Sand Creek facies; ECF = Elk Creek facies. A = abundant (more than 250 specimens), C = common (51-250 specimens), S = scarce (11-50 specimens), R = rare (4-10 specimens), VR = very rare (1 - 3 specimens).

Taxon	SCF	ECF
MULTITUBERCULATA		
Neoliotomus ultimus +	R	R
Parectypodus childei +	S	R
Parectypodus sp.	R	R
Ectypodus cf. *tardus*	R	
MARSUPIALIA		
Mimoperadectes labrus	VR	R
Peradectes chesteri +	S	R
Peratherium comstocki +		R
*Peratherium macgrewi** +	S	R
PROTEUTHERIA		
Didelphodus absarokae +	R	S
Cf. *Pararyctes* sp.		VR
Palaeoryctes cf. *punctatus* +		VR
Apatemys chardini	R	S
Apatemys kayi +	R	S
Apatemys bellulus		S
Apatemys cf. *rodens* +		R
Palaeosinopa lutreola	R	R
Palaeosinopa veterrima +		S
Palaeosinopa, sp. nov.**	VR	R
Prodiacodon tauricinerei +	S	S
Prodiacodon sp. 1		VR
Palaeictops bicuspis +		S
DERMOPTERA		
Worlandia inusitata		VR
Plagiomene multicuspis +		S
Plagiomene, sp. nov. (KDR)		VR
INSECTIVORA (LIPOTYPHLA)		
Leipsanolestes siegfriedti	VR	
Cf. *Leipsanolestes* sp.		VR
Erinaceid, gen. et sp. nov.**	VR	VR
Cf. "*Leptacodon*" *jepseni*		VR
Macrocranion nitens +	R	S
Cf. *Talpavus* sp. +		VR
Scenopagus, sp. nov.**	R	VR
Scenopagus sp. +	R	R
Dormaaliid, gen. et sp. nov.** +	S	VR
*Plagioctenodon krausae** +	S	R
Plagioctenodon, sp. nov.**		R
*Plagioctenoides microlestes** +	R	
Pontifactor cf. *bestiola* +	R	VR
Centetodon, sp. nov. 1**		VR
Centetodon, sp. nov. 2**		VR
Apternodontid, gen. et sp. nov.**	VR	
PRIMATES		
Microsyops wilsoni +	C	S
Microsyops angustidens +		C
Microsyops latidens +		S
Niptomomys doreenae +	C	S
Tinimomys graybulliensis +	R	VR
*Ignacius graybullianus** +	R	S
*Phenacolemur simonsi** +	S	R
Phenacolemur praecox +	S	C
PRIMATES (continued)		
Phenacolemur, sp. nov. 1		VR
Phenacolemur, sp. nov. 2		VR
Tetonoides tenuiculus +	S	S
Tetonoides, sp. nov.		VR
Tetonoides pearcei +	VR	
*Teilhardina americana**	VR	
Tetonius homunculus +	S	C
Tetonius cf. *musculus* +		S
Pseudotetonius ambiguus		R
Absarokius abbotti +		S
Omomyid, gen. et sp. nov.		VR
Pelycodus ralstoni +	C	C
Pelycodus mckennai +	C	C
Pelycodus trigonodus +	R	C
Pelycodus abditus +		S
Pelycodus cf. *frugivorus* +		S
Pelycodus, sp. nov. +	S	
Copelemur sp.		S
RODENTIA		
Paramys excavatus +	S	C
Paramys, sp. nov. +	VR	
Lophioparamys murimus		VR
Reithroparamys sp. +		S
Reithroparamys, sp. nov.	R	
Franimys cf. *amherstensis*	VR	R
Cf. *Franimys* sp. +		R
Microparamys sp +		R
PHOLIDOTA(?)		
Palaeanodon ignavus +	R	S
Palaeanodon sp. 1 +		R
*Alocodontulum atopum**		VR
TILLODONTIA		
Esthonyx grangeri	S	S
Esthonyx cf. *spatularius* +	S	S
Esthonyx bisulcatus +	C	C
Esthonyx cf. *acutidens* +		S
TAENIODONTA		
Cf. *Ectoganus* sp.		R
CREODONTA		
Oxyaena cf. *transiens*	S	S
Oxyaena cf. *forcipata* +		R
Oxyaena lupina		R
Oxyaena aequidens +		S
Dipsalidictides amplus	VR	
Palaeonictis cf. *occidentalis* +	VR	R
Ambloctonus sp.		VR
Arfia opisthotoma +	S	C
Prototomus sp. 1 +	R	S
Prototomus sp. 2 +		R
Proviverra sp.		R
Tritemnodon cf. *strenua*	S	R
Tritemnodon sp. 1 +		R
Prolimnocyon atavus +	R	R
MESONYCHIA		
Dissacus sp.		R
Pachyaena gracilis +	R	R
Pachyaena sp. 1 +		S
Hapalodectes sp. +		VR
ARCTOCYONIA		
Thryptacodon antiquus +	C	S
Chriacus sp. +	VR	R
Anacodon sp. 1 +		S
Anacodon sp. 2 +		R
CARNIVORA		
Didymictis protenus +	S	C
Didymictis cf. *lysitensis* +		S
Viverravus cf. *acutus* +	VR	C
Viverravus, sp. nov. (PDG)	S	S
Viverravus politus +	VR	S
Uintacyon massetericus +	S	S
Vulpavus australis +		S
Cf. *Vassacyon* sp. +	R	R
Oödectes cf. *herpestoides* +	VR	VR
Miacid, indet. 1 +		R
Miacid, indet. 2 +	VR	VR
PANTODONTA		
Coryphodon sp. 1 +	S	S
Coryphodon sp. 2 +		C
DINOCERATA		
Cf. *Probathyopsis* sp.		VR
CONDYLARTHRA		
Phenacodus primaevus group +	S	C
Phenacodus vortmani +	R	C
Phenacodus brachypternus +	VR	S
Ectocion osbornianus +	C	C
Hyopsodus sp. 1 +	C	A
Hyopsodus sp. 2 +		A
Hyopsodus sp. 3 +		C
Hyopsodus, sp. nov. +	S	
Haplomylus speirianus +	A	A
Apheliscus cf. *insidiosus* +	C	C
Apheliscus, sp. nov.		VR
PERISSODACTYLA		
Homogalax protapirinus +		C
Homogalax, sp. nov. (PDG) +		S
Heptodon cf. *calciculus* +		S
Heptodon cf. *posticus* +		R
Hyracotherium angustidens +	A	A
Hyracotherium sp. 1 +		A
Hyracotherium sp. 2 +		S
Hyracotherium sp. 3	VR	
Equid, gen. et sp. nov. +		R
ARTIODACTYLA		
Diacodexis metsiacus +	C	A
Diacodexis robustus +	VR	S
Diacodexis or *Hexacodus* sp. +		R
Bunophorus sp. 1 +		S
Bunophorus sp. 2 +		S

articulated bones that are not abraded by stream action, (4) presence of whole coprolites, (5) absence or paucity of sand in Class A gray mudstones (by hydraulic equivalence the bones, if hydraulically introduced, would be associated with sand), (6) high proportion of small (short lifespan) mammals, and (7) preferential distribution of fossils in certain gray mudstones and their exclusion from other gray mudstones that were likewise deposited by overbank flooding.

A clear understanding of Willwood taphonomy and pedogenesis is important to paleocommunity analyses and Willwood biostratigraphy. Soil accumulations of fossils provide attritional mortality assemblages that developed in a relative instant of geologic time. They may be continuously resampled and, as both well-defined faunules (Williams, 1903) and soil units, they are biostratigraphic units as well as lithologic marker beds.

Other vertebrate fossil accumulations whose relations to soil units are less clear also occur in the Willwood Formation and are currently under study (Bown and Rose, unpublished data). These include laterally impersistent "pockets" of fossils, fossil occurrences in red and orange mottled mudstones and orange and gray mottled mudstones, and occurrences in sandy gray mudstones that grade laterally into sandstones. This last type of fossil-bearing bed is especially common in the middle 300 m of the Willwood Formation and may be genetically related to the formation of overbank splays.

MAMMALIAN FAUNA

Willwood rocks in the southern Bighorn Basin yield an abundant and diverse fauna of fossil mammals that spans virtually all of Wasatchian (early Eocene) time (at least the lower 100 m of the overlying Tatman Formation is also of Wasatchian age; Bown, in press). The basal 100 m of the Willwood Formation in the southern Bighorn Basin contains an early Wasatchian fauna (No Water fauna of Bown, 1979; see Table 1) that is quite similar to that from rocks directly overlying strata of Clarkforkian age in the northern Bighorn Basin (Gingerich and Rose, 1977; Rose, 1978, 1979). The top 110 m of the Willwood Formation contains a fauna associated with the palaeothere *Lambdotherium* and is believed to be a rough age equivalent of the so-called "Lost Cabin" fauna. The intervening rocks (about 540 m) contain faunas representative of the "Gray Bull" and "Lysite" faunal zones, though the biostratigraphic utility of the terms "Gray Bull," "Lysite," and "Lost Cabin," as they are currently understood, is uncertain. D. Schankler (this volume) and Bown and Schankler (unpublished data) have offered preliminary biostratigraphic zonations of the Willwood Formation in the central and southern Bighorn Basin. However, further refinements will be based on section-controlled overlapping range, assemblage, and lineage-segment zones (T. M. Bown, P. D. Gingerich, K. D. Rose, and D. Schankler, unpublished data from both separate and integrated studies).

In the southern Bighorn Basin, the Willwood mammalian fauna is known from 78 named genera and 85 named species (Table 1). Descriptions of an additional 5 new genera and 20 new species are in press or under study, and several taxa have not yet been identified to species. These fossils were recovered from more than 300 localities and include more than 15,000 jaw specimens, numerous teeth and fragmentary postcranial bones, and several skulls and partial skeletons. The ten most abundantly represented genera, in order of their abundance and ignoring stratigraphic considerations, are: *Hyopsodus, Hyracotherium, Haplomylus, Diacodexis, Pelycodus, Ectocion, Phenacodus, Coryphodon, Microsyops,* and *Esthonyx.*

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APPENDIX

ROAD LOG -- ELK CREEK FACIES

Studies of Willwood faunas in the area covered by this log and adjoining regions are currently being undertaken by T.M. Bown, K.D. Rose, and D. Schankler. We respectfully request your cooperation in allowing one of us to collect all materials found by you during this part of the field conference. Thank you.

Mileage		
Cumul.	Increm.	
0.0	0.0	STOP 1: Elk Creek Rim. Yale fossil vertebrate locality 126 just off rim to right (530-m level of Willwood Formation). Superb view to north of middle Willwood badlands in valleys of Elk and Dorsey creeks (upper and middle parts of "Gray Bull" zone).
2.6	2.6	Junction (on left) with Red Butte road. Continue straight agead. Red Butte visible to southeast, about 3.8 miles away.
9.2	6.6	Northern area of Yale locality 45. Localities visible about 0.6-1.2 mi to left (east).
10.0	0.8	Junction (on left) with Fifteenmile Creek road. Continue straight (south).
17.2	7.2	Junction of dirt spur with Platte Pipeline road. Turn left (west).
17.7	0.5	STOP 2: USGS fossil vertebrate locality D-1162; lower part of "Lysite" zone, about 560 m above base of Willwood Formation. Nearly 100 jaw specimens were recovered here by Bown and Rose in 1979. Partial skeletons of *Chriacus* sp. and *Hyracotherium* sp., a nearly complete lower jaw of *Didymictis* sp., and a partial skull of *Palaeosinopa veterrima* were also found. The taphonomy of this site is unstudied but most of the fossils appear to come from sandy gray mudstones that grade laterally into possible cravasse-splay deposits. Collect for about 30 minutes and return to vehicles.
18.2	0.5	Junction with Platte Pipeline Road. Turn right (south).
20.4	2.2	Junction with dirt spur on right. Turn right.

20.9 0.5 STOP 3: Moocow Hollow (USGS D-1229 and Yale 42; about the 570-m level of the Willwood Formation). More than 150 jaw specimens were found in the alternating orange and gray mudstones beneath the prominent red and purple mudstones at the southwest corner of the hollow. Good view to west of the east side of the Squaw Buttes Divide. Return to vehicles and backtrack to Platte Pipeline Road.

21.4 0.5 Platte Pipeline Road. Continue across road to east.

22.7 1.3 Reservoir on left—good swimming if you are hot enough.

24.2 1.5 Cross Dry Cottonwood Creek. Fifteenmile Creek is referred to as Dry Cottonwood Creek in the early paleontological literature but current usage shows Dry Cottonwood Creek as a tributary of Fifteenmile Creek.

24.8 0.6 Junction (on right) with Reservoir Creek Road; continue on Fifteenmile Creek Road. Reservoir Creek road passes Yale locality 45-south about 0.7 miles to the east.

26.4 1.6 STOP 4: Junction with Dorsey Creek—Elk Creek Road (straight ahead to north) and Fifteenmile Creek Road (bend to right). View of Willwood badlands to west in central Bighorn Basin. High ridge about 9.0 miles to west-southwest is Squaw Buttes Divide with Squaw Teats visible on the divide about 4.0 miles farther west-southwest. Squaw Teats is capped by about 25-45 m of detached and highly deformed volcaniclastic rocks, probably of the later Eocene Tepee Trail Formation. The fluvio-lacustrine Tatman Formation of early and middle Eocene age forms the upper 275 m of the Squaw Buttes Divide. Tatman Mountain is visible about 15 miles away to the northwest and is capped by about 230 m of Tatman Formation and another 10-12 m of the Pleistocene(?) Fenton Pass Formation.

Fifteenmile Creek forms a broad valley between the Squaw Buttes Divide and Tatman Mountain that is known locally as the Buffalo Basin. Willwood rocks in the Buffalo Basin and on and adjacent to Tatman Mountain and the Squaw Buttes Divide are "Lysite" and "Lost Cabin" in age. The west margin of the Buffalo Basin is formed by the Meeteetse Divide (Figure 1) and in that area upper Willwood quartzite pebble and cobble conglomerates overlie the Cretaceous Lance Formation and the Paleocene Fort Union Formation with a pronounced angular unconformity (Figure 2). As we traveled eastward from locality D-1162 (Stop 1), we progressed down section from the upper into the middle part of the Willwood Formation. Mudstone coloration is principally red and gray in the upper 100 m of the Willwood but changes to red, orange, purple, and gray in the middle and lower upper Willwood Formation. These up-section changes reflect shifts to a drier climate from the middle to the late Wasatchian. In latest Wasatchian times, the Tatman lake basin was formed by local downwarping of the southern Bighorn Basin that impeded exterior drainage.

Return to vehicles and continue east on Fifteenmile Creek Road.

27.2 0.8 STOP 5: Yale locality 45, at about the 530-m level of the Willwood Formation. This site is probably the richest known Eocene mammal locality in the Bighorn Basin. At least 1,500 jaw and maxillary specimens and numerous teeth and postcranial bones are known. Yale 45 is actually a complex of 11 localities, all within about 10 m stratigraphically of one another, that are dispersed over nearly three sections along Reservoir Creek. The vehicles are parked at the discovery locality and from here localities 45-east (at 3 o'clock), 45-west (at 11 o'clock), and the Purple Hills (USGS D-1177 at 1:30 o'clock) are visible. At the northwest part of the discovery locality, bulldozing activity in 1970 disturbed some of the productive beds and subsequent weathering and erosion exposed many fossils. About 250 fragmentary jaws were collected from these flats in 1977 and 1978. Observe that purple beds are less common than in the Sand Creek

		facies and that iron and manganese sesquioxidic glaebules are rare or absent. Note abundance of calcium carbonate glaebules. Fossils at Yale 45 are recovered from a variety of paleosol units that are currently under study.
		Collect for 15 minutes. Return to vehicles and proceed east on Fifteenmile Creek Road.
28.4	1.2	Junction (on left) with Red Butte Road; continue east on Fifteenmile Creek Road. Red Butte, visible on skyline to left (north), contains mammals of the "Lysite" zone at the base and middle and yields the palaeothere *Lambdotherium* near the top. Several specimens of the extremely rare arctocyonid *Anacodon* have been collected from localities in the lower "Lysite" zone near the base of the butte.
30.3	1.9	Junction (on left) with Brinkerhoff Well Road; continue straight ahead. USGS locality D-1257 is 2.0 miles north.
30.4	0.1	Junction (on right) with old Fifteenmile Creek Road; continue straight ahead. The new road was constructed in the spring of 1976 and was relocated about a mile north of the old road and away from the ravages of Fifteenmile Creek.
34.5	4.1	Cross North Fork of Fifteenmile Creek.
35.1	0.6	USGS fossil vertebrate locality D-1350 to right and left of road. Fossils come from gray mudstone atop an orange mudstone.
37.4	2.3	Junction with "Elk Creek connector" on left. This road joins with Elk Creek roads about 16.0 miles to the north. USGS fossil vertebrate locality D-1218 in red badland hills 0.5 miles to northeast. USGS localities D-1203, 1204, 1207-9 of the upper "Gray Bull" zone occur 4-6 miles north.
38.3	0.9	USGS locality D-1216 to right and left of road.
38.8	0.5	STOP 6: USGS locality D-1251. Fossils come from a class A gray mudstone that overlies purple and mottled purple and orange mudstones. Geochemical and sedimentological samples for Elk Creek facies paleosol profile (Bown, unpubl.) were collected here in 1975 and 1977. Fossils probably collected on podzol soils as in the Sand Creek facies. Stop for 10 minutes to examine paleosol profile.
40.0	1.2	STOP 7: Junction (on right) with old Fifteenmile Creek Road. Exposure to east of road is of gray quartz sandstone and sandy mudstone that lies in a channel cut in red mudstone (B horizon of paleosol). Similar relations are common in the Willwood Formation and are one of many indications that coloration was acquired very early after deposition. Channel trough probably represents "plug" of chute or neck cutoff of a Willwood stream. USGS locality D-1200. Mudstone sequences that fill scour troughs are often very rich in vertebrate fossils (as at Yale-Michigan localities 419 and 421) but this is not the case here.
		Stop for 10 minutes to examine channel fill.
41.3	1.3	Junction (on left) with road to Triple Catch Reservoir. Yale localities 274, 447, 449, and USGS locality D-1205 are in badlands to left within 2.0 miles of Fifteenmile Creek road.
43.4	2.1	Junction (on left and right) with high-tension power line road; stay on main road. Yale locality 458 is 0.4 miles to north and Yale locality 459 is 1.8 miles to north. Rocks to south of Fifteenmile Creek (on right) on the Fifteenmile Creek—Gooseberry Creek Divide show intertonguing of Sand Creek facies and Elk Creek facies.
51.2	7.8	USGS localities D-1224 and D-1225 (Univ. Wyoming localities V-73125 and 73126) at right, 0.5 miles across valley of Fifteenmile Creek near base of scarp. Rocks are of Sand Creek facies of the Willwood Formation and are exposed along the axis of West Worland Dome (Bown, 1979, Pl. 1). Locality D-1224 is at about the 180-m level of the Willwood Formation, near the base of the *Pelycodus trigonodus* range zone [prob. *P. mckennai* zone, ed.].

		Locality D-1224 has yielded about 350 jaw fragments and more than 1,000 teeth, including a single specimen of the rare marsupial *Mimoperadectes labrus*.
53.5	2.3	Junction (T) with Wyoming State Secondary Road 433; turn right (south). Wyoming Highway Department and State Patrol on right—drive carefully.
53.7	0.2	Junction (T) with U.S. 20; turn left on U.S. 20.
54.0	0.3	Cross Bighorn River.
54.4	0.4	Washakie Hotel, Worland, Wyoming. End of Elk Creek Facies road log.

ROAD LOG -- SAND CREEK FACIES

Mileage		
Cumul.	Increm.	
0.0	0.0	Junction 10th Street and Bighorn Avenue, Worland, Wyoming.
1.4	1.4	Driving across north edge of Banjo Flats, an alluvial, colluvial, and terraced surface, next 3.2 miles.
2.6	1.2	Cross Slick Creek. Headlands of Slick Creek are on the Sand Creek Divide, the high north-south trending ridge on skyline to east.
3.5	0.9	Highland-Hanover Canal.
4.7	1.2	Junction old U.S. Highway 16 and new U.S. 16. Turn right on old highway. The old highway is now used for access to the Slick Creek, South Fork, No Water, and Sand Creek oil and gas fields.
4.9	0.2	STOP 1: Slick Creek Basin straight ahead is a small, semiradial topographic basin formed by dissection of the basal Willwood Formation by the headwaters of Slick Creek. Willwood badlands in the Slick Creek Basin are the most fossiliferous in the Sand Creek—No Water Creek area and contain the Supersite, Two Head Hill, Slick Creek, and Stonehenge quarries (UW localities V-73037, 73034, 73022, and 73027, respectively), between 30 and 46 m above the base of the Willwood Formation. Approximately 120 m of the Sand Creek facies of the Willwood are exposed in the Slick Creek Basin. To the right, near the small pond, is the Colby Site, a paleo-Indian kill site dated at 11,200 ± 350 years. Remains of several mammoth skeletons were found at this locality associated with Folsom projectile points. Excavations were completed in 1976 under the direction of Wyoming State Archaeologist George C. Frison. Turn right on unpaved road (Slick Creek Basin Road).
5.4	0.5	Cross North Fork of Slick Creek.
5.9	0.5	Junction with Sand Creek Divide road on left. Continue straight ahead.
6.2	0.3	Junction with pipeline road. Turn right.
6.8	0.6	STOP 2: Supersite Quarry beds. Walk 150 m south to Supersite Quarry. Mammals were recovered from the thin bluish-gray mudstone atop the thin purplish-red and mottled-purple-and-orange mudstone about half-way up the exposure to the southeast. Top of the gray bed in saddle is Supersite Quarry, 34 m above the base of the Willwood Formation. This locality yielded more than 350 jaw specimens and about 950 teeth. The productive bed is also exposed 0.2 miles to the north and was traced more than two miles to the southeast. In the intervening area, it is the source of Two Head Hill Quarry and 12 other localities of lesser productivity. In all, more than 900 jaw specimens and 1,500 teeth were collected from the bed, which is possibly a remnant of the leached A horizon of a subtropical podzol. Collect for 20 minutes. Keep your fossils if you want them but please record locality data. Return to vehicles and backtrack to junction with main Slick Creek Basin road.
7.4	0.6	Junction with Slick Creek Basin Road. Turn right.
8.3	0.9	STOP 3: Slick Creek Quarry beds, 46 m above base of Willwood Formation and about 12 m above Supersite Quarry beds (Stop 2). Walk 0.25 miles southeast to Slick Creek Quarry. The quarry beds are the

bluish-gray mudstone atop the mottled-purple-and-orange mudstone about 1/3 of the way up the north-south trending ridge. The Slick Creek Quarry beds are exposed as far as 2.5 miles south of where the vehicles are parked and at least one mile to the north. More than 450 jaw specimens and 1,000 teeth have been recovered from these beds and about 90 of the jaws and 200 of the teeth are from Slick Creek Quarry. Quarry materials include the type specimen of *Teilhardina americana*, as well as many specimens of the nyctitheriids *Plagioctenodon* and *Plagioctenoides* and the microsyopid *Niptomomys doreenae*.

As we walk to and from Slick Creek Quarry, observe the complete absence of calcium carbonate glaebules (nodules and concretions) and the local abundance of iron and manganese sesquioxide glaebules. The last indicate relatively wet conditions in Willwood paleosols. The Slick Creek Quarry beds are also possibly podzolic in origin.

Collect for 20 minutes and return to vehicles. Backtrack north to junction of Slick Creek road with old U.S. Highway 16.

10.8 2.5 Junction with old U.S. Highway 16. Turn right. Drive east toward Sand Creek Divide. Note relative paucity of red beds and sandstones and predominance of purple and gray mudstones. Paucity of sand and lack of connectedness of sand bodies in fluvial rocks indicates rapid deposition. Coloration of mudstones suggests that water tables were relatively high in Willwood paleosols.

13.0 2.2 Top of Sand Creek Divide, Sand Creek Basin to east. Road to right enters No Water oil and gas field.

13.8 0.8 Cross West Fork of Sand Creek.

14.4 0.6 Junction (on left) with dirt road connecting old and new U.S. Highway 16. Grant Meyer's Webb School peccary camp is to right of this road, about 0.15 miles to north.

14.6 0.2 Junction with Marconi Road on right. Turn right and parallel South Fork of Sand Creek.

15.3 0.7 Cross South Fork of Sand Creek.

16.0 0.7 STOP 4: Banjo Quarry. This site was discovered by Elwyn Simons in 1972. The quarry is in a gray sandy mudstone and silty sandstone with orange and red mottles. About 150 jaw specimens and 600 teeth are known from this site and it is still productive. Banjo Quarry is Yale locality 370a and UW locality V-73016a. One anthill in the area (Yale 370b) yielded about 10 jaws and 400 teeth of small mammals, and the Banjo Class A gray mudstone (Yale 370c) produced about 25 jaws and 80 teeth. The Banjo localities are about 61-70 m above the base of the Willwood Formation and have yielded principally micromammal remains, including the earliest apternodontid and numerous specimens of small nyctitheriids and primates (for example, *Plagioctenodon, Plagioctenoides, Pontifactor, Niptomomys, Microsyops, Tinimomys, Tetonoides, Tetonius, Phenacolemur*).

Collect for 15 minutes and return to vehicles. Proceed south on Marconi Road.

16.2 0.2 Bown's 1974-1976 field camp site at edge of small canyon 150 m to right.

16.3 0.1 Lantern Hill (UW v-73086) at base of hill to left of road.

17.1 0.8 UW localities V-73051, 73052 to left and right of road (88-97 m levels). Fossils at these sites also occur in gray mudstones atop purple or mottled-purple-and-orange mudstones.

17.6 0.5 STOP 5: Purple Hills (UW localities V-73020a and 73020b), 97-m level. Fossils again occur in gray mudstones atop purple or mottled-purple-and-orange mudstones. Anthills at this locality were very productive. Collect for 15 minutes and return to vehicles. Proceed south on Marconi Road.

18.1 0.5 Top of Sand Creek—No Water Creek Divide. View to south is of Willwood and Fort Union rocks in the valley of the East Fork of No Water Creek. Gray mudstone of UW localities V-73020a and V-73020b is exposed in hills 0.1 and 0.5 miles to left (east).

20.7 2.6 Cross contact of Willwood Formation and Fort Union Formation. In the

		No Water Creek area, the Fort Union Formation is about 450 m thick but thickens considerably to the west (basinward). No mammals are known from Fort Union rocks in this area. The East Fork of No Water Creek (major tree-lined drainage to south) is developed along the axis of Banjo Anticline.
21.1	0.4	Junction with Banjo Flats road. Turn right. About 6 miles to the east, this road provides access to the west edge of the Honeycombs Basin, a vast area of badlands developed on the Fort Union Formation. North Butte (on skyline to east) is at the northeast edge of the Honeycombs Basin.
21.9	0.8	Junction with road crossing East Fork of No Water Creek (on left). Continue west of Banjo Flats road. Fort Union—Willwood contact exposed on small butte to east.
22.7	0.8	Cross Fort Union—Willwood contact; driving on Willwood Formation. UW localities V-73090, 73091, 73092, and 73098 occur 1.0-2.5 miles to north.
24.4	1.7	Cross Willwood—Fort Union contact; driving on Fort Union Formation.
25.5	1.1	Oil wells and storage tanks. Badland exposures 0.3 miles to southwest are of upper Fort Union Formation. Fort Union—Willwood contact exposed 0.3-0.5 miles north of road. UW locality V-73041 (about 30-m level), type locality of a new erinaceid insectivore, is about 1.0 mile north.
26.3	0.8	Cross Fort Union—Willwood contact; driving on Willwood Formation.
27.1	0.8	UW locality V-73096 in exposures 0.4 miles to right (northeast). Next 4.0 miles is Banjo Flats alluvial and colluvial surface.
30.8	3.7	Banjo Ranch; beware barking dogs!
31.6	0.8	Highland-Hanover Canal.
33.4	1.8	Upper Hanover Canal.
35.2	1.8	Junction on right with 15th Street in Worland. Turn right.
36.0	0.8	Junction of 15th Street and Bighorn Avenue; turn left.
36.3	0.3	Junction of 10th St. and Bighorn Ave. End of Sand Creek Facies road log.

PRELIMINARY REPORT ON PALEONTOLOGICAL EXPLORATION OF THE SOUTHEASTERN ABSAROKA RANGE, WYOMING

Jeffrey G. Eaton

Abstract.— Fossil mammals have been recovered throughout the Eocene volcaniclastic section present in the Owl Creek region of the Absarokas, and preliminary faunal lists are presented. The faunas were collected from (oldest to youngest) the Aycross, Tepee Trail and Wiggins Formations and range in age from Bridgerian to Uintan. The fauna from the Wiggins is the first ever reported from that formation and appears to be early Uintan in age. However, a new locality from the Wiggins(?) Formation on Carter Mountain yields a Bridgerian fauna that is older than either the Tepee Trail or Wiggins Formations farther south in the Owl Creek area, indicating that more study is required to understand the relationships between the Aycross, Tepee Trail and Wiggins Formations.

INTRODUCTION

The Absaroka Range is a vast accumulation of Eocene volcanic material in northeastern Wyoming. Vertebrate fossils were first reported from the range by Dr. J. D. Love (U.S. Geological Survey) in 1939. In the late 1960s, Dr. M. C. McKenna (American Museum of Natural History) followed up on Love's report and initiated extensive collecting in the type section of the Tepee Trail Formation in the East Fork Basin, on the east fork of the Wind River northeast of Dubois, Wyoming (McKenna, 1972). Since McKenna's discoveries, there has been renewed interest in the recovery of vertebrate fossils from Absaroka volcaniclastic strata.

In 1977 a multidisciplinary approach to studying the Absaroka volcanics was designed by various workers at the University of Wyoming. This included attempts to collect vertebrate remains and fossil pollen throughout sections of volcaniclastic rocks in the Absaroka Range and the incorporation of paleomagnetic data and radiometric dates in those sections. The purposes of this approach were twofold: (1) development of reference sections in the Western Interior for middle and late Eocene radiometric, paleomagnetic, and vertebrate paleontological calendars; and (2) temporal correlation of rocks and faunas of the Western Interior with nonmarine strata in southern California that interdigitate with marine beds.

The area selected for initial study was in the Owl Creek drainage, west of Thermopolis, Wyoming (Figure 1), where a relatively complete and well exposed section of Eocene strata is present. Work in that area has been carried out by various workers at the University of Wyoming during the 1977, 1978, and 1979 field seasons.

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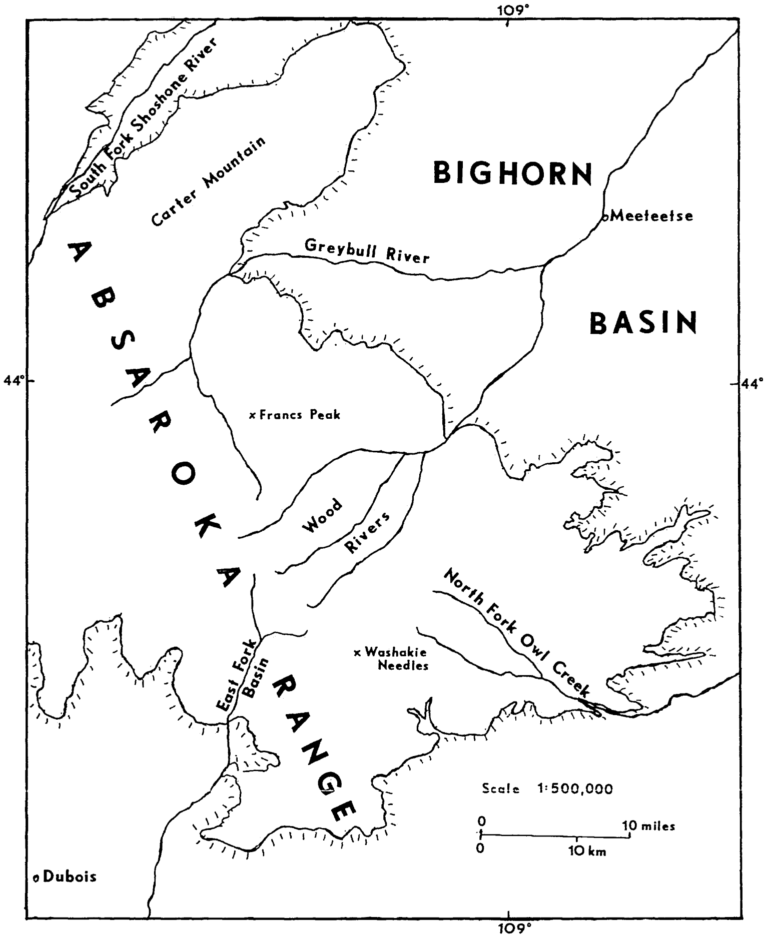

Figure 1. General location map of the southeastern Absaroka Range, Wyoming.

Kent A. Sundell (University of Wyoming) is preparing a detailed geological history and map of the North Fork of Owl Creek. Dr. Peter N. Shive (same institution) is currently evaluating paleomagnetic sections taken in the mapped area. Various workers at other institutions are studying the pollen and fossil wood. Sundell and the author have collected vertebrate fossils throughout the volcanic section in the Owl Creek region. The main purpose of the present paper is to summarize current knowledge of the vertebrate faunas.

EOCENE FAUNAS

The Aycross Formation (Love, 1939) represents the oldest recognized dominantly volcaniclastic strata in the region. Collections from the Aycross Formation along the North Fork of Owl Creek are being studied by the author, Dr. Thomas M. Bown (U.S. Geological Survey, Denver), Gustav F. Winterfeld (University of Wyoming), and Sundell. The age of the fauna is Bridgerian, and a partial faunal list is presented below.

Faunal List—Aycross Formation, Area of Owl Creek

- Marsupialia
  - *Peradectes* cf. *P. innominatus*
  - *Peratherium* cf. *P. marsupium*
- Insectivora
  - *Scenopagus curtidens*
- Primates
  - *Microsyops* sp.
  - *Notharctus* sp.
  - *Washakius insignis*
  - omomyid indet.
- Carnivora
  - miacid indet.
- Condylarthra
  - *Hyopsodus* sp.
- Perissodactyla
  - *Orohippus* sp.
  - tapiroid indet.
- Rodentia
  - *Paramys wyomingensis*
  - *Reithroparamys delicatissimus*
  - *Thisbemys plicatus*
  - *Leptotomus parvus*
  - *Microparamys* sp.
  - *Pseudotomus* sp.

Collections of fossil mammals have also been recovered at many horizons in the overlying Tepee Trail Formation. A tentative faunal list is presented below:

Faunal List—Lower Part of Tepee Trail Formation, Area of Owl Creek

- Marsupialia
  - *Peratherium* sp.
- Carnivora
  - *Viverravus* sp. cf. *V. sicarius*
- Perissodactyla
  - cf. *Orohippus* sp.
  - *Forstercooperia* sp. cf. *F. grandis*
  - *Hyrachyus eximius*
  - cf. *Dilophodon* sp.
- Condylarthra
  - *Hyopsodus* sp.
- Rodentia
  - *Sciuravus nitidus*

Faunal List—Middle and Upper Parts of the Tepee Trail Formation, Area of Owl Creek

- Condylarthra
  - *Hyopsodus* sp.
- Perissodactyla
  - *Metarhinus* sp. or *Mesatirhinus* sp.
  - *Amynodon* sp.
  - *Hyrachyus eximius*
  - *Forstercooperia* sp. (small)
  - *Epihippus* sp.
- Dinocerata
  - uintathere indet. (large)
- Artiodactyla
  - *Achaenodon* sp. cf. *A. robustus*
  - *Hylomeryx* sp. cf. *H. annectens*

The lower part of the Tepee Trail Formation as seen in the Owl Creek area is separated from its middle and upper parts in the faunal list because of an apparent discrepancy in the ages of the faunas. Most of the taxa in the lower part of the Tepee Trail Formation would be considered Bridgerian (e.g. *Viverravus* cf. *V. sicarius, Sciuravus nitidus*), but the presence of *Forstercooperia* may indicate a Uintan age (see Radinsky, 1967). As such, age assignment of the lower part of the Tepee Trail Formation as seen in the Owl Creek area is equivocal. The middle and upper parts of the local Tepee Trail Formation appear to be Uintan on the basis of the occurrence of *Amynodon, Fostercooperia,* a uintathere larger than *Uintatherium, Achaenodon, Hylomeryx,* and *Epihippus.* The local sedimentary regime favored the preservation of remains of large mammals whose taxonomic and systematic relationships are poorly understood. For this reason it has been difficult to specify with which stratigraphic interval in other basins these faunas correlate. The specimens compare favorably (though not identically) with material from other basins characterized as "Washakie B" and "Uinta B," which would suggest an early Uintan age.

The age of the Wiggins Formation, which usually caps the Eocene sequence in the southeastern Absaroka Range, has long been in debate (McKenna, 1972), and it has been variously considered to be Bridgerian to early Oligocene in age. Prior to our work, no identifiable fossil remains had even been recovered from rocks definitely referable to the Wiggins Formation (the possible exception at Carter Mountain is discussed below). We have discovered several localities near Cottonwood Peak on the north side of the North Fork of Owl Creek (Figure 1). A preliminary faunal list is presented below:

Faunal List—Wiggins Formation, Owl Creek Area

- Insectivora
  - erinaceid indet.
- Primates
  - *Microsyops* sp.
  - *Ourayia uintensis*
- Carnivora
  - cf. *Procynodictis* sp.
  - cf. *Prodaphaenus* sp.

- Condylarthra
  - *Hyopsodus uintensis*
- Perissodactyla
  - *Epihippus* sp.
  - titanothere indet.
  - *Amynodon* sp.
  - *Colodon* sp. (small)
- Artiodactyla
  - cf. *Auxontodon* sp.
  - *Protoreodon* sp.
- Rodentia
  - *Paramys* sp.
  - *Thisbemys* sp.
  - *Reithroparamys* sp. cf. *R. delicatissimus*

The fauna from the Cottonwood Peak area is clearly of Uintan age, though, again, the exact comparison to stratigraphic horizons in other basins has not been made. The presence of *Ourayia uintensis, Auxontodon,* a primitive form of *Colodon,* and exclusively paramyid rodents suggests an early Uintan age, possibly correlative with strata characterized as "Uinta B." Further collection and study are necessary.

The thick conglomerates and white ashes above the basalt flows on Carter Mountain have long been considered part of the Wiggins Formation. Using solely lithologic criteria it would appear that such a conclusion is justified. However, Dr. Elwyn L. Simons (Duke University) discovered a mammalian fossil-bearing locality on Carter Mountain in 1962; in 1978, Sundell and I found another locality. The University of Wyoming locality has so far yielded two skulls, several brain casts, and a large, diverse collection of small mammal teeth. The collection has not yet been studied in detail, and only a very tentative faunal list can be presented at this time. The age of the fauna is unequivocally Bridgerian.

Faunal List—Carter Mountain, University of Wyoming Locality

- Taeniodonta
  - *Stylinodon* sp.
- Insectivora
  - insectivore indet.
- Primates
  - *Notharctus* cf. *robustior*
  - *Microsyops annectens*
  - *Washakius* cf. *insignis*
  - cf. *Omomys* sp.
- Carnivora
  - *Viverravus* sp.
  - *Miacis* sp.
- Condylarthra
  - *Hyopsodus* cf. *lepidus*
  - *Phenacodus* cf. *primaevus*
  - mesonychid indet.
- Perissodactyla
  - *Orohippus* sp.
  - *Hyrachyus* sp.
- Artiodactyla
  - *Antiacodon* sp.
- Rodentia
  - *Paramys excavatus*
  - *Paramys wyomingensis*
  - *Leptotomus bridgerensis*
  - *Pseudotomus robustus*
  - *Microparamys* sp.

This fauna indicates that the age of the Wiggins Formation in the Carter Mountain area appears to be older than the Tepee Trail Formation in the East Fork Basin (McKenna, 1972) and in the Owl Creek region.

Several possibilities must be considered to explain these findings: (1) the Wiggins Formation is time transgressive in a major sense (Bridgerian through early Uintan); (2) the Wiggins Formation intertongues laterally with the Tepee Trail Formation in some complicated fashion such that the two formations are in part temporal equivalents; or (3) similar looking lithologies have led us astray in interpreting rock sequences. Resolution of this problem is among many requiring further detailed stratigraphic study of the southeastern part of the Absaroka Range.

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REMAINING EVIDENCE OF OLIGOCENE SEDIMENTARY ROCKS PREVIOUSLY PRESENT ACROSS THE BIGHORN BASIN, WYOMING

Malcolm C. McKenna

Abstract.— Oligocene (White River Group, lower part of the Arikaree Group older than 24 ma) and earlier Tertiary rocks once filled the Bighorn Basin. Recent paleontological research confirms that the Darton's Bluff locality on the crest of the Bighorn Range and also locality SR on the flank of the Washakie Range southwest of the Bighorn Basin are older than the Harrison Formation. Earlier Oligocene sediments are also present in both areas. As late as the early Arikareean the Bighorn Basin continued to fill with sediments, until only a small area of Precambrian igneous rocks marked the site of the buried Bighorn Range. Mid-Tertiary sediments covered the Absaroka Range and other parts of northwestern Wyoming as well, but these rocks were subsequently uplifted and stripped away except where protected by tectonic downdropping.

INTRODUCTION

The Bighorn Basin of northern Wyoming is bordered structurally on the east and northeast by the Bighorn Range and on the south and southwest by the Owl Creek and Washakie ranges. The Washakie Range (Love, 1939) has been buried by Tertiary rocks, notably the spectacular Eocene Absaroka volcanic pile that covers the southwestern and western Bighorn Basin, but above that are remnants of the Oligocene White River and the lower part of the Arikaree groups. Precambrian exposures of the Washakie Range, now being exhumed, may be taken as the true southwestern border of the Bighorn structural basin, 80 kilometers or so southwest of the erosional eastern edge of the Absaroka Volcanic Supergroup of Eocene age (Smedes and Prostka, 1972).

Although nowhere within the Bighorn Basin itself or in the Yellowstone area have mid-Tertiary rocks been reported, nevertheless remnants of both the White River and Arikaree groups occur in two areas critical for the interpretation of the geologic history of northern Wyoming. One area is near the crest of the Bighorn Range (McKenna and Love, 1972) and the other is in a downdropped block presently at about 2560 meters above mean sea level high on the western flank of the Washakie Range (Love *el al.,* 1976). During the mid-Tertiary the Bighorn Basin was evidently filled with sediments to what is now about the 2750 meter level on the Bighorn Range and to relatively higher levels to the west. In addition, White River sediments occur at about 3000 meters above mean sea level on the Gravelly Range in Madison County (Mann, 1954) and at lower elevations elsewhere in southwestern Montana. White River outcrops also occur at the 1860-2000 meter level in a downdropped block south of the Bighorn Range near Badwater, Wyoming (Setoguchi, 1978, fig. 2) and

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White River and Arikaree rocks crop out at various elevations elsewhere in Wyoming (Love *et al.,* 1976) and in Montana and Idaho (Dorr and Wheeler, 1964; Rasmussen, 1973, 1978; Nichols, 1976).

OLIGOCENE SEDIMENTS AND FAUNAS

Oligocene sediments of the White River Formation (Group) that buried all but the highest parts of the Bighorn Range are still present there high on the range at half a dozen localities (McKenna and Love, 1972, p. 12) but so far have yielded only a few mammalian specimens whose ages, while either Chadronian or Orellan, have yet to be determined with high resolution. Recently a new Oligocene locality (previously mapped as Paleozoic carbonates) has been discovered near the head of Tensleep Canyon (J. D. Love, T. Bown, J. Flynn, pers. comm.). In contrast, the White River of the west flank of the Washakie Range has produced 16 species of Chadronian mammals from rocks formerly thought to be part of the Wiggins Formation (Eocene) but now known to be about 8 million years or more younger than the Wiggins (Love *et al.,* 1976). These Chadronian sediments, formerly at a relatively higher elevation, have been protected from removal by erosion only because they have been dropped down along a normal fault that cuts the Buffalo Fork thrust fault.

Arikareean sediments overlying the White River Formation (Group) are preserved at Darton's Bluff at the headwaters of Canyon Creek on the Bighorns (Sect. 19, T. 48 N., R. 85 W., Hazelton Peak Quadrangle, Johnson County, Wyoming; see McKenna and Love, 1972, fig. 4) and at locality SR on the headwaters of Fox Creek on the west flank of the Washakie Range, five kilometers south of the southern border of Yellowstone Park (Lat. 44° 05′ N., Long. 110° 18′ W., Mount Hancock Quadrangle, Teton County, Wyoming; see Love *et al.,* 1976, figs. 3, 13). The mammalian assemblages known thus far at both sites are limited in variety but are adequate for an Arikareean age determination in each case and are probably early rather than late Arikareean in age. From Darton's Bluff in the Bighorns the following fossil mammals are known:

Proscalops cf. *P. secundus* Matthew, 1909
Desmatolagus sp.
Entoptychine geomyid (see comments below)
Pleurolicus-like geomyid cf. *Schizodontomys* Rensberger, 1973a (see comments below)
Promylagaulus sp. (see comments below)
Unnamed genus and species of rodent (? pathologic entoptychine dP_4)
Oreodont cf. *Oreodontoides* sp.
Miotylopus gibbi (Loomis, 1911)

Fossil gophers of the genus *Entoptychus* were reviewed by Rensberger (1971) but that publication was not seen by McKenna and Love in time for consideration. Since 1971 two additional species have been added to *Entoptychus* by Nichols (1976). It is now clear from Rensberger's review that the Darton's Bluff specimens are more primitive than described species of *Entoptychus* (other than Nichols' *"Entoptychus" fieldsi*) because the diastema is insufficiently long and the P_4 pattern more like that of *Gregorymys.* The Darton's Bluff entoptychine and *"Entoptychus" fieldsi* are worthy of additional taxonomic study because they are in some ways intermediate between *Gregorymys* and *Entoptychus* (see also Stevens, 1977, pp. 25-30; Rensberger, 1973b). A second taxonomic change involves the material referred by McKenna and Love to *Pleurolicus.* Rensberger (1973a, p. 30) has now shown that the type specimen of *Pleurolicus leptophrys* Cope, 1881, is "almost certainly an old individual of an indeterminate but primitive species of *Entoptychus.*" The Darton's Bluff *Pleurolicus*-like geomyid is morphologically close to species now placed by Rensberger in his new genus *Schizodontomys,* but the known range of that genus as presently understood is Hemingfordian. A third change involves *Promylagaulus.* In 1972 McKenna and Love referred the Darton's Bluff *Promylagaulus* to *P. riggsi,* then the only described species of *Promylagaulus.* Recently, Nichols (1976) and Rensberger (1979) have added three new species to the genus and Rensberger has suggested that the Darton's Bluff *Promylagaulus* may also be a distinct species.

McKenna and Love (1972) regarded the Darton's Bluff Arikareean site as approximately contemporaneous with the lower part (pre-Harrison Formation) of the Arikaree Group of eastern Wyoming, Nebraska, and South Dakota. The taxonomic changes mentioned do not contradict that view. Rensberger's (1979) conclusion that the Darton's Bluff Arikareean falls within the *Entoptychus-Gregorymys* concurrent range zone is contradicted by the primitive species of geomyids present there.

The Arikareean of the Washakie Range flank closely resembles that of Darton's Bluff lithologically. It is represented by only four species of mammals, all from a single limited exposure (Love *et al.,* 1976):

Allomys cf. *A. nitens*
Unnamed aplodontid rodent cf. *Meniscomys* and *Niglarodon*
Archaeolagus cf. *A. ennisianus*
Promerycochoerus leidyi

As is the case of the Darton's Bluff occurrence, the age of these fossils is thought to be the same as that of the lower part of the Arikaree Group of eastern Wyoming, Nebraska, and South Dakota. The deposits in which these fossils occur have been referred to the Colter Formation, the type section of which is in Jackson Hole, 29-32 kilometers to the southwest (Love *et al.,* 1976). In Jackson Hole the Colter Formation also contains Hemingfordian and Barstovian fossil mammals in its upper parts, but the lowest 850 meters of the type section has not yielded fossil mammals.

The widespread occurrence of lithologically similar Arikareean and still earlier mid-Tertiary sediments at many localities in the High Plains and as remnants as far west as the Washakie Range suggests that these sediments were once continuous over a wide area including the Bighorn Basin and the Absarokas (McKenna and Love, 1972, figs. 1, 2A, 2B; Love *et al.,* 1976, fig. 12). Subsequent to the deposition of these Arikareean sediments, deposition ceased at some unknown time and the Subsummit Surface of the Bighorn Mountains came into being during either the Miocene or the Pliocene. Crossing the buried Bighorn Basin and its bounding ranges, the Bighorn/Wind River system became established on this surface, relatively more than a kilometer higher than the present level of down-cutting by the river.

During the late Tertiary widespread uplift occurred in the Rocky Mountains. Uplift was especially pronounced in northwestern Wyoming, with resulting erosion stripping away mid-Tertiary sediments over the entire Absaroka Mountains and Yellowstone Park areas except where protected by tectonic down-dropping near the Buffalo Fork thrust fault trace 5 kilometers south of Yellowstone Park's southern border. A possible exception to this situation has been noted at Carter Mountain in the Absarokas, where questionably Oligocene rocks have been reported (Nelson and Pierce, 1968; Pierce and Nelson, 1969; McKenna and Love, 1972, fig. 2A) but middle Eocene vertebrates occur in volcaniclastics formerly thought to be Oligocene or late Eocene in age, just below the summit of Carter Mountain (E. L. Simons, *in* Wilson, 1963; J. G. Eaton, pers. comm.). A middle Eocene (see Berggren *et al.,* 1978, for revised definition) K-Ar date has been obtained from rocks stratigraphically above the vertebrates (J. D. Obradovich, pers. comm.). During the late Tertiary the Caldwell Canyon volcanic rocks (Love, 1939) were deposited directly on the Wiggins Formation. The restored section given by McKenna and Love (1972, fig. 2A) can thus be corrected to show an even greater thickness of mid-Tertiary fill in the Bighorn Basin. Removal of this fill by the Bighorn River and its tributaries in the late Tertiary and continuing to the present must have had numerous consequences such as isostatic rebound and possibly large-scale down-slope movements associated with gravity tectonics.

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PAPERS ON PALEONTOLOGY NO. 24

EARLY CENOZOIC OF THE BIGHORN BASIN, WYOMING