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# Paleocene mammalian biostratigraphy of the Carbon Basin, southeastern Wyoming, and age constraints on local phases of tectonism

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## ABSTRACT

Mammalian fossils from two principal collecting areas in the lower Hanna Formation of the Carbon Basin comprise three faunas, the Grayson Ridge, Halfway Hill, and Sand Creek faunas. The Grayson Ridge and Halfway Hill faunas are diverse, consisting cumulatively of 29 mammalian species, at least two of which are new. The faunas are approximately equivalent in age and are either latest Torrejonian or earliest Tiffanian, or possibly sample both NALMAs. In any event, the faunas are very close in age to the Torrejonian-Tiffanian boundary. Strata bearing the Grayson Ridge and Halfway Hill faunas were truncated by erosion, resulting in a previously unrecognized intraformational unconformity (IFU). The Sand Creek fauna consists of a meager sampling of mammalian fossils from directly above the unconformity and provides a Ti3-Ti5 age (middle or late Tiffanian) for strata overlying the unconformity.

Fortuitous stratigraphic positioning of the faunas allowed age constraints to be placed upon two local phases of deformation. Simpson Ridge anticline, which separates the Hanna and Carbon basins, resulted from the first phase. Based upon lithologic correlation of the lower Ferris Formation at Simpson Ridge to its type section, development of Simpson Ridge began in the Lancian or Puercan time. Based upon fossil ages in the lower Hanna Formation, which onlaps the anticline, most, or all, of Simpson Ridge had formed by the early Tiffanian. A younger episode of deformation occurred no earlier than Ti4 (middle Tiffanian) and overprinted the folding of Simpson Ridge. Additionally, fossils from above and below the IFU suggest a hiatus of 1 to 3.5 m.y. in the lower Hanna Formation. Age constraints and orientations of Simpson Ridge anticline and an overprinting syncline suggest a local change in the direction of maximum shortening from early Paleocene to late Paleocene or Eocene.

## INTRODUCTION

Orogenesis that led to the structure of the present day Rocky Mountains began in the Late Cretaceous during what is known as the Laramide orogeny and lasted into the early Eocene. Basement-involved thrusting led to large-scale uplifts. Debris shed off the uplifts into newly forming basins resulted in deposition of thick Late Cretaceous and Paleogene sedimentary sequences. The Hanna and Carbon basins are relatively small basins located in southeastern Wyoming formed during the Laramide orogeny (Fig. 1). The Hanna and Carbon basins were not distinct depositional centers until the early Paleocene, as this study demonstrates, but rather comprised a single basin during the Late

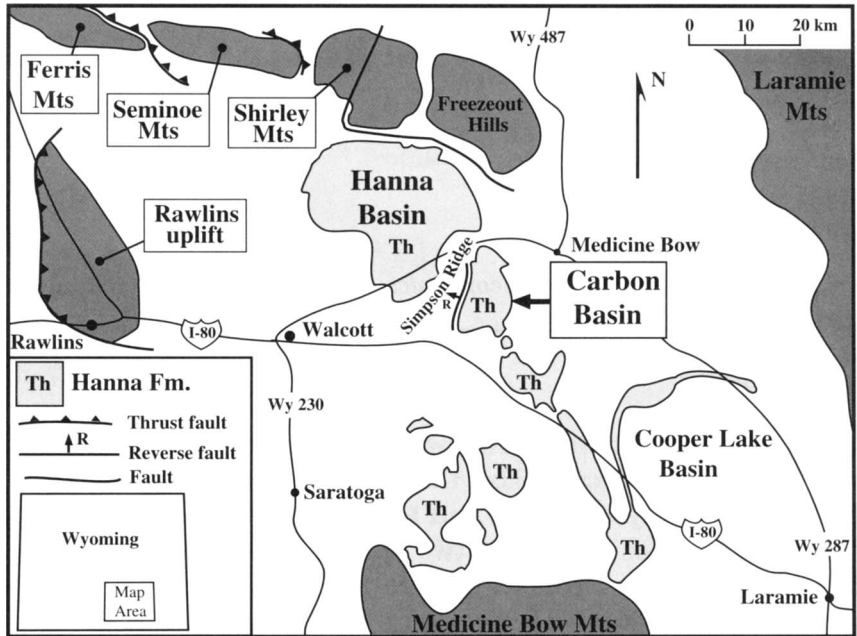
Cretaceous. The basins were separated by local uplift that began in the latest Cretaceous or early Paleocene and culminated in the formation of a large north-northeast trending anticline, known as Simpson Ridge (Figs. 1 and 2).

The Hanna Formation is a thick sequence of terrestrially derived sandstone, shale, and coal, filling the central parts of the Hanna and Carbon basins. The formation has only been recognized in and around the Hanna, Carbon, and the northern Laramie basins, and at the northern end of the Medicine Bow Mountains (Fig. 1). The Hanna Formation ranges in age from latest Torrejonian or earliest Tiffanian at its base, to at least late Tiffanian

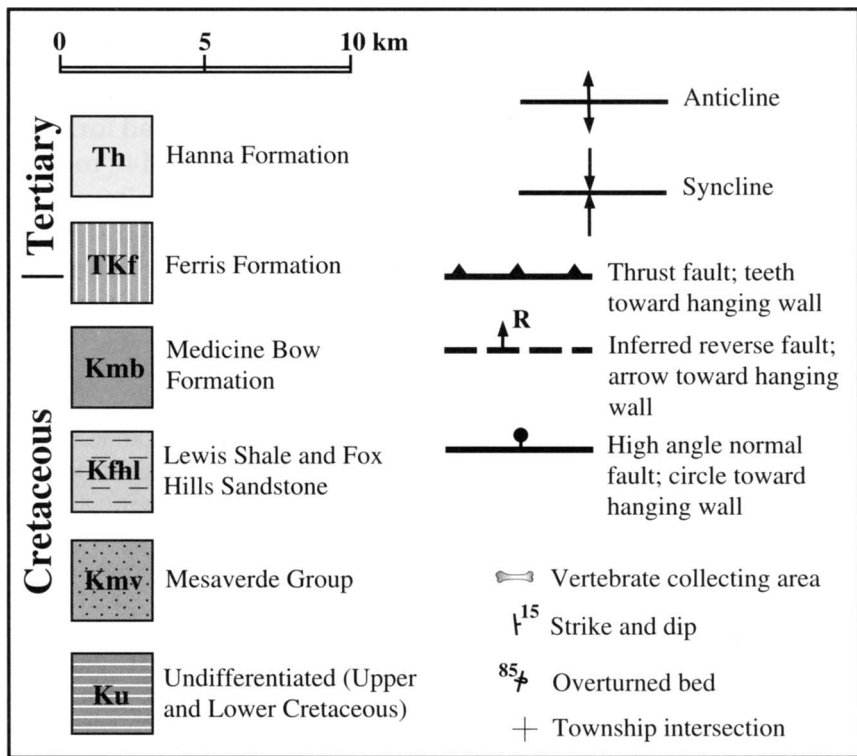
(Ti5–Ti6) in the northern and eastern Carbon Basin, which is the focus of this study (see Fig. 3 for geochronologic scale).

Vertebrate fossils are not common in most parts of the Hanna Formation and preservation is generally poor. Fossils are, however, occasionally found in local abundance, and recent discoveries of fragmentary mammalian remains in the Hanna and Carbon basins have greatly increased knowledge of Paleocene mammalian life in southeastern Wyoming. Mammalian fossils were first discovered in the Carbon Basin by a field party from The University of Wyoming led by Dr. Jason A. Lillegraven in the summer of 1980 in response to a report of a new vertebrate locality by Mr. Ted Grayson. Diligent collecting of fossil vertebrates, however, did not begin until 1994 when I devoted 14 weeks to collecting fossils and gathering geologic data for research leading to a Master of Science degree. A total of 170 mammalian specimens consisting of isolated teeth, tooth fragments, and jaw fragments has been cataloged to date. Although the number of specimens is small, taxonomic diversity is high. At least 33 mammalian species are represented, comprising 7 orders and 16 families.

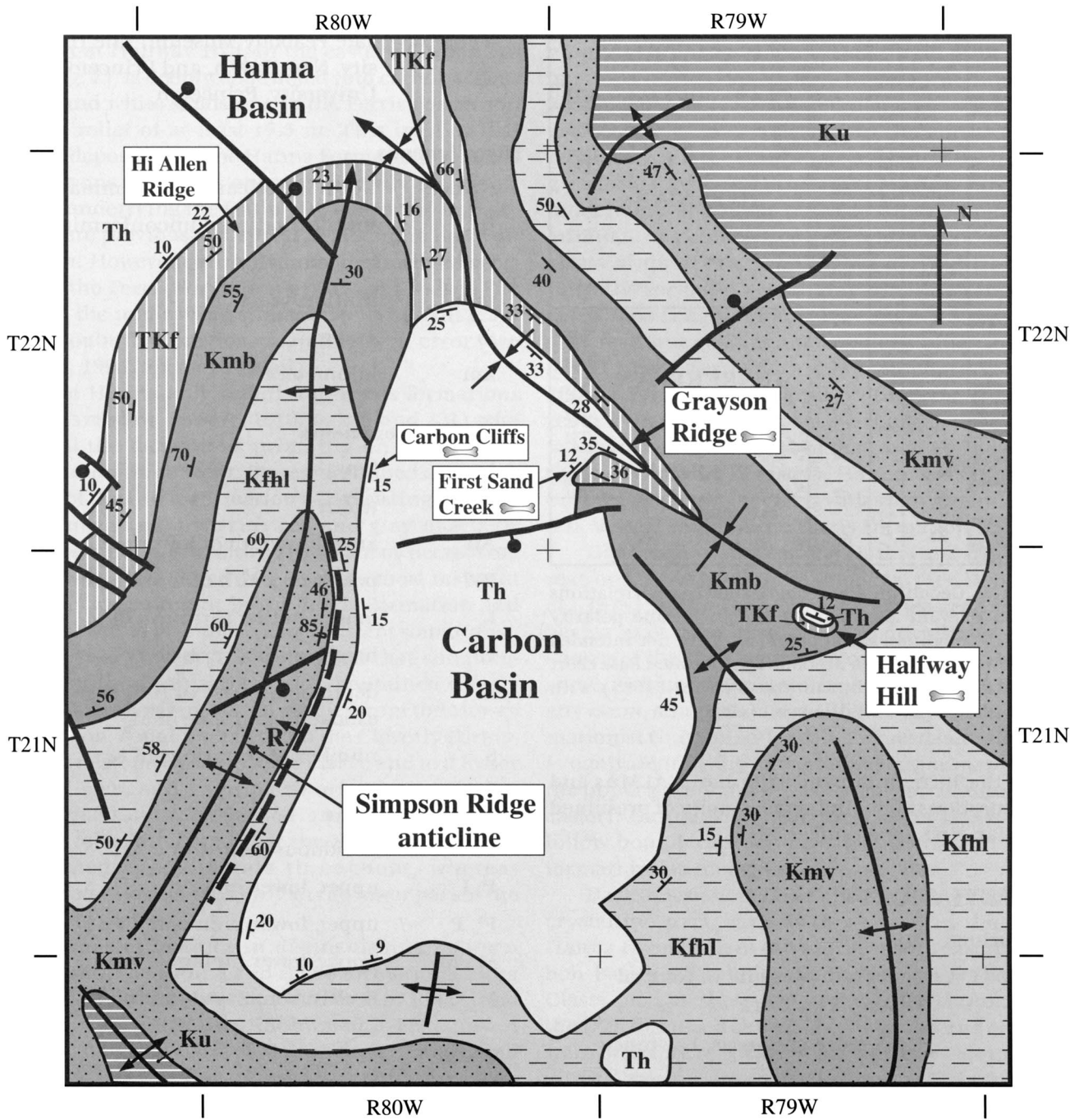
The Hanna Formation in the Carbon Basin onlaps previously formed geologic structures and was itself deformed late in the Laramide orogeny. Because of this overlapping relationship and subsequent deformation, mammalian fossils from the lower Hanna Formation are critical in providing age constraints on local phases of tectonism. The Grayson Ridge and Halfway Hill faunas have important biostratigraphic implications as well. They provide evidence for faunal changes near or across the boundary be-



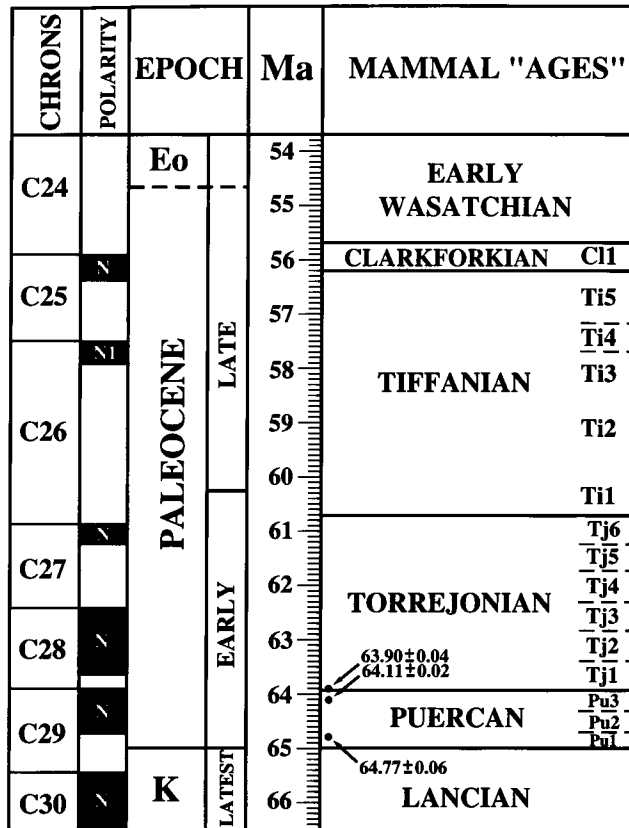
**Figure 1.** Map showing locations of Carbon and Hanna basins, surrounding uplifts, and distribution of Hanna Formation. Modified from Roberts (1989), Lillegraven (1994), and Brooks (1977). Dark areas show Laramide uplifts; arrows and teeth on faults toward hanging wall.



**Key to Figure 2.**



**Figure 2.** Geologic map of Carbon and southeastern Hanna basins, including Simpson Ridge anticline, vertebrate collecting areas, and other locations discussed in text. Simpson Ridge anticline extends from the southern end of T21N to the northern end of T22N. The Ferris-Hanna contact marks the northern outer trace of the anticline. Modified from Hansen (1986) and Dobbin et al. (1929).



**Figure 3.** Geochronologic chart showing correlations between relevant mammal "ages," epochs, and polarity chrons. Torrejonian zonal boundaries are not intended to represent durations or absolute ages of zones. Base chart modified from Woodburne and Swisher (1995) with Torrejonian zones of Williamson (1996).

tween the Torrejonian and Tiffanian NALMAs and raise questions about the synchronicity of presumed Tiffanian first appearances.

## ABBREVIATIONS

### Institutions

AMNH	American Museum of Natural History, New York
KU	University of Kansas, Lawrence
NMMNH	New Mexico Museum of Natural History and Science, Albuquerque
PU	Princeton University, Princeton
TMM	Texas Memorial Museum, University of Texas, Austin
USNM	U.S. National Museum, Smithsonian Institution, Washington

UW Collection of Fossil Vertebrates, Departmental Scientific Collections, Department of Geology and Geophysics, The University of Wyoming, Laramie

YPM-PU Yale Peabody Museum, Yale University, New Haven, and Princeton University, Princeton

### Miscellaneous

NALMA	North American land mammal "age"
IFU	intraformational unconformity
gen. indet.	genus indeterminate
m.y.	million years
m	meters
km	kilometers

### Dental Measurements

L	length
W	width
AW	anterior width of lower teeth
PW	posterior width of lower teeth
L <sub>1</sub>	length to first serration of M <sub>b</sub>
H	height of first serration of M <sub>b</sub>
D	depth below base of H to base of exodaenodont lobe of M <sub>b</sub>
S	number of serrations of M <sub>b</sub>

### Tooth Designations

D	deciduous dentition
I <sup>u</sup> , I <sub>x</sub>	upper, lower incisor
P <sup>u</sup> , P <sub>x</sub>	upper, lower premolar
M <sup>u</sup> , M <sub>x</sub>	upper, lower molar
M <sub>b</sub>	multituberculate lower blade (Sloan, 1987, p. 192)

## STRATIGRAPHY OF HANNA FORMATION

The Hanna Formation consists of sandstone, siltstone, conglomerate, carbonaceous shale, and coal. The formation reaches a maximum thickness in excess of 3,500 m in the northern Hanna Basin (Lillegraven and Snoke, 1996, fig. 13) and 325 m in the Carbon Basin (Brooks, 1977). The Hanna Formation in the Carbon Basin rests with depositional

unconformity upon Lewis Shale, Fox Hills Sandstone, Medicine Bow, and Ferris formations (Fig. 2). See Gill et al. (1970) for discussion of Late Cretaceous and Paleocene stratigraphy of southeastern Wyoming.

The unconformity at the base of the Hanna Formation at Halfway Hill, in the eastern Carbon Basin (Fig. 2), is deeply channeled into carbonaceous shale and white sandstone of the Ferris Formation with a relief of at least 17.5 m. This implies that initial deposition of the Hanna Formation occurred in canyons or valleys and was laterally restricted. Strata underlying the Hanna Formation at Halfway Hill were previously mapped as Medicine Bow Formation. However, strong lithologic similarities between the Ferris Formation at Grayson Ridge (Fig. 2) and the underlying strata at Halfway Hill leave little doubt that previous mapping is in error (see Secord, 1996, for more detail).

The Hanna and underlying Ferris formations were named by Bowen (1918, p. 230 and 231) who defined the formations primarily on the basis of conglomeratic content. Bowen described conglomerates of the Ferris Formation as consisting of chert, white quartz or quartzite, red and gray quartzite, rhyolite, and quartz latite (in order of decreasing abundance). He noted that only the most resistant of clasts were present in the Ferris Formation and believed this to be indicative of a distant source area. In contrast, Bowen (1918) reported that conglomerates of the Hanna Formation contained mostly clasts of local origin, namely shales from the Mowry Formation, conglomerate from the Cloverly Formation, sandstone clasts, granite clasts, and to a lesser extent, chert, and white quartz or quartzite. He also noted that sandstone of the Hanna Formation was highly feldspathic and that the Hanna Formation contained conglomerate throughout, whereas conglomerate occurred only in the lower part of the Ferris Formation.

Serious difficulties in distinguishing between outcrops of the Hanna and Ferris formations using Bowen's definitions were encountered by Eberle and Lillegraven (1998a, b). Eberle and Lillegraven (1998a) reported clasts of Mowry shale, granite, and quartzite (typical of the Hanna Formation) in lower reaches of the Ferris Formation in vicinity of its type area in the western Hanna Basin and elsewhere. Consequently, they were unable to determine any combination of lithologic criteria that could be used reliably in the field to distinguish between outcrops of the Ferris and Hanna formations. Such observations call into question the validity of retaining the formations as separate units. Eberle and

Lillegraven were reluctant to advocate combining the two formations, however, because use of the formational names is deeply entrenched within existing literature and local geologic tradition.

Although the presence or absence of locally derived clasts, such as Mowry shale and Cloverly conglomerate, do not serve to distinguish between outcrops of the Hanna and Ferris formations unequivocally, the relative abundance of such clasts is often useful in correlation. In the northern Carbon Basin and the southeastern Hanna Basin, conglomerate of the Hanna Formation contains moderately abundant clasts of Mowry Shale and granule- to pebble-sized red feldspar, occasional clasts of quartzite, presumably derived from the Cloverly Formation, and gray to silver sandstone clasts. The conglomerate also contains a variety of very resistant pebbles and cobbles similar to those found in the Ferris Formation. In contrast to the Hanna Formation, I found no Cloverly quartzite, red feldspar (or any gravel-sized feldspar), or gray to silver sandstone clasts in the Ferris Formation of the Carbon or southeastern Hanna basins. I found only a single clast that I felt with relative confidence was Mowry Shale in the Ferris Formation.

Distinctions between the Hanna and Ferris formations made by early mapmakers (see Dobbin et al., 1929) in the Carbon and southeastern Hanna basins may have been based upon relative abundances of the conglomeratic components discussed above and upon unconformable relationships. In any event, strata traditionally mapped as Ferris Formation at Grayson Ridge can be traced laterally and is equivalent to the fine-grained strata mapped as the upper part of the Ferris Formation in the southeastern Hanna Basin. For purposes of this paper, I follow boundaries between the Hanna and Ferris formations as traditionally mapped.

Dark, resistant pebbles and cobbles of chert and crystalline rock, such as those seen in the lower Hanna Formation in the northern and eastern Carbon Basin, are atypical of the Hanna Formation. Clasts such as these are particularly abundant at the IFU, discussed below. These pebbles and cobbles were probably reworked from the Ferris Formation during erosion associated with the unconformity at the base of the Hanna Formation and the IFU. Paleocurrent mean vector directions (this study) indicate that rivers depositing the lower Hanna Formation in the northern Carbon Basin and at Halfway Hill flowed in a southeasterly direction and suggest that upturned conglomeratic beds of the Ferris Formation around the northern nose of Simpson Ridge anticline (Fig. 2) were a source for

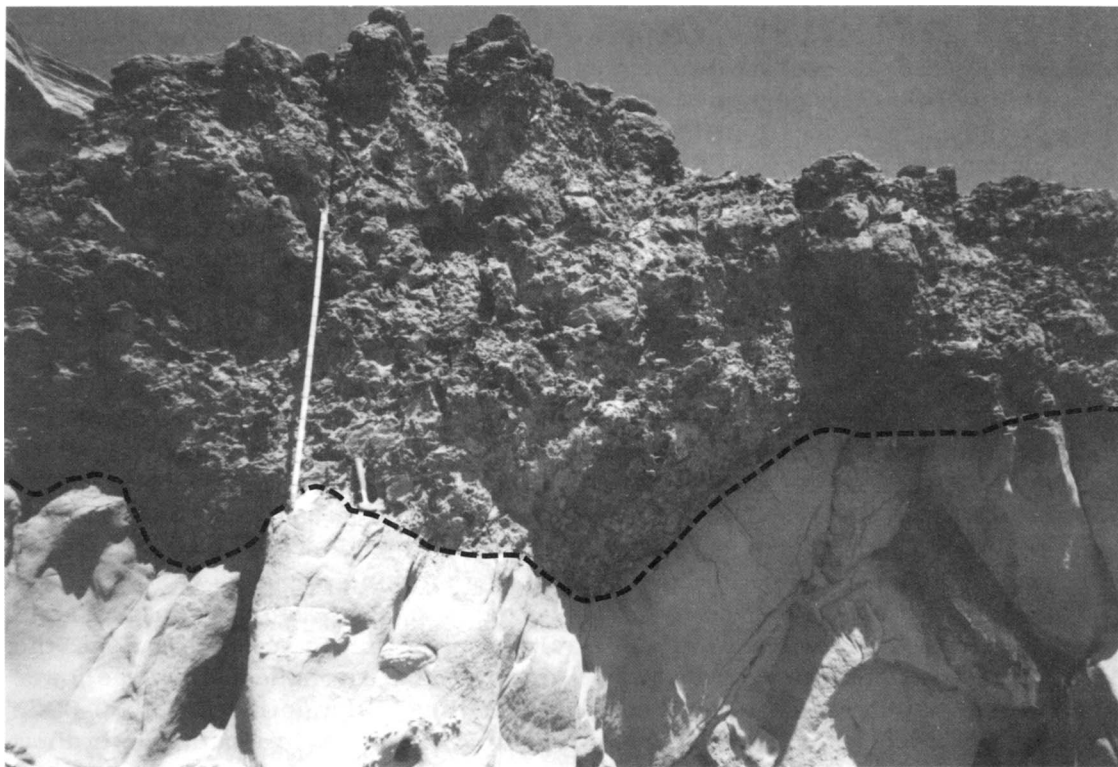
these gravels. Paleocurrent vectors were plotted using "Rockware" software from unidirectional measurements made on trough cross-stratification at Halfway Hill, Grayson Ridge, First Sand Creek, and Carbon Cliffs (see Fig. 2 for locations) with populations of 21, 22, 23, and 20, and mean vectors of 128, 111, 150, and 138, respectively (see Secord, 1996, for more detail).

A thick conglomerate marks the IFU in the lower part of the Hanna Formation in the northern Carbon Basin and at Halfway Hill. The IFU was unrecognized before this study. The conglomerate is as much as 2 m thick and consists typically of rounded quartzite, chert, and crystalline pebbles, and pebble- to cobble-sized rip-up clasts supported by a medium- to coarse-grained sandstone matrix. Rip-up clasts are composed of light green or gray siltstone and fine-grained sandstone, and reach boulder size. Matrix support occasionally grades into clast support, consisting chiefly of dark, resistant, well-rounded pebbles left as channel lag. Channels associated with the unconformity incise the Hanna Formation by as much as 2 m at Halfway Hill (Fig. 4). Dark heterogeneous iron staining (presumably sideritic) is often found in or below the conglomerate. Rust colored iron concretions (pre-

sumably limonitic) are abundant in the conglomerate (and in other beds) and often formed around rip-up clasts.

Matrix supported conglomerate deposited in channel scours also is common in the lower Hanna Formation below the IFU at Halfway Hill and Grayson Ridge (Fig. 2). This conglomerate is often lithologically indistinguishable from conglomerate associated with the IFU, but is, however, laterally restricted. The conglomerate typically is thinner, is rarely clast supported, and contains smaller rip-up clasts. Channel scours are typically not as deeply incised as those associated with the IFU, and bounding surfaces cannot be traced for more than about 75 m.

I correlate the IFU at Halfway Hill with reasonable confidence to thick, darkly stained conglomerate 65 m above the base of the Hanna Formation on the dip slope of Grayson Ridge and to conglomerate at the base of the Hanna Formation at First Sand Creek (Fig. 2). I also correlate the IFU to thick, dark conglomerate along the northern margin of the Carbon Basin. The conglomerate follows the top of an east-west trending ridge in the NE 1/4 of Section 14 and the NW 1/4 of Section 13, in T22N, R80W. Correlations to Grayson Ridge and First Sand Creek



**Figure 4.** Photograph showing channeling of IFU at Halfway Hill. Dashed line follows trace of IFU. Note dark staining at top of channel fill. 1.5 m Jacob staff and hammer for scale.

are supported by fossil ages from above and below the unconformity. At first Sand Creek the conglomerate bed is over 2 m thick and stained black. Here, the lower Hanna Formation below the unconformity was stripped by Paleocene erosion, or was never present. The IFU is obscured by cover for about 0.7 km between Grayson Ridge and First Sand Creek. Conglomerates associated with the IFU at Grayson Ridge are clast and matrix supported and up to 0.4 m thick.

Mineralogic analysis of the iron staining often found in and around the IFU and in other beds was beyond the scope of this project. Such staining, however, is common in Paleocene and Cretaceous non-marine strata in the northern Rocky Mountains. The staining could, in this case, have formed as a result of diagenetic alteration associated with the high permeability of conglomerate. Although useful in recognizing the unconformity, the staining is laterally discontinuous and by itself does not serve as a marker.

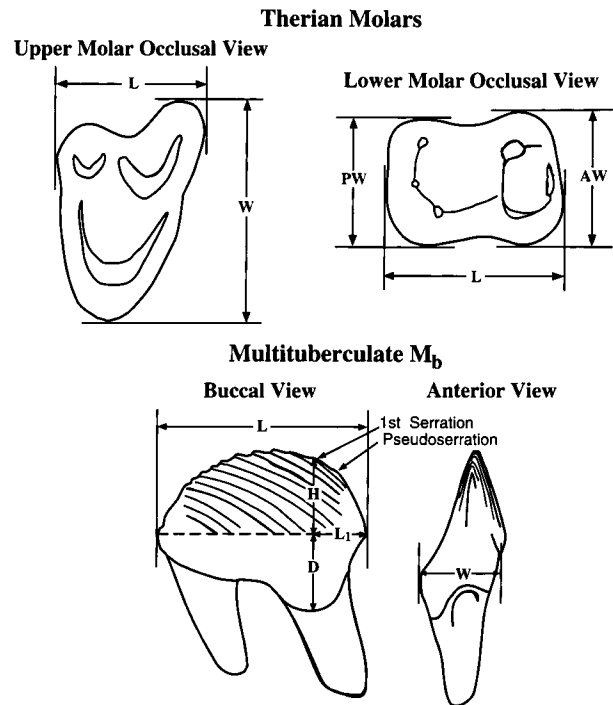
## VERTEBRATE PALEONTOLOGY

### Methods of Study

All specimens discussed in this study are in the UW collections. Dental terminology used for therian mammals is primarily that of Van Valen (1966). For instances in which Van Valen (1966) did not provide a name for a particular structure I used the terminology of Schiebout (1974). Unless otherwise noted, measuring techniques used for therian mammals (Fig. 5) follow those of Schiebout (1974). In several instances it was necessary to employ measurement techniques of other authors for meaningful size comparison with published data. "Primate" measurements follow Gingerich (1976) and phenacodontid measurements follow Thewissen (1990). Multituberculate measurements follow Krause (1987), with the exception of those for *Parectypodus sylviae*, which follow Rigby (1980). Sample sizes of all taxa were too small to yield meaningful statistical results and only elementary measurements, such as length and width are reported. Estimated measurements made on teeth with broken edges are marked with an asterisk. Estimates were not made when a large part of a tooth was missing.

### Fossil Localities

46 new vertebrate localities were documented and mapped in the lower Hanna Formation in the northern and the eastern Carbon Basin. Many lo-



**Figure 5.** Therian molars and a multituberculate  $M_b$  showing points of reference and measurement orientations. Exceptions to these techniques are noted in text.  $M_b$  modified from Krause (1987).

calities, however, mark the occurrence of single teeth. Taxa are represented primarily by isolated teeth and jaw fragments. Several identifications were based upon single specimens and are tentative. Localities can be grouped into four collecting areas: Grayson Ridge, First Sand Creek, and Carbon Cliffs (here named for cliffy exposures 1.5 km west of the old townsite of Carbon) in the northern Carbon Basin, and Halfway Hill, an isolated remnant of the Hanna Formation in the eastern Carbon Basin. The large majority of specimens, however, was collected below the IFU at Halfway Hill and Grayson Ridge.

I recognize and name three new faunas from the Carbon Basin: (1) the Halfway Hill fauna; (2) the Grayson Ridge fauna; and (3) the Sand Creek fauna. The Grayson Ridge and Halfway Hill faunas consist of specimens collected below the IFU at Grayson Ridge and Halfway Hill (Fig. 2) and are approximately equivalent in age. The Sand Creek fauna consists of specimens collected above the IFU from the Hanna Formation at First Sand Creek and at Halfway Hill, and is significantly younger than the others. Specimens comprising the Grayson Ridge and Halfway Hill faunas were collected from a series of superposed localities sampling a 65 m



interval over a lateral distance of 0.9 km. at Grayson Ridge and a 4 m interval over a lateral distance of 0.7 km at Halfway Hill.

The term "fauna," as used here, includes species of slightly different age. Specimens from the base of the Hanna Formation at Grayson Ridge, for example, are older than those collected 46 m higher in the section, at Boulder Quarry. An age difference, however, may or may not be recognizable, as discussed below. Although the Halfway Hill and Grayson Ridge faunas both occur in the base of the Hanna Formation and are approximately equivalent in age, I keep these faunas separate because strata can not be traced laterally between the two collecting areas. Additionally, I found no marker beds useful in stratigraphic correlation between Halfway Hill and Grayson Ridge or between Halfway Hill and First Sand Creek. Because deposition of the Hanna Formation upon the erosional surfaces at the base of the Hanna Formation and at the IFU may not have been synchronous among the various localities, the unconformities do not serve as reliable datums for temporal correlation. The Grayson Ridge and Halfway Hill faunas are "local" faunas in the sense that they occur in stratigraphically and laterally restricted exposures.

The Sand Creek fauna, as defined here, consists of specimens from exposures that can not be traced laterally and is not considered a local fauna. Of the five specimens that comprise this fauna, only two are identifiable to the generic level. Three teeth were recovered from Halfway Hill, two were identified as *Plesiadapis* sp., and a fragment of a lower molar probably belonging to either *Arctocyon* or *Phenacodus*. Two specimens, an upper jaw fragment identified as *Arctocyon mumak* and a fragment of a pantodont premolar, were recovered from First Sand Creek.

About one third of the specimens from Grayson Ridge were collected at the Boulder Quarry ("Boulder Quarry" locality V-94027). The Boulder Quarry is a lenticular, coarse-grained conglomeratic channel fill that yielded primarily large teeth which were often broken. Localities V-94033 ("Accidents Will Happen") and V-94037 ("Kathy's Dilemma") are minor quarries located at the base of the Hanna Formation at Grayson Ridge that also yielded important specimens. Teeth at nearly all Grayson Ridge localities were associated with olive green, gray, or rust colored clay, siltstone, and fine-grained sandstone rip-up clasts. I found no localities with material suitable for underwater screen washing anywhere in the Carbon Basin. In all instances specimens were quarried directly from outcrops, with the exception of UW 26369 (*Phenacodontidae*, gen. indet.), which was

found as float, and UW 26351 (*Plesiolestes* sp.), which was collected from an anthill.

The large majority of specimens comprising the Halfway Hill fauna was collected from the Halfway Hill Quarry ("Under the Maelstrom" locality V-94041). The Halfway Hill Quarry occurs in coarse- to medium-grained sandstone at the edge of a lenticular, conglomeratic channel fill and yielded mostly small, often complete teeth. Most teeth were found interspersed among granule- to pebble-sized mud rip-up clasts in pebbly sandstone distal to a clast-supported pebble conglomerate channel lag. Several teeth also were found at the edge of the conglomerate lens, in the interstitial space between pebbles.

The distribution of mammal teeth at Halfway Hill and Grayson Ridge is primarily the result of hydraulic sorting. Small teeth were found in predominantly sandy deposits with granule- to pebble-sized rip-up clasts, whereas large teeth usually were found in association with larger rip-up clasts in conglomeratic lenses. No articulated remains were recovered, and many specimens show evidence of transport.

### Biostratigraphy

#### *Zonations of the Torrejonian and Tiffanian*

The most recent mammalian biostratigraphic zonation of the early Paleocene in North America was developed by Williamson (1996). Williamson correlated numerous stratigraphically isolated faunas of the San Juan Basin using lithostratigraphic and magnetostratigraphic data from other studies. He recognized six mammalian interval zones in the Torrejonian. I use the symbols Tj1 through Tj6, respectively, to represent those zones from earliest to latest (Figs. 3 and 6). Prior to Williamson's zonation, the zonation of Archibald et al. (1987) was in common use. Archibald et al. divided the Torrejonian into three interval zones based upon successive first occurrences of unrelated taxa. Those zones were the: (1) *Peryptychus* - *Tetraclaenodon* Zone (To1); (2) *Tetraclaenodon* - *Pantolambda* Zone (To2); and (3) *Pantolambda* - *Plesiadapis praecursor* Zone (To3). Discovery of *Pantolambda intermedium* in Williamson's *Protoselene opisthacus* - *Ellipsodon grangeri* Zone (Tj2), however, extended the range of *Pantolambda* back in time. Consequently, Archibald et al.'s *Pantolambda* - *Plesiadapis praecursor* Interval Zone is no longer valid in a strict sense. However, their *Pantolambda* Zone could be redefined using the species *Pantolambda cavirictum* and thereby would cover the same temporal interval. This interval is equivalent to Williamson's two youngest zones of the Torrejonian (Tj5-Tj6). Addi-

tionally, *Tetraclaenodon*, the first occurrence of which defined the beginning of Archibald et al.'s To2 zone, is found throughout the Torrejonian in San Juan Basin (Williamson, 1996).

Archibald et al. (1987) presented the most recent zonation of the Tiffanian, which was a slight modification of an earlier zonation developed by Gingerich (1976). Archibald et al. divided the Tiffanian into five lineage zones and one interval subzone based upon successive first occurrences of species of *Plesiadapis* (Fig. 6). Division of the Tiffanian into plesiadapid lineage zones, however, presents several practical problems. First, many of the species of *Plesiadapis* used in the zonation are defined primarily on mean size differences of large samples (Gingerich, 1976). Consequently, large samples or unusually complete specimens are often required for confident specific identification. Secondly, *Plesiadapis* is known only from northerly faunas and is absent in the type strata of the Tiffanian, located in the northern San Juan Basin of Colorado, and in faunas south of Colorado. Additionally, Fox (1991) suggested that the temporal distribution of *Plesiadapis anceps* (used to define Ti2) in faunas of Alberta may differ from its temporal range in faunas of Montana and Wyoming.

Because the temporal durations of the biostratigraphic zones used in this paper are not well established, terms such as "early" Tiffanian are somewhat arbitrary and not formally defined. For discussion in this manuscript, however, I refer to Tj5-Tj6 as late Torrejonian, Ti1-Ti2, as early Tiffanian, Ti3-4, as middle Tiffanian, and Ti5-6, as late Tiffanian (Fig. 6). Also included in late Torrejonian are the taxa and faunas formerly included in Archibald et al.'s (1987) *Pantolambda - Plesiadapis praecursor* Zone (Tb3).

No section has been adequately described that bears fossils representative of the transition from latest Torrejonian to earliest Tiffanian. The Shotgun fauna (also called Keefer Hill or Twin Buttes) of Wyoming (Keefer, 1961; Gazin, 1971; Archibald et al., 1987; Gunnell, 1989) is intermediate in faunal composition between classic faunas of the Torrejonian and Tiffanian. The fauna has been considered both late Torrejonian and early Tiffanian in age. Based upon the presence of *Plesiadapis praecursor*, however, I follow Archibald et al. (1987) in referring it to the earliest Tiffanian. The relationship of the Shotgun fauna to faunas of latest Torrejonian age is unclear, and much of the fauna has not been studied. Archibald et al. cited Cub Creek and "Eagles Nest" local faunas from the Clark's Fork Basin as being the only clear superpo-

Mammal "Age"		Mammal Zones
<b>Tiffanian</b> lineage zones (Ti1-Ti5) and interval subzone (Ti6) of Archibald <i>et al.</i> (1987)	Ti6	<i>Plesiadapis gingerichi</i>
	Ti5	<i>Plesiadapis simpsoni</i>
	Ti4	<i>Plesiadapis churchilli</i>
	Ti3	<i>Plesiadapis rex</i>
	Ti2	<i>Plesiadapis anceps</i>
	Ti1	<i>Plesiadapis praecursor</i>
<b>Torrejonian</b> biostratigraphic zones of Williamson (1996) in San Juan Basin	?	?
	Tj6	<i>Mixodectes pungens</i>
	Tj5	<i>Pantolambda cavirictum</i>
	Tj4	<i>Arctocyon ferox</i>
	Tj3	<i>Ellipsodon grangeri</i>
	Tj2	<i>Protoselene opisthacus</i>
	Tj1	<i>Peripitychus carinidens</i>

**Figure 6.** Mammalian zonations of the Torrejonian and Tiffanian. Modified from Williamson (1996) and Archibald et al. (1987).

sition of Tiffanian over Torrejonian faunal assemblages, based upon "personal observation" by Dr. Everett Lindsay. However, only two taxa have been reported from Cub Creek local fauna, a rare condylarth and *Pronothodectes* (see Gingerich et al., 1980). Gingerich (1976) stated that the material referred to *Pronothodectes* was too fragmentary for unequivocal identification. A Torrejonian age for the Cub Creek local fauna seems tentative, at best. The overlying "Eagles Nest" local fauna is separated by 44 meters of section and has not been described.

#### Content of Carbon Basin Faunas

Thirteen taxa were identified in the Grayson Ridge fauna (Table 1), seventeen in the Halfway Hill fauna (Table 2), and four in the Sand Creek fauna (Table 3). The Systematic Paleontology section of this document covers reasons for identification of a few key taxa. See Secord (1996) for a more complete systematic treatment. Although the Grayson Ridge and Halfway Hill faunas are approximately the same age, only two species (*Ptilodus mediaevus* and *Paleotomus carbonensis* n. sp.) are definitely shared between them. This is largely the result of a bias in favor of large- and medium-sized teeth at Grayson Ridge and a bias for small teeth at Halfway Hill Quarry. Other taxa, such as *Mimotricentes*, may be shared, but identifications are uncertain.

Figures 7 and 8 show the approximate stratigraphic ranges of taxa at Grayson Ridge and Half-

**TABLE 1. LIST OF VERTEBRATE TAXA IDENTIFIED IN THIS STUDY FROM GRAYSON RIDGE FAUNA.**

Class Mammalia	Phenacodontidae
Order Multituberculata	<i>Tetraclaenodon puercensis</i>
Ptilodontidae	<i>Ectocion</i> sp.
<i>Ptilodus mediaevus</i>	Mioclaenidae
<i>Baiotomeus lamberti</i>	<i>Promioclaenus</i> sp. cf. <i>P. lemuroides</i>
Order "Proteutheria"	<i>Mioclaenus turgidus</i>
Pantolestidae	Hyopsodontidae
<i>Paleotomus</i> n. sp.	<i>Litomylus scaphicus</i>
Palaeoryctidae	Order Mesonychia
<i>Acmeodon secans</i>	Mesonychidae
Order Primates	<i>Dissacus</i> sp. cf. <i>D. navajovius</i>
Paromomyidae	Order Pantodonta
? <i>Paromomys</i> n. sp.	Pantolambdidae
Order Condylarthra	<i>Pantolambda</i> sp. cf. <i>P. cavirictum</i>
Arctocyonidae	Class Reptilia
<i>Arctocyon ferox</i>	Order Chelonia
<i>Mimotricentes subtrigonus</i>	Baenidae
Periptychidae	<i>Plesiobaena</i> n. sp.
<i>Periptychus</i> sp. cf. <i>P. carinidens</i>	

**TABLE 2. LIST OF VERTEBRATE TAXA IDENTIFIED IN THIS STUDY FROM HALFWAY HILL FAUNA.**

Class Mammalia	<i>Plesiolestes</i> sp.
Order Multituberculata	<i>Palaechthon</i> sp. cf. <i>P. alticuspis</i>
Ptilodontidae	Order Condylarthra
<i>Ptilodus mediaevus</i>	Arctocyonidae
<i>Ptilodus</i> sp. C	<i>Arctocyon ferox</i>
<i>Baiotomeus</i> sp. cf. <i>B. lamberti</i>	? <i>Mimotricentes subtrigonus</i>
Neoplagiulacidae	cf. <i>Mimotricentes</i>
<i>Parectypodus sylviae</i>	<i>Thryptacodon</i> sp.
<i>Neoplagiulax nelsoni</i>	Mioclaenidae
cf. <i>Mimetodon</i>	<i>Promioclaenus acolytus</i>
Cimolodontidae	<i>Promioclaenus</i> sp. cf. <i>P. lemuroides</i>
<i>Anconodon</i> sp.	cf. <i>Protoselene</i>
Order "Proteutheria"	Hyopsodontidae
Pantolestidae	<i>Haplaletes disceptatrix</i>
<i>Paleotomus</i> n. sp.	Order Carnivora
Palaeoryctidae	Viverravidae
<i>Gelastops</i> sp. cf. <i>G. joni</i>	<i>Intyriictis vanvaleni</i>
Order Primates	Class Osteichthyes
Plesiadapidae	Order Lepisosteiformes
species and genus indeterminate	Lepisosteidae
Palaechthonidae	? <i>Lepisosteus atrox</i>

**TABLE 3. LIST OF MAMMALIAN TAXA IDENTIFIED IN THIS STUDY FROM SAND CREEK FAUNA**

Class Mammalia
Order Condylarthra
genus and species indeterminate
Arctocyonidae
<i>Arctocyon mumak</i>
Order ?Primates
Plesiadapidae
<i>Plesiadapis</i> sp.
Order Pantodonta
genus and species indeterminate

way Hill, respectively. I include the occurrence of *Arctocyon mumak* at First Sand Creek in Figure 7, based upon correlation of the IFU to Grayson Ridge (see above). At all three collecting areas stratigraphic sections were measured from the base of the Hanna Formation. Deposits of the lower Hanna Formation consist largely of channel fill and sandstone truncated by channel incision, and individual beds can rarely be traced more than 100 m. Care was taken, however, to confirm the approximate superpositional order of the localities shown in Figures 7 and 8. Localities at Grayson Ridge and Halfway Hill are separated by a map distance of 5 to 6.7 km (Fig. 2).

Table 4 summarizes known ranges of species and genera from the Grayson Ridge and Halfway Hill faunas as presently understood from faunas outside of the Carbon Basin. Tj1–Tj6 symbols were used to represent Williamson's (1996) biostratigraphic zones of the Torrejonian in the San Juan Basin. Occurrences of taxa outside the San Juan Basin, however, also were included, involving taxa known and not known from the San Juan Basin. In these instances taxonomic ranges are based upon correlations with other faunas to those of the San Juan Basin. These correlations follow those of Williamson (Table 5) and assume that Tj5–Tj6 are temporally equivalent to the Tb3 zone of Archibald et al. (1987). Williamson did not include the ranges of multituberculates in his zonation. The range of *Ptilodus mediaevus* in the San Juan Basin and elsewhere is from Krause (1982). *Anconodon* was reported from Big Pocket (Tj3) in the San Juan Basin by Sloan (1981).

In compiling Table 4, I made the assumption that if a taxon were known from non-consecutive zones, that taxon also survived through the interme-

diated zones. Hence, the solid bar depicting the temporal range of a taxon does not always indicate that the taxon is actually known from every zone through which the bar passes. The “?” interval between Tj6 and Ti1 indicates the interval inferred by Williamson (1996) between the top of his Tj6 zone and the estimated beginning of the Tiffanian. New species and questionably identified taxa from the Carbon Basin were not included in Table 4. For instances in which the generic name is followed by “sp.,” the chart depicts the range of the genus. In all other instances the chart depicts the range of the species. For instances in which a taxon was referred to in the literature with “cf.,” a question mark appears in the table. A question mark also denotes cases in which the age of a particular fauna is not known with certainty. The range of *Plesiolestes* includes occurrences of *Palaechthon nacimienti*, synonymized with *Plesiolestes* by Gunnell (1989). Questionable occurrences of *Ptilodus mediaevus* in Ti2 and Ti3 are from Krause (1982). Other early Tiffanian and late Torrejonian questionable occurrences in Table 4 are discussed below.

Table 5 gives the ages of key faunas and localities discussed in this text and used to compile Table 4. References to most of these faunas and localities can be found in Archibald et al. (1987). Age of the Who Nose? locality is based upon preliminary identifications by Mr. Craig Scott (see below). Leite (1992) provided a faunal list for the False Lance locality. Robinson and Honey (1987) briefly discussed the USGS D-2003 fauna. Fox (1990) provided updated faunal lists for the Cochrane localities, Gunnell (1989) for Shotgun fauna, and Williamson (1996) for Swain, Gidley, and Rock Bench quarries. San Juan Basin faunas were discussed by Williamson (1996).

Both the Grayson Ridge and Halfway Hill faunas contain a mixture of taxa restricted elsewhere to Torrejonian and to Tiffanian and younger faunas. *Mioclaenus* and *Baiotomeus lamberti* are known elsewhere only from Torrejonian faunas (Table 4), and both were found in the Boulder Quarry at Grayson Ridge (Fig. 7). This is the first report of *Mioclaenus* outside of San Juan Basin. *Ectocion*, in contrast, which has been reported only from Tiffanian faunas, also was found at Boulder Quarry and at a level 21 m below Boulder Quarry. *Litomytus scaphicus*, confidently known outside the Carbon Basin only from the Tiffanian, also was found at Boulder Quarry.

At Halfway Hill, *Intyriactis vanvaleni*, elsewhere known only from the late Torrejonian, was recovered from a level 4 m below the Halfway Hill Quarry

(Fig. 8). Additionally, *Ptilodus mediaevus*, known only from the Torrejonian in the northern Rocky Mountains, and *Haplaletes disceptatrix*, known with confidence only from the Torrejonian, were recovered from Halfway Hill Quarry. *Thryptacodon*, however, which has been reported only from the Tiffanian, and *Ptilodus* sp. C (see Systematic Paleontology, below), known confidently only from the Tiffanian, also were found at the Halfway Hill Quarry.

*Ptilodus mediaevus* occurs both in the Halfway Hill and Grayson Ridge faunas and is a common element in many Torrejonian faunas. It has been reported only from Torrejonian faunas in the northern Rocky Mountains, but has been identified in the early Tiffanian of Big Bend, Texas (Schiebout, 1974; Krause, 1982). *Pantolambda*, found at Grayson Ridge, is known with confidence only from the Torrejonian, but may be present in Shotgun fauna (Til) and other younger faunas (Archibald et al., 1987; Gunnell, 1989). Likewise, *Tetraclaenodon*, found at Grayson Ridge, also is known with confidence only from the Torrejonian, but lower molars identified as *Phenacodus matthewi* from Shotgun fauna (Thewissen, 1990) could represent late occurrences of *Tetraclaenodon* (see Systematic Paleontology, below).

*Acmeodon secans* and *Haplaletes disceptatrix*, found in the base of the Hanna Formation at Grayson Ridge and at Halfway Hill Quarry, respectively (Figs. 7 and 8), also are known with confidence only from the Torrejonian. Hartman (1986), however, found teeth of *H. disceptatrix* and *A. secans* at a level in the southern Bighorn Basin that she considered earliest Tiffanian, based upon three isolated molars identified as

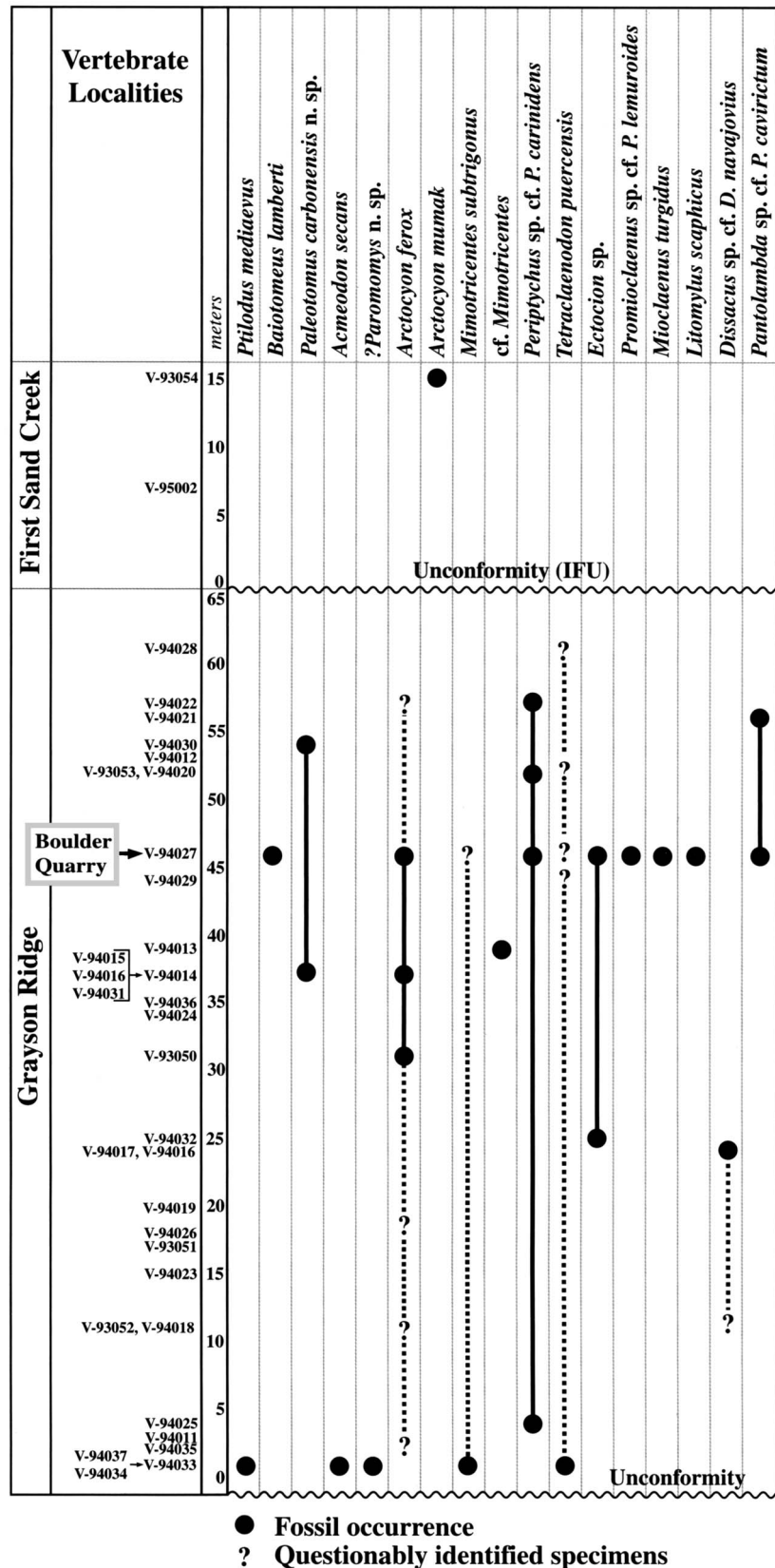
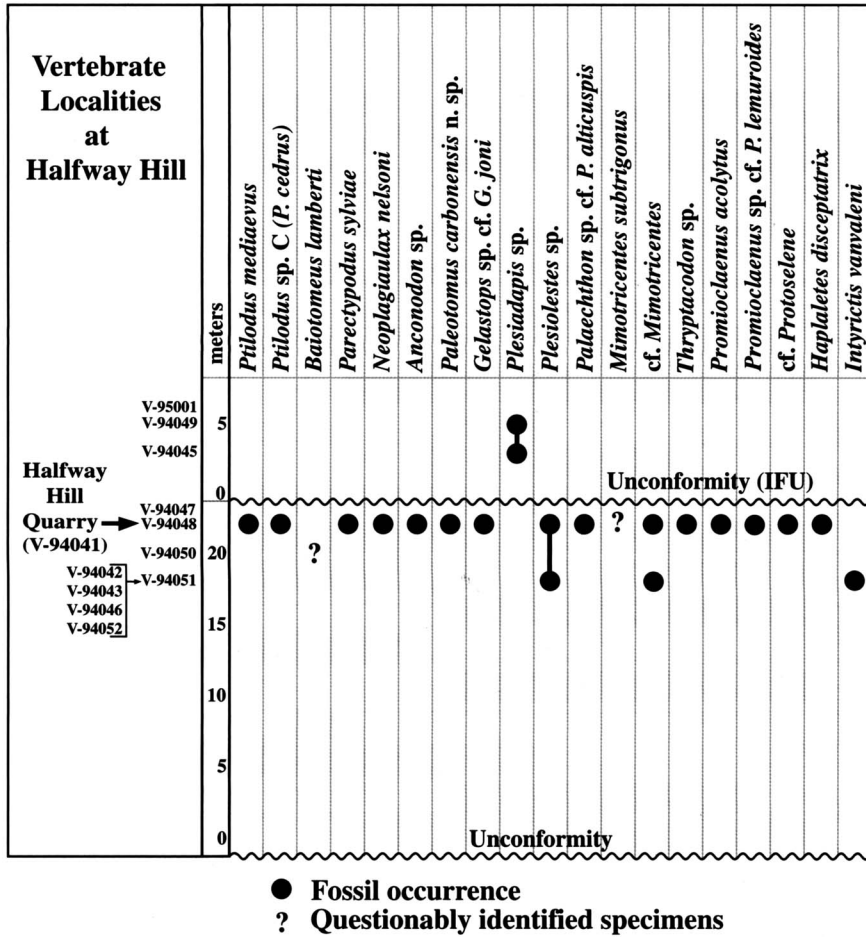


Figure 7. Stratigraphic occurrences and ranges of taxa in the Hanna Formation from Grayson Ridge and First Sand Creek. Datum is base of Hanna Formation.



**Figure 8.** Stratigraphic occurrences and ranges of taxa in the Hanna Formation from Halfway Hill. Datum is base of Hanna Formation.

*Plesiadapis praecursor* collected from anthills. All other faunal indicators suggest a Torrejonian age. Small samplings of isolated teeth are often inadequate to confidently distinguish between Torrejonian and earliest Tiffanian plesiadapids (see Gingerich, 1976), and I consider an early Tiffanian age for this level doubtful. Robinson and Honey (1987) identified *Haplaletes* sp. cf. *H. disceptatrix* in the USGS D-2003 fauna from the northern Powder River Basin. The D-2003 fauna is either earliest Tiffanian or latest Torrejonian (see below).

*Mimotricentes subtrigonus*, found at Grayson Ridge, is known with certainty outside of the Car-

bon Basin only from the Torrejonian (Table 4). However, the range of variation exhibited by this species is extreme (Gazin, 1956; Rigby, 1980), and the Tiffanian species *M. fremontensis* may represent a junior synonym of *M. subtrigonus*. A larger sample of *Mimotricentes* from the Tiffanian is needed to resolve this question. An M<sup>1</sup> (UW 26347) identified as *Dissacus* sp. cf. *D. navajovius* from Grayson Ridge is within the range of variation exhibited by *D. navajovius* (see Secord, 1996), a species known confidently only from the Torrejonian. However, the M<sup>1</sup> is also similar to that of *D. argentius*, known only from Princeton

Quarry, Wyoming, of late Tiffanian age (Ti5) (O'Leary and Rose, 1995). Because of the rarity and fragmentary nature of remains of *Dissacus* in the Tiffanian, little is known of its variation and diversity. Hence, I refrain from more specific identification.

*Periptychus carinidens* is known with certainty only from Torrejonian faunas and identifications of this species outside the San Juan Basin are based upon very fragmentary remains. Specimens from Grayson Ridge and Shotgun fauna identified as *Periptychus* sp. cf. *P. carinidens* could represent a new species (see Systematic Paleontology, below).

*Litomylus scaphicus*, found at Boulder Quarry, was previously known only from the Saddle Locality (Ti2) in Bison Basin (Gazin, 1956). Van Valen (1978), however, synonymized *L. scaphicus* with *L. dissentaneus*, known from the late Torrejonian and early Tiffanian (Ti1), reducing *L. scaphicus* to a junior synonym. Examination of unpublished specimens from Bison Basin, however, suggests that Van Valen's synonymy was premature (see Systematic Paleontology, below).

*Ptilodus* sp. C has been reported in published literature only from faunas of Tiffanian age. However, Mr. Craig Scott, a graduate student at the University of Alberta, Edmonton, identified *Ptilodus* sp. C in the Who Nose? fauna of Alberta (Scott, personal communication, 1997). The locality contains species that may be restricted to the Torrejonian, including *Pronothodectes matthewi* and *Elpidophorus minor*, but also contains taxa that suggest a Tiffanian age, such as *Ignacius* (see Gunnell, 1989) and *Colpoclaenus*. See Scott (1997) for a brief discussion of the fauna.

**TABLE 4. TEMPORAL RANGES OF MAMMALIAN SPECIES AND GENERA FROM THE GRAYSON RIDGE AND HALFWAY HILL FAUNAS, AS KNOWN FROM OTHER FAUNAS (SEE TABLE 5). "TJ" ZONES INCLUDE CORRELATIVE OCCURRENCES OF TAXA IN FAUNAS OUTSIDE OF SAN JUAN BASIN.**

Species and Genera		North American Land Mammal Age												
		Torrejonian							Tiffanian					
		Tj1	Tj2	Tj3	Tj4	Tj5	Tj6	?	Ti1	Ti2	Ti3	Ti4	Ti5	Ti6
Grayson Ridge fauna	<i>Ptilodus mediaevus</i>								T	? <sup>1</sup>	? <sup>1</sup>			
	<i>Baiotomeus lamberti</i> *					?	?	?						
	<i>Acmeodon secans</i>								? <sup>2</sup>					
	<i>Arctocyon ferox</i>													
	<i>Mimotricentes subtrigonus</i>													
	<i>Periptychus</i> sp. (cf. <i>P. carinidens</i> )													
	<i>Tetraclaenodon puercensis</i>								?	? <sup>3</sup>				
	<i>Ectocion</i> sp.													
	<i>Mioclaenus turgidus</i>								?					
	<i>Litomylus scaphicus</i>													
Halfway Hill fauna	<i>Ptilodus mediaevus</i>								T	? <sup>1</sup>	? <sup>1</sup>			
	<i>Ptilodus</i> sp. C								? <sup>4</sup>	?				
	<i>Parectypodus sylviae</i> *								S					
	<i>Neoplagiaulax nelsoni</i> *								S					
	<i>Anconodon</i> sp.													
	<i>Gelastops</i> sp.*(cf. <i>G. joni</i> )													
	<i>Plesiolestes</i> sp.								S					
	<i>Palaechthon</i> sp. (cf. <i>P. alticuspis</i> )								S					
	<i>Thryptacodon</i> sp.													
	<i>Promioclaenus acolytus</i>	? <sup>5</sup>												
<i>Haplaletes disceptatrix</i>														
<i>Intyriactis vanvaleni</i>								?						

■ Known range of taxon

\* = Taxon not known from Torrejonian of San Jaun Basin

T = Known only from Texas in this zone

S = Known only from Shotgun fauna in this zone

?<sup>1</sup> = Questionably known from Texas in this zone

?<sup>2</sup> = Known from Ti1? or latest Torrejonian localities in southern Bighorn Basin (Hartman, 1986)

?<sup>3</sup> = Questionably known from Shotgun fauna in this zone

?<sup>4</sup> = Known from Who Nose? fauna (either latest Torrejonian or Ti1)

?<sup>5</sup> = Questionably known from Dragon local fauna in this zone

?<sup>6</sup> = Questionably known from San Juan Basin in this zone

**TABLE 5. AGES OF KEY LOCALITIES AND FAUNAS DISCUSSED IN TEXT AND USED IN TABLE 4. TENTATIVE "TJ" AGES FROM WILLIAMSON (1996); "V" NUMBERS ARE UW VERTEBRATE LOCALITIES; TORR. = TORREJONIAN.**

<b>Fauna or Locality</b>	<b>Geologic Basin</b>	<b>State or Province</b>	<b>Age</b>
Joe's Bone Bed, Big Bend	"sunken block"	Texas	Ti5
V-77005 & V-77008	W. Washakie	Wyoming	Ti4
Circle Locality	W. Williston	Montana	Ti4
Mason Pocket	San Juan	Colorado	Ti4
Jepsen Quarry	N. Bighorn	Wyoming	Ti3
False Lance (V-76022)	S. Bighorn	Wyoming	Ti3
Cedar Point Quarry	N. Bighorn	Wyoming	Ti3
Love Quarry	N.W. Wind River	Wyoming	Ti3
Saddle Locality (V-53001)	Bison	Wyoming	Ti2
Schiebout-Reeves Quarry	"sunken block"	Texas	Ti1?
Douglass Quarry	Crazy Mountain	Montana	Ti1
Shotgun fauna	Wind River	Wyoming	Ti1
Cochrane 2	Alberta Syncline	Alberta	Ti1
Cochrane 1	Alberta Syncline	Alberta	latest Torr. or Ti1
Cub Creek local fauna	N. Bighorn	Wyoming	latest Torr. or Ti1
Bangtail Locality	Crazy Mountain	Montana	latest Torr. or Ti1
USGS D-2003 fauna	N. Powder River	Montana	latest Torr. or Ti1
V-81054 & V-82015	S. Bighorn	Wyoming	latest Torr. or Ti1
Who Nose?	Alberta Syncline	Alberta	late Torr. or Ti1
Medicine Rocks 1	W. Williston	Montana	late Torr.
Silberling Quarry	Crazy Mountain	Montana	late Torr.
Rock Bench Quarry	N. Bighorn	Wyoming	Tj5?
Gidley Quarry	Crazy Mountain	Montana	Tj5?
Swain Quarry	E. Washakie	Wyoming	Tj5?
San Juan Basin faunas	San Juan	New Mexico	Tj1-Tj6
Dragon local fauna	San Juan	New Mexico	Tj1? and Tj2?



Plesiadapids are rare in the Halfway Hill fauna and no teeth referable to this group were found at Grayson Ridge. A single plesiadapid molar was collected at Halfway Hill Quarry and could belong either to *Pronothodectes* (late Torrejonian – Ti1?) or *Nannodectes* (Ti1–Ti5), but is below the known size range of *Plesiadapis*. The only occurrences of *Plesiadapis* in the Carbon Basin were above the IFU at Halfway Hill and are included in the Sand Creek fauna.

#### Summary of Faunal Ages

There are three possible age interpretations for the Grayson Ridge and Halfway Hill faunas: (1) the faunas are latest Torrejonian; (2) the faunas are earliest Tiffanian; or (3) the faunas are latest Torrejonian and earliest Tiffanian. In the last instance, the Torrejonian-Tiffanian boundary would be present somewhere between the stratigraphically lowest localities and the first occurrences of *Ectocion* and *Thryptacodon* (Fig. 7 and 8). Any combination of these three interpretations, however, could be shared between the two faunas. I favor a latest Torrejonian age for both the Grayson Ridge and Halfway Hill faunas.

*Plesiadapis* has served traditionally as the taxon marking the beginning of the Tiffanian, and Archibald et al. (1987) defined advent of the Tiffanian upon its first appearance (Fig. 6). Although controversial, I believe that boundaries based upon a single taxon, such as this one, are more desirable than boundaries based upon assemblages or characterizations and offer a greater degree of precision (see Woodburne, 1977 and 1987, for detailed discussion). Referral of the Grayson Ridge and Halfway Hill faunas to the early Tiffanian (Ti1) would require two assumptions: (1) that first occurrences of *Ectocion*, *Thryptacodon*, and *Plesiadapis* were synchronous; and (2) that the absence of *Plesiadapis* is due to sampling bias and is not of temporal significance.

Archibald et al. (1987) listed *Ectocion* and *Thryptacodon* as Ti1 first appearances. The presence of these genera in Ti1 is well established, but their first appearances in Ti1 are not. The problem arises from: (1) lack of knowledge of the latest Torrejonian; and (2) questionable assignments of faunas to Ti1 that do not contain *Plesiadapis* and have not been correlated to other fossiliferous stratigraphic sections though independent means. In the latter instance, circular logic is invoked (*i. e.*, “*Ectocion* occurs with *Plesiadapis* in Ti1; therefore, if I have *Ectocion*, I have Ti1”). Such assignments may muddy

distinctions between the latest Torrejonian and Ti1 and could prevent genuine latest Torrejonian first occurrences from being recognized.

Faunas of latest Torrejonian age are not well established, and the first appearance of *Ectocion* and/or *Thryptacodon* could have preceded that of *Plesiadapis*. Williamson (1996) tentatively correlated the faunas of Gidley, Swain, and Rock Bench quarries (Table 5) to his *Pantolambda cavirictum* – *Mixodectes pungens* Zone (Tj5), based mostly upon overlapping ranges. He correlated no faunas, however, to his *M. pungens* Zone (Tj6). Additionally, Williamson placed the Torrejonian-Tiffanian boundary in the San Juan Basin above the top of his *M. pungens* Zone (Tj6), suggesting that this zone does not include latest Torrejonian. Unfortunately, no fossils of early Tiffanian age have been found in the San Juan Basin and the precise position of the boundary is not known. If Williamson's correlations are correct, none of the large Torrejonian faunas of North America is of latest Torrejonian age.

An important question regarding temporal significance of the Grayson Ridge and Halfway Hill faunas is if the absence of *Plesiadapis* is the result of sampling bias. This question can not be answered with satisfaction, but available evidence suggests that the absence of *Plesiadapis* is not the result of sampling bias. Tooth sizes of *Plesiadapis praecursor* (Ti1) fall within the size range of teeth sampled both at Grayson Ridge and Halfway Hill. In fact, the majority of teeth collected from Halfway Hill Quarry are close in size to those of *Plesiadapis praecursor*. Hence, size bias seems improbable. A bias due to unfavorable environmental conditions can not be ruled out, but presence of *Plesiadapis* above the IFU at Halfway Hill indicates that conditions were favorable there, at least in the middle or late Tiffanian (Ti3–5).

Some researchers have used the presence of *Ectocion* and other species in faunas close to the Torrejonian-Tiffanian boundary as indicators of Ti1. Such determinations in the absence of *Plesiadapis* are, in a sense, Tiffanian characterizations. Robinson and Honey (1987) tentatively referred the USGS D-2003 fauna to Ti1 based upon the presence of *Ectocion* and cf. *Nannodectes*, and upon the evolutionary stage of *Aphronorus*. Gingerich (1982) referred the Cochrane 1 fauna to Ti1 based upon *Ectocion collinus*. Gingerich et al. (1983) referred the Bangtail locality in Montana to Ti1 based upon the presence of *Nannodectes intermedius* and *Aphronorus orieli*. If the absence of *Plesiadapis* in these faunas is, however, not the result of sampling bias but rather an indication of time, and *Plesiadapis*

is accepted as the defining taxon, these are latest Torrejonian faunas. Uncertainties such as these highlight the need for further research near the Torrejonian-Tiffanian boundary and illustrate one drawback to using single-taxon definitions to define NALMA boundaries.

Because of the relatively small sample sizes from Grayson Ridge and Halfway Hill the only conclusion I can confidently make is that these faunas are close in age to the Torrejonian-Tiffanian boundary. Although somewhat unsatisfactory from a biostratigraphic standpoint, this does provide a relatively tight age constraint on the lower Hanna Formation in the Carbon Basin.

The Sand Creek fauna includes two age-diagnostic taxa, *Arctocyon mumak* and a medium sized species of *Plesiadapis*, collected at First Sand Creek and Halfway Hill, respectively (Figs. 7 and 8). The large size of the *Plesiadapis* teeth and the prominent mesostyle of UW 26353 preclude identification as either *P. praecursor* (Ti1) or *P. anceps* (Ti2), both characteristic of the early Tiffanian (Fig. 6). The teeth compare favorably, however, with *P. rex*, *P. churchilli*, and *P. fodinatus* (see Systematic Paleontology, below), known from Ti3, Ti4, and Ti5, respectively. Van Valen (1978) reported that *Arctocyon mumak* ranged from the middle to late Tiffanian and possibly into the early Clarkforkian, but he did not cite specific localities. Based upon these two taxa, the Sand Creek fauna is middle or late Tiffanian (Ti3-Ti5) in age. A fragment of a pantodont premolar collected above the IFU at First Sand Creek, not referable to *Pantolambda* (Tj2-Ti1?), also supports a younger age.

## TIMING OF LOCAL TECTONIC EVENTS

The Hanna and Carbon basins are bounded on nearly all sides by Laramide uplifts and are themselves primarily the products of Laramide tectonism. Major deformation with large-scale overthrust faulting did not begin in the Hanna Basin until post-Tiffanian time (Blackstone, 1993). The most profound deformation of the Hanna Formation occurred in post-early Wasatchian time (Lillegraven, 1994).

Data from this study demonstrate that the Carbon and southeastern Hanna basins were affected by at least two local phases of Laramide deformation. The first phase included development of Simpson Ridge anticline. First-phase deformation was followed by erosion and then by depositional onlap of the Hanna Formation. The second phase included formation of a gentle syncline that trends

northwest-southeast across the northern and eastern Carbon Basin and the eastern Hanna Basin, overprinting first-phase deformation (Fig. 2).

Simpson Ridge is a large, asymmetric anticline that plunges in a north-northeasterly direction and separates the Carbon and Hanna basins. Veronda (1951) reported considerable thrusting along the eastern flank of the anticline, evidenced by overturned beds in the Lewis Shale. Blackstone (1993) inferred a westerly dipping reverse fault along the eastern flank of Simpson Ridge, based upon Veronda's evidence.

Several scenarios have been proposed for the timing of formation of Simpson Ridge anticline. Ryan (1977) suggested that Simpson Ridge was tectonically active during deposition of the Ferris and Hanna formations (from Late Cretaceous through the Paleocene). LeFebvre (1988) suggested that Simpson Ridge became prominent during deposition of the Hanna Formation. Hansen (1986) proposed that Simpson Ridge formed in the middle Eocene. Structural relationships between the Hanna and Ferris formations, however, demonstrate that most of Simpson Ridge formed during or after deposition of the local lower Ferris Formation, but before deposition of local Hanna Formation.

The youngest rock unit incorporated into Simpson Ridge anticline is the Ferris Formation. Dips in the Ferris Formation at Hi Allen Ridge on the northwestern side of Simpson Ridge (Fig. 2) vary by an average of about 25 degrees from near the bottom of the section (where the average dip is about 55 degrees) to near the top (where the average dip is about 30 degrees). Changes in dip are relatively gradual on the north end of Hi Allen Ridge, but more abrupt on the south end. These changes probably can be attributed in part to small tectonic pulses associated with the early formation of Simpson Ridge that disrupted deposition of local Ferris Formation. However, some changes in attitude, especially in the upper part of the section, could be the result of thrust faulting, which may or may not have been associated with the formation of Simpson Ridge. A detailed study of the complex structure and stratigraphy in this area was out of the scope of this project.

The Hanna Formation in the western Carbon Basin along the eastern edge of Simpson Ridge anticline dips 15 to 20 degrees basinward and lies in angular unconformity upon Simpson Ridge (Fig. 2). The strike of the Hanna Formation along the western margin of the Carbon Basin follows basinward trends and does not appear to have been influenced by the formation of Simpson Ridge. Clearly,

the Hanna Formation overlapped Simpson Ridge, as evidenced by differences in dip and changes in strike trends between the Hanna Formation and the underlying units that comprise Simpson Ridge. This overlapping relationship coupled with attitudes in the Hanna Formation indicates that most, or all, of the anticline had formed before deposition of the lower Hanna Formation.

The lower Ferris Formation at Simpson Ridge provides a maximum age constraint for the primary formation of the anticline, while the Grayson Ridge and Halfway Hill faunas in the lower Hanna Formation provide a minimum age constraint (earliest Tiffanian). Unfortunately, no age-diagnostic fossils have been found in the Ferris Formation at Simpson Ridge. In western parts of the Hanna Basin, however, the vertebrate biostratigraphy of the lower Ferris Formation has been studied in detail by Eberle and Lillegraven (1998a, b) and Wroblewski (1997). In the western Hanna Basin the lower 625 m of Ferris Formation is Lancian in age. Lancian strata are overlain by a 537 m section that samples most, or all, of the Puercan. Lenses of pebbly sandstone are common in the lower part of the formation, especially so in strata of Lancian age. Because of the extraordinary thickness of the Cretaceous section in the Hanna Basin, the lower boundary of the Lancian is expected to lie well below the base of the Ferris Formation, in the lower part of the underlying Medicine Bow Formation or perhaps even lower (Eberle and Lillegraven, 1998a). Accordingly, the base of the Ferris Formation in the western Hanna Basin would sample the middle or late part of the Lancian.

In the Hanna Basin, the Ferris Formation rests conformably upon the Medicine Bow Formation and is distinguished from it primarily by the presence of pebbly sandstone. No pebbles or other conglomerate have been reported in the Medicine Bow Formation in the Hanna Basin. At Hi Allen Ridge, in the southeastern Hanna Basin (Fig. 2), the lower 500 meters of the Ferris Formation contains abundant, thick (up to a meter), conglomeratic lenses, overlain by about 350 m of sandstone and shale. A few small conglomeratic lenses also occur in the upper 350 m. If the increase in grain size that marks the base of the Ferris Formation (or top of the Medicine Bow Formation) in the western and southeastern Hanna Basin resulted from the same tectonic pulse or change in depositional regime, then the base of the Ferris Formation in the southeastern Hanna Basin would be equivalent in age to its base in the western Hanna Basin. In this event, the lower Ferris Formation in the southeastern Hanna Basin

could be considered Lancian in age. From this line of reasoning, Simpson Ridge probably began forming no earlier than Lancian time, and major deformation began in Lancian time or later (Puercan or Torrejonian).

Erosion followed deposition of the lower Hanna Formation in the northern and eastern Carbon Basin, as indicated by the IFU. The timing of erosion is bracketed by the age of the Halfway Hill Quarry (latest Torrejonian or Ti1), which lies 1 m below the IFU, and by the age of *Plesiadapis* teeth (Ti3–Ti5), collected 3 and 5 m above the IFU at Halfway Hill (Fig. 8). Based upon these ages, erosion occurred no earlier than Ti1 and no later than Ti4. The resulting hiatus is not less than about 1 m.y. (*i. e.*, Ti2 is missing) and not more than about 3.5 m.y. (*i. e.*, Ti1, Ti2, Ti3, and Ti4 are missing; Fig. 3). There is no definite evidence for deformation in the Carbon or Hanna basins at this time.

Folding of Halfway Hill occurred subsequent to deposition of local Hanna Formation above the IFU. The Sand Creek fauna, therefore, provides an earliest age constraint on the timing of that deformation. This episode of deformation resulted in a gentle northwest-southeast trending syncline that overprinted the folding of Simpson Ridge anticline and affected the northern margin of the Carbon Basin (Fig. 2). Based upon the age of the Sand Creek fauna (Ti3–Ti5), this event occurred no earlier than Ti4. Several other large-scale folds are present in the Hanna Formation of the Hanna Basin (see Lillegraven and Snoke, 1996; map by Hansen, 1986; Blackstone, 1993), but detailed ages of these folds are poorly known. Lillegraven (1994), however, was able to constrain the timing of major deformation in the northern Hanna Basin to post-early Wasatchian time, based upon the occurrence of *Hyracotherium grangeri*.

A plethora of tectonic models has sought to explain the diversity of structural trends in the Rocky Mountains resulting from Laramide deformation. Most models argue for either a single phase of protracted deformation (Sales, 1968; Stone, 1969; Kanter et al., 1981; Brown, 1993; Erslev, 1993; Molzer and Erslev, 1995) or multiple phases of deformation (Gries, 1983; Chapin and Cather, 1983). Multiple-phase models evoke changes in the direction of maximum shortening from the Late Cretaceous to the early Eocene. Unfortunately, age constraints on the timing of tectonism associated with most Laramide structures are not adequate to test these models.

Gries (1983) proposed that Laramide compressive force in the Late Cretaceous and early Paleocene

originally was oriented east-west, but rotated counterclockwise resulting in a more north-south orientation by the late Paleocene. Accordingly, structures formed early in the Laramide orogeny should generally trend in a north-south direction, while structures formed late in the orogeny should generally trend in an east-west direction. Alternatively, most authors who have proposed a single phase of deformation have used models with a static northeast-southwest direction of maximum shortening.

Work by Bergh and Snoke (1992) demonstrated that Laramide deformation was episodic, at least on a local scale. Bergh and Snoke (1992) established three relative ages for structures in the Shirley Mountains (just north of the Hanna Basin; see Fig. 1) using overprinting relationships. They concluded that their data were broadly consistent with the multiple-phase deformation model of Gries, but felt that a definite explanation for trends in the Shirley Mountains was premature. Recent work in the Shirley Mountains by Taft (1997) also demonstrated multiple phases of deformation.

The orientations and overprinting relationships of Simpson Ridge anticline and the associated syncline generally agree with the findings of Bergh and Snoke (1992) and Taft (1997). The orientations and ages of the deformation of Simpson Ridge and of the subsequently overprinting syncline are also in general agreement with Gries' model. Bergh and Snoke (1992) found that structural trends present in the Shirley Mountains are not easily explained by a northeast-southwest direction of regional compression, as proposed by single-phase models. Varga (1993), however, cautioned against the interpretation of regional paleostress from structures measured close to the tectonic fronts of Laramide uplifts. The possibility that at least part of the complex structural pattern of the Laramide foreland was derived from the reactivation of Precambrian trends also deserves consideration (Houston, 1971; Brown, 1987). Better age constraints on the timing of formation of Laramide structures throughout the Rocky Mountains are needed before a confident assessment of Laramide tectonic models can be made.

## SUMMARY AND CONCLUSIONS

The Grayson Ridge and Halfway Hill faunas are either latest Torrejonian or earliest Tiffanian in age, or sample both NALMAs. In the last instance, the boundary between these NALMAs would be present in the lower Hanna Formation below the Halfway

Hill and Boulder quarries, but above the base of the Hanna Formation. Occurrences of *Ectocion* and *Thryptacodon*, known elsewhere only from Tiffanian and younger faunas, could be indicative of an earliest Tiffanian age, or be late Torrejonian first appearances of these genera. *Plesiadapis*, whose first occurrence is used traditionally to define the beginning of the Tiffanian, was not found, and most taxa in the Grayson Ridge and Halfway Hill faunas are characteristic of the Torrejonian. This problem cannot be resolved with satisfaction until faunas of latest Torrejonian age are better known. It is clear, however, that the Grayson Ridge and Halfway Hill faunas are close in age to the Torrejonian-Tiffanian boundary.

The lower part of the Ferris Formation is the youngest rock unit incorporated into the Simpson Ridge anticline and provides an earliest age constraint on formation of the anticline. Evidence for syndepositional tectonism in the lower Ferris Formation suggests that deformation leading to the formation of Simpson Ridge began during deposition of the lower Ferris Formation in the southeastern Hanna Basin. Based upon tentative correlation to the type area of the lower Ferris Formation, uplift of Simpson Ridge probably began no earlier than Lancian time and continued into the Puercan and possibly Torrejonian. Major deformation of Simpson Ridge had ended by the late Torrejonian or early Tiffanian, when the Hanna Formation, containing the Grayson Ridge and Halfway Hill faunas, overlapped the anticline.

At Halfway Hill, taxa from the Halfway Hill Quarry (positioned directly below the IFU) and teeth of *Plesiadapis* (collected directly above the IFU) provide age constraints on a period of erosion that followed deposition of the lower Hanna Formation. Erosion occurred sometime after the late Torrejonian, but before the late Tiffanian (Ti5). The resulting hiatus could have ranged from 1 to 3.5 m.y.

A second phase of deformation affected the Carbon Basin after the formation of Simpson Ridge anticline. A gentle syncline trending northwest-southeast across the northern and eastern Carbon Basin and eastern Hanna Basin overprints the folding of Simpson Ridge. The Sand Creek fauna provides an earliest age constraint on the timing of the second-phase deformation. Deformation occurred no earlier than Ti4.

The ages and orientations of Simpson Ridge anticline and the overprinting syncline suggest a change in the direction of maximum shortening from the early Paleocene to the late Paleocene or early Eocene, at least on a local scale.

## SYSTEMATIC PALEONTOLOGY

### Class MAMMALIA

### Subclass ALLOTHERIA

### Order MULTITUBERCULATA

### PTILODONTIDAE Gregory and Simpson, 1926

### *Ptilodus* Cope, 1881a

### *Ptilodus* sp. C

*Referred specimen.*—UW 26412, right  $M_1$ .

*Locality.*—V-94041.

*Known distribution.*—Common in early and particularly middle Tiffanian faunas of Wyoming, Montana, North Dakota, and Alberta; Krause (1982) provided a detailed list of localities. To that list I add: Who Nose? (Tj5?, Tj6?, Ti1?), Alberta; and Halfway Hill Quarry, southeastern Wyoming.

*Description.*—*Ptilodus* sp. C was described in detail by Krause (1982) and by Leite (1992). Length = 4.15; width = 1.78; cusp count = 7.5:5.5.

*Discussion.*—Krause (1982) described a new species of *Ptilodus* and named it *P. cedrus* after Cedar Point Quarry, where it was abundantly represented. Because it was not formally named in publication, it has been referred to commonly as species "C."

UW 26412 is similar to  $M_1$ s of *Prochetodon*, but differs in lacking vertical grooves on the labial faces of its labial cusps (see Krause, 1982). It has more cusps and is larger than  $M_1$ s of *Baiotomeus*. It differs from *Ptilodus mediaevus*, *P. montanus*, and *P. wyomingensis* in a higher cusp count and greater length. It is narrower and has more cusps than  $M_1$ s of *P. titanus*.

$M_1$ s of *Ptilodus* sp. C exhibit a great deal of variation in robustness of cusps, incipient division of cusps, and length/width ratios. UW 26412 is within the variation exhibited in Bighorn Basin specimens from the False Lance locality (V-76022; Ti3), but approaches an extreme in cusp division and gracility. A small possibility exists that it represents a new species.

### **BAIOTOMEUS Krause, 1987**

### ***Baiotomeus lamberti* Krause, 1987**

*Baiotomeus lamberti* Krause, 1987, p. 601.

*Holotype.*—YPM-PU 18221A, left  $P_4$ .

*Type locality and horizon.*—Medicine Rocks site 1 (Tj5?, Tj6?), Fort Union Formation.

*Referred specimens.*—UW 26431, left  $M_b$ ; questionably referred specimen, 26434,  $M_b$  posterior fragment.

*Localities.*—V-94027, V-94050.

*Known distribution.*—Medicine Rocks Site I and III, and Mehling Site (late Torrejonian), southeastern Montana; Grayson Ridge, southeastern Wyoming.

*Description.*—An adequate description of *Baiotomeus lamberti* was given by Krause (1987). UW 26431 is slightly worn and weathered along its apical margin and moderately worn along its posterior margin. UW 26434 has a small lingual shelf developed at the posterior base of the crown. Dimensions of UW 26431: L = 6.15; W = 2.5;  $L_1$  = 1.43; H = 2.25; D = 2.38; S = 12.

*Discussion.*—UW 26431 most closely resembles  $M_b$ s of *Ptilodus* and *Baiotomeus*. It is distinguished from  $M_b$ s of *Prochetodon* by its smaller size. Krause (1987) distinguished the  $M_b$  of *Baiotomeus* from that of *Ptilodus* by its relatively lower height, more angular exodaenodont lobe, and variable presence of incipient (or pseudo-) serrations (*sensu* Johnston and Fox, 1984). However, comparison of length/height ratios shows that although the genotype, *B. douglassi*, is somewhat lower crowned, *B. lamberti* is higher crowned than most species of *Ptilodus*, and close to *P. mediaevus*. Although UW 26431 has a more angular exodaenodont lobe than many *Ptilodus* specimens, some are equally angular. No incipient serrations are present, but could have been lost from wear or weathering. I refer these specimens to *Baiotomeus* because they are closer to *B. lamberti* in size and form than to any species of *Ptilodus*, and not because of generic characters.

Three species of *Ptilodus* have similar sized  $M_b$ s to UW 26431: *P. tsoiensis*, *P. kummae*, and *P. fractus* (see Krause, 1982). *Ptilodus tsoiensis* and *P. kummae* have lower crowned  $M_b$ s with mean length/height ratios of about 3.4 and 2.9 respectively (2.73 for UW 26431). *Ptilodus kummae* and *P. fractus* have a break in slope just anterior to the first serration, which distinguishes them from other species of *Ptilodus*, and from UW 26431, which has a smooth and rounded anterior slope. Additionally, UW 26431 is greater in length and outside the size range reported for *P. fractus* by Krause (1982).

UW 26431 is within all dimensional ranges reported for the  $M_b$  of *Baiotomeus lamberti* by Krause (1987), except width, which is slightly greater in the referred specimen. However, Krause reported width for only 3 of 7 specimens. UW 26341 has a length/height ratio of 2.73, which is within the upper range of the sample reported for *B. lamberti* (mean = 2.58; n = 6). I refer this specimen to *B. lamberti* because of close similarity in size and form and absence of any other close species.

## NEOPLAGIAULACIDAE

**PARECTYPODUS** Matthew and Granger, 1921  
***Parectypodus sylviae*** (Rigby, 1980) Sloan, 1987

*Ectypodus sylviae* Rigby, 1980, p. 40.

*Parectypodus pattersoni* Sloan, 1987, p. 194.

*Holotype*.—AMNH 100939E, M<sub>b</sub>.

*Type locality and horizon*.—Swain Quarry (?Tj5), Fort Union Formation, eastern Washakie Basin, Wyoming.

*Referred specimens*.—UW 26426, right M<sub>b</sub>; questionably referred specimen: right M<sub>b</sub> 26427, anterior fragment.

*Known distribution*.—Shotgun Fauna (Ti1), Swain Quarry, and Halfway Hill Quarry, southeastern Wyoming.

*Description*.—The M<sub>b</sub> of *Parectypodus* (*Ectypodus*) *sylviae* was adequately described by Rigby (1980) and a camera lucida profile was published by Vianey-Liaud (1986). This specimen is relatively well preserved, but has minor damage to the apical margin around the first cusp. Length = 2.55; H<sub>3</sub> = 1.73; width = 1.20; H<sub>1</sub> = 2.63; H<sub>2</sub> = 1.94 (estimated); serrations = 10 or 11. Dental measurements follow the terminology and orientations of Rigby, 1980.

*Discussion*.—Sloan (1987) erected a new species of *Parectypodus*, *P. pattersoni*, from the Shotgun fauna of Wyoming, of earliest Tiffanian age. He distinguished it from specimens of *P. sylviae* from Swain Quarry (Tj5?) by a mean size difference of less than 2 percent. I believe this size difference is not significant and consider *P. pattersoni* a synonym of *P. sylviae*. This extends the range of *P. sylviae* into the early Tiffanian (Ti1).

**Order "PROTEUTHERIA"****PANTOLESTIDAE*****PALEOTOMUS*** Van Valen, 1967***Paleotomus carbonensis*, new species****Figure 9; Table 6**

*Holotype*.—UW 26398, left M<sub>2</sub>.

*Type locality and horizon*.—V-94041, lower Hanna Formation.

*Referred specimens*.—UW 26399, right M<sub>2</sub>; UW 26400, M<sub>2</sub> left protocone.

*Known distribution*.—Grayson Ridge and Halfway Hill Quarry, southeastern Wyoming.

*Localities*.—Holotype from V-94041; UW 26399 from V-94014; UW 26400 from V-94030.

*Etymology*.—In reference to the Carbon Basin, the sole area from which *Paleotomus carbonensis* n. sp. is known.

*Diagnosis*.—M<sub>2</sub>(UW 26398) is higher crowned, has a shorter talonid, and a deeper, less-open tal-

onid notch between the entoconid and trigonid than *Palaeosinopa*. It differs from other species of *Paleotomus* in the following characters: (1) M<sub>2</sub> entoconid and entoconulid are closer to the trigonid, resulting in a deep, distinctive, talonid notch (other species have a more open talonid notch); (2) labial side of the trigonid is more curved in posterior view; (3) hypoconid is more labial; (4) ectoflexus is more concave and the metacrista is wider and wears into a posterolabially projecting fan-shaped shelf (the metacrista of other species is more posteriorly directed); and (5) M<sub>2</sub> has a higher Mll/Br ratio (Table 6).

In addition to characters discussed, M<sub>2</sub> differs from *Paleotomus milleri*, from Swain Quarry (Tj5?), in: (1) larger size; (2) a larger paracone, higher than the metacone (paracone and metacone of *P. milleri* are equal in size and height); and (3) in a more anterior M<sub>2</sub> hypoconulid.

In addition to characters discussed, M<sub>2</sub> differs from *Paleotomus senior*, known from Douglass and Scarritt quarries (Ti1, Ti2), in having: (1) a smaller, less distinct and less connate hypocone (much like *P. milleri*); and (2) a wider, better developed postcingulum and precingulum (resulting in a higher Mll/Br ratio).

*Description*.—The M<sub>2</sub> (UW 26398) is slightly worn. Its crown is high. The protoconid is slightly larger and higher than the metaconid, while the paraconid is the lowest cusp. In occlusal view, the lingual border of the trigonid forms a crescentic arc, continuous with the paraconid, which is lingual to the metaconid. The paraconid is close to the metaconid and only slightly anteriorly projecting. A deep carnassial notch is present on the paralophid and a moderately deep notch exists on the protolophid. In posterior view the inner walls of the protoconid and hypoconid form an angle of about 80 degrees, and the labial border of the protoconid forms a smooth, crescentic arc. The precingulid is well developed and lingually expansive.

The talonid has a weak mesoconid and entoconulid positioned on the anterior slope of the entoconid. A deep talonid basin, open lingually through a distinctive, deep, narrow, lingual notch is present between the entoconulid and metaconid. The entoconid is the highest cusp, followed by hypoconulid and hypoconid. In posterior view, apices of these cusps form a straight line that plunges labially. The hypoconid is the largest cusp, followed by the entoconid. All three cusps are well developed, separate, and distinct. The hypoconulid is medially positioned.

The M<sup>2</sup> (UW 26399) is moderately worn, with the anterior half of the styler shelf missing; its hypocone is damaged. The lingual half of the crown is constricted. The hypocone appears to have been little more than an expansion of the postcingulum. The hypocone and postcingulum are basal and do not extend lingually beyond the base of the protocone. The precingulum is moderately developed. Both the precingulum and postcingulum terminate lingually at the base of the protocone and are not connected by an internal cingulum. The protocone is large, with a high apex and steep anterior and posterior sides. The protocone is inclined anteriorly about 12 degrees, with a shallow lingual slope of about 42 degrees. The lingual base of the crown is quadrate in occlusal outline. The paracone and metacone are proximal and joined for about two-thirds of the distance from the styler shelf to the apices. The paracone is larger than the metacone and connate at the base, while the metacone is anteroposteriorly elongate. Both cusps are inclined labially. The metacrista is expanded and worn into a fan-shaped shelf, with a crescentic border, and projects posterolabially. The remaining portion of the styler shelf is wide, with a deep, concave ectoflexus. Conules are well defined, but project only slightly above the protocone wings, which are confluent with premetaconule, postmetaconule, and preparaconule wings. A weak postparaconule wing is present. The paraconule is higher and more lingual than the metaconule. The trigon basin is asymmetric, with the deepest point just anterior of the metaconule. *Dimensions*: M<sub>2</sub> length = 4.75; anterior width = 3.32; posterior width = 2.87. M<sup>2</sup> width = 6.64; length = 3.53.

*Discussion*.—Molars of *Paleotomus carbonensis* n. sp. are similar to those of *P. milleri* and *P. senior*, known from the late Torrejonian and early Tiffanian, respectively, and to Tiffanian and Clarkforkian species of *Palaeosinopa*. Krause and Gingerich (1983) used three characters to distinguish *Paleotomus senior* (the genotype) from *Palaeosinopa*: (1) a smaller hypocone; (2) greater upper molar lingual constriction; and (3) higher crowned lower molars. The hypocone of UW 26399 is badly damaged. Based upon development of the postcingulum, however, the hypocone was small, basally positioned, and probably not more than an expansion of the postcingulum. This is consistent with *Paleotomus*. In other species of *Paleotomus*, however, the hypocone is positioned more lingually and is manifested as a large bulge extending lingually past the protocone. In this respect, UW 26399 resembles some species of *Palaeosinopa*, such as *P.*

*didelphoides* (see Van Valen, 1967). However, the hypocone of *Palaeosinopa* is positioned higher on the crown than in *Paleotomus*.

Gingerich (1980) used maximum lingual length (Mll) divided by breadth (Br) to quantify the degree of upper molar lingual constriction of *Paleotomus senior* and *Palaeosinopa*. Table 6 gives Mll/Br ratios for three species of *Paleotomus* and two of *Palaeosinopa*. The Mll/Br ratio for UW 26399 is between that of *Paleotomus* and *Palaeosinopa*. When the ratio of maximum lingual constriction (Mlc) divided by breadth is considered, UW 26399 is equal to *Paleotomus radagasti* and *P. senior*, and close to *P. milleri*. *Palaeosinopa* typically is less constricted than *Paleotomus*, and often shows little or no constriction. However, AMNH 56224, identified as *Palaeosinopa veterrima* by Bown and Schankler (1982), is only slightly less constricted than *Paleotomus* (Table 6). Morphological variation in *Palaeosinopa* is high (Delson, 1971), and Delson questioned the distinction among several contemporary species. For this reason, I do not consider such measurements alone to be indicators of generic distinction.

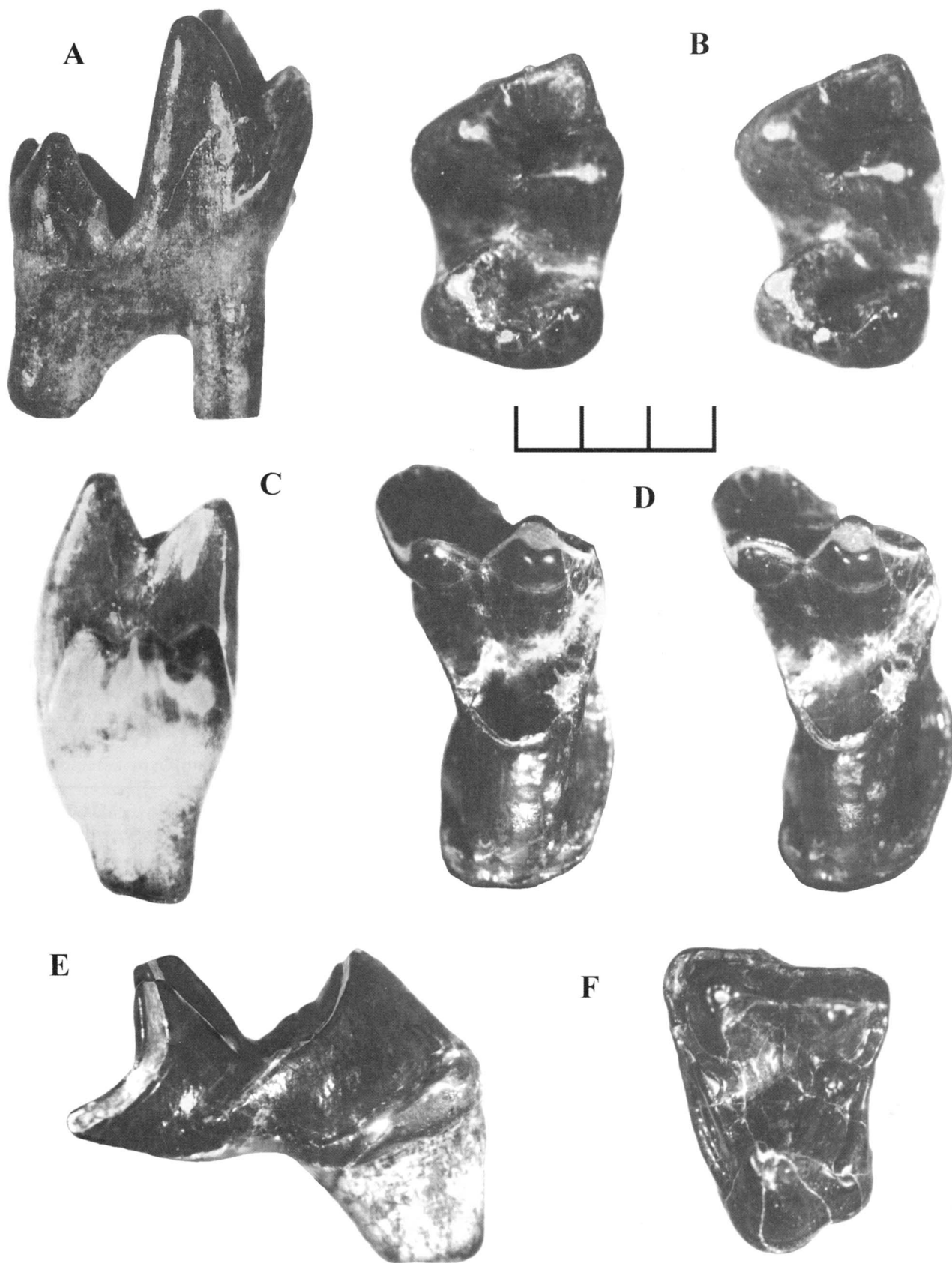
**Order ?PRIMATES**  
**Suborder PLESITARSIFORMES**  
**Infraorder PLESIADAPIFORMES**  
**PLESIADAPIDAE**  
***PLESIADAPIS* Gervais, 1877**  
***Plesiadapis* sp.**

*Referred specimens*.—UW 26353, left M<sup>1</sup>; 26354 left I<sub>1</sub>.

*Localities*.—V-94049, V-94045.

*Description*.—Gingerich (1976) adequately described *Plesiadapis*, but a brief description of UW 26353 is in order. UW 26353 is somewhat corroded, and suffered damage to the parastyle and precingulum. The M<sup>1</sup> is robust with high cones and conules, and a strong mesostyle. The paracone is lingual to the metacone, and the paraconule lingual to the metaconule. This specimen possibly could be an M<sup>2</sup>, but the position of the outer cones makes that unlikely. The paracone and metacone are large. M<sup>1</sup> length = 3.15'; width = 4.61; I<sub>1</sub> width = 2.25.

*Discussion*.—Gingerich (1975) recognized three general trends in the succession of species of *Plesiadapis* through the Tiffanian. These are (with regard to upper molars): (1) an increase in size; (2) a wrinkling of enamel on the occlusal surface; and (3) the development of a mesostyle. The first two characters are of limited value in distinguishing between successive species because size range and



**Figure 9.** *A-E*, *Paleotomus carbonensis* n. sp. *A-C*, holotype, UW 26398, left  $M_2$ ; *A*, lingual view; *B*, occlusal stereo view; *C*, posterior view; *D-E*, UW 26399, right  $M_2$ ; *D*, occlusal stereo view; and *E*, posterior view. *F*, *Litomytus scaphicus*, UW 26376, left  $M_2$ , occlusal view. Scale bar in millimeters.



degree of wrinkling overlap. Hence, specific identification of isolated teeth is exceedingly difficult. However, early Tiffanian species can be distinguished from middle and late Tiffanian species.

Both *Plesiadapis praecursor* and *P. anceps*, of the early Tiffanian (Ti1 and Ti2, respectively; Fig. 6), lack a mesostyle and are smaller than later species of *Plesiadapis* (see Gingerich, 1976). The referred M<sup>1</sup> has a strong mesostyle and is within the variation of *P. rex* (Ti3), *P. churchilli* (Ti4), and *P. fodinatus* (Ti5). The I<sub>1</sub> could belong to any of the middle or late Tiffanian species of *Plesiadapis*, but is outside the known size range of the early Tiffanian species.

Lack of an M<sup>1</sup> mesostyle in *Plesiadapis praecursor* was based upon a single specimen when reported by Gingerich (1976). However, mesostyles also are absent on numerous upper molars from Shotgun fauna in the UW collections referable to *P. praecursor*.

#### genus indeterminate

*Referred specimen.*—UW 26355, left M<sub>2</sub>.

*Locality.*—V-94041.

*Description.*—This lower molar suffered predepositional damage, resulting in the loss of the top lingual two thirds of the trigonid, and the talonid cusps. It matches descriptions of both

*Pronothodectes* and *Nannodectes* (see Gidley, 1923; Gingerich, 1976). Length = 2.45 (estimated); width = 2.28. Measuring techniques are those of Gingerich, 1976.

*Discussion.*—Although this specimen is damaged, its morphology is clearly characteristic of the plesiadapids. It closely resembles both *Pronothodectes*, known from the late Torrejonian and questionably early Tiffanian (Ti1), and *Nannodectes*, known only from the Tiffanian. *Pronothodectes* is distinguished from *Nannodectes* by retention of I<sub>2</sub> and I<sup>2</sup>, and by smaller mean size (Gingerich, 1976). The M<sub>2</sub> referred here is within the size ranges reported by Gingerich (1976) for both *P. jepi* and *N. intermedius*, and probably belongs to one of these species. It is, however, below the size range for *Plesiadapis* reported by Gingerich. The known M<sub>2</sub> range for *P. praecursor* is, however, based upon only three teeth.

#### PALAECHTHONIDAE Gunnell, 1989

##### PALAECHTHON Gidley, 1923

##### *Palaechthon* sp. cf. *P. alticuspis* Gidley, 1923

*Palaechthon alticuspis* Gidley, 1923, p. 6.

*Referred specimen.*—UW 26349, M<sup>1</sup>.

*Locality.*—V-94041.

**TABLE 6. COMPARISON OF M<sup>2</sup> LINGUAL CONSTRICTION IN *Paleotomus* AND *Palaeosinopa*. SEE GINGERICH, 1980, FOR MEASUREMENT TECHNIQUES.**

	Mll	Mlc	Br	Mll/Br	Mlc/Br
<i>Paleotomus carbonensis</i> UW 26399	2.73	2.22	6.05	0.45	0.37
<i>Paleotomus senior</i> AMNH 33828	3.00	2.90	7.85	0.38	0.37
<i>Paleotomus milleri</i> AMNH 100454a	2.30*	2.00*	5.5*	0.42*	0.36*
<i>Paleotomus radagasti</i> UM 64530	3.87*	3.52*	9.51*	0.41*	0.37*
<i>Palaeosinopa veterrima</i> AMNH 56224	4.2*	3.25*	8.5*	0.49*	0.38*
<i>Palaeosinopa didelphoides</i> AMNH 16943 & CM 22031	3.7*	3.3-3.4*	7.4-6.9*	0.50-0.53*	0.45-0.49*
<i>Palaeosinopa veterrima</i> (data from Gingerich, 1980)	3.9-4.0	?	8.0-8.5	?	0.47-0.50

\*Estimated from photos or diagrams. Mll-maximum lingual length; Mlc-maximum lingual constriction; Br-breadth

*Description.*—The paracone and metacone are joined by a centrocrista, the former being the larger. The stylar shelf is moderate, and lacks a mesostyle. A metacrasta is continuous to the posterolabial border of the crown. A weak paracrasta connects the paracone to a moderate parastyle. The paraconule is broken away, but was connected to the paracone by a transverse postparaconule wing. The metaconule is connected to the metacone by a transverse premetaconule wing. The protocone is small, and only slightly higher than outer cones. Two transverse furrows are present on the labial protocone slope. The precingulum and postcingulum are narrow. The postcingulum terminates on the posterolingual border of the protocone, about midway between the protocone base and apex, without ascending the protocone. The lingual slope of the protocone is about 75 degrees. Length = 2.22; width = 3.14.

*Discussion.*—The referred M<sup>1</sup> closely resembles upper molars of *Palaechthon*. When compared to the plesio-type and paratype of *P. alticuspis* (USNM 9551 and 9550 casts) this specimen is quite similar. The primary difference is a weak postcingulum that terminates well below the protocone apex. Such a termination is atypical for *Palaechthon*. It differs also in slightly greater length and in more centrally positioned and more transverse postparaconule and premetaconule wings.

The referred M<sup>1</sup> is slightly below the size range of *Plesiolestes problematicus* reported by Rigby (1980). It is easily distinguished from upper molars of *Plesiolestes* from Swain Quarry by a lesser degree of transverse widening. Upper molars of *Paromomys* are easily distinguished from those of *Palaechthon* and *Plesiolestes* by the former's more expanded inner bases and tendency toward division of lingual walls (Gidley, 1923).

Gunnell (1989) defined a new monotypic genus, *Premnoides*, that is similar to *Palaechthon*. *Premnoides*, however, is known only from lower dentition and only from Rock Bench Quarry. The referred M<sup>1</sup> is close to the size that would be expected for the upper molars of *Premnoides*, but given its close similarities to *P. alticuspis*, I tentatively refer it to that species.

The referred M<sup>1</sup> could be an aberrant form of *Palaechthon alticuspis*, or possibly an M<sup>1</sup> of ?*Paromomys* n. sp., described below. Because the referred M<sup>1</sup> is much closer to *Palaechthon* than to known species of *Paromomys*, I refer it to *Palaechthon*. *Palaechthon*, as defined by Gunnell (1989), includes *P. alticuspis* and *P. woodi*. The referred specimen is well outside the known size range of *P. woodi*.

## PAROMOMYIDAE (Simpson, 1940)

### ?*Paromomys* new species, unnamed

Figure 10

*Referred specimen.*—UW 26355, right M<sub>2</sub>.

*Known distribution.*—Grayson Ridge, southeastern Wyoming.

*Locality.*—V-94037.

*Description.*—The crown is quadrate in occlusal outline. The trigonid is higher and more vertical than *Paromomys maturus*, but lower than *Palaechthon alticuspis* with approximately the same degree of forward inclination. The postvallid is more transverse than most specimens of either *Paromomys* or *Palaechthon* and is parallel to the prevallid in occlusal view. The trigonid is more anteroposteriorly compressed than that of *Palaechthon alticuspis*, but slightly less than that of *Paromomys depressidens*. The paraconid is connate, poorly defined, closely appressed against the metaconid, and positioned near the metaconid apex, as in *Paromomys*. The paraconid is unlike the lower, more anterior and more prominent paraconid of *P. alticuspis*. The trigonid basin is divided transversely by a weak centrocristid, bounded anteriorly by a strong paralophid, and posteriorly by a weak protolophid. In posterior view, the trigonid notch (between the metaconid and protoconid) is deeper than that of *P. maturus*, but not as deep as *Palaechthon*. The talonid is only slightly wider than the trigonid, unlike *Paromomys*, but like some specimens of *Palaechthon*. The talonid basin is shallow, and encircled by low cusps, as in *Paromomys depressidens*, but unlike *Paromomys maturus* or *Palaechthon*. The hypoconulid is merely a ridge connecting the entoconid and hypoconid. The mesoconid is large and the highest talonid cusp, followed by the hypoconid and the entoconid. A weak cingulum begins on the anterolabial border of the trigonid and continues labially, where it is interrupted at the posterolabial base of the hypoconid. The cingulum then continues to the hypoconulid, much like *Palaechthon*. Length = 2.02; anterior width = 1.67; posterior width = 1.70.

*Discussion.*—This M<sub>2</sub> is similar to M<sub>2</sub>s of *Palaechthon*, *Plesiolestes*, *Paromomys*, *Premnoides*, and *Ignacius (Phenacolemur)*. Simpson, 1955, synonymized *Ignacius* with *Phenacolemur*, but Bown and Rose (1976) and Gunnell (1989), argued to keep the genera separate. Lower M<sub>2</sub>s of *Paromomys depressidens* differ from those of *Ignacius* only in that *Ignacius* lacks a labial cingulum (Bown and Rose, 1976). Hence, other characters discussed for *P. depressidens* also apply to *Ignacius*. In overall character the referred M<sub>2</sub> is closest to *Paromomys*.

The referred specimen is within the size range of *Paromomys depressidens* (see Rigby, 1980; Simpson, 1937), known from the late Torrejonian and possibly Shotgun fauna (T11), *Palaechthon alticuspis* (see Gunnell, 1989), known from Gidley Quarry (Tj5?) and possibly Shotgun fauna, and early species of *Ignacius* (see Simpson, 1955; Gazin, 1971; Schiebout, 1974), known from the late Torrejonian and Tiffanian. It is, however, much smaller than *Paromomys maturus*, known from Swain (Tj5?) and Gidley quarries. The height of the trigonid and depth of the trigonid notch are intermediate between those of *P. maturus* and *Palaechthon*. The trigonid notch is filled in *P. depressidens*. The degree of anteroposterior compression of the trigonid is less than, but closest to, that of *Paromomys*.

The referred  $M_2$  differs from that of *Paromomys depressidens* in having: (1) a better developed mesoconid; (2) a trigonid notch; (3) a more quadrate outline in occlusal view; and (4) a less anteriorly inclined, higher, and slightly less anteroposterior compressed trigonid. It differs from the  $M_2$  of *Palaechthon* in having: (1) a prominent mesoconid; (2) a less acute hypocone, hypoconulid, and entoconid; (3) a shallower talonid basin; (4) a smaller, higher, less defined paraconid that is almost connate with the protocone; and (5) a lower, more anteroposteriorly compressed trigonid, with a shallower trigonid notch.

Direct comparison with specimens of *Premnoides* Gunnell, 1989, known only from Rock Bench Quarry (Tj5?), was not possible. However, based upon the figure and description provided by Gunnell, the paraconid of *Premnoides* is more prominent

and lower than UW 26355. The paraconid of *Premnoides* is not connate with the metaconid. UW 26355 differs further from *Premnoides* in having: (1) a shorter entocristid; (2) a weaker (almost non-existent) hypoconulid; and (3) a more anteroposteriorly compressed trigonid (comparison courtesy of Dr. Gregory Gunnell, written communication, 1996). In other respects *Premnoides* is similar to *Palaechthon*.

?*Paromomys* n. sp. appears to be near the ancestry of *Paromomys depressidens*. It is more progressive than *Palaechthon*, but not as derived as *P. depressidens*. UW 26349 ( $M^1$ ), identified as *Palaechthon* sp. cf. *P. alticuspis* (see above), could possibly be an upper molar of ?*Paromomys* n. sp. I hesitate to formally name a new species based upon a single tooth, but recognize this specimen as such. Distinctions between ?*Paromomys* n.

sp. and similar forms may be of generic magnitude.

#### Order CONDYLARTHRA

#### ARCTOCYONIDAE

#### ARCTOCYON Blainville, 1841

#### *Arctocyon mumak*

(Van Valen, 1978)

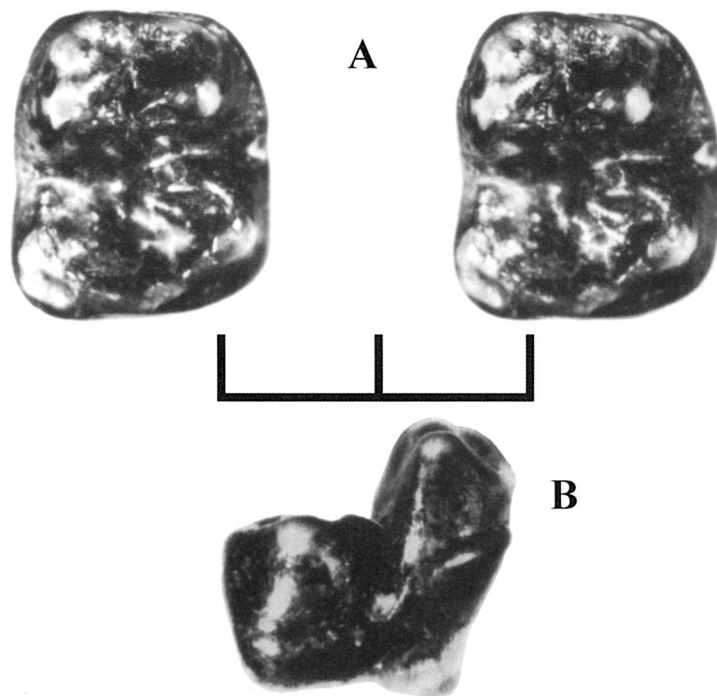
*Arctocyonides mumak* Van Valen, 1978, p. 55.

*Holotype*.—PU 17406, left mandible with  $P_4$ - $M_3$ .

*Type locality and horizon*.—"East border of Section 10, T56N, R99W, north of Powell, Wyoming," Van Valen (1978).

*Referred specimen*.—UW 26343, left maxillary fragment,  $P^4$  roots,  $M^1$ - $M^2$ .

*Known distribution*.—Washakie Basin (UW locality V-77008) (Ti4), Wyoming; Joe's Bone Bed (Ti5), Big Bend, Texas; First Sand Creek, southeastern Wyoming; and additional middle and late Tiffanian localities mentioned by Van Valen (1978), but not specified.



**Figure 10.** ?*Paromomys* n. sp., unnamed, UW 26355, right  $M_2$ . **A**, occlusal stereo view; and **B**, labial view. Scale bar in millimeters.

*Locality.*—V-93054.

*Description.*—The occlusal surface of M<sup>1</sup> is badly damaged, and only the labial border of M<sup>2</sup> remains. M<sup>1</sup> and M<sup>2</sup> have massive inner roots. M<sup>1</sup> is low crowned with equal sized protocone and paracone. The labial borders of the M<sup>1</sup> paracone and metacone are wrinkled, as is the stylar shelf. The outer cingulum is strong. M<sup>1</sup> is nearly square in occlusal view, with rounded corners. M<sup>1</sup> is more inflated than in *Arctocyon ferox*. M<sup>1</sup> length = 14.4, width = 16.6; M<sup>2</sup> length = 15.

*Discussion.*—Van Valen (1978) described *Arctocyon (Arctocyonides) mumak* as the largest known arctocyonid. He distinguished *A. mumak* from *A. ferox* on the basis of: (1) more squared upper molars; (2) lower cusps; and (3) a more proximal paracone and metacone, with respect to one another. Although UW 26343 is badly damaged, enough remains to show that these characters compare favorably with Van Valen's description, with the possible exception of cusp height (which appears to have been about the same as *Arctocyon ferox*).

Only a few isolated upper molars of *Arctocyon mumak* are known, and to my knowledge a detailed description has not been published. Direct comparison with a cast of the type specimen (a left mandible) revealed a similar degree of molar inflation and a similar style of enamel wrinkling around the borders. This specimen is above the size range reported for *A. ferox*, the next smallest species, known from Tj4–Tj6 and Ti1–Ti4?

An M<sup>2</sup> labial fragment (UW 13216) from UW locality V-77008 (Ti4), Rock Springs uplift, Wyoming, identified as *Arctocyonides* sp. probably *mumak* by Winterfeld (1982), is nearly identical to the specimen from the Carbon Basin. An M<sup>2</sup> (TMM 41366-81) identified as *Arctocyon* sp. cf. *A. ferox* by Schiebout (1974) from Joe's Bone Bed (Ti5), Big Bend, Texas, approaches the referred specimen in size, and differs primarily in the lack of wrinkling around the cusps.

**THRYPACODON Matthew and Granger, 1915**  
***Thryptacodon* sp.**

*Referred specimen.*—UW 26344, right M<sub>1</sub> trigonid.

*Known distribution.*—Common in Tiffanian and younger faunas throughout the Rocky Mountain region.

*Locality.*—V-94041.

*Description.*—The M<sub>1</sub> trigonid is steeply inclined lingually. The paraconid is steeply inclined anteriorly. A long, smooth paralophid ends high on the

protoconid. In lingual view the angle between the anterior slope of the protoconid and the upper surface of the paraconid is about 85 degrees. The protoconid is higher than the metaconid, and the paraconid is well below the base of the protolophid. The cristid obliqua contacted the trigonid medially. Trigonid width = 3.57.

*Discussion.*—This trigonid is nearly identical to the M<sub>1</sub> trigonid of the type specimen of *Thryptacodon "belli"* Gazin, 1956 (UW 1045), from the Saddle locality (Ti2), Bison Basin, Wyoming (synonymized with *T. demari* by Van Valen, 1978). It differs only in a slightly less anteriorly inclined, and slightly less acute paraconid. It is also similar to two damaged specimens in the UW collections from Swain Quarry (Tj5?), identified as *Prothryptacodon* sp. cf. *P. furens*, but differs in having a lower and less acute paraconid and a deeper trigonid basin (see Simpson, 1935b).

**PERIPTYCHIDAE Cope, 1882a**

***PERIPTYCHUS* Cope, 1881b**

***Periptychus* sp. cf. *P. carinidens* Cope, 1881b**

**Table 7**

*Periptychus carinidens* Cope, 1881b, p. 337.

*Referred specimens.*—UW 26382, right mandible, P<sub>2</sub>-M<sub>1</sub>; UW 26381, right P<sub>4</sub>; UW 26490, left P<sub>3</sub>; UW 26380, left P<sup>1</sup>.

*Localities.*—V-93053, V-94027, V-94022, V-80009.

*Description.*—A detailed description of *Periptychus carinidens* was given by Matthew (1937).

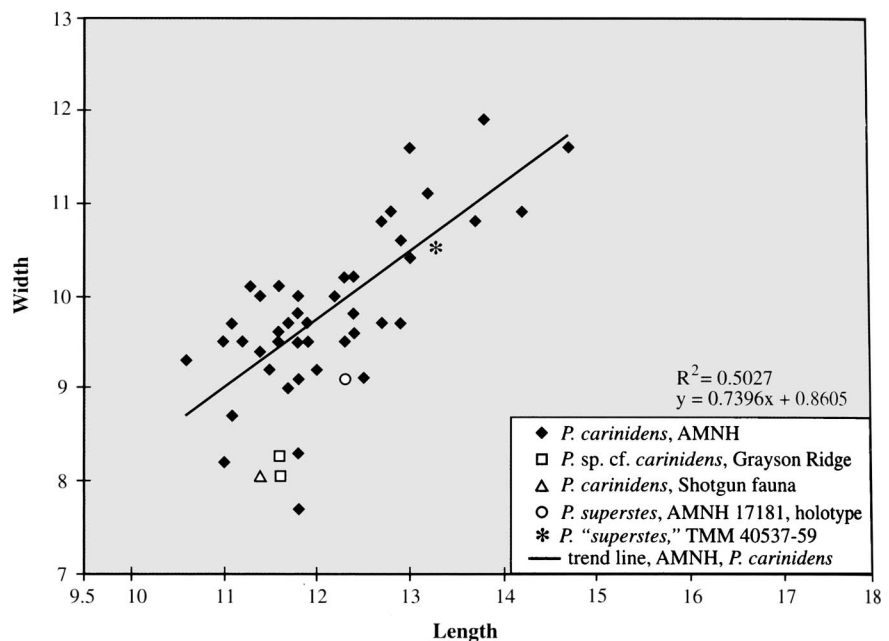
*Discussion.*—*Periptychus* specimens from the Carbon Basin compare favorably with *P. carinidens* in nearly every respect. An exception includes extreme narrowness, relative to length, of lower premolars. The ratio of length divided by width is greater in premolars from the Carbon Basin than in over 30 premolars of *P. carinidens* from the San Juan Basin in the NMMNH collections. However, when compared with premolar measurements of *P. carinidens* in the AMNH collections (also from San Juan Basin; data courtesy of Dr. Thomas E. Williamson), three specimens yielded a similar ratio.

Figure 11 is a scatter plot of P<sub>4</sub> length vs. width of *Periptychus* sp. cf. *P. carinidens* from Grayson Ridge and Shotgun faunas (UW collections; uncataloged; V-60014), *Periptychus carinidens* from the AMNH collections, the holotype of *P. superstes*, and a specimen from Texas identified as *P. superstes* by Schiebout (1974). Specimens from the AMNH collections were collected in the San Juan Basin, New Mexico, and are from several localities, many of which lack detailed stratigraphic and geographic

data. Specimens from Grayson Ridge and Shotgun fauna form a tight cluster that deviates from the main trend (Fig. 11). Three specimens from the San Juan Basin, however, also plot close to the cluster. The Grayson Ridge specimens may represent a new species whose variation partly overlaps that of *P. carinidens*. However, because these specimens do seem to be within the outer variation exhibited by *P. carinidens* from the San Juan Basin, and because of the small sample size from Grayson Ridge coupled with my lack of primary data for *P. carinidens*, I refrain from naming a new species.

Simpson (1935a) gave specific rank to *Periptychus rhabdodon superstes*, from Mason Pocket (T14), stating that it was as distinct from *P. carinidens* or *P. rhabdodon* as they were from one another. He described the overall dimensions of its dentition as being intermediate between *P. carinidens* and *P. rhabdodon*. Simpson (1959) later synonymized *P. carinidens* with *P. rhabdodon*, recognizing that *P. carinidens* had been named on deciduous dentition.

Simpson (1935a, p. 26) stated that *Periptychus superstes* was "...at once distinguishable [from *P. carinidens*] by the last premolar's being considerably smaller relative to the molar series...". In an attempt to quantify the relative areas of  $P_4$  and  $M_1$ , I plotted the natural log of  $P_4$  length x width vs.  $M_1$  length x width (Fig. 12). Included are the type of *P. superstes*, *P. superstes* from Texas, UW 26382 from Grayson Ridge, and 26 specimens of *P. carinidens* in the AMNH collections. The type of *P. superstes* plots well within the normal range of *P. carinidens*. Williamson (1996) suggested that the specimen from Texas (TMM 40537-59) might rep-



**Figure 11.** Scatter-plot of  $P_4$  length and width of *Periptychus*; values are in millimeters; trend line determined by least squares method with a 95% confidence interval.

resent a new species because of its large size. I agree with Williamson. The dentition of *Periptychus carinidens* is highly variable and although it was not possible to compare the size of the entire molar series relative to  $P_4$  size in a large sample, *P. superstes* appears to be within the range of variation of *P. carinidens*. Because of the very limited number of specimens known of *P. superstes*, however, I am hesitant to formally synonymize these species.

**PHENACODONTIDAE**  
**TETRACLAENODON** Scott,  
1893  
***Tetraclaenodon puercensis***  
(Cope, 1881c)

Table 8

*Phenacodus puercensis* Cope, 1881c, p. 492.

**Holotype.**—AMNH 3832, left dentary with  $M_{2,3}$ , right dentary with  $P_4$  fragment and  $M_{1,3}$ ; left maxilla with  $M^{1-3}$ .

**Type locality and horizon.**—Unknown locality in the San

Juan Basin, New Mexico, probably Nacimiento Formation.

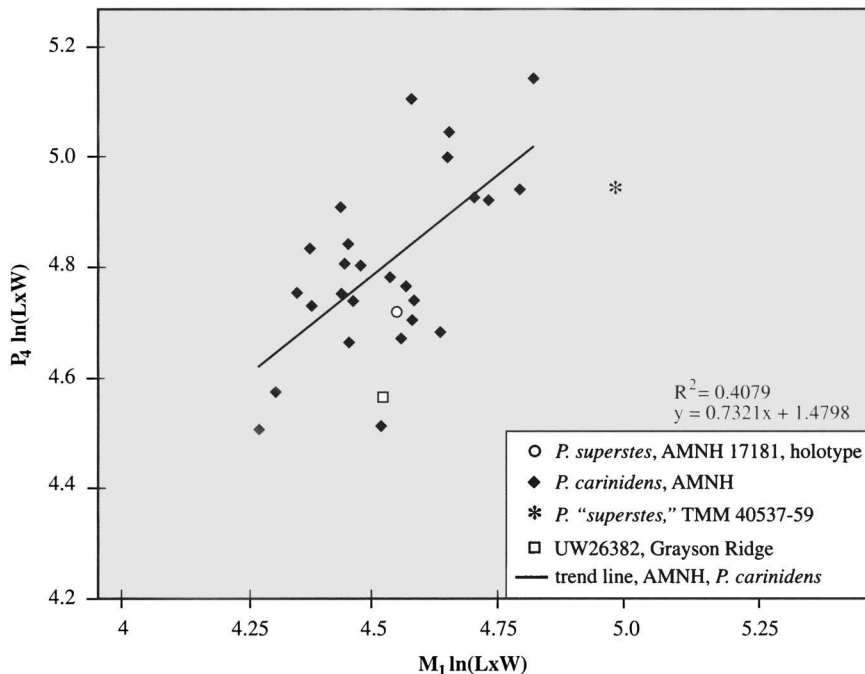
**Referred specimen.**—UW 14151, left mandible,  $P_2$ - $M_3$ ,  $P_1$  alveolus, with moderate wear.

**Known distribution.**—Common in Torrejonian faunas from southern California, to New Mexico, to Alberta (see Thewissen, 1990, for a list of localities); known throughout the Torrejonian of the San Juan Basin; may occur in Shotgun fauna (T11), Wyoming.

**Locality.**—V-94037 (V-80009).

**Description.**—Descriptions of *Tetraclaenodon puercensis* have been given by Thewissen (1990) and West (1971, 1976). To those descriptions I add that  $P_3$  and  $P_4$  are highly variable. The  $P_4$  ranges from molariform to simple, resembling a derived  $P_3$ . The  $P_3$  metaconid varies from prominent to absent.

The  $P_4$  of UW 14151 is typical.  $P_3$  is simple and lacks a metaconid. Diastemata are present between  $P_1$  and  $P_2$ , and between



**Figure 12.** Scatter-plot of  $M_1 \ln(\text{length} \times \text{width})$  and  $P_4 \ln(\text{length} \times \text{width})$  of *Peripitychus*; values are in  $\text{mm}^2$ ; trend line determined by least squares method with a 95% confidence interval.

$P_2$  and  $P_3$  (2.62 and 2.55, respectively; measured between roots or alveoli).

**Discussion.**—The referred specimen is well within the variation exhibited in specimens of *Tetraclaenodon puercensis* from the San Juan Basin. However, UW 14151 also is similar to early species of *Phenacodus* (see Thewissen, 1990), a genus reported only from Tiffanian and younger faunas. Lower molars of *Phenacodus* cannot be confidently distinguished from those of *Tetraclaenodon* unless they are outside the size range of *Tetraclaenodon*. However, *Phenacodus* has a strong  $P_3$  metaconid, while that of *Tetraclaenodon* ranges from strong to absent. The referred specimen has no  $P_3$  metaconid. UW 14151 is close to the mean size of *Tetraclaenodon*, but is significantly smaller than *T. septentrionalis* (see Thewissen, 1990), from the Torrejonian of Crazy Mountain Basin. The re-

ferred specimen also resembles early species of *Ectocion*, known only from Tiffanian and younger faunas, but is distinguished from *Ectocion* by less lophodont molars, distinct paraconids, and larger size (about ten percent larger than any of *E. collinus* from Douglass Quarry; Thewissen, 1990; table A-1, A-2, and A-4).

A slim possibility exists that UW 14151 belongs to *Phenacodus matthewi*, which is about the same size as *Tetraclaenodon puercensis* and can be confidently distinguished only with upper dentition. However, the only described component of upper dentition of *P. matthewi* is a single molar from the middle Tiffanian of Texas (Thewissen, 1990). Early Tiffanian identifications of *P. matthewi* based upon lower molars (e. g., Shotgun fauna) could be late occurrences of *Tetraclaenodon*.

Specimens identified as *Tetraclaenodon puercensis* curated

in the NMMNH collections exhibit extreme dental variability. It seems probable that more than one species is present. If this is the case, however, the species appear to intergrade. Isolated lower teeth from other localities at and above occurrences of *Ectocion* at Grayson Ridge (Fig. 7) and Halfway Hill Quarry are identical to those of *Tetraclaenodon puercensis* and may also belong to this species. Because of the difficulty distinguishing between lower teeth of *Tetraclaenodon* and *Phenacodus*, however, I refrain from generic referral.

### ***Ectocion* Cope, 1882b**

#### ***Ectocion* sp.**

#### **Table 9**

**Referred specimens.**—UW 26362, left  $M^2$ ; 26361, right maxillary fragment,  $M^2$ - $M^3$ .

**Known distribution.**—Common in Tiffanian and younger faunas throughout the Rocky Mountain region (see Thewissen, 1990, for specific localities).

**Localities.**—V-94027, V-94032.

**Description.**—Thewissen (1990) gave an adequate description of *Ectocion* in his revision of the Phenacodontidae.

**Discussion.**—The referred specimens resemble *Ectocion* most closely, but also are similar to teeth of *Tetraclaenodon*. Thewissen (1990) distinguished upper molars of *Ectocion* from those of *Tetraclaenodon* by: (1) greater lophodonty; (2) the presence of a mesostyle; (3) a stronger parastyle; (4) absence of an  $M^3$  hypocone; and (5) smaller size. Thewissen's report that *Tetraclaenodon* lacks a mesostyle (p. 21L) is puzzling, because several specimens in the NMMNH, KU, and AMNH collections have mesostyles.

Unlike all other species of *Ectocion*, the earliest recognized species, *Ectocion collinus* (Til-

**TABLE 7. DENTAL MEASUREMENTS OF *Periptychus* sp. cf. *P. carinidens* FROM GRAYSON RIDGE, AND SHOTGUN FAUNA (UNCATALOGED P<sub>4</sub>).**

Specimen No.	P <sup>1</sup>		P <sub>2</sub>		P <sub>3</sub>		P <sub>4</sub>		M <sub>1</sub>		
	L	W	L	W	L	W	L	W	L	AW	PW
UW 26380	8.7	7.6									
UW 26382			11.4	7.2							
UW 26382					12.3	8.3					
UW 26490					13.6	8.7					
UW 26382							11.6	8.3			
UW 26381							11.6*	8.0			
UW 26382									11.0	8.4	8.3
Shotgun fauna							11.4	8.0			

\*Estimated dimension (from breakage)

Ti3), occasionally has a hypocone on M<sup>3</sup>. The hypocone of *Tetraclaenodon* ranges from large to very reduced. The referred specimens had reduced or absent M<sup>3</sup> hypocones, are more lophodont than *Tetraclaenodon*, possess mesostyles and well developed parastyles, and are smaller than most specimens of *T. puercensis* (see Thewissen, 1990, tables A-1,2,3).

The size of UW 26362 (M<sup>2</sup>) is within the upper range of *Ectocion* and the lower range of *Tetraclaenodon* (see Thewissen, 1990). The size of UW 26361 (M<sup>2</sup>-M<sup>3</sup>) is within the range of *Tetraclaenodon*, but is about ten percent wider than the largest specimens of *E. collinus* reported by Thewissen (n = 5). However, uncataloged molars of *Ectocion* in the UW collections from Shotgun fauna (V-60014) are equivalent in size to UW 26361. Parastylar and hypoconular development on specimens from the Carbon Basin are consistent with *Ectocion*, but development of this degree is not unusual in *Tetraclaenodon*.

A very high degree of variability in size and morphology is exhibited in teeth of *Ectocion* from Shotgun fauna (Ti1). The variability suggests the presence of more than one early Tiffanian species of *Ectocion*. Molars from the Carbon Basin are within the variation seen at Shotgun fauna, but are larger and more primitive than most. No characters useful in distinguishing between upper molars of early species of *Ectocion* have been recognized. Although the primitive characters and large size of the referred molars suggest identification as *E. collinus*, indi-

viduals of other Tiffanian species (*i. e.*, UW 13247, *E. mediotuber*, Thewissen, 1990, from V-77008, Washakie Basin, Ti4) can be this primitive, and I refrain from making a specific identification.

#### MIOCLAENIDAE

#### PROMIOCLAENUS Trouessart, 1904

#### *Promioclaenus* sp. cf.

#### *P. lemuroides* (Matthew, 1897)

Table 10

*Mioclaenus lemuroides* Matthew, 1897, p. 314.

*Referred specimens.*—UW 26328, right M<sup>2</sup>; 26329, left M<sup>17</sup>.

**TABLE 8. DENTAL MEASUREMENTS OF *Tetraclaenodon puercensis* FROM GRAYSON RIDGE.**

	P <sub>2</sub>	P <sub>3</sub>	P <sub>4</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>3</sub>
L	6.0	7.1	7.8	8.0	8.4	9.0
W	3.2	4.2	5.3			
AW				6.4	7.1	6.1
PW				6.6	6.7	5.3

*Localities.*—V-94041, V-94027.

*Description.*—Taylor (1984) provided a detailed description of *Promioclænus lemuroides*. UW 26329 (M<sup>17</sup>) is well preserved and moderately worn. It differs from described specimens and available casts (AMNH 16636, composite) of *Promioclænus lemuroides* in: (1) greater lingual inflation; (2) a precingulum that terminates more lingually; (3) weaker pre- and postcingula; and (4) a better defined metaconule, more independent of the protocone. The greater inflation results in a more quadrate outline of the crown in occlusal view. The paracone is slightly labial to the metacone, suggesting that this is an M<sup>2</sup>. The longer, more squared protocone, however, is more like M<sup>1</sup>.

*Discussion.*—The degree of inflation seen in UW 26329 (M<sup>17</sup>) is greater than in any of 13 M<sup>1</sup>'s of *Promioclænus lemuroides* available to me for comparison. It approaches that of *Mioclænus*, which is extreme for the mioclænids. Other differences between UW 26329 and *P. lemuroides* were described above. UW 26329 appears different enough from *P. lemuroides* to warrant definition of a new species of *Promioclænus*. However, teeth of other species of *Promioclænus* are highly variable and I refrain from naming a new species without a larger sample.

UW 26328 (M<sup>2</sup>) is within the variation of specimens of *Promioclænus lemuroides*, known with confidence only from the Torrejonian, but also is close to *P. pipiringosi* (UW 2263, M<sup>2</sup>; Saddle Locality, Ti2). Gazin (1956) distinguished *P. pipiringosi* from *P. lemuroides* primarily by characters of the lower dentition, and I know of no adequate diagnosis of upper molars.

**TABLE 9. DENTAL MEASUREMENTS OF *Ectocion* sp. FROM GRAYSON RIDGE.**

Specimen No.	M <sup>2</sup>		M <sup>3</sup>	
	L	W	L	W
UW 26361	8.7*	9.85	6.65	7.45
UW 26362	8.05	8.66		

\*Estimated dimension (from breakage)

**TABLE 10. UPPER MOLAR MEASUREMENTS OF *Promioclænus* sp. cf. *P. lemuroides*, FROM GRAYSON RIDGE, *P. lemuroides* FROM SAN JUAN BASIN (AMNH 16636), AND *P. pipiringosi*, FROM BISON BASIN.**

	M <sup>17</sup>		M <sup>1</sup>		M <sup>2</sup>	
	L	W	L	W	L	W
<i>Promioclænus</i> cf. <i>P. lemuroides</i>						
UW 26328					3.8*	5.89
UW 26329	4.38	5.96				
<i>P. lemuroides</i> (cast)						
AMNH 16636			4.46	5.75		
AMNH 16636			4.42	5.88		
AMNH 16636			4.36	5.83		
AMNH 16636					3.91	6.24
AMNH 16636					4.09	6.15
<i>P. pipiringosi</i>						
UW 2263					4.00	5.87

\*Estimated dimension (from breakage)

#### HYOPSODONTIDAE

**LITOMYLUS Simpson, 1935b**  
*Litomylus scaphicus* Gazin, 1956  
**Figure 9; Table 10**

*Litomylus scaphicus* Gazin, 1956, p. 37.

*Holotype.*—USNM 21014, right ramus of mandible with M<sub>2</sub> and M<sub>3</sub>.

*Type locality and horizon.*—Saddle Locality (Ti2), Bison Basin, Wyoming.

*Referred specimen.*—UW 26376, left M<sup>2</sup>.

*Known distribution.*—Saddle Locality (Ti2) and Boulder Quarry, Wyoming.

*Locality.*—V-94027.



**Description.**—M<sup>2</sup> has a triangular outline in occlusal view and is transversely elongate. The trigon basin is wide and shallow, with a transverse long axis. The hypocone is moderate, oval, and positioned at the lingual termination of the postcingulum, just lingual to the protocone apex. The hypocone is appressed against the protocone, midway between the protocone base and its apex. The paracone and metacone are subequal, the former being almost connate, and the latter more angular. A median centrocrista is present. The parastyle is too worn for description. No mesostyle is present. The metastyle is little more than a slightly enlarged posterior termination of the metacrista. The postcingulum is moderately strong and terminates below and just lingual to the metacingulum. The precingulum is moderate and nearly confluent with the paracingulum. The protocristae are long with distinct conules adjacent to the outer cones. Preparaconule and postparaconule wings are present, as well as a postmetaconule wing.

**Discussion.**—This molar is structurally close to an undescribed M<sup>2</sup> (UW 2254) from the early Tiffanian of Bison Basin, Wyoming, identified as *Litomyilus scaphicus* Gazin, 1956. Gazin's diagnosis of *L. scaphicus* was based upon lower dentition, and the upper dentition has never been adequately described. Van Valen (1978) believed that *L. scaphicus* was a junior synonym of *L. dissentaneus* Simpson, 1937, known from the late Torrejonian and early Tiffanian (Tt1), and synonymized the species without discussion.

The referred M<sup>2</sup> and that of *Litomyilus scaphicus* (UW 2254 M<sup>2</sup>-M<sup>3</sup>) from Bison Basin differ from those

of *L. dissentaneus* in having: (1) greater width, relative to length; (2) wider and shallower trigon basins; and (3) a hypocone that is smaller, more labially positioned, and appressed against the protocone. An M<sup>1</sup> from Bison Basin (USNM 21013 cast), identified as *L. scaphicus*, is wider (relative to length) than is typical for the M<sup>1</sup> of *L. dissentaneus*, but agrees in hypocone size and position. The molars of UW 2254 and USNM 21013 from Bison Basin exceed the maximum range for width of *L. dissentaneus* of a large sample reported by Rigby (1980) from Swain Quarry; M<sup>1</sup>, n = 35; M<sup>2</sup>, n = 30; M<sup>3</sup>, n = 33, but are within the range for length. The M<sup>2</sup> from Boulder Quarry is within the length and width of *L. dissentaneus* (Table 11).

Gazin (1956) described the lower molars of *Litomyilus scaphicus* as being relatively wider and larger than those of *L. dissentaneus*. Such dimensions should correspond to wider and larger upper molars, suggesting that specimens from Bison Basin were correctly identified. Rigby (1980) stated that nearly all of the morphologic distance separating these species was present in the Swain Quarry sample, but questionably retained *L. scaphicus*. The characters and measurements of UW 2254 (M<sup>2</sup>-M<sup>3</sup>) and USNM 21013 (M<sup>1</sup>) suggest that although there is overlap in variation between *L. scaphicus* and *L. dissentaneus*, the variation of *L. scaphicus* is, in part, outside that of *L. dissentaneus*, and that synonymy is premature.

Based upon characters shared with *Litomyilus scaphicus* (as exemplified in UW 2254 and USNM 21013), I refer UW 26376 to that species. An M<sub>2</sub> (UW 26375) from the Carbon Basin identified as cf. *Litomyilus* may also represent this species (Table 11).

**TABLE 11. DENTAL MEASUREMENTS OF *Litomyilus scaphicus* (UW 26376) AND cf. *Litomyilus* (UW 26375) FROM CARBON BASIN, AND MEASUREMENTS OF *Litomyilus scaphicus* (UW 2254 AND USNM 21013) FROM BISON BASIN, SADDLE LOCALITY (Tt2) AND LEDGE LOCALITY (Tt3), RESPECTIVELY.**

	M <sup>2</sup>		M <sub>27</sub>			M <sup>1</sup>		M <sup>3</sup>	
	L	W	L	AW	PW	L	W	L	W
UW 26376	3.49	4.72							
UW 26375			3.46	2.71	2.75				
UW 2254 <sup>†</sup>	3.65*	5.3*						2.77	4.70
USNM 21013 <sup>§</sup>						3.30	4.77		

\*Estimated dimension; <sup>†</sup>Bison Basin Saddle locality; <sup>§</sup>Bison Basin Ledge locality

The referred  $M^2$  and UW 2254 from Bison Basin could possibly represent a new species.

**Order CARNIVORA  
VIVERRAVIDAE**

***Intyriactis* Gingerich and Winkler, 1985  
*Intyriactis vanvaleni* (MacIntyre, 1966)**

*Bryanictis vanvaleni* MacIntyre, 1966, p. 190.

*Holotype*.—AMNH 16031, dentary fragment with  $P_4$  and broken  $M_1$ .

*Type locality and horizon*.—East fork of Torrejon Arroyo, Nacimiento Formation, San Juan Basin, New Mexico.

*Referred specimen*.—UW 26345, left  $P_4$ .

*Known distribution*.—Late Torrejonian (Tj5–Tj6) of the San Juan Basin, New Mexico; Swain Quarry (Tj5?) and Halfway Hill, Wyoming.

*Locality*.—V-94046.

*Description*.—Cusps with light to moderate wear. *Intyriactis* (*Bryanictis*) *vanvaleni* was figured and described in detail by MacIntyre (1966). Length = 4.29; width = 1.87.

*Discussion*.—MacIntyre (1966) elevated Matthew's subgenus *Protictis* to generic rank and established three subgenera within *Protictis* (*Bryanictis*, *Simpsonictis*, and *Protictis*). Rigby (1980) elevated MacIntyre's subgenera to generic rank, which is the taxonomic scheme I follow here. Gingerich and Winkler (1985) defined the genus *Intyriactis* in order to accommodate specimens of "*Bryanictis*" *vanvaleni*. *Intyriactis vanvaleni* exhibits the consistent presence of a  $P_4$  metaconid in the sample from Swain Quarry, a character absent in *Bryanictis sensu stricto*.

The  $P_4$  of *Intyriactis*, from the late Torrejonian (Tj5–Tj6), is distinguished from that of *Protictis* by a relatively lower crown and a prominent metaconid. It is distinguished from *Simpsonictis* by a less triangular shape and by a prominent metaconid (Gingerich and Winkler, 1985). On the basis of these characters, I identify UW 26345 as *Intyriactis*.

*Intyriactis vanvaleni* is monotypic for the genus. Direct comparison of the referred  $P_4$  with specimens of *I. (Bryanictis) vanvaleni* from Swain Quarry revealed no significant differences.

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