Thirty-Fourth Annual Field Conference — 1983
Wyoming Geological Association Guidebook

PALEOCENE-EOCENE FAUNAL ZONES AND A PRELIMINARY ANALYSIS OF LARAMIDE STRUCTURAL DEFORMATION IN THE CLARK'S FORK BASIN, WYOMING

PHILIP D. GINGERICH[1]

INTRODUCTION

Fossil vertebrate remains were first found in the Bighorn Basin of northwestern Wyoming in 1880, and the Bighorn Basin and adjacent Clark's Fork Basin have since become classic collecting areas documenting the succession of early Cenozoic vertebrate faunas in western North America (Gingerich, 1980a). The biochronology of Paleocene and early Eocene mammalian faunas in these basins is among the best known anywhere, and this knowledge can be used to determine the age of enclosing sedimentary rocks with unprecedented accuracy. The resulting biochronological zonation can in turn be used to study the history of sedimentation in this area, which reflects temporal and geographical patterns of structural deformation and tectonic subsidence.

The Paleocene and early Eocene are represented by two geological formations in the Clark's Fork and Bighorn Basins: the Fort Union (or "Polecat Bench") Formation spanning much of Paleocene time, and the Willwood Formation spanning much of early Eocene time. The Fort Union Formation is comprised of predominantly fluvial sandstones, and drab mudstones, lignites, and fresh-water carbonate lenses. This sequence reaches a maximum thickness of about 3,500 meters (11,500 feet) along the western margin of the Clark's Fork Basin, where lacustrine, paludal, and conglomeratic facies occur in addition to more typical fluvial facies (Hickey, 1980). The geometry and morphology of lithofacies indicate that Fort Union streams were broad, shallow, sluggish, and of low sinuosity. Distal floodplains were poorly drained, with large areas of backswamp, while proximal floodplains were better drained. Vertebrate fossils are locally abundant at the base of channel sandstones and in proximal floodplain sediments, but they are very rare in distal floodplain sediments (Alexander, 1982).

The Willwood Formation is a wedge of fluvial sandstones, variegated mudstones, and locally abundant carbonaceous shales. It is readily distinguished from the Fort Union Formation by the presence of conspicuous red beds. The Willwood Formation is approximately 700 meters (2300 feet) thick in the central Bighorn Basin, and it reaches a maximum thickness of about 1,000 - 1,200 meters (3300 - 3900 feet) along the western margin of the Clark's Fork Basin in the vicinity of Heart Mountain. The geometry of sandstone bodies and proximal overbank deposits indicates that Willwood streams were generally narrow, with shallow channels. Paleosols are well developed in the Willwood Formation, and fossil mammals are most abundant in distal rather than proximal floodplain facies (Bown and Kraus, 1981 a,b). The Willwood Formation appears to represent deposition in dryer, better drained, and more open, less densely forested environments than were present during Fort Union time.

The Willwood Formation conformably overlies the Fort Union Formation in most parts of the central Clark's Fork and Bighorn Basins. The transition between formations is usually gradational, and the two formations intertongue in areas of facies transition. Along the margins of the Clark's Fork and Bighorn Basins the Fort Union and Willwood Formations are sometimes separated by angular unconformities, indicating that the basin margins were being uplifted as axial areas subsided (Van Houten, 1944).

In the past ten years, field parties from the University of Michigan have made collections of fossil mammals and other vertebrates from some 400 localities in the Fort Union and Willwood Formations of the Clark's Fork Basin and the northern Bighorn Basin. These new collections contribute significantly to understanding mammalian faunal succession in this area, and they permit a more detailed biostratigraphic zonation of the Fort Union and Willwood Formations than was possible previously. The purpose of this paper is to document the geographic distribution of faunal zones in the Clark's Fork Basin and adjacent Bighorn Basin, and to record some preliminary ideas

---

[1] Department of Geological Sciences and Museum of Paleontology, The University of Michigan, Ann Arbor, Michigan 48109.

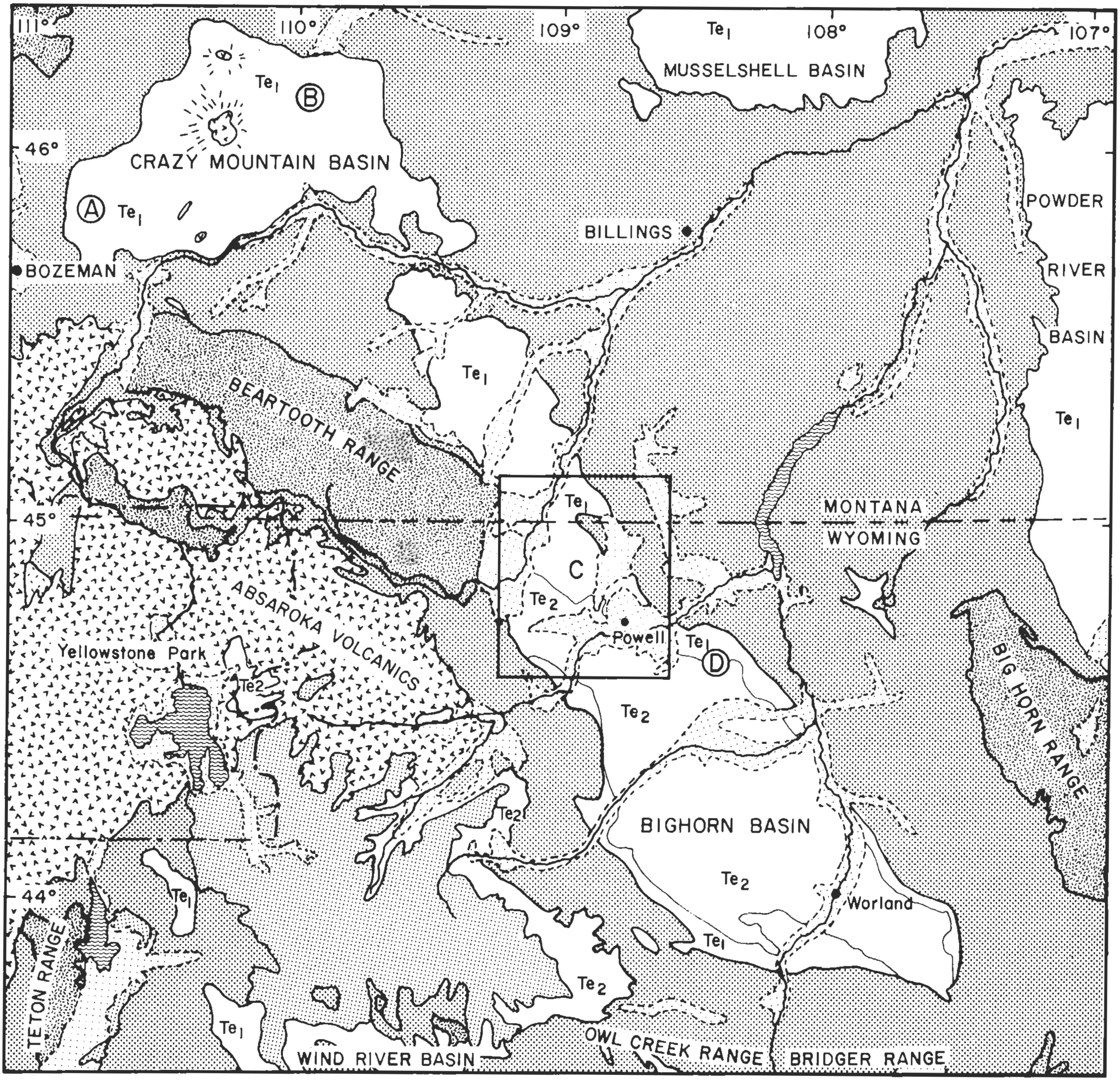

Figure 1: Simplified geological map of northwestern Wyoming and south central Montana, showing structural continuity of the Crazy Mountain Basin, Clark's Fork Basin, and Bighorn Basin, and their relationship to the Beartooth massif. Fossil mammals are known principally from the Fort Union Formation (Te_1) in two areas of the Crazy Mountain Basin (A and B), throughout the Clark's Fork Basin (C), and from the northern Bighorn Basin (D). The Willwood Formation (Te_2) is richly fossiliferous throughout most of the Clark's Fork and Bighorn Basins. Densest stippling shows outcrop of Cretaceous and older sedimentary rocks, intermediate stippling shows outcrop of middle Eocene and younger sedimentary rocks, light stippling shows Quaternary alluvium. Source: American Association of Petroleum Geologists geological map of the Northern Rocky Mountains.

regarding the structural history of the Clark's Fork Basin based on these observations. While present interpretations are necessarily tentative, continuing work should fill many gaps in current biostratigraphic coverage, leading to more tightly constrained models in the future.

GEOGRAPHIC AND TECTONIC SETTING OF THE CLARK'S FORK BASIN

The Clark's Fork Basin is located in the central part of a major northwest-southeast trending structural trough that extends from central Montana to northwestern Wyoming (Figure 1). This trough includes four structural and depositional basins: the Crazy Mountain and Stillwater Basins in the north, the Clark's Fork Basin in the center, and the Bighorn Basin in the south. The individual basins are most clearly defined on isopach maps (cf. Moore, 1961). Thev are separated by the Reed Point Arch, Nye-Bowler Zone (Wilson, 1936), and Shoshone River Arch, respectively. The Fort Union Formation is widely distributed throughout the length of the Crazy Mountain -Bighorn trough, and it has yielded abundant fossil mammals of Paleocene age in four areas (A-D in Figure 1). The Willwood Formation does not presently extend north of the Montana-Wyoming state line, although it undoubtedly covered extensive areas of southern Montana before being removed by erosion. During the Paleocene and early Eocene, the Crazy Mountain Basin, Stillwater Basin, Clark's Fork Basin, and Bighorn Basin were all parts of a single large depositional province that was, initially at least, joined to the Wind River Basin in the south, the Powder River Basin in the east, and the Musselshell and Williston Basins to the north.

The presence of a thick sequence of Livingston and Lance-equivalent continental sediments of Late Cretaceous age, together with doming and possibly some faulting along the Nye-Bowler lineament in southern Montana, indicates that initial subsidence of the Crazy Mountain - Bighorn trough was underway by the end of the Cretaceous (Wilson, 1936). Foose et al. (1961) postulated that tear faults, imbrication, lateral shearing, and most of the structural detail along the Beartooth front developed during late Fort Union and Willwood time, a view consistent with results presented here. The style of deformation, not discussed explicitly here, is consistent with Berg's (1962) model of folding and thrusting rather than block faulting to explain the geometry of intermontane basins in the Western Interior.

Most of the structural relief seen in the Clark's Fork Basin and Beartooth Mountains area developed in the early Cenozoic, but the present topographic expression of this structural relief did not develop until the late Cenozoic when broad regional uplift of the Western Interior rejuvenated streams and initiated a major cycle of erosion excavating intermontane basins and exposing the mountains themselves. The entire region under study was nearer to sea level and much flatter topographically during the Paleocene and Eocene than it is today (Van Houten, 1952).

PALEOCENE AND EARLY EOCENE BIOCHRONOLOGY

The following study of deformational history requires that the ages of successive stratigraphic intervals be determined with considerable precision. This is possible because early Cenozoic mammalian faunas evolved rapidly, and because identifiable fossil remains are abundantly preserved in both the Fort Union and Willwood Formations. Cenozoic mammalian faunas are conventionally divided in- a series of provincial land-mammal ages in North America, reflecting major events of faunal evolution and turnover during the course of mammalian diversification. Early in this century, paleontologists working in the San Juan Basin of New Mexico, on the Wasatch Plateau in Utah, and in the Wind River, Bighorn, and Clark's Fork Basins of Wyoming established a composite sequence of mammalian faunas related temporally by superposition. These faunal assemblages were designated, from oldest to youngest: Puerco, Dragon, Torrejon, Tiffany, Clark Fork, Sand Coulee, Gray Bull, Lysite, and Lost Cabin. In establishing the current system of land-mammal ages, the Wood Committee (Wood et al., 1941) recognized each of the first five assemblages as a land-mammal age in its own right: Puercan, Dragonian, Torrejonian, Tiffanian, and Clarkforkian, respectively. The Sand Coulee, Gray Bull, Lysite, and Lost Cabin assemblages were grouped together as successive zones of a single land-mammal age: Wasatchian. The only significant change made subsequently was inclusion of the Dragonian as part of the Troejonian Land-Mammal Age. Consequently, three land-mammal ages are confined to the Paleocene. These are the Puercan, Torrejonian, and Tiffanian, representing the early, middle, and late Paleocene, respectively. The fourth land-mammal age, the Clarkforkian, includes the Paleocene-Eocene transition, and the final land-mammal age of interest here, the Wasatchian, represents most of early Eocene time.

As presently conceived, the five Paleocene and early Eocene land-mammal ages span approximately 15 million years *(my)* of geological time, from 65 to 49.5 *my* before present. A land-mammal age represents, on average, about three *my*. The shortest ages, the Puercan and Clarkforkian, probably represent about two *my* each, while

TABLE 1. Biostratigraphic zones recognized in Paleocene and early Eocene formations of western North America. Zones involving taxa preceded by asterisks are found in the Clark's Fork and Bighorn Basins (see map in Figure 2). Age estimates from Berggren et al. (1978)

	AGE (Ma)			ZONE	PRINCIPAL TAXON MAKING FIRST APPEARANCE AT BEGINNING OF ZONE	AUXILIARY TAXON MAKING FIRST APPEARANCE AT BEGINNING OF ZONE	ALTERNATIVE NAME FOR ZONE
EOCENE	49.5	Wasatchian	Late	Wa_7	* *Lambdotherium primaevum*		Lostcabinian
				Wa_6 ◇C	* *Heptodon calciculus*		Lysitean
			Middle	Wa_5 ◇B	* *Homogalax protapirinus*	* *Bunophorus etsagicus*	Late Graybullian
				Wa_4		* *Hyracotherium pernix*	Middle Graybullian
				Wa_3 ◇A		* *Hyracotherium aemulor*	Early Graybullian
			Early	Wa_2	* *Hyracotherium grangeri*	* *Cantius mckennai*	Late Sandcouleean
	53.5			Wa_1		* *Cantius ralstoni*	Early Sandcouleean
		Clarkfork.	L	Cf_3	* *Phenacodus - Ectocion Zone*	* *Plesiadapis dubius*	
	55.0		M	Cf_2	* *Plesiadapis cookei*		
PALEOCENE			E	Cf_1	* *Plesiadapis gingerichi*		
		Tiffanian	Late	Ti_5	* *Plesiadapis simonsi*	* *Plesiadapis fodinatus*	
				Ti_4	* *Plesiadapis churchilli*		
			M	Ti_3	* *Plesiadapis rex*		
			Early	Ti_2	* *Plesiadapis anceps*		
	60.0			Ti_1	* *Plesiadapis praecursor*		
		Torrejonian	Late	To_4	* *Pantolambda cavirictum*	* *Pronothodectes jepi*	
				To_3	*Pantolambda intermedium*	*Pronothodectes gidleyi*	
			Early	To_2	*Deltatherium fundaminis*		
				To_1	*Conoryctella dragonensis*		Dragonian
		Puercan	L	Pu_3	*Taeniolabis taoensis*		
			M	Pu_2	*Ectoconus ditrigonus*		
	65.0		E	Pu_1	* *Mimatuta minuial*		Mantuan

the longest the Tiffanian and Wasatchian, represent about four *my* each. To interpret the timing and duration of geological events, it is desirable that time be recorded with greater precision than is provided by land-mammal ages. Recent biostratigraphic work indicates that each of the Paleocene and early Eocene land-mammal ages can be subdivided. Currently recognized subdivisions are listed in Table 1.

The Puercan and Torrejonian land-mammal ages were first subdivided by Sinclair and Granger (1914), who recognized *Ectoconus* and *Taeniolabis* (*"Polymastodon"*) zones within the Puerco faunal assemblage, and lower (now *Deltatherium*) and *Pantolambda* zones within the Torrejon assemblage. Van Valen (1979) recently proposed a new "Mantuan" land mammal age, but it is generally recognized as an early zone of the Puercan (Archibald, 1982), just as the Dragonian is regarded as an early zone of the Torrejonian. The late Torrejonian can be subdivided in northern faunas based on the presence of one or another species of *Pronothodectes*, a common plesiadapid primate. *Plesiadapis* itself is a genus in which many dental characteristics evolved rapidly and independently, and five successive *Plesiadapis* zones are recognized in the Tiffanian (Gingerich, 1975, 1976).

The composition of the Clarkforkian Land-Mammal Age has been thoroughly documented in recent years by Rose (1980, 1981), who recognizes within it three well defined zones. The first two of these are again based on *Plesiadapis*, while the third is based on an absence of large *Plesiadapis* and an abundance of two common condylarths, *Phenacodus* and *Ectocion.*

Several different schemes have been proposed for subdivision of the Wasatchian Land-Mammal Age. Granger (1914) recognized successive Sand Coulee, Gray Bull, Lysite, and Lost Cabin faunas in the Bighorn and adjacent Clark's Fork Basins. The first of these he distinguished from the underlying Clark Fork faunal assemblage by the presence of the "dawn horse" *Hyracotherium.* The Gray Bull was distinguished by the presence of *Hyracotherium* together with a second, larger perissodactyl *"Systemodon" protapirinus (Homogalax protapirinus* of modern terminology). The Lysite was distinguished by the first appearance of *Heptodon,* and the Lost Cabin by the first appearance of *Lambdotherium.*

It has only recently become possible to subdivide "Gray Bull" faunas based on extensive faunal evidence. Schankler (1980) identified three major episodes of faunal turnover within Wasatchian faunas of the central Bighorn Basin, labeling these events Biohorizon A, B, and C, respectively. These turnover events are indicated by diamond-shaped symbols in Table 1. Many taxa appear to have been affected by each turnover event, although it is not yet clear that a single sharp stratigraphic "horizon" of turnover can be identified. Each turnover appears to have occupied a significant interval of stratigraphic section and geological time.

Jepsen (1930) reported "Systemodon" from the type area of the Sand Coulee fauna, and regarded the latter as equivalent to the Gray Bull fauna. This opinion became widely accepted, in spite of a strongly worded note to the contrary by Simpson (1937). Ironically, collection of additional specimens of both *Hyracotherium* and *Homogalax* from the Clark's Fork and Bighorn Basins only served to confound separation of the Sand Coulee and Gray Bull faunas by confusing the systematic relationships of early species of these genera. Consequently, most early and middle Wasatchian faunas have been included in a single "Gray Bull" faunal zone, sometimes modified by addition of an equally poorly defined adjective early, middle, or late, based on a subjective impression of where a fauna might fall within the Graybullian.

Detailed quantitative study of the systematics of early Eocene perissodactyls based on more than a thousand new specimens indicates that *Homogalax protapirinus ("Systemodon"* of Granger) first appeared in the Clark's Fork Basin at the beginning of Schankler's Biohorizon A faunal turnover. The species of *Homogalax* present before this turnover is a smaller one closely related to *Homogalax semihians.* As Granger (1914) stated, *"Systemodon"* did make a sudden appearance in the early Wasatchian subsequent to the appearance of *Hyracotherium,* and the Sand Coulee faunal assemblage differs significantly from the succeeding Gray Bull assemblage. Furthermore, both of these faunal units can be subdivided as shown in Table 1. *Cantius ralstoni* is but one of many early Wasatchian species present in the early Sandcouleean and replaced by a more advanced descendant in the late Sandcouleean.

The early and middle Graybullian each contain distinctive species of *Hyracotherium* more advanced than *Hyracotherium grangeri* found in the Sandcouleean. The late Graybullian corresponds to Shankler's *"Bunophorus* Interval Zone", between Biohorizons B and C. The Lysitean corresponds to the lower and middle parts of Schankler's *"Heptodon* Range Zone," and the Lostcabinian corresponds to the upper part of the *"Heptodon* Range Zone," marked, as Granger (1914) noted, by the first appearance of *Lambdotherium.* Interpreted in this way, Schankler's detailed biostratigraphic work on Wasatchian mammals from the central Bighorn Basin appears to corroborate Granger's zonation and give clear meaning to the terms Sandcouleean, Graybullian, Lysitean, and Lostcabinian. These subages are now characterized by many taxa and bounded by relatively short intervals of significant faunal turnover. The Granger-Schankler zonation of Wasatchian sediments is undoubtedly superior at this point to the zonation that I proposed based on successive species in a lineage of *Cantius* or *Pelycodus* (Gingerich, 1980b).

For ease of reference, each of the successive Paleocene and early Eocene zones listed in Table 1 has been given an alphanumeric designation (e.g., Pu_1, Pu_2, etc.), based on a two-letter abbreviation of the corresponding land-mammal age and a subscript denoting sequential position within it. Seventeen of the twenty-two Paleocene and early Eocene zones shown in Table 1 are found in the Clark's Fork and Bighorn Basins. These are marked with an asterisk in Table 1.

To place the temporal positions of zones in global context, it should be noted that zone Cf_1, corresponds to paleomagnetic polarity zone 25N, and zones Ti_3-Ti_4 bracket polarity zone 26N on the standard worldwide magnetic polarity time scale (Butler et al., 1981). Zones To_3-To_4 may approximate the position of polarity zone 27N.

BIOSTRATIGRAPHIC ZONATION OF THE FORT UNION AND WILLWOOD FORMATIONS

The present surface distribution of early Cenozoic faunal zones in the Clark's Fork and northern Bighorn Basin is mapped in Figure 2. Present surface distribution says little about continuation of a zone in the subsurface or about former extensions of a distribution now removed by

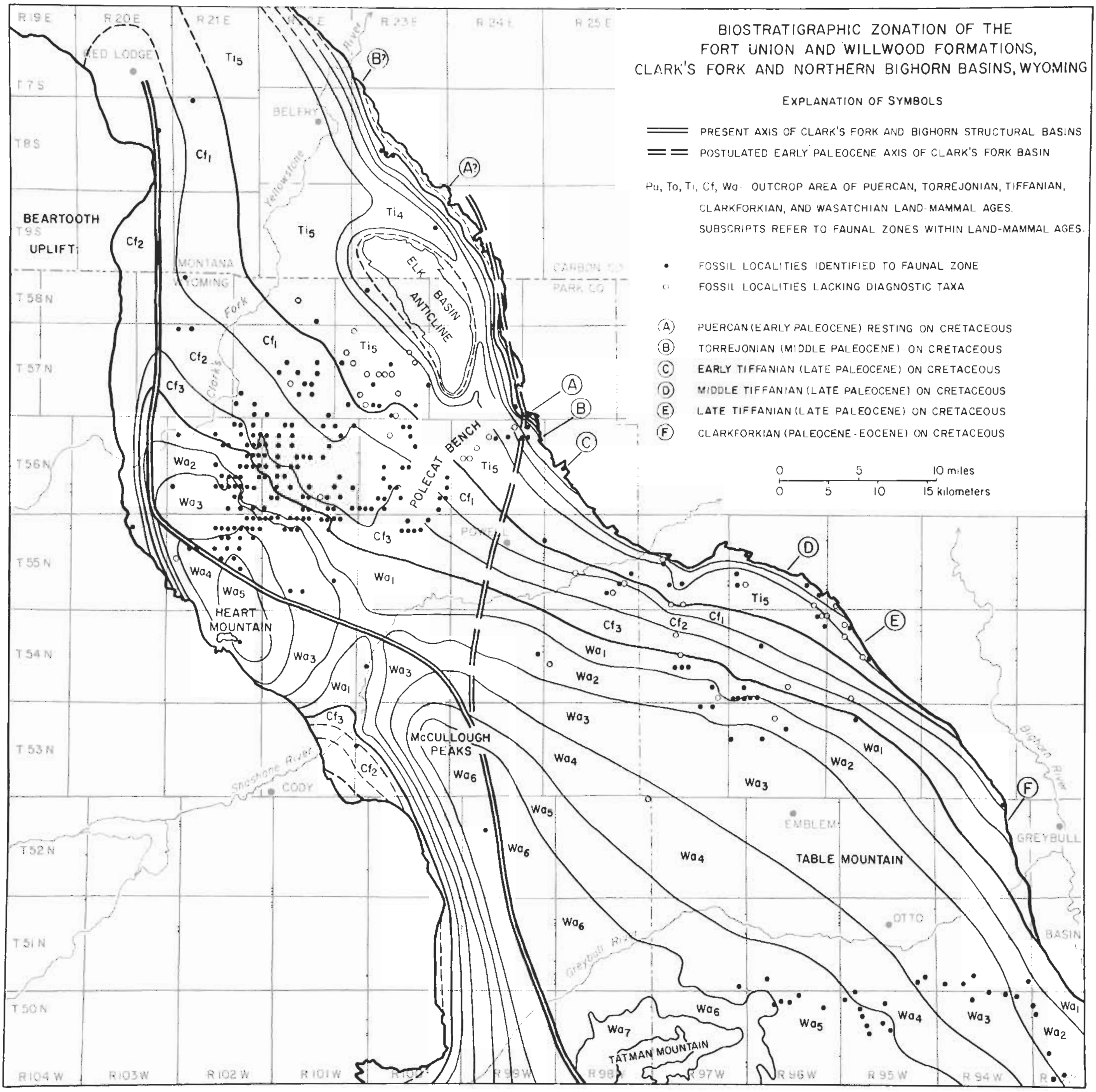

Figure 2. Biostratigraphic zonation of the Fort Union and Willwood Formations exposed at the surface in the Clark's Fork and northern Bighorn Basins. Contours are based on successive computer plots of localities containing taxa characteristic of zones listed in Table 1. This is not an isopach map nor is it a structural contour map, although the positions of zones are clearly related to both sediment thickness and structure. Note narrow range of Puercan (early Paleocene) outcrop resting on the Late Cretaceous, and pattern of southward onlap of Fort Union zones onto the Late Cretaceous along the eastern edge of the Fort Union outcrop belt. Note also left-lateral offset of present basin axes in the vicinity of Heart Mountain and McCullough Peaks. Structure axis of basins is taken from Andrews et al. (1947). Boundary of Fort Union and Willwood Formations is taken from Pierce (1978).

erosion, and the possible influence of these unknown factors must be considered in evaluating interpretations of surface patterns. Nevertheless, there are a number of important characteristics of the surface distributions of Paleocene and early Eocene biostratigraphic zones to be noted:

(1) The distribution of biostratigraphic zones in the Clark's Fork Basin is markedly asymmetric. All zones recorded from this basin are represented east of the present basin axis, but only the highest zones (Cf_2 and higher) are represented west of the present basin axis. Comparable information about the distribution of biostratigraphic zones is not available for the central and southern Bighorn Basin, but isopach contours of the Fort Union Formation (Moore, 1961) and the continuous outcrop belt of Fort Union Formation around the eastern, southern, and western margins of the Bighorn Basin (Glass et al., 1975) indicate that the Bighorn Basin is not nearly so asymmetrical as the Clark's Fork Basin.

(2) Tiffanian, Clarkforkian, and Wasatchian biostratigraphic zones are much thicker than those representing the Puercan and Torregonian. The Puercan and Torrejonian on Polecat Bench together comprise only about 100 meters (330 feet) of stratigraphic section, while the Tiffianian there is about 850 meters (2800 feet) thick, and the Clarkforkian is about 570 meters (1900 feet) thick. The lower half of the Wasatchian in the Clark's Fork Basin is about 500 meters (1650 feet) thick. These thicknesses correspond to net rates of sediment accumulation of about 20 meters/*my* (654 feet/*my*) for the Puercan-Torrejonian, 130 meters/*my* (425 feet/*my*) for the early Tiffanian, 280 meters/*my* (920 feet/*my*) for the late Tiffanian, 280 meters/*my* (920 feet/*my*) for the Clarkforkian, and 250 meters/*my* (820 feet/*my*) for the early Wasatchian.

(3) Finally, there is a progressive onlap of Paleocene and early Eocene faunal zones on Late Cretaceous Lance-equivalent sediments from northwest to southeast along the east side of the Bighorn Basin beginning near Polecat Bench and ending near the town of Greybull, a distance of about 60 kilometers (40 miles). This onlap is indicated by circled letters A - F in Figure 2. Northwest of Polecat Bench along the eastern edge of Fort Union exposures in the Clark's Fork Basin, few localities yielding diagnostic mammalian fossils have been found to date, and thus onlap relationships are not as clear. The Torrejonian-Tiffanian boundary is well defined by fossil mammals in one restricted area between Hunt Creek and Cub Creek to the southeast of Belfry, and Hickey (1980) has reported a Puercan flora from his locality D5778 at the base of the Fort Union Formation northeast of the town of Belfry. The entire Puercan-Torrejonian section south of Hunt Creek is about 100 meters (330 feet) thick, as it is on Polecat Bench. Puercan and Torrejonian faunas and floras have not been found west of the Clark's Fork River to the north of Belfry, permitting one to hypothesize a progressive northward onlap of Paleocene faunal zones on the Cretaceous along the east side of the Clark's Fork Basin. Possible positions of suggested, but as yet unsubstantiated, northward onlap of the Puercan and Torrejonian on the Cretaceous are indicated by circled letters "A?" and "B?" in Figure 2.

INTERPRETATION

The markedly asymmetrical distribution of biostratigraphic zones exposed at the surface in the Clark's Fork Basin, and a progressive increase in the thickness and rate of accumulation of given faunal zones in a westward direction (for zones that can be compared on Polecat Bench and in the axial part of the Clark's Fork Basin) can be explained as a result of differential subsidence of the western edge of the basin. A sharp left-lateral deflection of the present structural axis of the Clark's Fork and Bighorn Basins is present in the vicinity of McCullough Peaks and Heart Mountain (Figure 2). Judging from thickness contours of the Fort Union Formation published by Moore (1961) and greater lithostratigraphic symmetry about the present structural axis, the floor of the Bighorn Basin was depressed more uniformly, without the marked differential depression of the western margin apparent in the Clark's Fork Basin. This difference in deformational styles is sufficient to explain the left-lateral offset in the present structural axes of the Clark's Fork and Bighorn Basins.

Figure 1 shows that the Fort Union Formation presently occupies a restricted trough extending from the Crazy Mountain Basin to the Bighorn Basin. The progressive southward onlap of first Puercan, then Torrejonian, Tiffanian, Clarkforkian, and possibly Wasatchian sediments on the Late Cretaceous along the eastern margin of Fort Union outcrops in the northern Bighorn Basin (Figure 2) suggests that the part of this trough receiving and retaining sediment was probably much narrower in the early Paleocene than it was in the late Paleocene and early Eocene. The Clark's Fork sedimentary basin clearly did not extend very far east of present day Polecat Bench in the early and middle Paleocene, as evidenced by early Tiffanian sediments lapping over the Puercan and Torrejonian onto the Cretaceous within a few kilometers of Polecat Bench (C in Figure 2). The western edge of the Puercan-

Torrejonian trough is not well defined at present, but there is no thickening of Puercan and Torrejonian sediments north and westward from Polecat Bench, suggesting that the entire linear basin receiving sediment at this time may have been as little as 10-20 kilometers (6-12 miles) wide. If the Clark's Fork sedimentary basin was only 10-20 kilometers (6-12 miles) wide in the early and middle Paleocene, the structural axis of the basin at that time must have been oriented in a north-south direction near the eastern end of Polecat Bench. Such a trajectory would connect directly with the present axis of the Bighorn Basin in the vicinity of McCullough Peaks (Figure 2). This alignment lends credibility to the idea that the axis of the Clark's Fork Basin in the early and middle Paleocene ran along the eastern margin of present Fort Union outcrops in this area.

Early and middle Paleocene sediments are known in the southern Bighorn Basin. An early Puercan locality, Leidy Quarry, is located on Cedar Mountain just east of the town of Kirby. These southern outcrops indicate that the narrow band of Puercan and Torrejonian sediment disappearing under a covering of younger strata in the vicinity of Polecat Bench does reappear at the surface in the south.

During the early and middle Tiffanian (late Paleocene) the rate of sediment accumulation increased progressively, and the trough receiving sediment became broader and less symmetrical. The structural axis of the Clark's Fork Basin probably shifted to the western edge of the basin in the middle Tiffanian. The Clark's Fork Basin was clearly highly asymmetrical by the late Tiffanian, and it has remained so ever since. Sediment accumulated at a rate of about 280 meters/*my* (920 feet/*my*) during the late Tiffanian and Clarkforkian, judging from the thickness of strata representing these ages on Polecat Bench, and deposition in the axial part of the basin to the west was undoubtedly more rapid. A diagrammatic cross-section illustrating the geometry of successive wedges of Paleocene and earliest Eocene sediment in the Clark's Fork Basin at the end of the Clarkforkian Land-Mammal Age is illustrated in Figure 3. It should be noted that Rea and Barlow's (1975) paleogeographic map of the "lower part" of the Fort Union Formation in the Clark's Fork Basin probably reflects more accurately late Paleocene paleogeography than it reflects what was happening in the early or middle Paleocene.

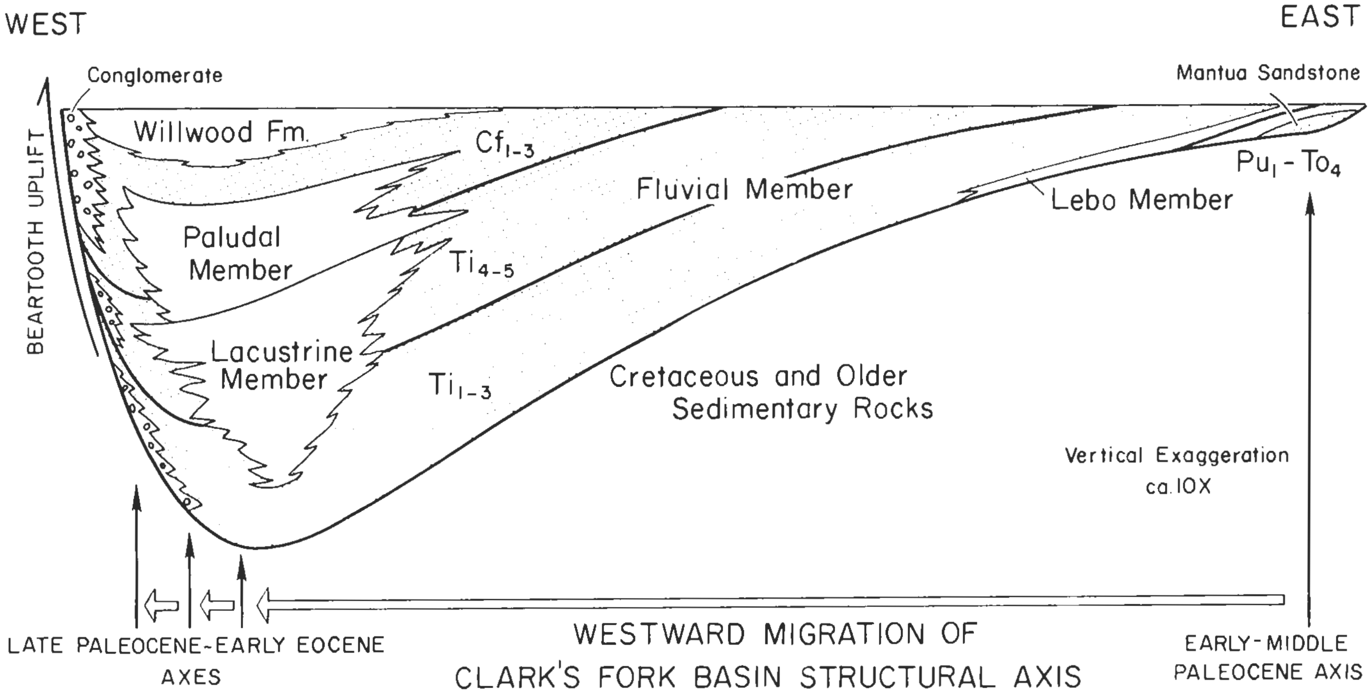

Figure 3. Diagrammatic cross-section of the Clark's Fork Basin as it appeared at the end of Clarkforkian time (earliest Eocene). Section is drawn from the east end of Polecat Bench (east) to the Beartooth Uplift (west). Note relatively small volume of early and middle Paleocene sediments (Pu$_1$-To$_4$) relative to volume of late Paleocene and earliest Eocene sediments (Ti$_1$-Cf$_3$). Same section drawn farther to north would have lacustrine and paludal members exposed at surface; section drawn farther to south would have Ti$_{1-3}$ lapping over Pu$_1$-To$_4$ to rest on the Cretaceous and a more extensive cover of red-banded Willwood Formation. Note rapid westward migration of the structural axis of the Clark's Fork Basin in mid-Tiffanian (late Paleocene) time when subsidence was greatest and a major lake system first occupied the axial part of the basin.

The rapid accumulation of sediment in a basin becoming increasingly asymmetrical during the late Tiffanian, Clarkforkian, and Washatchian is undoubtedly related to two factors: rapid tilting of the floor of the Clark's Fork Basin toward the west, and coincident uplift of the adjacent Beartooth Mountains. The lineament defined by an abrupt left-lateral shift of the Clark's Fork Basin axis relative to the Bighorn Basin axis in the Heart Mountain - McCullough Peaks area is aligned with the Clark's Fork Fault bounding the southern margin of the Beartooth Plateau (Foose et al., 1961), suggesting that there has been some structural accommodation along this lineament far out into the adjacent basin. Left-lateral offset of the structural axis of the Clark's Fork and Bighorn Basins along the Heart Mountain - McCullough Peaks lineament parallels that along the Nye-Bowler lineament marking the northern edge of the Clark's Fork structural basin (Wilson, 1936). If the Heart Mountain - McCullough Peaks lineament had any surface expression during the early and middle Eocene, it may help to explain why Heart Mountain detachment blocks and debris of Madison Limestone are where they are today on Heart Mountain and on McCullough Peaks. That is, it may be more than a coincidence that Heart Mountain and McCullough Peaks rest over an important subsurface structural lineament.

The deformational history of the Clark's Fork Basin outlined above places a number of distinctive sedimentary environments of the Fort Union and Willwood Formations in clearer perspective (Figure 3). In a recent study, Hickey (1980) recognized a basal Lebo Member of the Fort Union Formation overlain by informally designated fluvial, lacustrine, and paludal members. A conglomeratic member is developed along the edge of the Beartooth uplift. The Lebo Member is Puercan, Torrejonian, and probably early Tiffanian in age. It includes the 40 meter (130 foot) thick Mantua sandstone lentil of Jepsen (1940) at its base, overlain by a somber sequence of gray to olive gray carbonaceous shale and mudstone with subordinate sandstone and lignite. The Mantua sandstone is probably a sheet sandstone representing extensive reworking of Puercan and possibly Torrejonian sediments developed when the depositional basin was narrow and located at the eastern edge of present Fort Union exposures. Hickey's (1980) light gray, cleanly washed, cross-bedded Hunt Creek sandstone at the base of the Lebo north of the Mantua lentil probably developed in a similar way. The remainder of the Lebo Member has greater geographic extent but it too probably developed in a restricted band along the eastern margin of the present outcrop area before any major structural deformation of the Clark's Fork Basin. Taken as a whole, the Lebo Member represents a relatively slow accumulation of sediment in a shallow, relatively stable sedimentary basin.

Hickey's fluvial member consists of massive to cross-bedded channel sandstones and mudstones, with some interbedded lignites and freshwater carbonates. These tend to occur in cyclical succession (Gingerich, 1969), with a fully developed sedimentary cycle initiated by sandstone, representing stream deposition, followed by mudstone, representing lower energy overbank sediments, followed by lignite, representing backswamp conditions. Freshwater carbonates occur intercalated within the mudstones. This sequence is typical of autocyclical deposition in rapidly aggrading fluvial systems (Beerbower, 1964), and the transition from Lebo to fluvial member deposition in the Clark's Fork Basin may coincide with the onset of more rapid depression of the basin floor.

The presence of a lacustrine member in the axial part of the Clark's Fork Basin during the late Tiffanian is clear evidence of drainage ponding because the rate of basin subsidence exceeded the rate of influx of sediment. Subsidence probably reversed paleoslope locally during this interval. As sedimentation again caught up with subsidence near the end of the Tiffanian, lacustrine environments were replaced by swamps and marshes. The paludal member of the Fort Union Formation was succeeded by upper beds of the fluvial member, and this was in turn replaced during the Clarkforkian by red-banded sediments of the Willwood Formation, indicating development of well drained floodplain environments.

In conclusion, important features of the interpretation offered here are: (1) The Clark's Fork Basin was a shallow, relatively stable northern extension of the Bighorn structural basin until about mid-Tiffanian time. (2) In the mid-Tiffanian the western margin of the Clark's Fork Basin subsided and the structural axis of the basin shifted rapidly to the west, decoupling from that of the Bighorn Basin. (3) Depression of the floor of the Clark's Fork Basin was so rapid along its western margin in the late Tiffanian that sedimentary deposition could not keep up with subsidence, and a large lake system developed in the axial part of the basin. (4) This lake system was replaced by swamps and marshes as sedimentation began to catch up with subsidence. (5) Once sedimentation equalled or exceeded subsidence in the middle to late Clarkforkian and early Wasatchian the area became better drained, and red-banded mudstones of the Willwood Formation represent formation of successive paleosols under oxidizing conditions. (6) The total amount of sediment deposited in the Clark's Fork Basin during the Puercan, Torrejonian, and early Tiffanian Land-Mammal Ages was probably a small fraction of that deposited during the late Tiffanian, Clarkforkian, and Wasatchian Land-Mammal Ages. (7) Maximum subsidence of the Clark's Fork Basin and, by inference, uplift of the Beartooth massif probably occurred from the mid-

Tiffanian through the Clarkforkian, i.e., from about 57 to 53 *my* before present.

FUTURE WORK

Some of the structural interpretation offered here is hypothetical and, as yet, poorly substantiated. The map in Figure 2 shows what is known about the ages of many parts of the Fort Union and Willwood Formations in the Clark's Fork Basin area, and it provides a context for interpretation of new localities as these are discovered and dated biochronologically. The relationship of Fort Union sediments to the underlying Late Cretaceous can profitably be studied in three areas: on the northeastern side of the Clark's Fork Basin along Hunt, Cub, and Dry Creeks, around the margin of the Elk Basin anticline, and on the southwestern side of the basin near the town of Cody. Collection of new mammilian faunas that can be dated precisely will be required in each of these areas.

It is now possible to study detailed stratigraphic relationships and paleocurrent directions within relatively narrow temporal intervals and to make paleoenvironmental and paleogeographical reconstructions for individual biostratigraphic zones. Documentation of the distribution of lithofacies and corresponding paleoenvironments in each zone, and a better knowledge of their evolution over time promises to amplify (and probably modify) the simple model presented in Figure 3. New data will undoubtedly contribute a still more refined understanding of the chronology and tectonic style of Laramide deformation in the Clark's Fork Basin.

ACKNOWLEDGMENTS

I am much indebted to Drs. C. Badgley and J.A. Dorr, and to Mr. N.A. Wells for discussion of the ideas developed here and for careful reading of the manuscript. Figures were drawn by Karen Klitz. Ongoing research on faunal history of the Clark's Fork Basin is supported by National Science Foundation grant DEB 82-06242.

REFERENCES

Alexander, A.J., 1982, Sedimentology and taphonomy of a middle Clarkforkian (early Eocene) fossil vertebrate locality, Fort Union Formation, Bighorn Basin, Wyoming: Unpublished M.Sc. thesis, University of Michigan, Ann Arbor, 1-115p.

Andrews, D.A., Pierce, W.G., and Eargle, D.H., 1947, Geologic map of the Bighorn Basin, Wyoming and Montana, showing terrace deposits and physiographic features: U.S. Geol. Surv. Oil and Gas Investigations, Preliminary Map 71.

Archibald, J.D., 1982, A study of Mammalia and geology across the Cretaceous-Tertiary boundary in Garfield County, Montana: Univ. Calif. Publ. Geol. Sci., v. 122, 1-286 p.

Beerbower, J.R., 1964, Cyclothems and cyclic depositional mechanisms in alluvial plain sedimentation: Kans. Geol. Surv. Bull. 169, p. 31-42.

Berg, R.R., 1962, Mountain flank thrusting in Rocky Mountain foreland, Wyoming and Colorado: Amer. Assoc. Petrol. Geol. Bull., v. 46, p. 2019-2032.

Berggren, W.A., McKenna, M.C., Hardenbol, J., and Obradovich, J.D., 1978, Revised Paleogene polarity time scale: Jour. Geol., v. 86, p. 67-81.

Bown, T.M., and Kraus, M.J., 1982a, Lower Eocene alluvial paleosols (Willwood Formation, northwest Wyoming, U.S.A.) and their significance for paleoecology, paleoclimatology, and basin analysis: Palaeogeogr., Palaeoclimatol., Palaeoecol., v. 34, p. 1-30.

Bown, T.M. and Kraus, M.J., 1982b, Vertebrate fossil-bearing paleosol units (Willwood Formation, northwest Wyoming, U.S.A.): implications for taphonomy, biostratigraphy, and assemblage analysis. Palaeogeogr., Palaeoclimatol., Palaeoecol., v. 34, p. 31-56.

Butler, R.F., Gingerich, P.D., and Lindsay, E.H., 1981, Magnetic polarity stratigraphy and biostratigraphy of Paleocene and lower Eocene continental deposits, Clark's Fork Basin, Wyoming: Jour. Geol., v. 89, p. 299-316.

Foose, R.M., Wise, D.U., and Garbarini, G.S., 1961, Structural geology of the Beartooth Mountains, Montana and Wyoming: Geol. Soc. Amer. Bull., v. 72, p. 1143-1172.

Gingerich, P.D., 1969, Markov analysis of cyclic alluvial sediments: Jour. Sed. Petrol., v. 39, p. 330-332.

———, 1975, New North American Plesiadapidae and a biostratigraphic zonation of the middle and upper Paleocene: Contrib. Mus. Paleont. Univ. Mich., v. 24, p. 135-148.

———, 1976, Cranial anatomy and evolution of early Tertiary Plesiadapidae (Mammalia, Primates): Univ. Mich. Pap. Paleontol., v. 15, 1-140 p.

———, (ed.), 1980a, Early Cenozoic paleontology and stratigraphy of the Bighorn Basin, Wyoming: Univ. Mich. Pap. Paleontol., v. 24, 1-146 p.

———, 1980b, Evolutionary patterns in early Cenozoic mammals: Ann. Rev. Earth Planet. Sci., v. 8, p. 407-424.

Glass, G.B., Westervelt, K., and Oviat, C.G., 1975, Coal mining in the Bighorn coal basin of Wyoming: Wyo. Geol. Assoc. Guidebook, 27th Annual Field Conference, p. 221-228.

Granger, W., 1914, On the names of lower Eocene faunal horizons of Wyoming and New Mexico: Amer. Mus. Nat. Hist. Bull., v. 33, p. 201-207.

Hickey, L.J., 1980, Paleocene stratigraphy and flora of the Clark's Fork Basin: *In* Gingerich, P.D. (ed.), Early Cenozoic paleontology and stratigraphy of the Bighorn Basin, Wyoming, Univ. Mich. Pap. Paleontol, v. 24, p. 33-49.

Jepsen, G.L., 1930, New vertebrate fossils from the lower Eocene of the Bighorn Basin, Wyoming: Amer. Phil. Soc. Proc., v. 69, p. 117-131.

———, 1940, Paleocene faunas of the Polecat Bench Formation, Park County, Wyoming, Part 1: Amer. Phil. Soc. Proc., v. 83, p. 217-340.

Moore, D.A., 1961, Isopachous map Fort Union Formation, Bighorn Basin: Wyo. Geol. Assoc. Guidebook, 16th Annual Field Conference, p. 200-204.

Pierce, W.G., 1978, Geologic map of the Cody 1° x 2° Quadrangle, Wyoming: U.S. Geol. Surv. Miscellaneous Investigations Map MF-963.

Rea, B.D. and Barlow, J.A., 1975, Upper Cretaceous and Tertiary rocks, northern part of Bighorn Basin, Wyoming and Montana: Wyo. Geol. Assoc. Guidebook, 27th Annual Field Conference, p. 63-71.

Rose, K.D., 1980, Clarkforkian Land-Mammal Age: revised definition, zonation, and tentative intercontinental correlations: Science, v. 208, p. 744-746.

———, 1981, The Clarkforkian Land-Mammal Age and mammalian faunal composition across the Paleocene-Eocene boundary: Univ. Mich. Pap. Paleontol, v. 26, p. 1-196 p.

Schankler, D.M., 1980, Faunal zonation of the Willwood Formation in the central Bighorn Basin, Wyoming: *In* Gingerich, P.D. (ed.), Early Cenozoic paleontology and stratigraphy of the Bighorn Basin, Wyoming, Univ. Mich. Pap. Paleontol, v. 24, p. 99-114.

Simpson, G.G., 1937, Notes on the Clark Fork, upper Paleocene, fauna: Amer. Mus. Novitates, No. 954, p. 1-24.

Sinclair, W.J. and Granger, W., 1911, Eocene and Oilgocene of the Wind River and Bighorn Basins: Amer. Mus. Nat. Hist. Bull. 30, p. 83-117.

Van Houten, F.B., 1944, Stratigraphy of the Willwood and Tatman Formations in northwestern Wyoming: Geol. Soc. Amer. Bull., v. 55, p. 165-210.

______, 1952, Sedimentary record of Cenozoic orogenic and erosional events, Bighorn Basin, Wyoming: Wyo. Geol. Assoc. Guidebook, 7th Annual Field Conference, p. 74-79.

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

Wilson, C.W. 1936, Geology of the Nye-Bowler lineament, Stillwater and Carbon counties, Montana: Amer. Assoc. Petrol. Geol. Bull., v. 20, p. 1161-1188.

Wood, H.E. et al., 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. Amer. Bull, v. 52, p. 1-48.