THE GEOLOGICAL SURVEY OF WYOMING

Daniel N. Miller, Jr., State Geologist

MEMOIR No. 2

GEOLOGY AND MAMMALIAN PALEONTOLOGY
OF THE SAND CREEK FACIES,
LOWER WILLWOOD FORMATION (LOWER EOCENE),
WASHAKIE COUNTY, WYOMING

by

Thomas M. Bown

LARAMIE, WYOMING

1979

Front cover photograph. Sandstones and mudstones of the middle
part of the Sand Creek facies in the valley of Sand Creek, sec.
33, T.47N., R.91W. and secs. 3 and 4, T.46N., R.91W., Washakie
County, Wyoming. View is to the southeast.
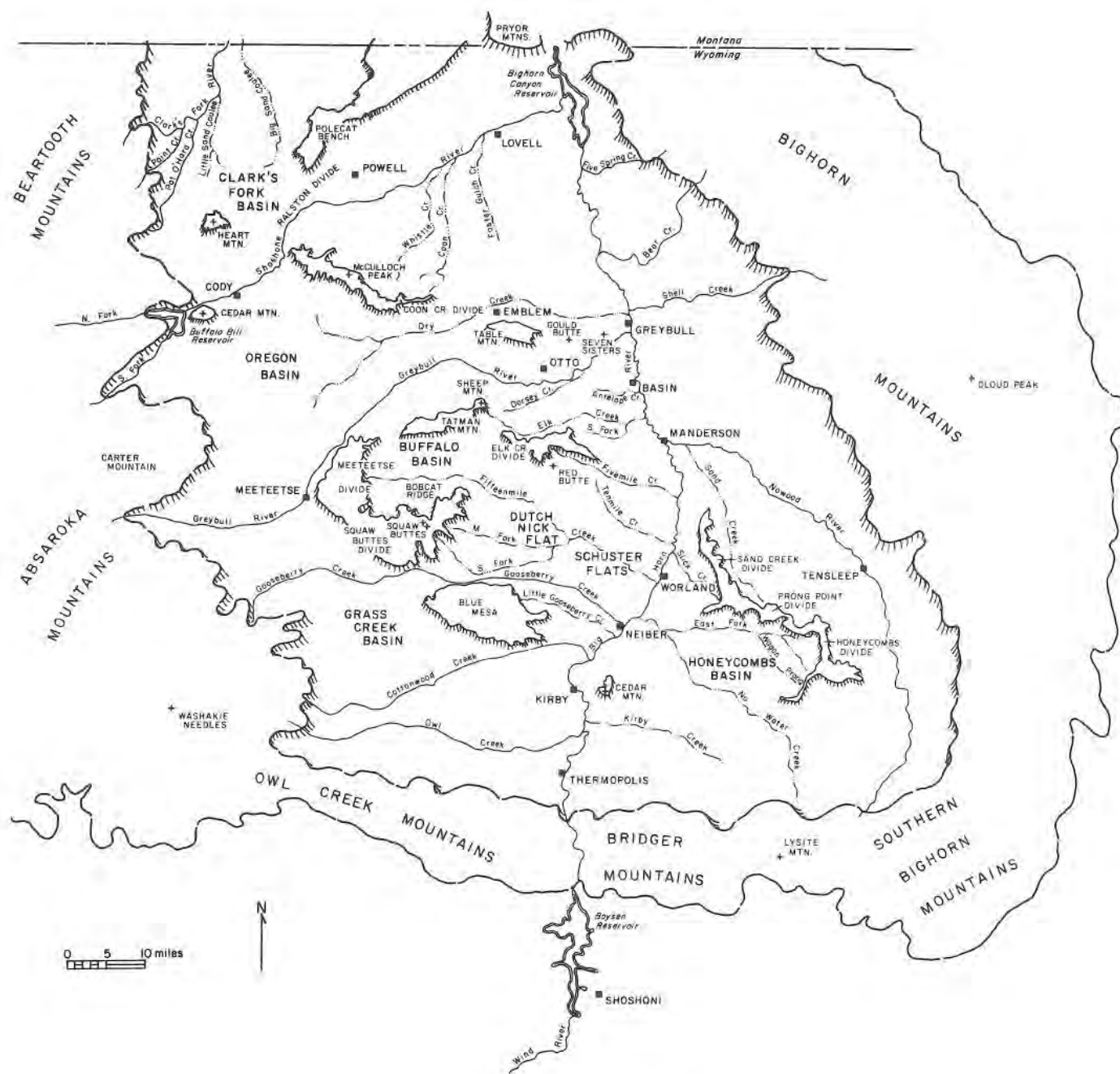
ERRATA AND NOTES

Page 4, column 1, line 11
For Murpny *read* Murphy

Page 9, column 1, paragraph 6, line 2
For appear to be truncated *read* appear to be both faulted and truncated

Page 11, column 1, last paragraph, line 2 from bottom
For T.49N. *read* T.45N.

Page 20, column 1, paragraph 2
M.J. Kraus (1979; unpubl. Master's thesis, University of Wyoming) observes that sheet sandstones are common in the lower Willwood Formation in the Clark's Fork Basin and gives a sedimentologic analysis of one such sandstone.

Page 20, column 2, paragraph 1
Apron-channel sandstones were recently described by P.F. Friend, M.J. Slater, and R.C. Williams (1979; Journ. Geol. Soc. London, v. 136, p. 39-46) under the name "ribbon sandstones." Similar sandstone bodies were also described by C. Puigdefabregas (1943; Sedimentology, v. 20, p. 133-144).

Page 22, column 1, paragraph 1
Original bedding, obscure in hand specimens, is often seen in thin section.

Page 22, caption for Figure 9, line 3
For demarkated *read* demarcated

Page 23, column 1, paragraph 1, line 4
For posses *read* possess

Page 23, column 2, paragraph 1, line 7
For 0.6-10.0 *read* 0.6-1.0

Page 26, column 1, paragraph 1, line 8
The reference as illustrated in Figure 15 *is incorrect for fining-upwards sequences in mudstone, as can be seen in the caption for Figure 15.*

Page 38, column 2, paragraph 1, line 14
For by clay minerals *read* from clay minerals

Page 45, column 2, paragraph 3, lines 7-10
This statement is made only within the context of this paper with reference to the lower part of the Willwood Formation.

Page 50, column 2, last paragraph, line 2
For progressive size *read* progressive tooth size

Page 51, column 2, quotation
Simpson's question is quoted out of his context; he is in agreement with the conclusions of my paragraph following the quotation. As quoted, his question mistakenly shows Simpson to have taken a contrary view.

Page 52, column 1, paragraph 5, last line
For 56b *read* 39b

Page 53,   column 1, paragraph 3, line 3
          For appearnace *read* appearance

Page 53,   column 2, paragraph 11, line 1
          For 6553 *read* 6552

Page 54,   column 1, paragraph 4, lines 3-5
          Since this paper was written, more complete specimens of Peradectes chesteri *have been found in Willwood rocks by the University of Michigan.*

Page 54,   column 1, last paragraph, line 3
          For fregment *read* fragment

Page 59,   column 2, paragraph 1, line 4
          For trongest *read* strongest

Page 61,   column 1, footnote
          For subseqeuntly *read* subsequently

Page 62
          Bown and Schankler (in press) now consider both Plagioctenodon *and* Plagioctenoides *to be nyctitheriids*

Page 65,   column 2, paragraph 11, line 3
          For and Macrocranion *read* and some Macrocranion

Page 66,   column 2, paragraph 2, line 7
          For as in other known *read* as in most other known

Page 66
          Adapisoricid, indeterminate has been referred to a new species of Scenopagus *by Bown and Schankler (in press).*

Page 67,   column 2, last paragraph, line 5
          For (1975) *read* (1976)

Page 71,   column 2, paragraph 3, line 2
          For hypothesis the Niptomomys *read* hypothesis that Niptomomys

Page 81,   Column 2, paragraph 3, line 1
          For do not occur in *read* do not occur consistently in

Page 91
Page 94
          Figures 26 and 27 (but not their captions) are exchanged.

Page 111, caption for Figure 41, last line
          For seigfriedti *read* siegfriedti

Page 115, caption for Figure 45, line 3
          Read C/ and P^2

Page 134, column 2, paragraph 5, line 9
          For beds *read* areas

Page 135, column 2, paragraph 2, next from last line
          Wildcat Ridge was omitted from the frontispiece. It is situated at the southeast end of Tatman Mountain.

Page 136, column 1, paragraph 3, line 5
          For Wind River Basin as replacements *read* Wind River Basin (where they are members of the Wind River Formation) as replacements

Page 137, column 2, paragraph 4, line 7
          For and in western Buffalo *read* and in the western Buffalo

Page 139, column 1, paragraph 1, line 9
          For belived *read* believed

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ABSTRACT

The early Eocene Willwood Formation of the Bighorn Basin in northwestern Wyoming is a fluviatile deposit about 700 meters thick of lenticular sandstones, shales, and variegated mudstones. Two essentially isochronous facies exist in the lower part of the Willwood sequence, the Elk Creek facies and the Sand Creek facies.

The Elk Creek facies of the lower Willwood is at least 365 meters thick in the central Bighorn Basin and is characterized by relatively bright red and orange mudstones, calcium carbonate cemented sandstones, and calcium carbonate nodules. Most vertebrate fossils in the Elk Creek facies occur in thin, gray mudstones that alternate with thicker, orange mudstones.

About 145 meters of the Sand Creek facies of the lower Willwood sequence is preserved in the southeastern Bighorn Basin. It is characterized by relatively thin, pale, purple and gray mudstones, drab friable sandstones with little or no calcium carbonate cement, and ferric oxyhydrate nodules and concretions. Most vertebrate fossils in this facies occur in thin, bluish-gray mudstones, here termed Class A gray mudstones, that invariably overlie mottled purple and orange mudstones.

Chemical analyses demonstrate that mudstone coloration and concentration of free Fe, Mn, and organic carbon in some beds of the Sand Creek facies are related to ancient pedogenesis. In the Elk Creek facies, red and orange mudstones and calcium carbonate nodules occur because of geochemical conditions that developed in floodbasin alluvium as the result of alternating wet and dry intervals. In the Sand Creek facies, however, mottled mudstones with ferric oxyhydrate nodules and concretions resulted from geochemical conditions in floodbasin alluvium related to water table fluctuation and variable conditions of drainage. The Sand Creek facies probably developed as a result of moister conditions in the southeastern Bighorn Basin resulting from proximity to the rising southern Bighorn Mountains.

Vertebrate fossils accumulated in Class A gray mudstones during intervals of slowed sediment accumulation and floodbasin soil formation. Drab Willwood mudstones do not yield a predominantly arboreal fauna and red mudstones do not yield a predominantly ungulate fauna, contrary to Van Houten (1945).

Sixty-nine mammalian taxa are now recognized from the Sand Creek facies and constitute the No Water fauna. Fifty named species are identified, representing 49 genera of 15 orders and 27 families.* Most specimens are condylarths, with the primates, perissodactyls, and artiodactyls following in numerical importance. The most common species, in order of abundance, are: *Haplomylus speirianus*, *Hyracotherium* Cf. *angustidens*, *Pelycodus ralstoni*[†], *Hyopsodus* sp., *Diacodexis metsiacus*, and *Ectocion* Cf. *osbornianus*.

The No Water fauna is early Wasatchian in age, about the same age as the Four Mile fauna of northwestern Colorado. The mammals of these faunas are approximately equivalent in known taxonomic diversity; however, *Haplomylus*, *Pelycodus*, *Hyracotherium*, and *Ectocion* are more common in the No Water fauna. Rodents, insectivores, proteutherians, multituberculates, and *Hyopsodus* are better represented in the Four Mile fauna. The No Water fauna differs from the typical Willwood "Gray Bull" assemblage in the abnormal abundances of *Haplomylus*, *Apheliscus*, and *Ectocion*, in the relative paucities of *Phenacodus* and *Hyopsodus*, and in the absence of *Homogalax*. The forms *Parectypodus* sp. "A" (Multituberculata), *Peradectes chesteri* (Marsupialia), *Leipsanolestes* Cf. *siegfriedti* and *Scenopagus* sp. (Insectivora), *Chriacus* (Arctocyonia), and *Oödectes* Cf. *herpestoides* (Carnivora) are recorded for the first time from Willwood rocks. *Homogalax*, *Plagiomene*, *Dissacus*, and *Miacis*, mammals commonly found in other early Wasatchian assemblages, are unknown in the No Water fauna.

Two new genera and four new species are described and named from the No Water fauna. *Peratherium macgrewi*, sp. nov., is the smallest Eocene marsupial now referred to *Peratherium* and closely resembles the larger *Peratherium comstocki*. The adapisoricid insectivores *Plagioctenodon krausae*, gen. *et* sp. nov., and *Plagioctenoides microlestes*, gen. *et* sp. nov., resemble the enigmatic "*Leptacodon*" *jepseni* but differ from it and most other adapisoricids in premolar morphology. The erinaceid insectivore *Leipsanolestes simpsoni*, sp. nov., is more advanced than the larger *L. siegfriedti* in the greater reduction of the P_4 talonid and the smaller size of M_2, relative to M_1.

Stratigraphically arranged plots of tooth dimensions for many mammals of the No Water fauna demonstrate that measurable changes in these dimensions have occurred through time and support the hypothesis that sympatric phylogenetic

gradualism was an important factor in the evolution of many early Eocene mammals. Comparison of stratigraphically plotted tooth dimensions of *Pelycodus*, *Hyopsodus*, and *Diacodexis* with similar plots made by other workers demonstrates that these plots have potential usefulness in intrabasinal biostratigraphic correlation.

Homogalax (Perissodactyla, Tapiroidea) was probably stenotopic in comparison to many early Eocene primates, condylarths, and other perissodactyls and is not an adequate index fossil for a "Gray Bull" sub-Provincial Age.

*See footnote, page 130.

†See footnote, page 80.

ABBREVIATIONS USED IN TEXT

Repositories

AMNH	American Museum of Natural History, New York, New York
CM	Carnegie Museum, Pittsburgh, Pennsylvania
MCZ	Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts
PU	Princeton University Museum, Princeton, New Jersey
UCMP	Museum of Paleontology, University of California, Berkeley, California
UCR	University of California, Riverside, California
UM	University of Minnesota, Minneapolis, Minnesota
UMMP	Museum of Paleontology, University of Michigan, Ann Arbor, Michigan
USGS	United States Geological Survey, Denver, Colorado
USNM	United States National Museum, Washington, D.C.
UW	Geological Museum, University of Wyoming, Laramie, Wyoming
YPM	Peabody Museum of Natural History, Yale University, New Haven, Connecticut

Statistical

N	Number of observations in sample
OR	Observed range of sample
X	Mean of sample
SD	Standard deviation of sample
CV	Coefficient of variation of sample

*Dental**

L	Greatest anteroposterior measurement (length)
W	Greatest transverse measurement (width)
Tr	Trigonid
Ta	Talonid

*Dental terminology follows that of Van Valen (1966) as modified by Szalay (1969a)

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INTRODUCTION

GEOLOGIC AND GEOGRAPHIC SETTING

The area of study occupies approximately 500 square miles in the southeastern Bighorn Basin in north central Wyoming (Pl. 1). The Bighorn Basin is part of the middle Rocky Mountain physiographic province (Fenneman, 1931) and is one of several intermontane depressions formed by differential structural elevation during the Late Cretaceous and Early Tertiary. The basin is bounded by positive Laramide structural features: the Beartooth, Owl Creek, Bridger, and Bighorn mountains are broad, asymmetrical anticlines, complicated by reverse faulting on their asymmetrical eastern, southern, and northwestern limbs, respectively. The history of the Beartooths has been complicated by intrusive and extrusive igneous activity. The Absaroka Mountains, an immense, partly dissected accumulation of extrusive igneous and volcaniclastic rocks deposited between late early Eocene and Oligocene times, covers a complex of folded Paleozoic and Mesozoic rocks collectively termed the Washakie Range (Love, 1939). The Pryor Mountains bound the Bighorn Basin to the northeast and are a structurally disjunct extension of the Bighorn Mountains. The Bighorn Basin is both structurally and topographically open to the north between the Beartooth and Pryor mountains.

The Beartooth, Bighorn, and Owl Creek mountains have been unroofed to their Precambrian crystalline cores, to expose rocks of Cambrian through Early Tertiary ages, except Silurian, at the margins of the basin. Fluviatile Oligocene and Miocene sediments comprise remnant outliers at a few places on the subsummit surface of the Bighorn Mountains (see, *e.g.*, Darton, 1906; Van Houten, 1952; Love, 1952b; McKenna and Love, 1972).

The Bighorn Basin is an arcuate structure that trends approximately NW-SE. The attitudes of pre-Tertiary sedimentary rocks demonstrate that the basin is normally asymmetrical to the west. Laramide differential structural elevation between the Bighorn Basin and surrounding mountainous regions probably totaled 25,000 to 30,000 feet (A.A.P.G. and U.S.G.S., 1967).

The Bighorn Basin is drained by two principal streams, the Clark's Fork of the Yellowstone River and the Bighorn River, and their tributaries. Five principal perennial tributaries head in the Absaroka Mountains and cross the Bighorn Basin to join the Bighorn River. Innumerable intermittent streams originate in the Tertiary badlands of the central Bighorn Basin. Sand and No Water creeks, within the report area, are the only major intermittent streams in the basin east of the Bighorn River. These streams have their sources on the high badland divides south and east of the town of Worland (Pl. 1).

LOCATION AND DEFINITION

The area of study for this report is depicted on the geologic map (Pl. 1). Mapping studies were conducted in Late Cretaceous (Montana Group) and Early Tertiary (Paleocene and Eocene Series) rocks, and detailed stratigraphic studies were con-

ducted in the Willwood Formation (early Eocene). The area is roughly included in Tns. 43-48 N., Rs. 89-95 W., Washakie County, Wyoming.

HISTORY OF INVESTIGATIONS

EOCENE ROCKS OF THE BIGHORN BASIN

Nace (1936) and Van Houten (1944) adequately summarized the history of early investigations of Early Tertiary rocks and faunas of the Bighorn Basin. Paleontological studies in more recent years were conducted by E.L. Simons of Yale University from 1961 to 1976 in the Willwood Formation. Studies of Willwood faunas by P.D. Gingerich (University of Michigan, 1974-1976) and by the present writer (1973-1976) are in progress.

Small but important collections of Willwood mammals are housed at the Carnegie Museum (Pitts-

burgh), Royal Ontario Museum (Toronto, Canada), University of Nebraska State Museum (Lincoln), University of Kansas Museum of Natural History (Lawrence), Raymond Alf Museum (Webb School, Claremont, California), and the University of California (Riverside).

Important stratigraphical and sedimentological studies of Willwood rocks have been carried out in recent years by Neasham (1967, 1970), Bredall (1971), and Neasham and Vondra (1972). Current studies are underway by P.D. Gingerich in the Clark's Fork Basin, by D. Schankler (Yale Peabody Museum) in the Elk Creek drainage and Buffalo Basin, and by the present writer in the drainage of Fifteenmile Creek.

SAND CREEK—NO WATER CREEK AREA

The history of geological investigations of Early

Table 1. Summary of geological investigations, Sand Creek —No Water Creek area

1882	Wortman (*in* Cope, 1882a) published the first map of Tertiary rocks in the Bighorn Basin.		Wold, and Summerford described the correlation of "Fort Union" rocks and the production of oil and gas structures in the southern Bighorn Basin.
1894	Eldridge published a geologic map of the Bighorn Basin.		
1905	Fisher described the occurrence of coal in the "Laramie" Formation in the eastern part of the report area.	1950's	G.L. Jepsen (oral communication) prospected for vertebrate fossils in Paleocene rocks of the Sand Creek—No Water Creek area.
1906	Fisher published a geologic map of the Bighorn Basin.	1961	Moore published an isopachous map of the "Fort Union" Formation of the Bighorn Basin.
1910	Woodruff described coal deposits in "Laramie" and "Fort Union" rocks in the report area, described the physiography of the region, and was the first to describe "Wasatch" rocks east of the Bighorn River.	1962	Houston and Murphy described occurrences of titaniferous black sandstones in Mesaverde rocks within the report area.
1917	Hewett and Lupton described oil and gas producing structures of the southern Bighorn Basin.	1963	Horn mapped Late Cretaceous and Early Tertiary rocks in the southern part of the report area.
1925	The United States Geologic Survey published the Geologic Map of Wyoming.	1963 and 1972	A Yale Peabody Museum field party prospected for vertebrate fossils in Willwood rocks of the report area.
1944	Van Houten obtained a small collection of fossil mammals from the Willwood Formation in sec. 21, T.46N., R.92W.	1966-1976	J.R. Macdonald (oral communication) prospected for vertebrate fossils in Willwood rocks of the report area.
1952	Weitz and Love compiled a geologic map of the southern Bighorn Basin; this interpretation appeared on the (Love, Weitz, and Hose) 1955 U.S. Geological Survey Geologic Map of Wyoming.	1970	Neasham reported paleocurrent directions in Willwood sandstones of the report area (published by Neasham and Vondra, 1972).
1952	Papers by Love (1952a), Harris (1952a,b),	1975	Bown published a preliminary interpretation of the distribution of Late Cretaceous and Early Tertiary rocks in the report area.

Tertiary rocks east of the Bighorn River is summarized briefly in Table 1.

Few Willwood vertebrate fossils were known from the Sand Creek — No Water Creek Area prior to this study. It is probable that the deeply weathered, often lichen covered exposures of Willwood rocks in this area have made the Sand Creek facies relatively unappealing to fossil collectors. Much of the supposed drab Willwood sequence prospected by the 1972 Yale field party is now known to be in the upper part of the Polecat Bench Formation (Fig. 1).

OBJECTIVES

The purpose of this study is to present an introductory and comparative account of various parameters of the stratigraphical, paleontological, and sedimentological anatomy of the Sand Creek facies of the Willwood Formation. Objectives of this work include an areal delimitation of Tertiary rocks in the southeastern Bighorn Basin, a description of the stratigraphy and sedimentology of the Sand Creek facies, and a description and evaluation of the fossil Mammalia of the lower Willwood Formation of the southeastern Bighorn Basin.

The degree to which Willwood rocks and faunas of the Sand Creek facies differ from those described in earlier studies has demanded that much of the discussion be presented in a comparative form. Several essentially isochronous, heteropic lithologic facies exist within the Willwood Formation. The Sand Creek facies, described below, is only one such unit and has a number of distinctive sedimentological and paleontological parameters which serve to define it and by which it may be contrasted with other facies.

The comparative approach has necessitated reliance on data from adjoining or widely disparate areas that were studied in less detail by the writer and from the studies of others who worked with different objectives. Most other students of Willwood rocks have worked with more specific goals in mind, have concentrated their efforts on rather limited areas, and have rarely made use of the wealth of available fossil data.

This study offers a picture of a clearly heterogeneous and complex Willwood stratigraphy and paleontology and demands the reappraisal of many old problems. Among these problems are: (1) the origin of red beds, (2) the nature and meaning of fluviatile cyclothems, (3) vertebrate taphonomy, (4) paleoecological differences and paleontological correlation, and (5) rapid allopatric *versus* gradual sympatric speciation in populations of fossil mammals.

ACKNOWLEDGMENTS

Dr. R. Sloan (UM) aided with the identification of the multituberculates and Drs. J.H. Hutchison (UCMP), M.R. Dawson (CM), and J.H. Hanley (USGS, Denver) identified the fossil turtles, rodents, and invertebrates, respectively. J. Damuth (University of Chicago) and Jacob Reitenbach (UW) provided analytical data for specimens of *Diacodexis* and *Hyrocotherium*. Drs. M.J. Novacek and L. Krishtalka kindly forwarded their pre-publication manuscripts on fossil insectivores and proteutherians. J. Murpny (University of Wyoming) and U. Scharum (U.S. Bureau of Mines) aided with the free iron and manganese and carbon analyses.

PHYSIOGRAPHY

The Sand Creek — No Water Creek Area is a region of rugged badlands developed on the Early Tertiary Polecat Bench and Willwood formations. North (Devil's) Butte (elevation 5462 feet) offers the most scenic vantage-point in the report area. Prong Point, North Butte, Middle Butte, and South Butte are prominent topographic highs on the Prong Point, North Butte, and Honeycombs divides which enclose a vast badland depression, the Honeycombs Basin (Pl. 1). The Sand Creek Divide (Pl. 1) has relief of about 400 feet and constitutes the high scarp north and east of the town of Worland. Badland breaks bordering the Sand Creek Divide are separated into the Slick Creek, Sand Creek, and Banjo basins, which contain the most important vertebrate fossil localities.

The Banjo Flats, Schuster Flats, and Dutch Nick Flats surfaces are vegetated alluvial and colluvial flats developed southeast and west of the town of Worland (Pl. 1). At least three levels of Bighorn River terraces are developed on drainage divides west of the Bighorn River (Van Houten, 1944, p. 170).

The best outcrops of Tertiary rocks occur along the drainages of the many intermittent streams that traverse the area. The Honeycombs Basin is the only extensive badland tract east of the Bighorn River that is comparable to the Willwood badlands in the central Bighorn Basin. Wortman (*in* Osborn and Wortman, 1892) reported that the outcrops of Tertiary rocks in the Bighorn Basin are typically best exposed on the west and northwest sides of hills and ridges. These are the directions of incidence of prevailing spring and summer storms. Therefore, west-facing exposures are generally steeper and less deeply weathered than those which face to the east.

Road access to most parts of the Sand Creek — No Water Creek Area is excellent. Fair-weather roads are maintained in much of the report area by the Bureau of Land Management. Access to the Rattlesnake, South Frisby, Slick Creek, No Water Creek, Banjo Flats, Worland, South Fork, Neiber, Sand Creek, and Cottonwood Creek oil and gas fields is maintained by several oil companies. A maze of jeep trails and seismograph survey tracks exists in more remote areas. Most of the Honeycombs Basin is, however, accessible only on foot or by a combination of four-wheel-drive vehicle transport and spade work.

STRUCTURAL GEOLOGY

SAND CREEK — NO WATER CREEK AREA

INTRODUCTION

Tertiary strata east of the Bighorn River and bordering the Sand Creek — No Water Creek area are structurally controlled by several anticlines that flank and roughly parallel the northwest-southeast trending axis of the southeastern Bighorn Basin (Pl. 1). The Tertiary rocks appear to form part of a continuous sequence that was uniformly deformed by compressive or vertical forces, or both, during the latter part of the Laramide orogeny (see, *e.g.*, Eardley, 1962). A widespread angular unconformity

between the Polecat Bench Formation and the underlying Lance Formation (or older rocks), and local minor angular unconformities between the Willwood and Polecat Bench formations, have, however, obscured what is actually a more complex structural history.

LANCE — POLECAT BENCH UNCONFORMITY

The Polecat Bench Formation overlaps Montana Group rocks with a sharp angular unconformity at a large fishhook-shaped topographic salient north of Sand Point, in secs. 21 and 28-33, T.44N., R.89W., and secs. 4-6, T.43N., R.89W. Here, a sequence of at least 37 meters (120 feet) of fluviatile white carbonaceous sandstones and interbedded mudstones is preserved in an exhumed Polecat Bench channel deposit preserved on shales of the upper Cody Formation (Pl. 1 and Fig. 1b). This channel deposit is that of a stream that was deeply entrenched in steeply upturned Cody shales, and the sinuous channel variously follows strike valleys and cuts transversely across high Cody hogbacks.

On the west, south, and east margins of the fishhook-shaped salient, Cody rocks dip approximately 30-55° NE and are overlain by Polecat Bench strata that dip roughly 4-6° NNW. This unconformity, involving increasingly younger Montana Group rocks, was traced approximately five miles north over patchy exposures on the Honeycombs Divide (southwest of "Honeycombs" on plate 1) to a point in sec. 33, T.45N., R.89W. where the rocks are obscured by alluvial and vegetation cover. Farther north, the position of the Polecat Bench — Lance Contact is uncertain and remains to be clearly defined by mapping.

Figure 1. Outcrops of rocks of the Cody Shale and the Polecat Bench Formation in the southwest Bighorn Basin.

A. Exposures of carbonaceous mudstone, drab mudstone, sandstone, and reddish clinkered mudstone (arrow) in the lower Polecat Bench Formation, SW¼ sec. 21, T.45N., R.89W., Washakie County, Wyoming. This and other clinkered mudstones were erroneously used as the basal beds of the Willwood Formation on the compilation map of Weitz and Love (1952) and on the 1955 Geologic Map of Wyoming (Love, Weitz, and Hose). View is to the north.
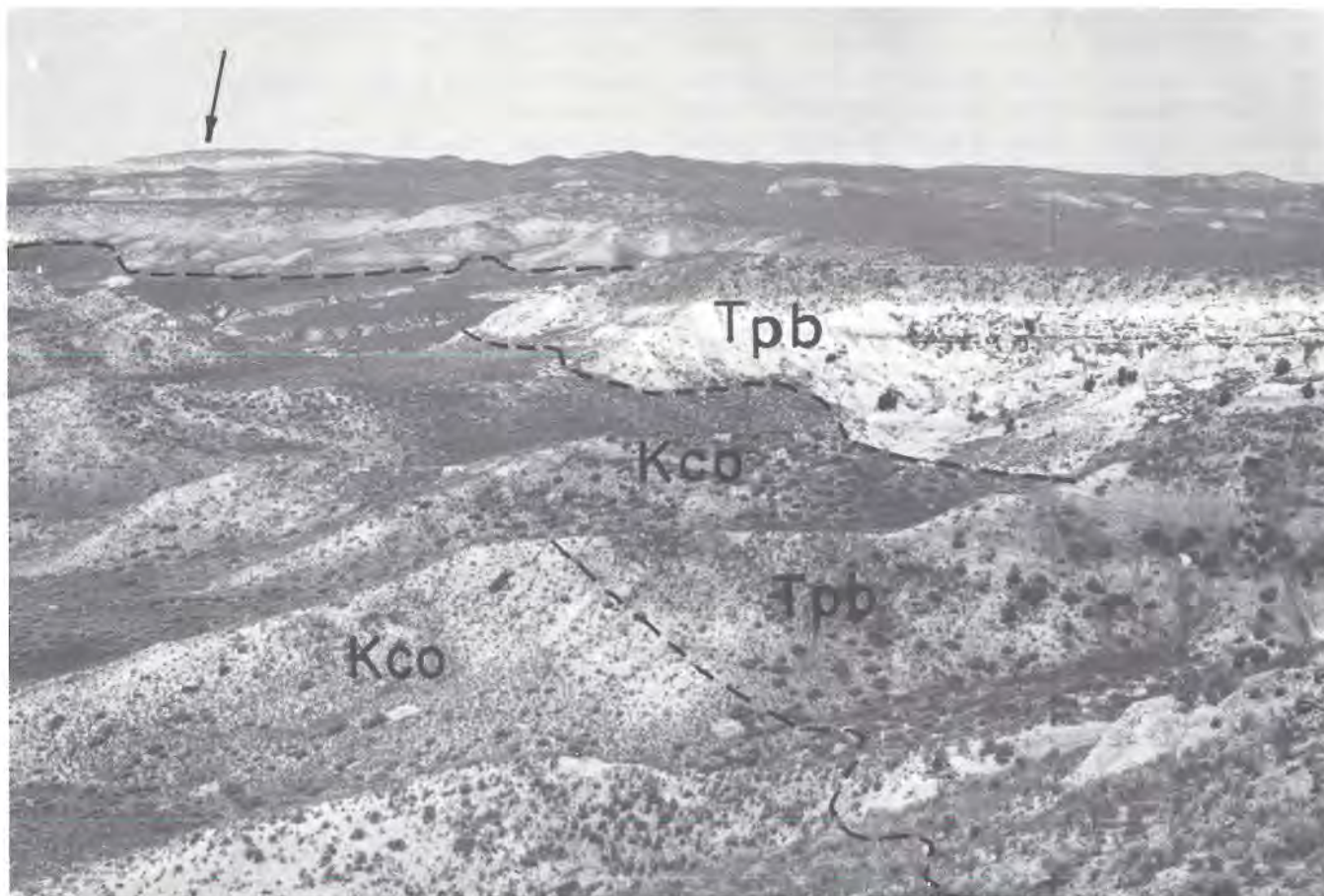
B. Outcrops of rocks of the Cody Shale (Kco) and the Polecat Bench Formation (Tpb) north of Sand Point, mostly in the E½ sec. 1, T.43N., R.90W; sec. 6, T.43N., R.89W.; W½ sec. 31, T.44N., R.89W.; and sec. 36, T.44N., R.90W., Washakie County, Wyoming. Polecat Bench rocks at this locality are composed of a broad, thick channel sandstone complex that dips about 4-6° NNW and truncates hogbacks of the upper part of the Cody Shale that dip 30-55° NE. South Butte (arrow) forms the skyline in the left distance and is dominantly composed of Polecat Bench rocks. View is to the northnorthwest.

The unconformity is traceable westward into the NW¼ T.44N., R.91W., where the Polecat Bench overlaps the steeply-northward-dipping Meeteetse and Lance formations.

Horn (1963) did not recognize an unconformity between the Polecat Bench Formation and Cretaceous rocks on the southern Honeycombs Divide, but relied instead on the "Brown formula" (see *e.g.*, Brown, 1962) and drew the "Fort Union—Lance" contact at the lowest coal bed above the last observed occurrence of dinosaur bone.

POLECAT BENCH—WILLWOOD CONTACT

The Willwood Formation overlies the Polecat Bench Formation with a slight angular unconformity in secs. 8, 15-17, 22, and 23, T.47N., R.91W.

Polecat Bench rocks that dip approximately 35° southwest in this area flatten rapidly in dip west of the Meyer Gulch oil and gas field to about 8-9° at the contact with the Willwood Formation. The overlying Willwood Formation dips about 4° southwest. This unconformity is local, however, and was not seen east or south of sec. 23 or north of sec. 8, T.47N., R.91W. The contact is also conformable on the northern Sand Creek Divide (secs. 1, 2, and 12, T.48N., R.92W.), along the East and South (main) forks of No Water Creek, and on North Butte.

West of the Bighorn River, the Polecat Bench Formation—Willwood Formation contact is conformable in the drainages of Cottonwood and Little Gooseberry creeks (Pl. 1), but grades to an angular relationship on the northwest flank of Blue Mesa (northwest of Kirby).

WORLAND ANTICLINE

Four major anticlines and three synclines control the expression of Willwood and Polecat Bench rocks east of the Bighorn River. These structures trend generally NW or WNW, roughly parallel to the structural axis of the Bighorn Basin, and (with the exception of Worland Anticline) traverse the whole of the Sand Creek — No Water Creek area. The axial traces of all of these structures were mapped west of the Bighorn River beyond the report area. Only Neiber and Worland anticlines and Neiber Syncline have been named in previous literature (*e.g.*, Hewett and Lupton, 1917).

Worland Anticline is a doubly-plunging oil and gas structure with little expression in the surface Willwood Formation (see Wold, 1952; Wyoming Geological Association, 1957). A northwestern extension of Worland Anticline (northwest of plate 1 map area), the North Frisby Dome, shows surface closure in the NE¼ T.49N., R.94W. Approximate dips measured on Willwood rocks in secs. 1 and 2, T.48N., R.93W. show dip reversals on an anticlinal fold, but this structure was not detected in Willwood strata exposed in the southern part of the Worland oil and gas fields in secs. 2, 3, 10, and 11, T.47N., R.92W. Worland Anticline is approximately 9 miles long and manifests dips of 2-6° in the surface Willwood Formation.

SAND CREEK SYNCLINE

The Sand Creek Syncline (Pl.1) is a large structure that originates, and possibly plunges to the west, near North Butte in sec. 19, T.46N., R.89W. The fold was traced for more than 25 miles to the western margin of the study area in sec. 9, T.48N., R.93W. The axis of the structure is sinuous but maintains a general NW bearing. The Sand Creek Syncline disharmonically overlies several positive seismically mapped oil and gas structures.

BANJO ANTICLINE

Banjo Anticline is a long, sinuous structure developed on Willwood and Polecat Bench rocks in the heart of the Sand Creek — No Water Creek area (Pl.1). The fold is expressed by shallow but obvious dip reversals along its 12 mile course and by the mapped distribution of Tertiary rocks. Banjo Anticline is breached by the East Fork of No Water Creek, and this stream maintains an essentially east-west course along the axis of the fold.

Dip reversals on West Worland Dome in the SE¼ sec. 27, T.47N., R.93W. suggest that Banjo Anticline plunges beneath the alluvial cover on the Banjo Flats surface. The structure becomes a monocline in Polecat Bench rocks of the Honeycombs.

Harris (1952a, 1952b) noted a slight anticlinal surface expression in the Slick Creek (Tns.46-47N., R.92W.) and Sand Creek (sec. 26, T.46N., R.91W.) oil and gas fields. But because these fields produce from seismically mapped closures, I believe that part of the Banjo Anticline either reflects or is coincident with subsurface trends.

EAST FORK SYNCLINE

The East Fork Syncline is a broad, symmetrical structure that manifests dips of 3-7°. The structure was traced approximately 26 miles. The axis of the East Fork Syncline is coincident with the pre-Tertiary structural axis of the Bighorn sedimentary basin for most of its eastern course and is probably a surface reflection of that trend. The structure plunges westward in the center of the N½ T.44N., R.89W., and continues out of the report area south and west of the town of Worland.

The Bighorn Basin axis depicted by Osterwald and Dean (1961, Pl. 28) coincides with the axis of the East Fork Syncline from sec. 22, T.45N., R.90W., to a point in the W½ sec. 1, T.45N., R.92W. Here, I have continued the synclinal axis northwestward, following surface trends. It is probable that the Osterwald and Dean (1961) axis of the Bighorn Basin follows subsurface trends that parallel Fourteenmile Anticline (Wyoming Geological Association, 1957, p. 182), a trend that is not reflected in surface rocks that I studied between Gooseberry and Little Gooseberry Creeks.

NEIBER ANTICLINE

Neiber Anticline is a well-known structure that was first delimited by Hewett and Lupton (1917). It is at least 25 miles long and is mildly asymmetrical to the south, with local dips on that limb exceeding 15°. In the subsurface, this steep southern limb has been reverse faulted over much of the length of the structure (Wyoming Geological Association, 1957).

Neiber Anticline plunges to the east in secs. 22, 23, 26, 27, 34, and 35, T.45N., R.91W. (Pl. 1), but extends to the west across the Bighorn River valley and out of the report area.

NEIBER SYNCLINE

Neiber Syncline is at least 27 miles long, and its axis closely parallels that of Neiber Anticline (Pl.1). The structure becomes a monocline in secs. 35 and 36, T.45N., R.91W., where it merges with north-dipping Polecat Bench rocks on the south limb of East Fork Syncline and, to the south, on the Honeycombs Divide.

The axis of Neiber Syncline is offset by two high angle normal faults in secs. 27-29 and 32-34, T.45N., R92W. These faults may coincide with a large normal fault that offsets upper Cody and lower Mesaverde rocks in secs. 19, 30, and 31, T.44N., R.92W. (see Weitz and Love, 1952).

Divergent dips on Neiber Syncline were measured as far west as sec. 10, T.45N., R.95W., where the structure apparently becomes a monocline and merges with north-dipping Willwood rocks on the northeastern flank of Blue Mesa (Pl. 1). Dips measured on the structure vary from 4-7° on the south limb to 11-15° on the north limb.

WEST WORLAND DOME

West Worland Dome is a small, doubly-plunging structure about 5 miles long that has good expression in the surface Willwood Formation in the S½ T.47N., R.93W., west of Worland (Pl. 1). Dips of 9°ESE were recorded on the east plunge of the dome in the SE¼ sec. 27, T.47N., R.93W., and dips of 5° W and 6° NNW on the west plunge in secs. 21 and 29, respectively.

West Worland Dome is covered by alluvium in the Bighorn River valley and on the Banjo Flats surface, south and southeast of Worland, but the structure probably constitutes a closure that is continuous with the NW trending Banjo Anticline. Willwood rocks in sec. 1, T.47N., R.94W. dip gently northwest off this structure.

TENSLEEP FAULT

The Tensleep Fault (see, *e.g.*, Wilson, 1938; Rogers, *et al.*, 1948) is a major east-west lineament that originates at the eastern margin of the Bighorn Mountains (but see Hoppin and Jennings, 1971, p. 42). The fault is continuous across the Bighorn Range (*e.g.*, Hoppin *et al.*, 1965) and is best expressed in the Bighorn Basin border belt by its markedly asymmetrical displacement of Chugwater and younger Mesozoic rocks on Signal Butte, west of the town of Ten Sleep. The fault is covered by

Tertiary rocks in the central Bighorn Basin, but Hodgson (1965) has suggested that the structure may continue westward entirely across the basin.

The locus of the Tensleep Fault extends west of the town of Ten Sleep and transects the northern part of the Sand Creek — No Water Creek area in the Meyer Gulch, No Water Creek, and Slick Creek oil and gas fields (see Pedry, 1975, Fig. 2). The fault does not offset Tertiary rocks in the Sand Creek — No Water Creek area, but is covered by these rocks.

The axis of the buried Slick Creek oil and gas structure (*e.g.*, Wyoming Geological Association, 1957 and supplements) trends almost due east-west, paralleling the Tensleep Fault. This orientation contrasts with the northwest bearings of Worland and Bonanza anticlines which lie north of the fault. The axis of the Sand Creek Syncline in Willwood rocks passes over the buried Tensleep Fault in sec. 31, T.47N., R.91W., but closely parallels it south and east of this intersection. The axes of Banjo Anticline and the East Fork Syncline that are also expressed in Willwood rocks roughly parallel the Tensleep Fault throughout their long courses, matching several irregularities of bearing (see Pl. 1 and Pedry, 1975, Fig. 2). These relationships clearly demonstrate basement control of both pre-Tertiary and post-Willwood folding in the northern part of the Sand Creek — No Water Creek area.

BIGHORN BASIN AXIS

The axis of the Bighorn Basin syncline is a major structural feature that is, in the area of this report, developed south of the Tensleep Fault. An examination of folds expressed in Willwood rocks shows that the Bighorn Basin axis demarks the southern limit of the effect of the Tensleep Fault on the contour and bearing of folds in Tertiary rocks. This is further suggested by the relatively straight axes of Neiber Anticline and Neiber Syncline.

OTHER AREAS OF TERTIARY OUTCROP IN THE BIGHORN BASIN

LANCE — POLECAT BENCH UNCONFORMITY

Along the margins of the Bighorn Basin, the Polecat Bench Formation typically truncates Lance

and older rocks (Jepsen and Van Houten, 1947). Hewett (1926), however, did not observe this relationship in either the Meeteetse area or in the Grass Creek Basin. Jepsen (1930b) described an "erosional disconformity" between the "Fort Union" and Lance formations on the east end of the Polecat Bench. The angular relationship between the two formations is best exposed on the south banks of Dry Creek and the Greybull River, west and southwest, respectively, of Greybull, Wyoming.

My reconnaissance mapping investigations indicate that Polecat Bench and Lance rocks do not have an angular relationship throughout much, if not most, of the south-central Bighorn Basin southwest of the area of this report.

POLECAT BENCH — WILLWOOD CONTACT

The Willwood Formation overlies the Polecat Bench Formation with a slight angular unconformity in several areas of the Bighorn Basin. In many areas, however, younger Willwood rocks have overlapped the Paleocene sequence (*e.g.*, at Heart Mountain and at Hole-in-the-Ground).

Sinclair and Granger (1912, p. 59) observed that the "...red banded Knight beds with *Eohippus*..." overlie more steeply dipping "Laramie" with a slight discordance in strike on the southwest slopes of McCulloch Peaks, east of Cody.

Hewett (1926, Pl. XVI) illustrated a gradational angular unconformity between "Wasatch" (=Willwood) and "Fort Union" (=Polecat Bench) rocks in sec. 5, T.46N., R.97W. Angular or erosional disconformities typify the contact between Willwood and older rocks in T.44-45N., R.99W., and near Sleeper's Ranch on the Meeteetse Divide.

The lowest beds of the Willwood Formation appear to be truncated by younger Willwood beds in secs. 29 and 32, T.51N., R.93W., in the drainage of Antelope Creek southwest of Basin, Wyoming.

STRUCTURES EXPRESSED IN WILLWOOD ROCKS

Folded Willwood rocks in the McCulloch Peaks Syncline east of Cody (Sinclair and Granger, 1912), Frisby Dome southwest of Basin, Neiber Syncline south of Worland, and the gentle basinward dip of Willwood and Tatman rocks on the Hillberry Rim, Squaw Buttes, and East Ridge Divides are evidence of significant post-Willwood deformation. Anticlinal structures expressed in Willwood rocks are not, however, restricted to the basin margins or to its folded border belt. Gentle, plunging *en echelon* folds are developed on Willwood rocks throughout much of the central Bighorn Basin. Most of these structures remain to be adequately defined.

The Elk Creek Anticline (Sinclair and Granger, 1911), one of the most obvious and best documented of these structures, is a broad, asymmetrical fold that is best developed in the SW¼ T.51N., R.94W., and NW¼ T.50N., R.94W., southwest of Basin. This anticline trends approximately N30°E, manifests dips ranging from 3-5° to more than 20° in sec. 32, T.51N., R.94W., and plunges to the southwest in secs. 31-33, T.51N., R.94W., and secs. 3-9, T.50N., R.94W.

The variable dips on this fold, coupled with areas of poor outcrop, have complicated stratigraphic correlation in the valleys of the Middle and South forks of Elk Creek (see CORRELATION).

STRUCTURAL HISTORY

The strong deformation of pre-Tertiary rocks in the Sand Creek — No Water Creek area that is evident in the border fold belt does not die out toward the basin axis as is suggested by the attitudes of surface rocks in the Honeycombs and by shallow dips observed for Eocene rocks farther west and north. Rather, these folds continue beneath the erosional Polecat Bench — Lance unconformity as a series of breached structures whose subsurface trends have been mapped using structure contours derived from seismic data on reservoir or marker beds. These seismically mapped anticlines, synclines, and domes do not, in the main, coincide with more gently dipping surface trends (*e.g.*, Harris, 1952 a, b; Summerford, 1952; Wold, 1952; Wyoming Geological Association, 1957 and supplements; Pedry, 1975), and sometimes depart radically from these trends (Osterwald and Dean, 1961, Pl. 28).

The evidence from folded rocks in the southeastern Bighorn Basin suggests that at least three episodes of Laramide border belt deformation occurred. The earliest of these is reflected in buried structures developed on Montana Group and older rocks that lie beneath the Lance — Polecat Bench unconformity. Abrupt strike changes in pre-Tertiary rocks in the SE¼ T.44N., R.89W. (Pl. 1) define the Bighorn Basin axis during this deformation.

The local development of an angular unconformity between the Willwood and Polecat Bench formations implies that a second period of folding occurred slightly before or during earliest Willwood deposition. It is unlikely that these unconformable relationships are all temporally equivalent; and, as suggested by Stearns (1975, p. 150), it is possible that they represent the differential folding of borderlands adjacent to tectonically mobile but structurally disjunct mountain blocks.

Folded Willwood rocks in the Sand Creek — No Water Creek area and elsewhere in the Bighorn Basin record a post-Paleocene episode of deformation. The gentle inclination of Tatman rocks on the Squaw Buttes Divide indicates that some of this folding took place in post-Tatman time. Loomis (1907b) believed that the high dips of "Wasatch" strata adjoining the Owl Creek Mountains (up to 23°) suggest that these mountains had been somewhat elevated since the affected beds were laid down. Jepsen and Van Houten (1947) thought that the gentle basinward dips of the border Willwood reflected basin subsidence as well as minor uplift of the peripheral fold mountains.

The absence of an angular relationship between the Lance and Polecat Bench formations in much of the south-central Bighorn Basin indicates that the Owl Creek arch (south of the report area) was not very active in earliest Tertiary time. This interpretation is consistent with the interpretations of Love (1960) and others that the major drainage of the Bighorn Basin in the Paleocene and earliest

Eocene was to the southeast. The major unconformity between these rocks elsewhere in the Bighorn Basin suggests that the Bighorn and Beartooth Mountains were tectonically active for a period following Lance deposition. The Owl Creek arch was not very active during earliest Willwood deposition, however, and Keefer and Troyer (1956) have demonstrated that the central and eastern Owl Creek Mountains may not have been substantially uplifted until post-Indian Meadows time. If their interpretation is correct, this schedule of orogenic activity is consistent with the absence of an angular relationship between the Willwood and Polecat Bench formations in the south-central Bighorn Basin and with the tilted Willwood rocks bordering the Owl Creek Mountains.

Hoppin and Jennings (1971) and Hoppin (1974) observed that fold asymmetries reverse across the Tensleep Fault. North of the fault, the border belt folds have steep east flanks and south of the fault the folds are asymmetrical to the west. Structural contour maps of oil and gas structures that lie beneath the Lance — Polecat Bench unconformity in the Sand Creek — No Water Creek area demonstrate that most of these structures have steep east or northeast flanks even though they lie south of the Tensleep Fault.

The bearings of the folds proximal to the Tensleep Fault are obviously related to the fault (see above). Their asymmetry appears, however, to be geometrically more closely related to the position of the Bighorn Basin axis (see Fanshawe, 1952, p. 21).

SEDIMENTARY GEOLOGY

INTRODUCTION

DEFINITION OF WILLWOOD FORMATION

Van Houten (1944) proposed the name Willwood Formation for about 760 meters (2,500 feet) of red banded Early Tertiary rocks in the Bighorn Basin. This term supplanted the "Big Horn Wasatch" of Wood, *et al.* (1941) and earlier workers. Van Houten named no type section; however, he named the formation for a well exposed sequence of these rocks south of the town of Willwood, Park County, Wyoming.

Van Houten proposed that the first occurrence of red banding was the best criterion to distinguish the lowest beds of the Willwood from the upper beds of the Polecat Bench Formation. Jepsen and Van Houten (1947) and Neasham (1970) also noted these color differences; however, Jepsen and Van Houten observed that Willwood sediments also have a greater range of grain size and form thinner and less persistent beds than their Polecat Bench counterparts.

I have observed that the following characteristics are most useful in distinguishing Willwood and Polecat Bench rocks in the field (excluding Willwood rocks in the Clarks Fork Basin):

Willwood Formation	Polecat Bench Formation
1. Red and purple mud-stones occur within a variegated sequence.	Red and purple mudstones are rare or absent.
2 Apron-channel sand-stones (see below) are common; sheet sand-stones are rare.	Sheet sandstones are common in the lower part of the section; apron-channel sandstones are rare.
3 Calcium carbonate and red or purple ferric iron nodules are locally common.	Calcium carbonate and red or purple ferric iron nodules are rare. Yellow, brown, or black ferric iron nodules are locally common.
4 Colored mudstone beds are less persistent than in the Polecat Bench Formation.	Colored mudstone beds are more persistent than in the Willwood Formation.

GEOLOGIC MAP

The areal distributions of Early Tertiary and adjoining Late Cretaceous rocks in the Sand Creek — No Water Creek area were mapped at a scale of 1:24,000 and compiled at a scale of 1:160,000 (Pl. 1). The "Geologic Map of the Southern Bighorn Basin" (Weitz and Love, 1952) was used as a base in the compilation of the final map. The characteristics listed above were used to establish the base of the Willwood Formation. The solid contacts were walked out in the field. The dashed contacts were established by reconnaissance mapping or were transferred from the maps of Weitz and Love (1952) and Horn (1963).

I believe that the large distribution of Willwood rocks depicted on the map of Weitz and Love (1952) resulted from the incorrect identification of clinkered mudstones as the lowest red beds of the Willwood Formation. Clinker beds (Fig. 1a) occur at various levels in the Polecat Bench Formation. Red beds, however, do occur infrequently at levels well beneath those that most authors familiar with these rocks would consider to be Willwood strata. These red beds are solitary occurrences surrounded by thick sections of drab strata, or are rare mottled zones in drab strata. Thin and impersistent pale red mudstones (two units) were encountered in the upper part of the Polecat Bench Formation in the SE¼ sec. 23, T.49N., R.92W., and in secs. 21 and 29, T.49N., R.90W., Washakie County.

GENERAL STATEMENT

The Willwood Formation is a variegated fluviatile deposit characterized by heterogeneity of lithology and of grain size. The formation consists dominantly of pastel-colored mudstones and gray and yellow sandstones, with a few carbonaceous mudstones, carbonaceous paper shales, and local conglomerates. The sandstones invariably have erosional lower contacts and the mudstones usually have sharp or mottled contacts. All units are laterally impersistent.

The central basin Willwood Formation is conformably overlain by the Tatman Formation (Sinclair and Granger, 1912; Van Houten, 1944), a dominantly lacustrine unit of green and brown shales, carbonaceous shales, drab mudstones, and brown or yellow sandstones. Willwood and Tatman rocks intertongue at several points on the Squaw Buttes Divide (west of Dutch Nick Flat).

Formal stratigraphic subdivision of the Willwood Formation has not been attempted by previous workers. Sinclair and Granger (1911) observed no significant lithologic changes from "Wasatch" to "Wind River" faunal horizons recognized by them in the Bighorn Basin. It seems doubtful that stratigraphic division of the Willwood Formation can ever be accomplished without the arbitrary use of marker beds (see, e.g., Rohrer and Gazin, 1965). The thicknesses and numerical proportions of red mudstones, however, increase dramatically at successively higher levels of the Willwood Formation.

The lowest 1,000-1,200 feet of the formation in the Elk Creek — Tatman Mountain section (Neasham and Vondra, 1972) offer the most brilliantly variegated mudstones in the Willwood section. Above the 1,200 foot level, about 95% of all units are orange, red, or purple mudstones or drab sandstones. Orange mudstones are increasingly less frequent above about the 1,800 foot level. The upper part of the Willwood section in the Buffalo Basin is dominated by red, purple, and gray rocks, and the top 300-400 feet of the section is formed almost exclusively of red and gray mudstone and drab sandstone.

The subdivision of the Willwood Formation into color-dominant suites is, therefore, possible. These suites intertongue and constitute facies in the broad sense, and can be defined and delimited with the goal of reconstructing their separate paleoenvironments. The Sand Creek facies and the Elk Creek facies are two such suites, and intertongue in the report area.

Figure 2. Sand Creek Master Section: schematic composite sections of Willwood rocks exposed in the northern Sand Creek Basin. Numbers to the left of the graphic columns indicate stratigraphic positions of vertebrate fossil localities discussed in the text. The suffix "L" following a fossil locality number denotes the stratigraphic position of the locality but indicates that the locality does not occur in the bed indicated. Numbers and letters to the right of the graphic column indicate the ordinal number of each unit above the base of the Willwood Formation. Stippled units are sandstones; alternating stippled-and-dashed units and blank units are mudstones; lined units are carbonaceous shales; stippled and obliquely lined units indicate casehardened, calcareous sandstone.
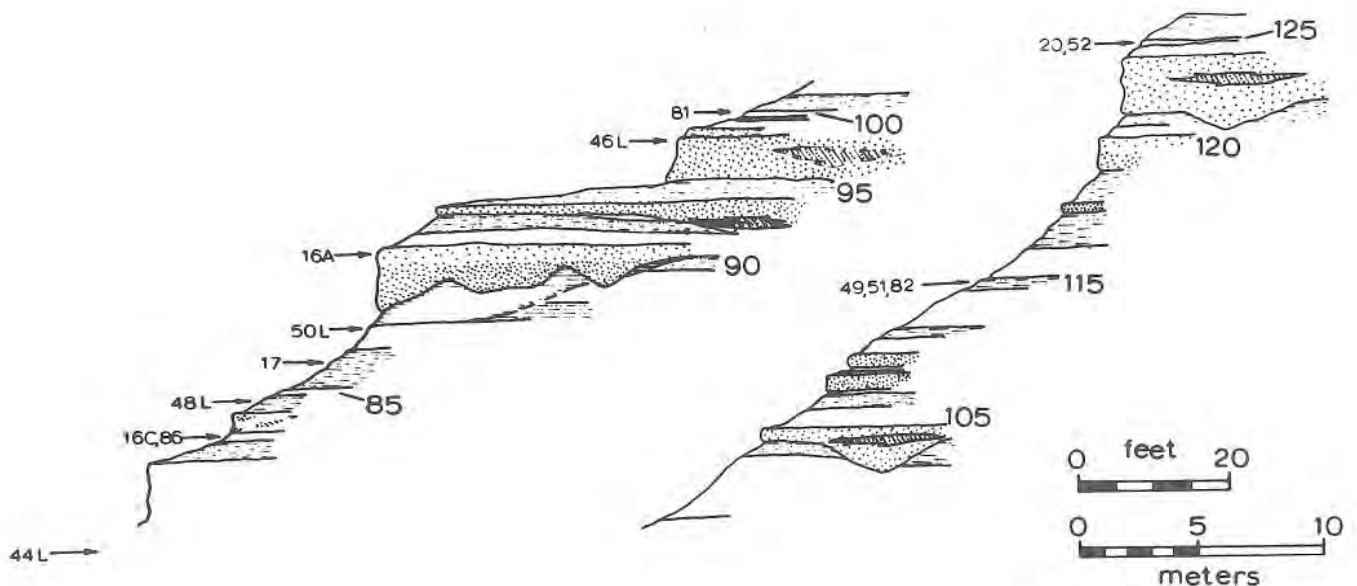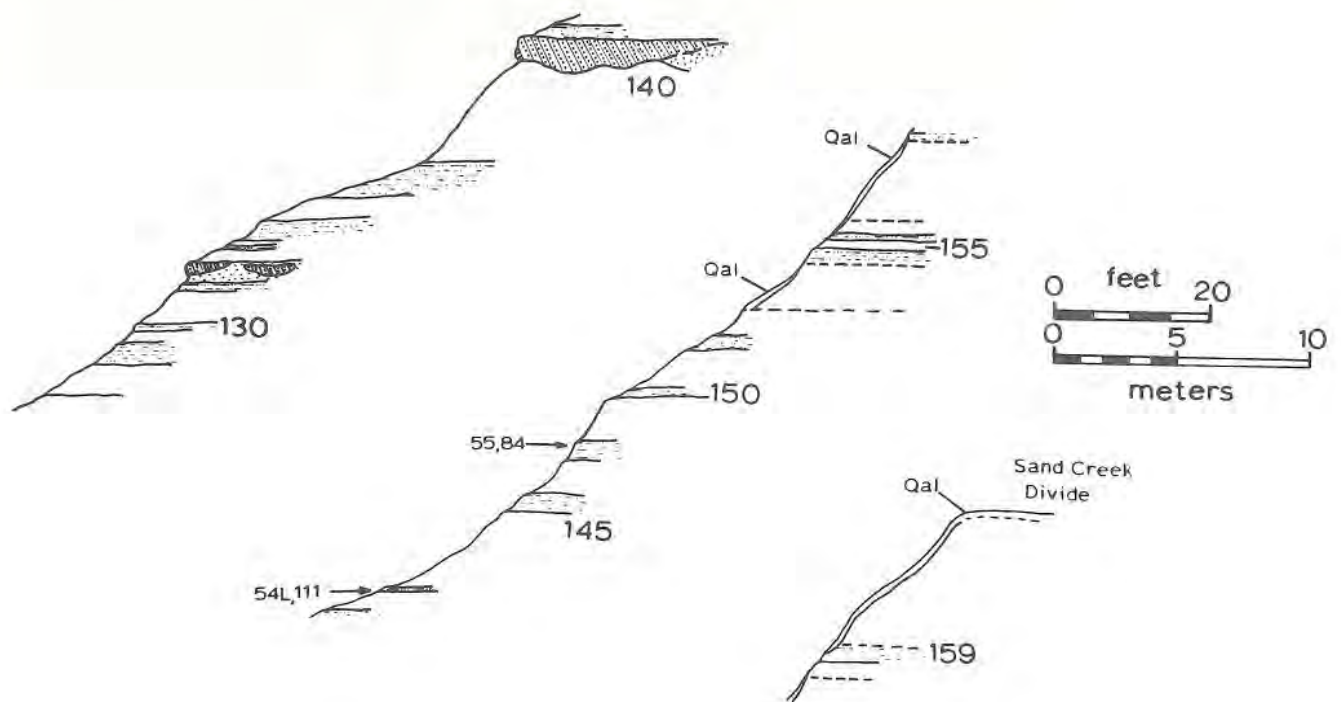
ELK CREEK FACIES

DISTINCTIVE CHARACTERISTICS

Mudstone beds are relatively thick in the Elk Creek facies ($\overline{X}$ = 1.72 meters, N = 300 beds) and are dominanted by red and orange mudstones (41 percent) and by calcium carbonate cemented sandstones (26 percent). The colored mudstones have brighter tones and a smaller mean grain size than their counterparts in the Sand Creek facies. The sandstones are dominantly of the apron-channel variety (see below); shoestring and sheet sandstones are rare. Calcium carbonate nodules

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comprise up to 99 percent of concretionary and nodular litter on exposed rock. The colored mudstone and sandstone cyclothem of the Elk Creek facies is strongly Markovian and differs in relative proportions of recognized units from the Sand Creek facies cyclothem. In the Elk Creek facies, approximately 10 percent of vertebrate fossil specimens occur in Class A gray mudstone units, about 17 percent are associated with purple mudstones, and about 72 percent occur in thin gray mudstones that alternate with thicker orange mudstones.

DISTRIBUTION

The Elk Creek facies is widely distributed throughout the central Bighorn Basin. The best sections are developed: (1) in the drainages of Elk, Antelope, and Dorsey creeks, west of the town of Basin; (2) in the lower drainage of Fifteenmile Creek, west of the town of Worland; (3) on and adjacent to the Y-U and Emblem benches, on Bridger Butte, and in the drainages of Foster, Coon, and Whistle creeks, between Greybull and Cody and north of Emblem (see Robinove and Langford, 1963); and (4) in the type area of the Willwood on and adjacent to the McCulloch Peaks Divide, south of Willwood.

This distribution is specifically meant to exclude the following areas of exposure: (1) the upper 305 meters (1,000 feet) of the Willwood as exposed in the Buffalo Basin between and on the Squaw Buttes Divide and the Tatman Mountain table; (2) Willwood exposures in the Clark's Fork Basin; (3) conglomeratic Willwood sequences along the Beartooth Mountain front (see, *e.g.*, Pierce, 1965; Bredall, 1971), on Meeteetse and Hillberry rims (Neasham and Vondra, 1972), and on and adjacent to Blue Mesa (see, *e.g.*, Hewett, 1926; Young, 1971); and (4) Willwood rocks exposed along the Shoshone River, west of Cody, (see, *e.g.*, Hewett, 1914; Jepsen, 1939), and those exposed adjacent to and underneath the eastern Absaroka volcanic field (see, *e.g.*, Hewett, 1914, 1926; Pierce and Andrews, 1941; Rohrer, 1966; Wilson, 1970).

SAND CREEK FACIES

DISTINCTIVE CHARACTERISTICS

Mudstone beds of the Sand Creek facies are thinner ($\overline{X}$ = 0.81 meters, N = 306 beds) than those

of the Elk Creek facies and are dominated by purple and gray mudstones (22 percent and 21 percent, respectively), and by friable sandstone (22 percent). Sandstones of the Sand Creek facies are only rarely cemented with calcium carbonate. Orange mudstone (15 percent) and red mudstone (5.8 percent) are less prevalent than in the Elk Creek facies (27 percent and 14 percent, respectively). Colored mudstones have paler tones and a slightly coarser mean grain size than those of the Elk Creek facies. Sandstone geometry is dominated by apron-channels with a subordinate number of shoestring bodies. Sheet sandstones do not occur in the Sand Creek facies. Calcium carbonate nodules comprise none of concretionary and nodular litter on exposed rock. The Sand Creek facies cyclothem is Markovian and differs from that of the Elk Creek facies in the relative proportions of recognized units. In the Sand Creek facies, approximately 90 percent of vertebrate fossil specimens occur in Class A gray mudstones, about 7 percent in mottled purple and orange mudstones, and only 2 percent in sandstones or orange mudstones.

DISTRIBUTION

The Sand Creek facies comprises the whole of the Willwood section exposed east of the Bighorn River with the exception of Willwood rocks preserved along the axis of Neiber Syncline (Pl. 1). There, about 30-45 meters of the basal Willwood Formation is composed dominantly of gray mudstone and carbonate cemented sandstone with a few beds of colored mudstone and thin stringers of conglomerate. Several red mudstones occur in this section, and about one-third of the mudstone exposures are littered with calcium carbonate nodules. Most of the colored mudstones, however, are pale in hue, and this section is believed to represent a transitional sequence that possesses characteristics of both the Sand Creek and Elk Creek facies.

West of the Bighorn River, rocks of the Sand Creek facies intertongue with a thick sequence of sandstones, conglomeratic sandstones, and thin mudstones along and south of the drainage of Little Gooseberry Creek. North of this drainage, in an area extending approximately five miles west of the Bighorn River, the Sand Creek facies intertongues with thick red and orange mudstones and calcium carbonate cemented sandstones of the Elk

Creek facies. This transition is best observed in exposures developed along West Worland Dome in the drainage of Fifteenmile Creek, west of Worland (Pl. 1). Rocks of the 165-250-meter level of the Willwood Formation are exposed here along the breached axis of the dome and represent the upper part of the Sand Creek facies and the lower part of the Elk Creek facies.

STRATIGRAPHIC SECTIONS

Thirty-nine stratigraphic sections were measured and described for rocks of the Sand Creek facies. These were combined into three major composite sections, here termed the Sand Creek Basin Master Section, the East Sand Creek Basin Section, and the Slick Creek Basin Section (see Figs. 2-4). The preserved portion of the Sand Creek facies east of the Bighorn River is approximately 135 meters (445 feet) thick. About 250 meters of the Sand Creek facies intertongues with the Elk Creek facies west of Worland.

The locations of the sections were established by the limitations of surface outcrops and by the dispersion of fossil localities. The lines of section therefore include the most continuous exposures that may be transected and still allow the stratigraphic documentation of as many vertebrate fossil localities as possible.

The base of the Willwood Formation is exposed in the SW¼ sec. 16, T.47N., R.91W., and a point on this contact is the control point for all described estimates of stratal thickness. The East Sand Creek Basin Section was begun in Willwood rocks in the SE¼ NE¼ SE¼ sec. 33, T.47N., R.91W., and joins the Sand Creek Basin Master Section in the SW¼ SW¼ NW¼ sec. 4, T.46N., R.91W.

The base of the Willwood Formation is not exposed in the Slick Creek Basin. The Slick Creek Basin Section was begun in lower Willwood rocks in the SW¼ NE¼ NW¼ sec. 35, T.47N., R.92W., and was measured southeastward and eastward to the NE¼ SW¼ SW¼ sec. 31, T.47N., R.91W., at the top of the Sand Creek Divide. Estimates of strike and dip were obtained, and the thickness of
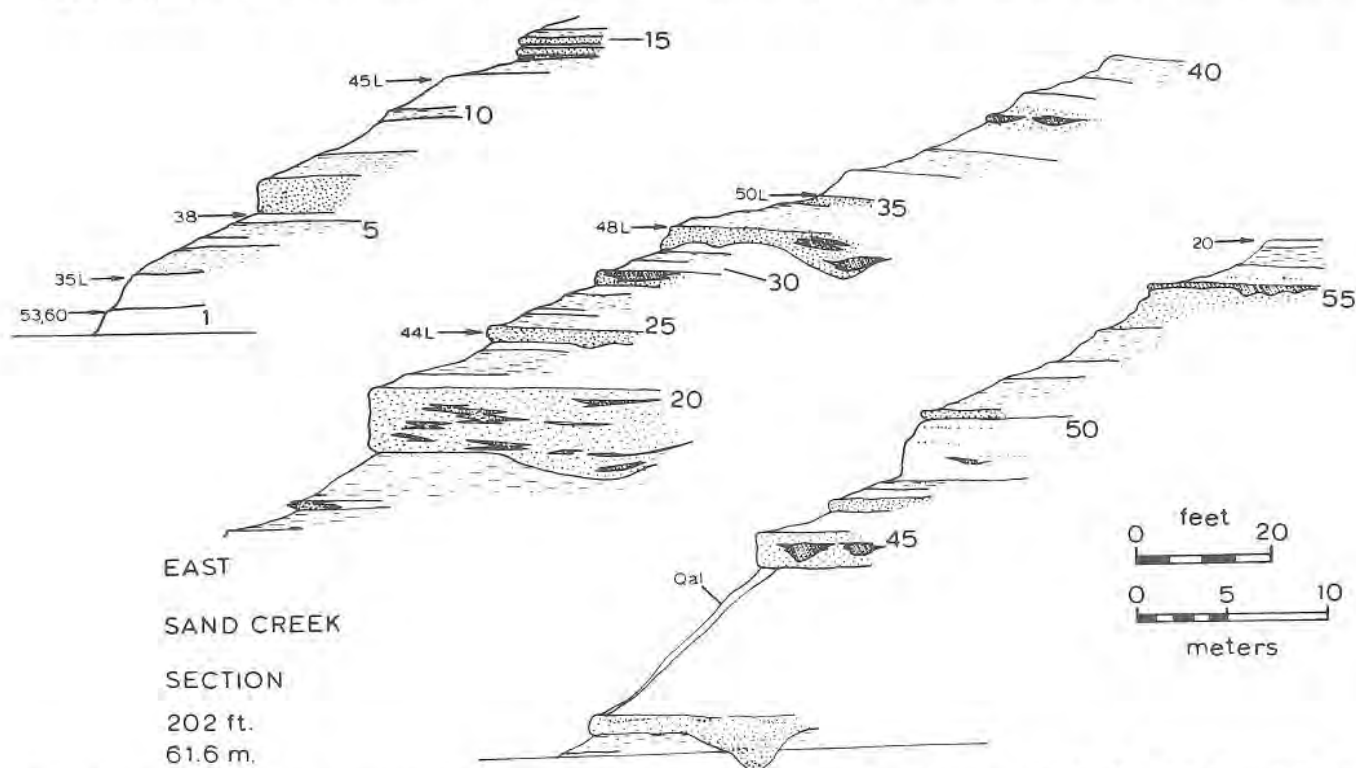
Figure 3. East Sand Creek Section: schematic composite sections of Willwood rocks exposed in the East Sand Creek Basin. Numbers to the left of the columns indicate stratigraphic positions of vertebrate fossil localities discussed in the text. The suffix "L" following a fossil locality number denotes the stratigraphic position of that locality but indicates that the fossils do not occur in the bed indicated. Numbers and letters to the right of the column indicate the ordinal number of each unit above the base of the East Sand Creek Section. Stippled units are sandstones; alternating stippled-and-dashed units and blank units are mudstones; lined units are carbonaceous shales; stippled and obliquely lined units indicate casehardened, calcareous sandstone.

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the intervening covered strata between the two sections was then calculated trigonometrically. The covered interval (about 12 meters) was checked by walking out beds along the southwest, south, and east margins of the Sand Creek Divide. A final check was made by measuring the stratigraphic distance from fossil locality 30 to the top of the divide a few hundred yards to the west. It was possible, by this procedure, to locate the same fossil producing layer (a Class A gray bed) on the west side of the divide and then to trace this unit southward into the upper part of the Slick Creek Basin section. I obtained an estimate of stratigraphic separation between the tops of the two sections of about 10 meters, a figure close to the 12 meters obtained by trigonometric methods.

It is likely that a slight depositional dip has resulted in the gradual westward thickening of the Willwood Formation and that the Willwood section in the Sand Creek Basin can be expected to be slightly thinner than that in the Slick Creek Basin. This possibility can be further explored only by an examination of surface sections with reference to good subsurface data. Unfortunately, only five of more than 200 oil and gas wells in this area have records for Tertiary stratal thickness (AMSTRAT, Inc., 1976, written communication).

MEASUREMENT AND DESCRIPTIVE TECHNIQUES

The stratigraphic sections were measured using the Jacob's staff technique described by Low (1957) and the Brunton compass and tape procedure (see, *e.g.*, Compton, 1962). Additional control was obtained by solving for total section thicknesses trigonometrically (see Compton, 1962, p. 236). Because most Willwood exposures in the report area are developed at very low dips (2-10°) and because few bedding surfaces are planar, it was necessary to determine attitudes by (1) the derivation true dips from apparent dips, (2) the measurement of approximate attitudes, and (3) the solution of true attitudes by the three-point method (see, *e.g.*, Badgley, 1959).

The procedure for describing a section was as follows: (1) a base for the desired section was located and the attitude of the rocks was determined; (2) the basal unit and the superjacent unit were described and measured; (3) the basal unit was traced laterally as far as possible in the direction of the most completely exposed and continuous section; and (4) the next superjacent unit was described and measured and a new attitude calculated if necessary, and the subjacent unit was
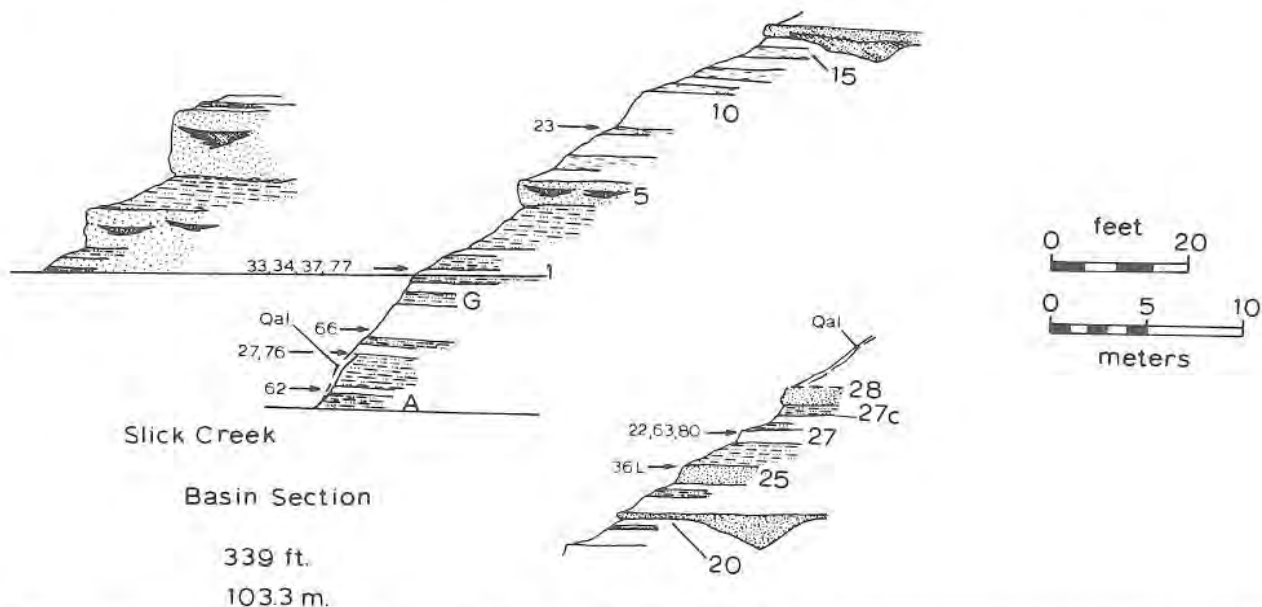
Figure 4. Slick Creek Basin Section: schematic composite sections of Willwood rocks exposed in the Slick Creek Basin. Numbers to the left of the columns indicate stratigraphic positions of vertebrate fossil localities discussed in the text. The suffix "L" following a fossil locality number denotes the stratigraphic position of that locality but indicates that the fossils do not occur in the bed indicated. Numbers and letters to the right of the graphic columns indicate the ordinal number of each unit above the base of the Slick Creek Basin section. Stippled units are sandstones; alternating stippled-and-dashed units and blank units are mudstones; lined units are carbonaceous shales; stippled and obliquely lined units are casehardened, calcareous sandstones.

16

?30L, 84

70

65

Sand
Creek
Divide

Qal

60

79

75

feet
0   20

0   5   10
meters

Qal

Qal

40

Qal

35

24L

27

55

feet
0   20

50

0   5   10
meters

30

45

Qal
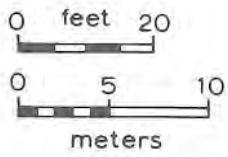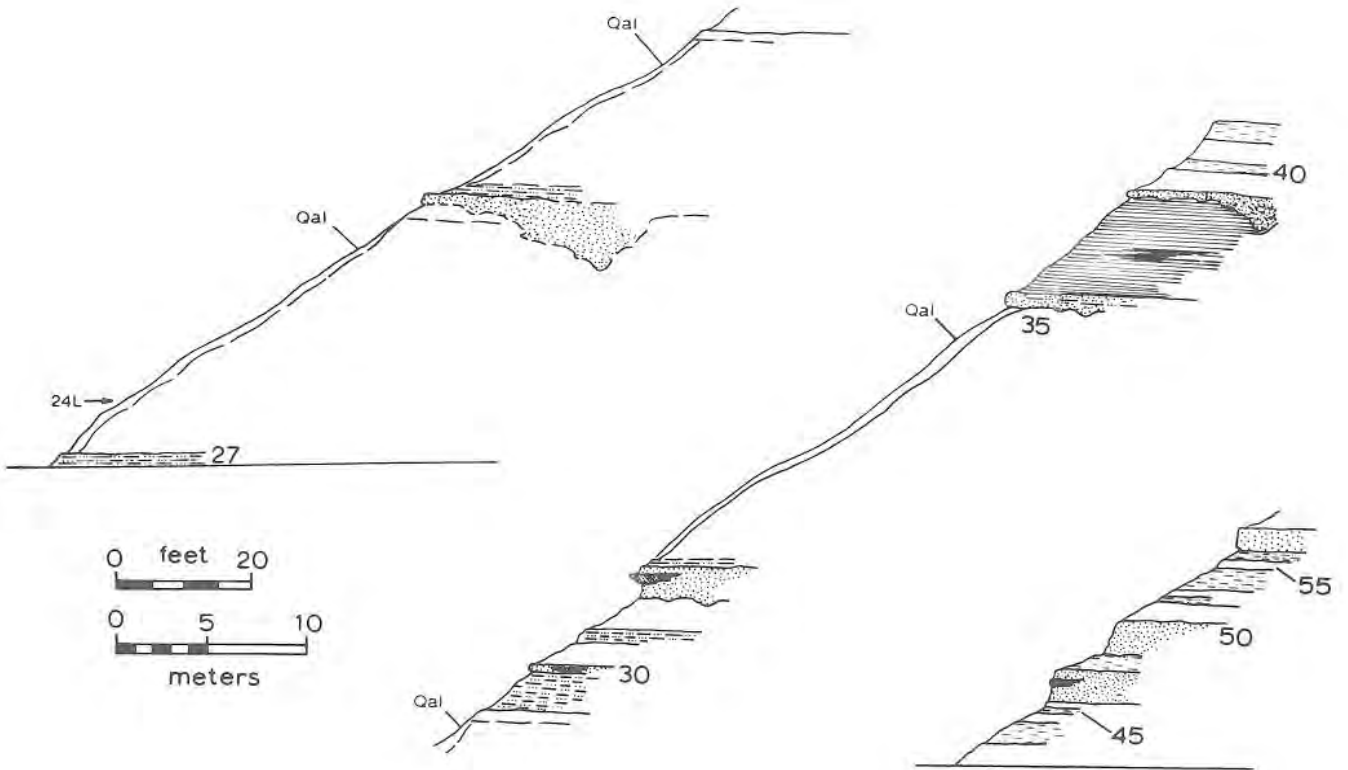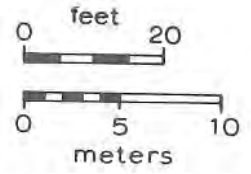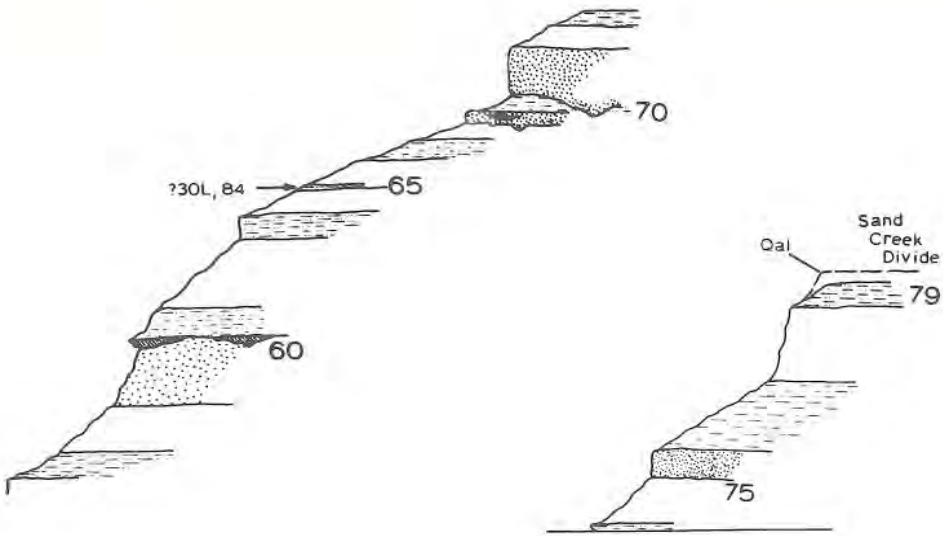
measured and described again at the new locality. Bedding irregularities, lateral thickening and thinning of units, and the relative positions of fossil localities were noted during procedure 3.

In areas of high relief, the units were described in vertical succession until it was necessary to relocate the section laterally to provide continuity of succession.

Lithologies recognized were sandstones, mudstones, and shales. Multistory mudstone units were recognized and were distinguished in the field on the basis of color. Multistory colored mudstones (stories of the same color) were not recognized. Multistory sandstone units occur as different stratification types that may be developed together in a single sandstone body. (For an explanation of multistory sequences, see, *e.g.*, Schwarzacher, 1975.)

Samples were taken at irregular intervals from the color differentiated mudstones and from the sandstones and shales. More detailed sampling is described below for each of these units.

Graphic sections of Willwood rocks of the Sand Creek facies are presented in Figures 2-4. Detailed field descriptions of all units are in preparation by the present author.

MECHANICAL AND GEOCHEMICAL ANALYSES

Conglomerate, sandstone, and mudstone samples were disaggregated, prepared, and analyzed following the procedure of Folk (1968) for mechanical sieve and pipette analyses. The sandstones, mudstones, and the sand fraction of the conglomerates were analyzed for composition by X-ray diffractometry (72 samples) and by thin section studies (9 samples of sandstone).

Weight percentages of free iron, manganese, and organic and inorganic carbon were calculated for 17 units of color differentiated mudstones. Free iron and manganese weights were obtained from disaggregated mudstone and nodule samples by the dithionate citrate extraction method (Mehra and Jackson, 1960). Total carbon percentages were determined by use of a pyrolytic carbon analyzer, and inorganic carbon was assessed using the coulometric titration method (Boniface and Jenkins, 1975).

CONGLOMERATES

Conglomerates comprise an insignificant fraction of Willwood rocks in the Sand Creek facies. No pebble or boulder conglomerates were encountered in the measured sections.

Two chert pebble and granule conglomerates were discovered during reconnaissance field work in the Sand Creek facies. Intercalated zones of chert granules and pebbles were found near the base of a medium- to coarse-grained subarkosic channel sandstone on North Butte in the NE¼ NE¼ NE¼ NW¼ sec. 30, T.46N., R.89W., approximately 90 meters above the base of the Willwood Formation.

Angular to moderately-rounded chert pebbles comprise about 5 percent of his unit (Fig. 5A) and are restricted to several 7.5-15.0-cm bands in a sandstone body approximately 2.75 meters thick. The largest clast is 20.3 mm in long diameter.

A second pebble- to granule-size conglomerate outcrops at the base of a medium-grained quartzarenite (Fig. 5B) in the NW¼ NW¼ NW¼ sec. 10, T.46N., R.91W., approximately 96 meters above the base of the Willwood. The pebbles and granules are composed about equally of angular to moderately-rounded chert and rolled mudstone fragments, and occur in two conspicuous 15.0 and 41.0 cm-thick bands.

Fossil mammal and crocodile teeth are rare clasts in the upper band. The largest clast seen in this deposit measured 7.2 mm in long diameter. Both this and the North Butte conglomeratic sandstone are cemented with calcium carbonate.

The black chert clasts are of uncertain provenance, but one large red chert clast from the North Butte conglomeratic sandstone preserves part of a colony of the schizocoral *Chaetetes*, a fossil common in the Pennsylvanian Amsden and Tensleep formations of the Bighorn Mountains.

Both of the pebble and granule conglomerates are developed as intercalations in finer grained subarkose or quartzarenite matrices. The coarse fraction occurs at or near the bases of horizontal sets or at the bases of gently inclined foreset cross beds. The grain size decreases abruptly above the zone of granule or pebble clasts.

Mud gall conglomerates occur at the bases of three channel sandstones in measured sections of the Sand Creek facies. The mud gall zones are
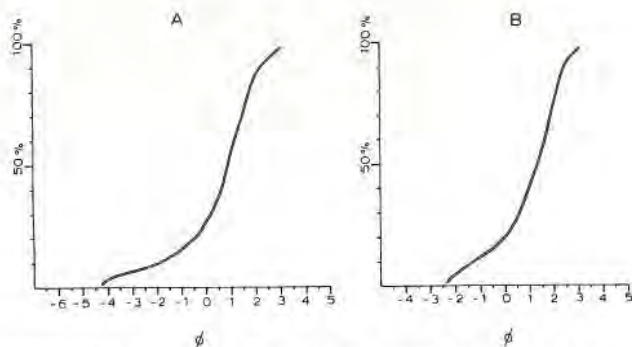
Figure 5. Cumulative percentage graph of grain sizes in two Willwood conglomerates. A. Chert pebble and granule conglomerates from North Butte, in the NE¼ NE¼NE¼NW¼ sec. 30, T.46N., R.89W., Washakie County, Wyoming. B. Chert granule and mud gall conglomerate from the NW¼NW¼NW¼ sec. 10, T.46N., R.91W., Washakie County, Wyoming.

restricted to the basal 7.5 - 61.0 cm of the channel deposits and appear to have accumulated as bedload lag deposits.

The galls are normally well rounded, and vary

in size from coarse sand particles to oblate or roller-shaped clasts up to 5.1 cm in long diameter. None of the mud galls are armored and most are gray to green (10.0 G 8/2) and may contain centers mottled with orange (2.5 Y 6/8; Munsell Color Company, 1928-1942).

SANDSTONES

Sandstones comprise approximately 22 percent by thickness of lithologies recognized in the Sand Creek facies. This percentage is slightly, but probably not significantly, smaller than that recorded by Neasham and Vondra (1972) for rocks of the Elk Creek facies in the drainages of Antelope and Elk creeks (26 percent). Three types of sandstones, distinguished by their geometry, are recognized.

SHEET SANDSTONES

Sheet sandstones (Fig. 6A) are characterized by relatively great breadth and variable but rela-
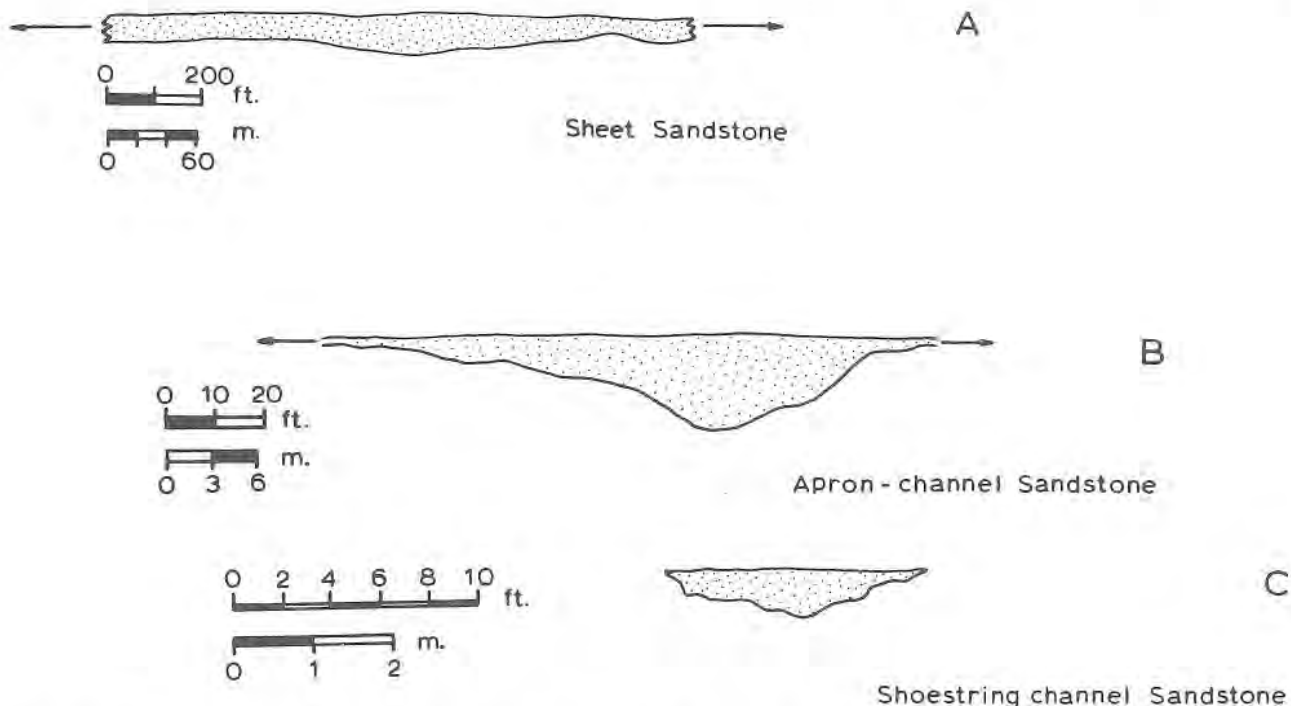
Figure 6. Willwood sandstone geometries. Sheet sandstones (A) may persist laterally for several miles with little change in thickness, and are more than an order of magnitude greater in both dimensions than apron-channel sandstones. The apron-channel sandstone figured here (B) is somewhat larger than most such units encountered in the Sand Creek facies, but is representative of several channels encountered in the Elk Creek facies. Apron-channel sandstones are commonly at least an order of magnitude larger than shoestring sandstones (C); but considerable variance in size within both forms exists. The lateral apron (B, arrows) nearly always grades laterally into a gray or green mudstone that may persist from a few hundred yards to more than a mile. Shoestring sands rarely possess a lateral apron, but are remarkably persistent in their longitudinal dimension.

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tively uniform thickness. These bodies are fluviatile variants of the "tabular sand bodies" of Krynine (1948), Johnson and Vondra (1972), Jacob (1973), and others.

Sheet sandstones are locally quite rare in Willwood rocks and are absent in the Sand Creek facies. Sheets are common in the lower part of the Polecat Bench Formation and occur occasionally in upper Willwood rocks exposed on the Squaw Buttes Divide.

Sheet sandstones commonly have horizontal or low-angle planar beds developed at the middle and bottom of the sequence, and small-scale ripple cross-stratification at the top. The basal contacts of sheet sandstones are almost always shallowly erosional and contain local scour channels.

APRON-CHANNEL SANDSTONES

Apron-channel sandstones (Fig. 6B) are volumetrically the most important sandstone bodies in the Willwood Formation and are frequently developed in the middle and upper parts of the Polecat Bench Formation. These bodies are the same as the "linear sand bodies" of Jacob (1973) and the "sheet" sandstones of Neasham (1967, 1970).

These bodies are normally at least one order of magnitude smaller than sheet sandstones and consist of a deeply-incised channel or channels and a broad, tabular apron that extends laterally from the top of the trough (Figs. 6, 7, and 8). The channel breadth-to-depth ratio varies from 2:1 to 20:1 for channel-apron sandstones in the Sand Creek facies.
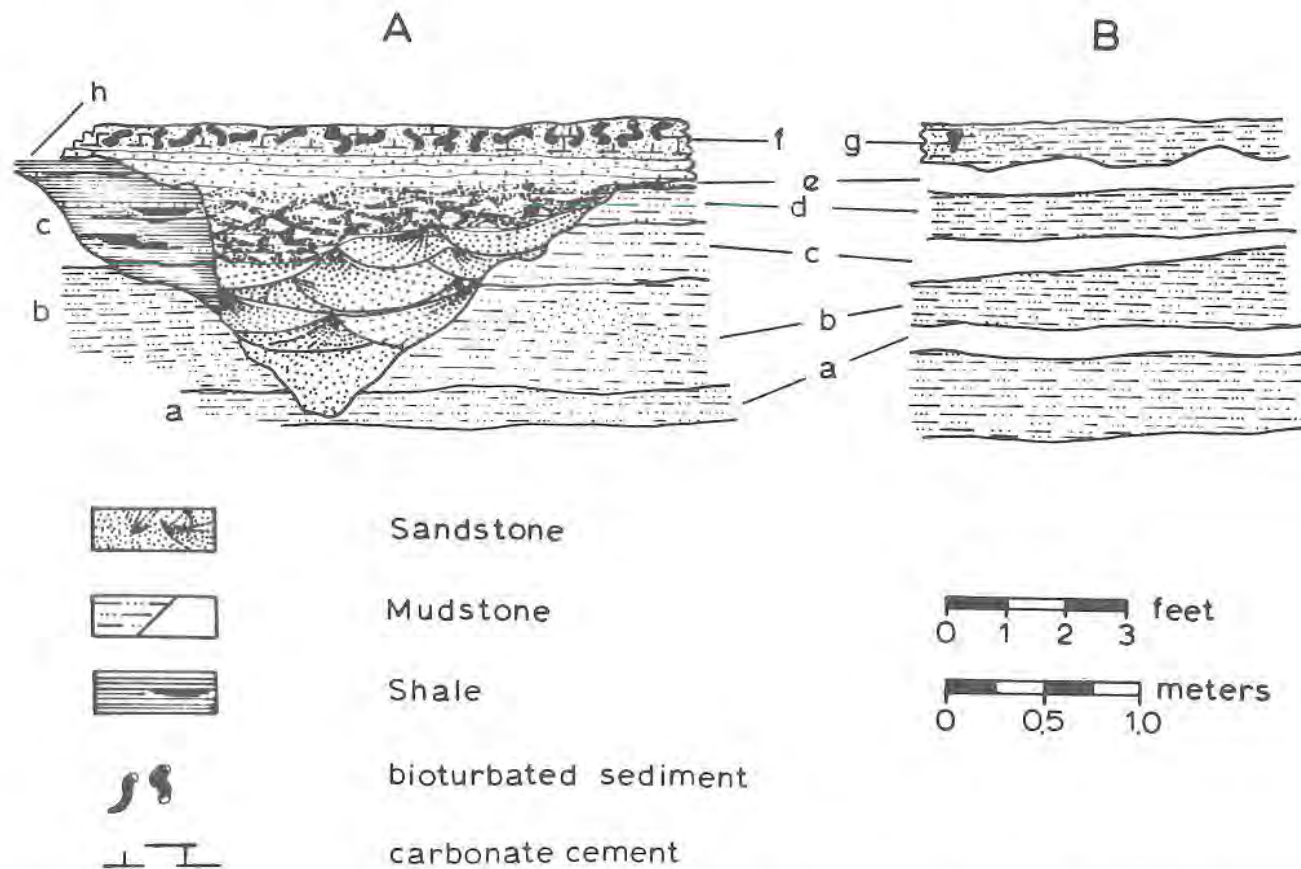
Figure 7. Diagrammatic cross section of (A) apron-channel sandstones and surrounding beds and (B) their lateral equivalents as exposed 185 feet (56 m) away along strike to the south in the NE¼NE¼ sec. 4, T.46N., R.91W., Washakie County, Wyoming. Units *f* and *g* are the apron. Unit *f*, a casehardened, bioturbated, calcareous sandstone apron, grades laterally into a mudstone unit, *g*; units *b* and *c* show variable thickness. The occurrence of carbonaceous shale *h* beneath the apron-channel sandstone is a common one. From bottom to top, the superposed stratification types developed in this channel are: massive, friable sand; large-scale erosional trough cross-stratification; small-scale erosional trough cross-stratification; horizontal stratification; and strongly calcite-indurated, casehardened, bioturbated sandstone.

Neasham and Vondra (1972) observed that the aprons extend laterally from the upper level of the channel fills up to 500 feet (152 meters) in the area studied by them; however, my observations indicate that a persistence of more than 3 km is not uncommon.

A well developed coarse-to-fine gradational sequence of sand to sandy silt to mud is developed laterally along the sandstone aprons. This grain size gradation occurs even in fine-grained deposits at relatively great distances from the channel trough (see Fig. 15). Graded bedding also commonly occurs in these aprons at least as far as 400 meters from the channel trough.

The troughs of apron-channel sandstones commonly exhibit a relatively uniform suite of sequential stratification types (Fig. 7). The basal part of the channel is usually massive; however, in the few instances where this part of the channel is well indurated, the sands usually exhibit relatively large-scale trough cross-stratification.

Large-scale trough cross-stratification is commonly succeeded by a thinner zone of tabular or relatively small-scale trough cross-stratification. The uppermost depositional sedimentary structure developed over the channel trough is frequently obliterated by bioturbation. Where bioturbation does not occur, horizontal stratification is commonly developed.

SHOESTRING SANDSTONES

Shoestring sandstone bodies are distinguished by their relatively small cross-sectional area and by a relatively high thickness-to-breadth ratio (Fig. 6C). They are common in the Sand Creek facies and usually have linear channels that are straight or broadly sinuous. One exhumed shoestring was traced for nearly 1,000 meters and maintained an essentially straight course over this distance.

Nearly all shoestring sandstones in the Sand Creek facies are 1.8 meters or less in thickness, are strongly bioturbated in their upper parts, and are casehardened with calcium carbonate and iron oxyhydrate minerals. Horizontal (Fig. 9) and tabular stratification types are most commonly represented in shoestring bodies. These sands, however,
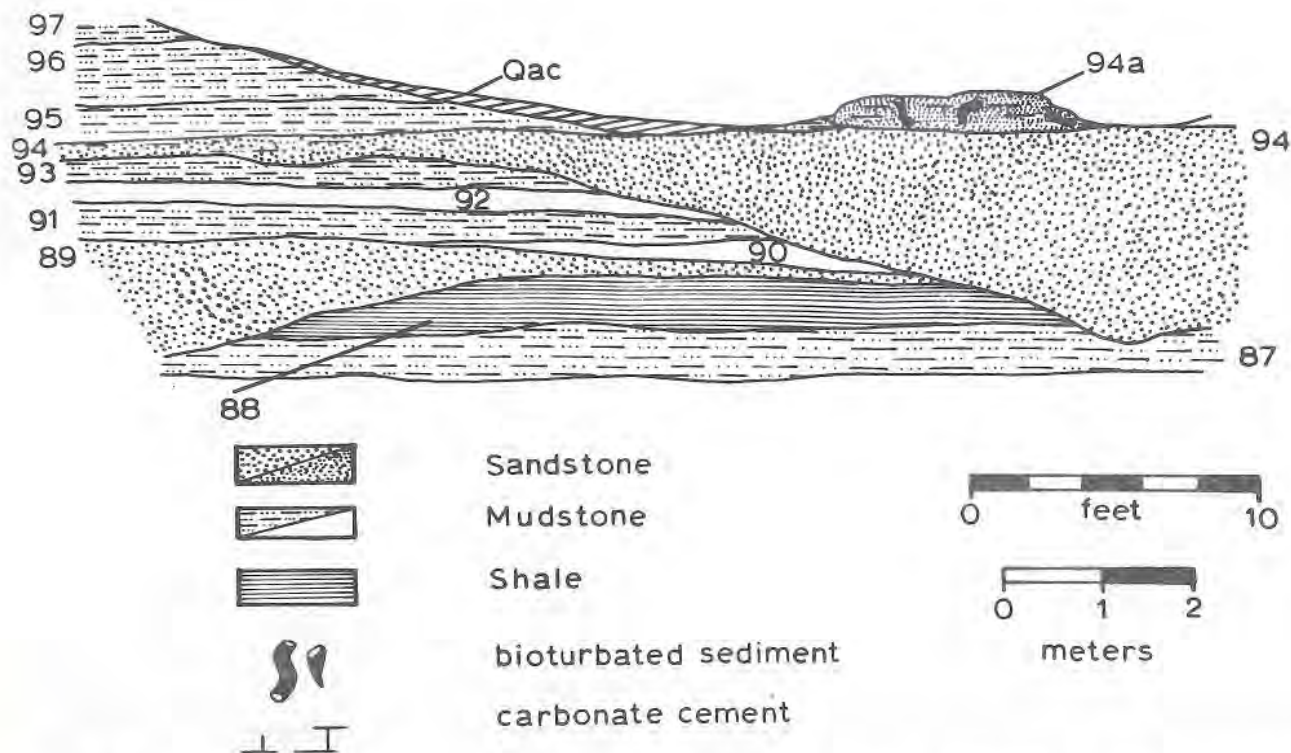
Figure 8. Detail of units 87-97 in the Sand Creek Master Section as developed in the NW¼NE¼ sec. 28, T.47N., R.91W., Washakie County, Wyoming. Note (1) the occurrence of carbonaceous shale 88 beneath apron-channel sandstone 89; (2) the truncation of units 87 and 88 by sandstone 89 and the truncation of units 87-93 by sandstone 94; (3) the aprons extending laterally from the tops of apron-channel units 89 and 94; and (4) the superposition of the shoestring sandstone Unit 94a on units 94 and 95. Qac is undifferentiated alluvium and colluvium.

are often concretionary and rarely preserve original bedding.

PETROGRAPHY

The sandstones of the Sand Creek facies are dominantly subarkoses and quartzarenites (*sensu* McBride, 1963); however, two specimens of lithic subarkose and one example of sublitharenite were identified (Fig. 10).

The sandstone composition is similar to that of 24 Willwood sandstones studied by Neasham and Vondra (1972) but relatively less lithic than the three examples of basin margin sands reported by them. The sandstones of the Sand Creek facies are neutral gray (N 6.0 - 7.0) but may also be brownish, yellow, or green; and no satisfactory color identifications could be accomplished with existing color charts. The sands have occasional zones of rusty concretions (5.0 YR 5/10 to 5.0 YR 3/2), or in-durated yellow zones (2.5 Y 8/8 to 5 Y 8/10) that contain little or no CaCO$_3$ cement.

The detrital quartz particles are angular and subangular to moderately well rounded. This heterogeneity of particle shape suggests that some fraction of the sediment was obtained from primary rock sources (probably felsic igneous) and that another fraction was derived from the reworking of older sedimentary rocks.

The chemical cementation of sandstones in the Sand Creek facies is irregular and is normally accomplished by calcium carbonate. This mineral occurs as sparite that impregnates a relatively open framework. Calcium carbonate cement is most common in the best sorted sandstones, *i.e.*, those with a relatively low content of silt. For the most part, however, the sandstones are friable or, if hard, are strongly compacted and contain little or no CaCO$_3$. Most of the shoestring sandstone bodies and the tops of the larger apron-channel sandstones

Figure 9. Horizontal stratification in medium- to fine-grained sandstone exposed in the upper three feet of a casehardened shoestring sandstone body, SE¼SE¼ sec. 5, T.46N., R.91W., Washakie County, Wyoming. Individual horizontal sets, demarkated at the left by dashed lines, average 1 inch (25 mm) in thickness. The handle of the knife (right) is 4.3 inches (10.9 cm) long.

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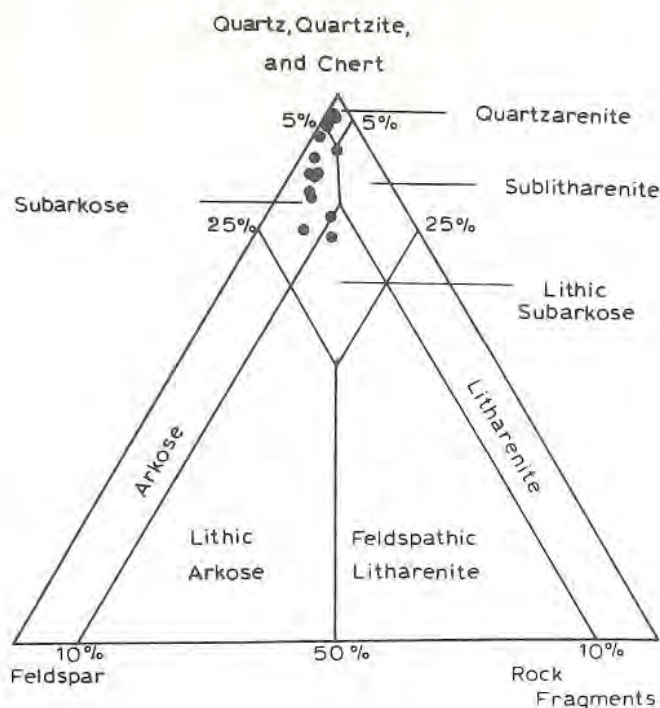
Figure 10. End-member diagram showing percentages of feldspar; rock fragments; and quartz, quartzite, and chert in fifteen sandstones from the Sand Creek facies of the Willwood Formation (compare with Neasham and Vondra, 1972, fig. 6). Diagram after McBride (1963).

are casehardened by a combination of calcium carbonate and hydrated ferric iron compounds that forms a thin (usually less than 1.2 mm) rind on the rock. These casehardened sandstones posses internal calcium carbonate cement even though the much greater volume of sandstone beneath the zone of casehardening is almost invariably uncemented and friable.

The casehardened crusts always show either burrow casts at their upper contacts (Fig. 11) or horizontal (Fig. 9) or small-scale cross-stratification. The bioturbated upper portions commonly have much higher proportions of calcium carbonate cement than do the unbioturbated portions. Individual filled burrows may contain as much as 12-20 percent $CaCO_3$. Calcium carbonate cement is often found *only* in association with bioturbation features in the Sand Creek facies: this strongly suggests that increased permeability accompanied the disordering of the sandstone framework by invertebrate animals. Apron-channel sandstones commonly have invertebrate burrows associated with the finer grained aprons; however, the parts of these aprons that are composed of dominantly silt particles or muds are rarely calcareous.

Invertebrate burrows in sandstones of the Sand Creek facies are dominantly vertical (see Neasham, 1967, p. 46-47); but oblique and even horizontal structures are not uncommon (Fig. 11). Burrows in casehardened sandstones are generally larger in cross-sectional diameter (1.0 — 1.5 cm) than are burrows in mudstones (0.6 — 10.0 cm), and are usually vertical.

Sandstone concretions casehardened with iron oxyhydrates (probably limonite or goethite) and pipy, weakly calcareous concretions are frequently encountered in the friable parts of the channel sandstone bodies. I found no colored sandstones of the kind noted by Neasham (1967, p. 37).

MECHANICAL ANALYSIS

Size analyses of 15 sandstones from the Sand Creek facies show a mean grain long diameter of 2.09 $\emptyset$ (fine sand) with a standard deviation of 0.69 $\emptyset$ (moderately sorted). Samples for this analysis were obtained 45 cm above the bases of the sandstone channel troughs, usually from massive or large-scale trough cross-stratified sand. In instances where the lower 45 cm of the channel was occupied by mud galls, the sample was obtained from the top of the superjacent 45 cm.

Most Willwood sandstones contain a small to moderate fraction of silt or mud particles (Fig. 12). The presence of mud in even minor percentages in sandstones is significant because only a relatively small amount of turbulence is necessary to winnow out most fine detrital particles. Horizontally bedded sandstones in the Sand Creek facies are generally better sorted than sandstones with tabular or relatively large-scale trough cross-stratification (Fig. 12B), and are commonly well cemented with calcium carbonate.

SHALES

Shales occupy approximately 2.5 percent of the stratal thickness of the Sand Creek facies of the Willwood Formation. They form only three units in the measured sections. Each unit is carbonaceous and is developed beneath an apron-channel sandstone. The individual shale units vary internally in content of carbonaceous matter, a constituent that occurs principally as black flecks or black or brown films. Poorly preserved leaf and twig impressions are locally abundant.

Carbonaceous shales are dominantly 7.5 YR 5-6/2 with less fissile carbonaceous mudstones

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that are about 2.5 YR 5/2 and 10.0 YR 5/8. Plant remains are a dark reddish brown (7.5 YR 3-4/2).

The carbonaceous shales are thicker than are color differentiated mudstone units (Fig. 13) and invariably contain zones of non-fissile sandy silt that is impregnated with a yellow iron oxyhydrate. Selenite crystals commonly litter exposures of carbonaceous shale and are almost never encountered elsewhere. The shales also contain appreciable amounts of gypsum as grains finely dispersed throughout the rock or as stringers of satin spar along bedding or fracture surfaces.

Because of their frequent association with erosional channel fill sandstones, carbonaceous shales are often truncated and rarely preserve their original geometric configuration.

A few thin carbonaceous shale beds were encountered on the Sand Creek Divide. These beds are broadly lens shaped and usually persist laterally for less than 300 meters. Several shallow lenses
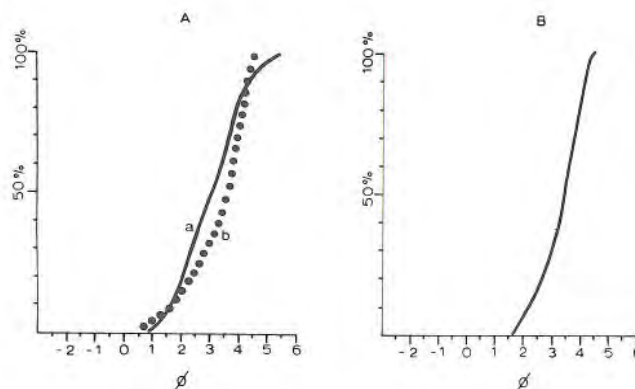
Figure 12. A. Mean cumulative percentage graph of grain size distributions in two samples of sandstone from (a) large-scale trough cross stratified sets and (b) three small-scale trough cross stratified sets. B. Cumulative percentage graph of grain sizes in one sample of sandstone from horizontally stratified sets.

often occur together to make up one broad, more continuous unit in the Sand Creek Divide section.

Figure 11. Casehardened top of a bioturbated shoestring sandstone body in the NW¼ sec. 33, T.47N., R.91W., Washakie County, Wyoming. Arrows point to certain external and internal molds of burrows. Bioturbation structures such as these are evident in the tops of most well indurated shoestring sandstones in the Sand Creek facies and have often completely obliterated primary stratification in these bodies (but see fig. 13). The pen (left) is 5.8 inches (14.7 cm) long.

MUDSTONES

DEFINITION

The term mudstone, as used in this report, denotes non-fissile admixtures of clay and silt (see Neasham and Vondra, 1972). Most mudstones in the Sand Creek facies contain a small percentage of sand (Fig. 14), and all consist dominantly of silt.

It was impossible to distinguish the relative fractions of sand, silt, and clay in Willwood muds in the field, and these units were differentiated on color alone. Multistory colored mudstones, if present, could not be distinguished. The mechanical analysis of these rocks indicates that the color-differentiated mudstones commonly contain multistory sets of claystone and siltstone.

BED GEOMETRY AND THICKNESS

The boundaries between subjacent and superjacent colored mudstones are variable, but in no instances are these contacts erosional. At most transitions, the contacts are sharp (70 percent of observations), or are preceded by a thin mottled zone (30 percent of observations). The contacts are not noticeably weathered, contrary to the observations of Van Houten (1948, p. 2088).

Mottled units commonly include about 10 per-

Figure 14. Cumulative percentage graph of grain size distributions in four mudstones of different colors from the Sand Creek facies of the Willwood Formation.

cent of the color of the next superjacent unit at the base of the mottled profile. The percent of the mottle invariably increases upward through the bed to the top where about 50 percent of subjacent and superjacent colors occur. An exception is found at the upper contacts of most purple mudstones, where the mottling is invariably orange or reddish-brown, regardless of the color of the superjacent unit. Color-differentiated mudstones intertongue laterally with one another or are truncated by sandstones, sandy mudstones, or lenses of carbonaceous shale (see Figs. 7 and 8).

Color-differentiated mudstones measured along the lines of section show remarkably consistent mean-thickness distributions (Fig. 13). Van Houten (1948) observed that drab mudstones are thicker and more numerous than red mudstones. The thickness comparison of red mudstones with the whole of the drab suite (green, gray, brown) is an artificial one. A comparison of frequencies and thicknesses of drab units and variegated units shows that the drab sequence in the Sand Creek facies (32.6 percent by thickness; 118 units) comprises less of the section than does the variegated sequence (42.8 percent by thickness; 141 units).

MECHANICAL ANALYSIS

Mechanical analyses of bulk samples of 22 varicolored mudstones demonstrate a relatively

Figure 13. Graph showing section thicknesses in feet (ordinate) occupied by various units in the Sand Creek facies of the Willwood Formation. Open bars indicate percentages of the section thickness, with the total number of units given above the percentage figures. Solid bars indicate the mean thickness of each type of unit.

consistent grain size (Fig. 14): determinations for these samples show no tendency to separate into size groupings that can be correlated with particular colors. The mean particle size of most of the mudstones changes laterally along strike. Often, particle size was observed to decrease upward through a mudstone profile, *independent of color transitions*, as illustrated in Figure 15. This characteristic, observed in about 56 percent of the mudstone profiles analyzed, is indicative of a fining-upward sequence.

PETROGRAPHY

Detrital quartz (50-62 percent), is the dominant mudstone constituent in the Sand Creek facies,
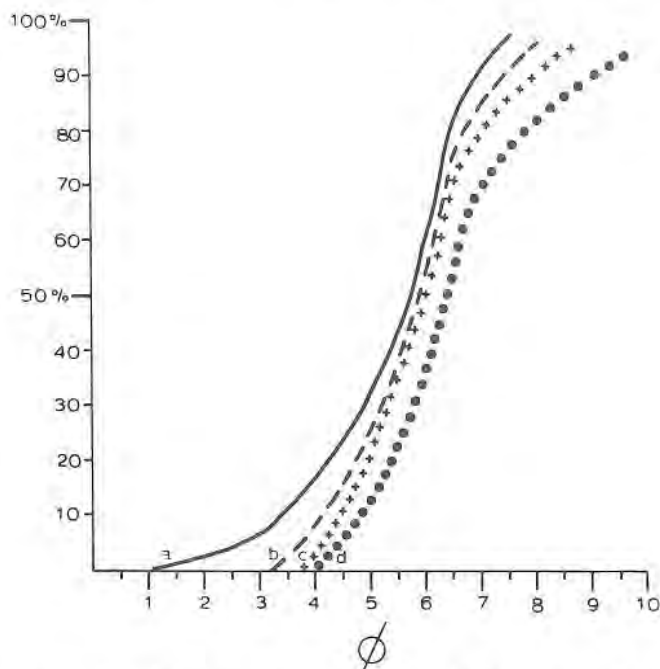
Figure 15. Cumulative percentage graph of grain size distributions in a "Class A gray" mudstone unit. a. Mean cumulative percentage size distribution of three samples taken from unit 27 (Slick Creek Basin Section) in the SE¼NW¼NE¼ sec. 1, T.46N., R.92W., Washakie County, Wyoming. b. Mean cumulative percentage size distribution of three samples taken also from unit 27 at Slick Creek Quarry, about 770 meters northwest of site a. c. Mean cumulative percentage size distribution of three samples taken from unit 27, approximately 200 meters farther north. d. Mean cumulative percentage size distribution of three samples secured from unit 27 at the top of a graded oil well platform in the SE¼SW¼ sec. 36, T.47N., R.92W.
Note decrease in mean grain size and increase in tail of fines in samples from localities a through d. Unit 27 grades laterally into the apron of a large apron-channel sandstone approximately 300 meters south of site a.

and clays (22-45 percent) and feldspars (5-31 percent) are subordinate.

Van Houten (1948) and Neasham (1970) observed that illite is the dominant clay mineral in Willwood mudstones. I have observed that illite comprises 40-50 percent of the clay mineral assemblage in the Sand Creek facies, that mixed-layer smectites follow illite in importance and comprise 30-42 percent, and that kaolinite supplements the other clays at 15-22 percent. Van Houten (1948), alternatively, recorded illite, kaolinite, and the montmorillonite group to be the dominant clay minerals, in that order, in his samples.

The observation of Neasham and Vondra (1972, p. 2174), that basin margin Willwood mudstones contain relatively higher proportions of feldspar and lower proportions of kaolinite, is tentatively confirmed.

COLOR

Varicolored mudstones in the Sand Creek facies were separated into seven color groupings. Some discrete colors were lumped for comparative treatments by the Markovian and other analyses (see below). The designations "orange mudstone" and "green mudstone" are composite categories that include ranges of color hues. The following color groupings are recognized in this study (Munsell Color Company, 1929-1942):

purple = 5.0 RP 6/4, reddish-purple
MPO, mottled purple and orange = 5.0 RP
    6/4 mottled with about 20 percent 2.5 Y
    6/8 and occasional minor amounts of
    Y-GY 7/2
red = 10.0 R 4/8, red to yellowish-red
orange = 2.5 Y 6/8, yellow, to 10.0 YR 6/10,
    orange
green = 10.0 G 8/2, green to greenish-gray
gray = N 6.5-7.0/, neutral gray, to Y-GY 7/2
CAG, Class A gray mudstone (see below) =
    largely N 7.0/, neutral gray, with a bluish
    cast that could not be successfully matched
    on the Munsell Color Charts

GEOCHEMISTRY

Colored mudstones of the Sand Creek facies were analyzed for percent weights of free iron and manganese and of organic carbon. The results of these analyses (Figs. 16-18) are in general agreement with those obtained by Neasham and Vondra

(1972); however, sampling differences affect some of these comparisons. Those authors did not recognize orange (or yellow) mudstones, but chose to lump them with red beds. Mottled purple and orange mudstones and Class A gray mudstones, common in the Sand Creek facies, are rare in the Elk Creek facies sections studied by those authors.

The chemical analyses show that free iron (including oxyhydrates) and free manganese are most abundant in yellow, mottled purple and orange, purple, and red mudstones, and less important in drab (gray and green) mudstones. Mottled purple and orange mudstones in the Sand Creek facies have abnormally high organic carbon and free manganese contents, and Class A gray mudstones are abnormally high in organic carbon.

NODULES AND CONCRETIONS

Ten varieties of nodules and concretions (*glaebules* of Brewer, 1964) were recognized in this study. Variety 1 occurs only in the Elk Creek facies and varieties 2, 3, 5, 6, 8, and 10 occur only in the Sand Creek facies. Varieties 4, 7, and 9 were found in rocks of both facies. Varieties 2-4 and 7-10 are probably types of the *sesquioxidic glaebules* of Brewer (1964).

Representative specimens of the nodule and concretion types recognized in this report occupy UW numbers 10344 and 10345 in the vertebrate paleontology collection (variety 5) and numbers TC-068-1 to TC-068-9 (varieties 1-4 and 6-10) in the rock and mineral catalog of The Geological Museum, University of Wyoming, Laramie.
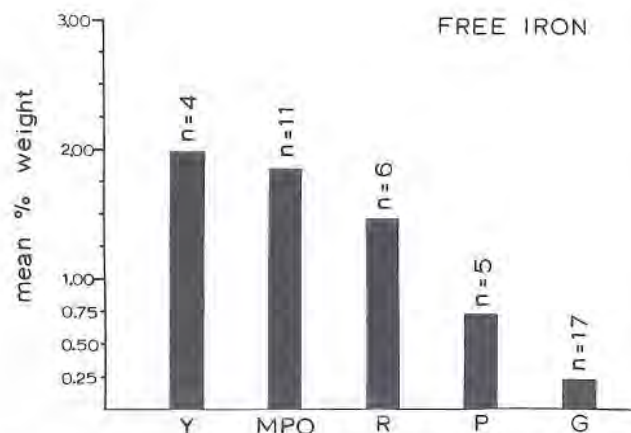
Figure 17. Mean percent weights (ordinate) of free manganese in colored mudstones, Sand Creek facies; abbreviations as in fig. 16.

Variety 1 is the abundant calcareous nodule noted by Wortman (*in* Osborn and Wortman, 1892). These nodules are typically light yellow-brown (10 YR 5/4 - 5/6) and usually contain more than 96 percent $CaCO_3$. They commonly have some admixture of detrital quartz sand or silt (generally < 5 percent) and have very small admixtures of clay minerals.

The nodules have a rugose surface, are essentially unstructured in thin section, and may occur as pisolites (2-10 mm in long diameter), as larger nodules (10-100 mm in long diameter), or as encrustations on fossil bone. When *in situ*, they are usually contained in red or yellow mudstones but occur rarely in purple mudstones. Neasham (1967, Fig. 10-D; p. 54-55) has figured and described variety 1 nodules from the Elk Creek facies.

Wortman (*in* Osborn and Wortman, 1892) mentioned the occurrence of lime nodules in sandstones, and I have found them *in situ* in two separate apron-channels in the Elk Creek facies. Nodules in sandstones are frequently rounded. Where nodules occur in mudstones, they are abundant and commonly form surface lags (Fig. 19). These are the *carbonate glaebules* of Brewer (1964).

Variety 2 occurs as nodules or as encrustations on fossil bone. The latter occurrence was observed only at UW fossil localities V-73044, V-73055, and V-73111. The encrustations are normally smooth, may contain significant percentages of sand- and silt-size detrital quartz, and contain a yellow to yellow-brown (5 Y 8/10) hydrated ferric oxide mineral.

Variety 3 structures are dark, cindery aggregates of iron oxyhydrate and manganese minerals.

Figure 16. Mean percent weights (ordinate) of free iron in colored mudstones, Sand Creek facies: Y = yellow (orange), MPO = mottled purple and orange, R = red, P = purple, and G = gray and green mudstones; n = number of samples.

27

They have rugose surfaces and occur only in gray mudstones. The specimens collected are a very dark yellow-brown (5.0 YR 2/2 to 5.0 YR 3/4). These are a variety of the *manganiferous glaebules* of Brewer (1964).

Variety 4 concretions and nodules occur variously as large, purple (5.0 P 5/4 with some 5.0 R 3/6 mottle; streak about 10.0 RP 6/8), podlike structures or as nodules. Their composition is dominantly clastic quartz with some admixture of hydrated and dehydrated ferric oxides (Fig. 20). The surface texture of the nodular form is moderately rugose, but the podlike concretions are invariably smooth.

Variety 4 structures are the dominant structures of the Sand Creek facies, locally as abundant as are variety 1 nodules in the Elk Creek facies.

The variety 5 structure is a type of indurated mudstone found principally as matrix around some vertebrate fossils. The surface texture is normally smooth and the color is approximately neutral gray (N 7.0/) with some purple mottle (5.0 RP 7/2). Variety 5 is associated with fossil material in mottled purple and orange mudstones and, possibly, in Class A gray mudstones.
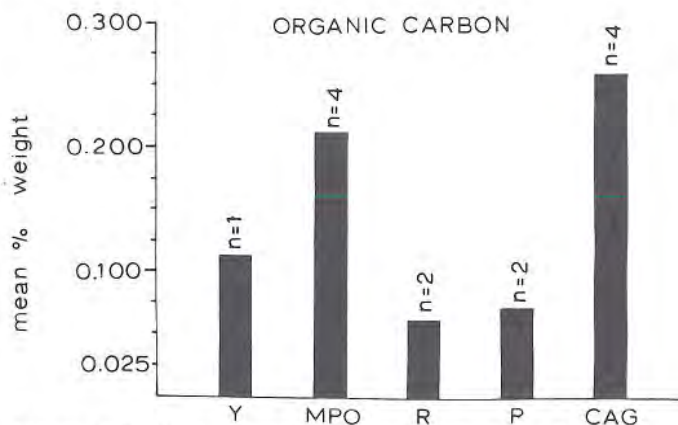
Figure 18. Mean percent weights (ordinate) of organic carbon in colored mudstones, Sand Creek facies; abbreviations as in fig. 16.

Figure 19. Outcrop of middle Willwood Formation in NE¼NW¼ sec. 3, T.50N., R.96W., north of Dorsey Creek, Big Horn County, Wyoming. Note the variety 1 calcareous nodules. The handle of the ice pick is 9.0 cm long.

Variety 6 structures are concretionary, have relatively smooth surface textures, and often have purple siltstone centers. The outer rind is composed of well-indurated detrital quartz sand and silt with minor amounts of calcite cement. These concretions are commonly pipy. Variety 6 structures occur only near the tops of friable apron-channel sandstones, or in the associated lateral apron sands.

Variety 7 structures variously occur as concretions, as nodules, or as encrustations on fossil bone. These are the commonly cited iron oxide concretions of the Willwood paleontological literature.

In my experience, the occurrence of this variety is almost entirely restricted to gray mudstones and is nearly always associated with fossil vertebrate remains.

In all forms, the variety 7 iron oxide structure has a smooth surface texture, contains small amounts of sand or silt-sized detrital quartz, and is usually non-calcareous.

The structures are a deep purple (about 10.0 RP 3/6) and may be distinguished from other concretions and nodules by their brilliant red streak (5.0 R 4/10). The association of this variety with fossil bone is nearly ubiquitous in Class A gray mudstone beds of the Sand Creek facies.

Variety 8 structures occur as pisolites that are brown (5 YR 5/10) with a smooth to granular surface texture. The structures are characterized by their high percentages of hydrated iron oxide (Fig. 20), and commonly contain large admixtures of sand and silt-sized detrital quartz particles. They are never calcareous. They are found in mottled purple and orange mudstones of the Sand Creek facies.

Variety 9 structures occur as yellow (5 Y 8/10), rugose, cornflake-like nodules associated with carbonaceous shales, carbonaceous mudstones, and green mudstones. The nodules are silty, non-calcareous, and have a bright yellow streak (5 Y 8/10). They are characterized by a relatively high content of hydrated ferric iron (Fig. 20).

Variety 10 nodules are dark purple to purplish red (10.0 RP 4/6) tubular structures (*pedotubules;* see Brewer, 1964) with smooth surfaces. They contain little or no calcium carbonate, and the color, texture, and iron oxyhydrate percentages are similar to those of variety 4. These structures occur only in mottled purple and orange mudstones.

These forms probably represent the induration of invertebrate burrow casts by variety 4 concretionary material. The tubular form and structured nature of the matrix are most suggestive of the bioturbation origin of these forms.

Figure 20 depicts the percentages of free iron and manganese, associated lithologies, relationships to vertebrate fossil occurrences, and distributions of these structures in the Sand Creek and Elk Creek facies of the Willwood Formation.

Variety	wt. % Free Fe	wt. % Free Mn	CaCO₃	Lithol.	Fossil	Facies
1	0.454	0.045	~97 %	R,O,P	+	EC
2	7.89	0.026	N	CAG	+	SC
3	26.5	4.53	N	G	-	SC
4	4.12	0.016	N	O, MPO	-	SC,EC
5	1.027	0.009	N	MPO, ?CAG	+	SC
6	0.631	0.013	T	SS	-	SC
7	6.79	0.019	N	G,CAG	+	SC,EC
8	32.9	0.207	N	MPO	-	SC
9	22.4	0.118	N	CS,GR	-	SC,EC
10	4.01	0.016	N	MPO	-	SC

Figure 20. Comparison of free iron, free manganese, and calcium carbonate in nodules and concretions with their lithologic, fossil, and facies associations.

N = little or no detectable CaCo₃
T = trace of CaCO₃
CAG = "Class A Gray" mudstone
CS = carbonaceous shale
G = gray mudstone
GR = green mudstone
MPO = mottled purple and orange mudstone
O = orange mudstone
P = purple mudstone
R = red mudstone
SS = sandstone
+ = often associated with fossil bone
− = rarely or never associated with fossil bone
EC = present in Elk Creek facies
SC = present in Sand Creek facies

MARKOV ANALYSIS

INTRODUCTION

Weller (1930) presented the original statement of the cyclothem concept. Since that time, numerous papers have described marine and fluviatile cyclothemic deposits from many different parts of the world.

Vistelius (1949) was the first to develop a probability matrix analysis that described a cyclothem sequence. In 1969, Gingerich first applied

a probability matrix analysis (Markov Chain Analysis) to Paleocene fluviatile deposits in the Bighorn Basin. The study of Neasham and Vondra (1972) for the overlying early Eocene Willwood Formation soon followed.

The utility of probability matrices for the determination of random or controlled cyclic deposition is acknowledged by most sedimentary geologists. The use of Markov chains was recently reviewed by Schwarzacher (1975).

The finite Markov chain has been described (Kemeny and Snell, 1960) as ". . . a stochastic process which moves through a finite number of states, and for which the probability of entering a certain state depends only on the last state occupied." In the application of this analysis to sedimentary rocks, the states entered are the finite number of sedimentary units of lithologies A_1 . . . . . A_m, or colors B_1 . . . . . B_n. The probability of entering a lithologic or a color state, $e.g.$ A_i or B_j, is determined by the last (underlying) state occupied, $e.g.$ $P(c) = P(c/b)$.

CYCLIC UNITS

The Markov Chain Analysis was applied to the measured sections of Willwood rocks of the Sand Creek facies. The stratigraphic sequence in the Sand Creek facies is composed of a finite number of color differentiated mudstone units and sandstones. Multistory units are those rock or color units that contain one or more sequentially arranged units of either the same color or the same lithology. For example, a multistory siltstone unit might contain sequential green, red, and gray siltstones. Multistory color units are virtually impossible to recognize in the field and are not utilized in this study. The Markov Analysis of the Sand Creek facies was, therefore, solved only for discrete units.

Simple vectors and matrices are employed to facilitate the array of data used in the Markov Analysis. A count of the recognized non-multistory color units therefore determines the possible number of transitions in the sequence. These data form the frequency occurrence vector, f_i. The following unit states were recognized in sections of the Sand Creek facies:

    1 - red and orange mudstones = RO
    2 - purple and mottled purple and orange
        mudstones = MPOP
    3 - green and gray mudstones = DRAB
    4 - sandstones = SS

For the Sand Creek Master Section (Fig. 2), the frequency occurrence vector is defined as follows:

$$f_i = \begin{matrix} 54 \\ 16 \\ 32 \\ 40 \end{matrix} = \begin{matrix} \text{DRAB} \\ \text{SS} \\ \text{MPOP} \\ \text{RO} \end{matrix} \quad N = 142 \text{ transitions}$$

To test the degree of randomness in the transitions between these units, matrices are required. If P_{ij} is defined as the probability of moving from state X_i to state X_j, the computation of these probabilities from all data afforded by the f_i vector above forms the independent trials matrix, e_{ij}. This matrix has the form:

$$e_{ij} = \begin{array}{c|cccc} & X_1 & X_2 & X_3 & X_4 \\ \hline X_1 & 0 & P_{1,2} & P_{1,3} & P_{1,4} \\ X_2 & P_{2,1} & 0 & P_{2,3} & P_{2,4} \\ X_3 & P_{3,1} & P_{3,2} & 0 & P_{3,4} \\ X_4 & P_{4,1} & P_{4,2} & P_{4,3} & 0 \end{array}$$

where, for example, $P_{1,4}$ is the probability of the transition X_1 to X_4. The independent trials probability, $P_{1,4}$, of a red bed overlying a gray bed (RO/DRAB) for a non-multistory sequence (i.e., where $P_{1,1} = P_{2,2} = P_{3,3} = P_{4,4} = 0$) is calculated by dividing the total number of red beds (RO = 40) by the total number of non-gray units (SS + MPOP + RO = 16 + 32 + 40 = 88), or 40/88 = 0.455 = $P_{1,4}$ (below). The independent trials matrix for the data in vector f_i above is:

$e_{ij} =$	DRAB	SS	MPOP	RO
DRAB	.00	.182	.364	.455
SS	.429	.00	.254	.317
MPOP	.491	.145	.00	.364
RO	.529	.157	.314	.00

This matrix assumes the sequence of transitions was determined *randomly* within the frequency array vector f_i.

The *actual* transition count of red to gray units (RO to DRAB), gray to red, etc., is summarized in a second matrix termed the transition count matrix, f_{ij}. This transition count is made from the stratigraphic section in Figure 2 and the record of transitions observed in the field. The transition count for non-multistory colored mudstones and sandstones in the Sand Creek Master Section is:

$f_{ij} =$	DRAB	SS	MPOP	RO
DRAB	0	9	16	29
SS	6	0	8	2
MPOP	21	3	0	8
RO	29	4	7	0

where, for example, the actual number of transitions upward from DRAB to RO is 29.

In probability form, this matrix, p_{ij}, describes the *actual* transition proportions, and is formed by normalizing the rows of the transition count matrix, f_{ij}; e.g., the actual transition proportion of DRAB to RO is $29/(9 + 16 + 29) = .537$. The probability form of the transition count matrix for the Sand Creek Basin Master Section is:

		DRAB	SS	MPOP	RO
	DRAB	.00	.167	.296	.537
	SS	.375	.00	.500	.125
$p_{ij} =$	MPOP	.656	.094	.00	.250
	RO	.725	.100	.175	.00

When the independent trials matrix e_{ij}, is subtracted from the transition probability matrix, p_{ij}, a difference matrix $D(p_{ij} - e_{ij})$ is obtained. This matrix contains both positive and negative elements. The positive elements represent those transitions which have occurred at greater than the random probabilities predicted by the e_{ij} matrix. The negative elements represent transitions which have occurred at less than the random e_{ij} probabilities. The .00 elements represent either non-observed units ($f_i = 0$), or transitions which occur exactly as predicted by the e_{ij} matrix. The difference matrix for the non-multistory colored mudstone and sandstone units in the Sand Creek Basin Master Section is:

		DRAB	SS	MPOP	RO
	DRAB	.00	−.015	−.068	.082
	SS	−.054	.00	.246	−.192
$D(p_{ij} - e_{ij}) =$	MPOP	.165	−.051	.00	−.114
	RO	.196	−.057	−.139	.00

Because positive elements in the difference matrix are those transitions which have occurred at greater frequencies than expected by random processes, the cyclothem is described by following the positive elements through the difference matrix. (If there is no positive element representing a transition to a unit (as to SS here), the least negative of the elements representing transition to the unit is used to complete the cyclothem: here, −.015 is the least negative element in the SS column.) The fully developed non-multistory colored mudstone and sandstone cyclothem for the Sand Creek Basin Master Section is

MPOP (23%) → DRAB (38%) ⇌ RO (28%)
SS (11%)
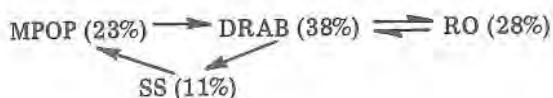
where, for example, 23 percent of the units in the f_i vector are MPOP.

Because the fully developed cycle predicted by the Markov Analysis is not observed in its entirety at most places in the Sand Creek Master Section, we recognize the cyclothem as an ideal and modal one; i.e., the cycle which will occur most frequently. The imperfect ordering of transitions observed at most places in the section represents the premature occurrences of one or another of the units.

In summary, the following results were obtained for the Sand Creek Master Section (Fig. 2). (e_{ij} and p_{ij} matrices can be derived from f_i and f_{ij} matrices, respectively, and are not given in the following summaries.)

	DRAB	54	
	SS	16	
$f_i =$	MPOP =	32	
	RO	40	N = 142 transitions

		DRAB	SS	MPOP	RO
	DRAB	0	9	16	29
	SS	6	0	8	2
$f_{ij} =$	MPOP	21	3	0	8
	RO	29	4	7	0

		DRAB	SS	MPOP	RO
	DRAB	.00	−.015	−.086	.082
	SS	−.054	.00	.246	−.092
$D(p_{ij} - e_{ij}) =$	MPOP	.165	−.051	.00	−.114
	RO	.196	−.057	−.139	.00

Ideal Cyclothem:

MPOP (23%) → DRAB (38%) ⇌ RO (28%)
SS (11%)
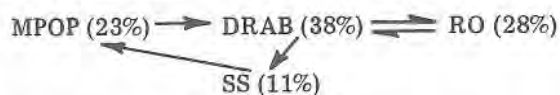
The Markov Analysis was also solved for discrete colored mudstones and units of sandstone in the lower part of the Sand Creek Master Section, the East Sand Creek Basin Section, the East Sand Creek Basin Section combined with the top of the Sand Creek Basin Master Section, and the Slick Creek Basin Section:

Lower Sand Creek Master Section (Fig. 2)

	DRAB	46	
	SS	14	
$f_i =$	MPOP =	25	
	RO	36	N = 121 transitions

	DRAB	SS	MPOP	RO
DRAB	0	8	12	26
SS	6	0	6	2
MPOP	16	2	0	7
RO	25	4	7	0

$f_{ij} =$

	DRAB	SS	MPOP	RO
DRAB	.00	−.015	−.077	.089
SS	−.010	.00	.195	−.184
MPOP	.150	−.066	.00	−.085
RO	.147	−.052	−.097	.00

$D(p_{ij} - e_{ij}) =$

Ideal Cyclothem:

MPOP (20.7%) → DRAB (38.8%) ⇌ RO (28.9%)

SS (11.6%)

East Sand Creek Basin Section (Fig. 3)

$f_i =$ DRAB 20, SS 11, MPOP 13, RO 9 N = 53 transitions

	DRAB	SS	MPOP	RO
DRAB	0	8	5	7
SS	5	0	4	2
MPOP	11	2	0	0
RO	4	1	4	0

$f_{ij} =$

	DRAB	SS	MPOP	RO
DRAB	.00	.067	−.144	.077
SS	−.021	.00	.054	−.032
MPOP	.346	−.121	.00	−.225
RO	−.011	−.139	.149	.00

$D(p_{ij} - e_{ij}) =$

Ideal Cyclothem

MPOP (24.5%) → DRAB (37.7%) → RO (17.0%)

SS (20.8%)

East Sand Creek Basin Section and top Sand Creek Basin Master Section (Figs. 2 and 3).

$f_i =$ 29 DRAB, 13 SS, 20 MPOP, 12 RO N = 74 transitions

	DRAB	SS	MPOP	RO
DRAB	0	9	10	10
SS	5	0	6	2
MPOP	16	3	0	1
RO	7	1	4	0

$f_{ij} =$

	DRAB	SS	MPOP	RO
DRAB	.00	.027	−.090	.062
SS	−.074	.00	.134	−.059
MPOP	.281	−.091	.00	−.191
RO	.124	−.130	.005	.00

$D(p_{ij} - e_{ij}) =$

Ideal Cyclothem:

MPOP (27.0%) → DRAB (37.8%) ⇌ RO (17.6%)

SS (17.6%)

Slick Creek Basin Section (Fig. 4).

$f_i =$ 32 DRAB, 13 SS, 24 MPOP, 18 RO N = 87 transitions

	DRAB	SS	MPOP	RO
DRAB	0	6	15	11
SS	2	0	8	3
MPOP	15	4	0	5
RO	14	3	1	0

$f_{ij} =$

	DRAB	SS	MPOP	RO
DRAB	.00	−.044	.040	.005
SS	−.265	.00	.291	−.026
MPOP	.133	−.039	.00	−.094
RO	.322	−.024	−.297	.00

$D(p_{ij} - e_{ij}) =$

Ideal Cyclothem:

MPOP (27.6%) ⇌ DRAB (35.6%) ⇌ RO (21.8%)

SS (14.9%)
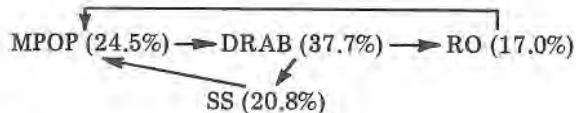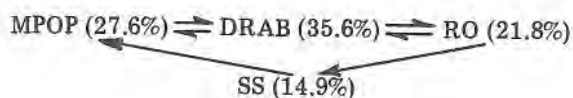
A chi^2 or χ^2 statistic (Billingsley, 1961) gives the probability that the transition count matrix was generated ". . . as the result of a random process operating within the observed frequency of rock types (f$_i$) . . ." (Vistelius, 1949). In algebraic form, this statistic is computed:

$$\chi^2_\nu = \sum_{ij} \frac{(f_{ij} - f_i e_{ij})^2}{f_i e_{ij}} \; ,$$

where ν equals the number of degrees of freedom (df) in the operation. ν is determined by subtracting the rank of the e_{ij} (independent trials matrix, =4) from the total number of positive elements in the e_{ij} matrix. Since four entries of the non-multistory e_{ij} matrix are occupied by .00, the total number of positive entries is 12, and the degrees of freedom are 12 − 4 = 8. The following χ^2 statistics were computed for the five measured sections, and the probabilities, p, of obtaining the χ^2 values with eight degrees of freedom, taken from χ^2 tables:

Sand Creek Basin Master Section	$\chi^2 = 15.971$ df = 8	p = about 1/20
Lower Sand Creek Master Section	$\chi^2 = 10.874$ df = 8	p = about 1/4
East Sand Creek Basin Section	$\chi^2 = 10.03$ df = 8	p = about 1/4
East Sand Creek Basin Section and top of Sand Creek Basin Master Section	$\chi^2 = 10.197$ df = 8	p = about 1/4
Slick Creek Basin Section	$\chi^2 = 16.408$ df = 8	p = about 1/30

The non-multistory colored mudstone and sandstone sediments of the Sand Creek facies were apparently developed with some measure of non-random superposition. Neasham and Vondra (1972, p. 2171) obtained a χ^2 value of 0.04 (1/25) for the Markov analysis of the Meeteetse — Tatman Mountain section of the Willwood Formation (largely in the Elk Creek facies), a value that ". . . is considered to be statistically significant (Folk, 1968) for a cyclic interpretation." The value of p = 0.04 obtained by these authors is closely comparable with the values obtained above for the Sand Creek Basin Master Section (about 1/20) and for the Slick Creek Basin Section (about 1/30). The χ^2 values obtained from the remaining three sections (all of which are based on fewer transitions) are somewhat less significant.

An attempt to solve the Markov analysis for a variable 8 x 8 matrix recognizing purple, mottled purple and orange, orange, red, gray, green, and Class A gray mudstones and sandstones was unsuccessful and resulted in a difference matrix that was saturated with positive values. Although the lumping of recognized color differentiated units naturally must result in some loss of resolution, the resulting cyclothems described by this process are quite similar to each other. The 8 x 8 matrices, however, produce extremely complex transition data that are difficult to resolve meaningfully.

CLASS A GRAY MUDSTONES

DEFINITION

Class A gray mudstones are gray mudstones with a bluish cast that are invariably underlain by mottled purple and orange mudstones. These units are from 12 to 70 cm thick and are uniformly characterized by large concentrations of fossil vertebrate remains. The lower contacts of Class A gray mudstones are frequently undulating, but never have a relief of more than 50 cm.

About 90 percent of all vertebrate fossils collected in the Sand Creek facies was obtained from Class A gray mudstones. These units, originally described by Bown (1975, p. 58), are illustrated in Figures 21 and 22.

DISTRIBUTION

Class A gray mudstones are best developed in the Sand Creek facies of the Willwood Formation, but do occur rarely in the Elk Creek facies, where six such beds were encountered between the 60- and 230-meter levels of the Willwood Formation.

More than seventy Yale Peabody Museum Willwood vertebrate fossil localities were visited to determine the distribution of these beds. Among the most important of these sites, YPM localities 97, 104, 157 (part), 158, 290, 293, 296 (part), 303, 327, 341, 358 (part), and 363 (part) owe their productivity to Class A gray mudstones exposed nearby. More than 380 YPM sites were not revisited, however, and the provenance of fossils for these localities is presently unknown (see below, under DISCUSSION). The YPM fossil localities noted above are distributed through about 200

meters of the Elk Creek facies in the drainages of Antelope, Elk, and Tenmile creeks.

Class A gray mudstone beds are remarkably persistent units. One of these beds in the Slick Creek Basin was traced for more than 3,400 meters.

DISCUSSION

CONGLOMERATES

The near absence of Eocene gravels from the easterly exposures of the Bighorn Basin Willwood Formation is, as observed by Sinclair and Granger (1912, p. 64), "rather remarkable" considering the widespread development of conglomerates in these rocks along the southern and western margins of the basin (see, *e.g.*, Hewett, 1926; Pierce, 1965, 1966; Bredall, 1971).

Neasham (1970), however, noted "intraformational" conglomerates that occur as pebbles at or near the bases of some sandstones in the central basin Willwood Formation. These occurrences are quite similar to those described above for the Sand Creek facies.

Ore (1964, p. 9-10) has observed that:

"... the deposition of coarser elements of bedload to initiate longitudinal bars in streams, and their subsequent trapping of finer material is a process leading to essentially horizontal stratification .... Where more sand size material is available, the proportion of foreset lamination on the downstream end and sides of bars increases."

Pebbles also often accumulate on the upstream faces of point bar sands. Unfortunately, the two examples of conglomerates in the Sand Creek facies are poorly exposed and do not permit an assessment of cross-sectional geometry or a meaningful sample of directional data. Both parameters would be useful in determining whether the sand and conglomerate bodies represent longitudinal or point bar deposits and whether the channel was a meandering or a braided one.

The presence of pebble and granule clasts in a horizontally bedded sandstone is, however, indicative of plane bed transport in the upper flow regime

Figure 21. Wadi Kraus Quarry beds in the Sand Creek Basin, sec. 4, T.46N., R.91W., Washakie County, Wyoming. The productive unit is a Class A gray mudstone (arrows); Wadi Kraus Quarry is designated by +. Note the absence of concretions or nodules on the flats. The low ridges are about 2 to 2.5 feet (61-67 cm) high. View is to the southeast.

Figure 22A. Bone and jaw fragments as found on the surface of Class A gray mudstone at UW locality V-73076, NW¼ sec. 1, T.46N., R.92W., Washakie County, Wyoming. Arrow #1 points to a jaw fragment of *Hyopsodus* with P_4-M_1. Arrow #2 points to a jaw fragment of *Hyracotherium* with M_3. The knife is 10.4 inches (26.4 cm) long.

Figure 22B. Femur of *Coryphodon* Cf. *eocaenus* as found on the surface of a Class A gray mudstone bed at locality V-73023, NE¼ sec. 1, T.46N., R.92W., Washakie County, Wyoming. The hand level is 5 inches (12.7 cm) long.

(Simons and Richardson, 1961; Harms and Fahnestock, 1965). The introduction of relatively coarse sediment into stream bedloads at punctuated intervals undoubtedly reflects increased discharge and competence during these intervals. The absence of larger cobbles and boulders from the Sand Creek facies indicates that, during the deposition of that body, gradients in the southern Bighorn Mountains and on the Owl Creek arch were insufficient to transport them.

Studies by Lugn (1928) and McKee *et al.* (1967) indicate that mud galls are developed at or near the bases of the troughs of channel sandstones. Mud gall conglomerates in the Polecat Bench Formation occasionally contain large concentrations of carbonized plant material and vertebrate fossils. It seems likely that the formation of mud galls is, in these instances, related to flooding that immediately preceded the establishment of runoff water in a new channel. The mud galls were derived from the erosion of the confining unconsolidated or partly consolidated overbank alluvial muds and were concentrated, along with plant matter and fossils, as bedload lags at low points on the irregular channel bed.

This interpretation is consistent with the available evidence of channel geometries, all of which show evidence of the truncation of and incision in finer grained sediments (see below).

SANDSTONE GEOMETRY

Johnson and Vondra (1972) and Jacob (1973), among others, have attributed the development of sheet sandstones to the lateral accretion of point bars in high-sinuosity and relatively low-gradient streams. This interpretation is borne out for most of these bodies by analyses of stratification types and paleocurrent directional data.

Coleman (1969) has observed that sands deposited by large braided rivers are commonly blanket-like, but that these bodies possess a large volume of relatively large-scale trough cross-stratification. Large-scale trough cross-stratification is subordinate to tabular cross-stratification in most Willwood sheet sandstones.

Neasham and Vondra (1972, p. 2167) believed that apron-channel sandstones were related to natural levee formation. Natural levee deposits, however, imply the accumulation of a prism of proximal overbank sediment that lends the deposit a measure of consistent geometrical integrity (see, *e.g.*, text and figures in Fisk, 1947; Allen, 1965;

Jacob, 1973). Natural levee deposits are distinguished from episodic single overbank deposits in that they are accumulations of deposits from several overbank events. These events result in the eventual buildup of alluvial ridges parallel to the channel.

Sandstone channel aprons in the Willwood Formation have a prismatic geometry as the channel trough fill is approached; however, this geometry is the inverse of that expected to result from levee development: the sand body thickens downward into the trough (Figs. 6B, 7, and 8), and not upward into an alluvial ridge.

Allen (1965) observed that an important characteristic of natural levees is a vertical alternation of coarse and fine sediment. I find little evidence for coarse and fine alternation in channel aprons. The fine clastics that make up the bulk of channel aprons at points well removed from the channels themselves commonly show graded bedding; however, only one graded set is usually present in the apron. The graded bedding indicates settling of suspended fines in relatively slack water. That only one such set is commonly found in the channel aprons shows that the aprons represent individual depositional events, not a period of intermittent overbank accumulation.

Large-scale trough cross-stratification is common in the lower parts of the apron-channel troughs. Harms and Fahnestock (1965) attributed this stratification type to dune migration in the upper part of the lower flow regime. This type is commonly succeeded by a thinner zone of tabular or relatively small-scale trough cross-stratification. These structures are often formed in the lower flow regime by, respectively, the migration of bars and development of ripples. Horizontal stratification that normally lies above the small-scale trough cross-beds is formed by relatively fast-moving water in the upper flow regime.

Sequences similar to those described above were observed in the Paleocene Tongue River Formation by Jacob (1973). Planar cross-stratification (some tabular sets) occasionally forms on bars and can form in braided streams or in unbraided streams with low sinuosity (see, *e.g.*, Allen, 1968).

The geometry of apron-channel sandstones is characterized by very broadly sinuous channels. These bodies probably developed essentially straight valleys with meandering confined to the contours of point bars or longitudinal bars in the thalweg. The filling of the channel was probably gradual and was punctuated by some erosional intervals.

The apron was developed by an episode of relatively rapid channel aggradation coupled with widespread overbank flooding. The topload of the channel and the lateral contiguous apron represent the final aggradational stage of the stream. The formation of the apron was roughly coincident with the relocation of the drainage at a topographically lower point on the floor of the floodbasin. The essentially planar geometry of the channel apron deposits indicates that the floodbasin topography was relatively featureless. The floodbasin lithotopes of adjacent streams may, to some extent, have been shared.

The low sinuosity of streams in the Sand Creek facies and the lack of appreciable alluvial relief (recognizable natural levee deposits) suggest that much stream relocation was accomplished by the simple aggradation of channels. Chute and neck cutoffs and avulsion (Allen, 1965; Jacob, 1973) were probably rare events.

Following the abandonment of a channel by a stream, drainage was reestablished by relatively rapid downcutting in unconsolidated alluvium at a lower point on the floodbasin. The accumulation of mud gall conglomerate lags at the bases of some apron-channel sandstones (see above) possibly reflects this episode of downcutting.

This model of channel development has a close genetic analogue in the accumulation of alluvial fan sediments (see, e.g., Blissenbach, 1954). It seems likely that apron-channel sandstones are the deposits of streams that maintained relatively high gradients with respect to streams responsible for the formation of sheet sandstones.

Sandy mudstone channels are relatively common in Willwood rocks. Neasham and Vondra (1972, p. 2175) classified these occurrences as "transitional deposits" and noted their pronounced erosional basal contacts. In a few instances, mudstone shoestrings were observed adjacent to sand-filled channels and contiguous with channel aprons. Some of these supplementary channels are filled with carbonaceous mudstone or shale (Fig. 7A) and probably represent swamps or oxbow pond deposits.

Fisk et al. (1954) have demonstrated that interdistributary trough fills are deposits that fill depressions between distributaries on the seaward edges of deltaic plains. It is possible that some of these Willwood mudstones are of similar origin but without the nearshore setting. These mudstones may have developed erosional lower contacts be-cause of rapid runoff that accompanied overbank flooding.

Willwood shoestring sandstones probably represent minor distributary channels that supplemented the major streams. The linear geometry of shoestring sands coupled with the frequency of horizontal stratification in these bodies suggests sediment accumulation in a channel with a moderate gradient or during flood stages.

Neasham and Vondra (1972), following Allen and Friend (1968), attributed a predominance of overbank mudstones in fluviatile sections to the confinement of streams within entrenched meander belts. Such confinement would certainly lead to the ultimate deposition of equally thick meander belt deposits or would require considerable alluvial relief (Bown, 1975). Channel cross-sectional geometry indicates that few streams were deeply incised; no channels in the Sand Creek facies are demonstrated to fulfill the geometric requirements for natural levee deposits.

The predominance of mudstones in the Willwood section is more likely related to a general lack of stream stabilization. Those streams that did achieve brief stability by episodes of downcutting during relocation were filled relatively rapidly by the more-or-less-constant influxes of sediment.

SHALES

The distribution and configuration of carbonaceous shale bodies in the Sand Creek facies of the Willwood Formation suggest an origin through slow infilling of topographic lows on a broad distal floodbasin with some vegetational ground litter. These lows were eventually filled by fine sediment that was deposited largely from suspension, probably during overbank flows.

The thicker and less laterally extensive carbonaceous shales that are overlain and truncated by apron-channel fills (Figs. 7 and 8) probably were deposited in ponds on the distal floodbasin. Because of their relatively low topographic positions, these ponds were frequently overlain by channel deposits, following stream relocation.

MUDSTONE COLORATION

Sinclair and Granger (1911) regarded the colored mudstones of the "Wasatch" (= Willwood) to have been controlled by conditions active at the time of deposition of each individual stratum. They believed (1912) that the red clays generally possess about 1.5 percent more iron than the blue beds and they attributed this phenomenon to the

accumulation of iron salts at certain horizons and their oxidation to hematite during dry climatic cycles.

The studies of Sinclair and Granger (1911), Neasham (1970), and the present author demonstrate that there are no important mineralogical differences between the clastic components of mudstones of different colors in the Willwood Formation. This fact is important to an understanding of the genesis of color in these rocks.

Many investigators have proposed origins for red beds, but no current theory satisfactorily accounts for the formation of red beds in variegated sequences. McKee (1963) observed that red beds *per se* are not indicative of any single climatic regime and require only an adequate supply of ferric oxides and an oxidizing environment. Van Houten (1968) has stated that there may be no reliable way to determine the source of the hematite pigment in red beds. Dorsey (1926), however, has pointed out that, under many and varied conditions of weathering, Fe_2O_3 is the expected and most stable of the common autochthonous iron minerals. It has long been recognized that ferric iron often forms interparticular films that may coat sand and mud particles (see, *e.g.*, Russell, 1889; Hager, 1928).

The ferric iron minerals believed to be most important in determining the color of ancient and modern alluvial sediments are:

Goethite ($Fe_2O_3 \cdot 2H_2O$); yellow, gold, brown
Limonite ($2Fe_2O_3 \cdot 3H_2O$); yellow, brown
Turgite ($2Fe_2O_3 \cdot H_2O$); red, reddish-brown
Hematite (Fe_2O_3); red

Posnjak and Merwin (1919) believed that no such sequences (progressive hydration or dehydration) could exist under surface conditions. Hager (1928) and Krynine (1949), however, have noted that goethite, the most hydrated of the minerals above, can and occasionally does alter to hematite under conditions existing at a sedimentary depositional surface. Because of difficulties in duplicating the reactions at low temperatures in the laboratory, Van Houten (1948) suggested that time was an important factor in completing the reactions. Eyles (1952) has demonstrated the dehydration of goethite to hematite in lateritic soils. Thus, it is apparent that the time sufficient for this process can be geologically brief, as brief as the period of genesis of lateritic soils.

Walker (1974) has offered supplementary evidence that certain buried alluvial profiles in Puerto Rico that contain brown hydrated ferric oxides lie chemically within the stability field of hematite. Walker (1967a, b; 1974) has described the dehydration and aging of limonite formed by the interstratal alteration of unstable iron-bearing silicates in sediments in hot, dry climates. Neasham (1970) and this study demonstrate that the essentially uniform mineralogy of all colors of Willwood mudstones suggests that no appreciable *in situ* alteration of minerals has occurred in these rocks. Moreover, Blatt, Middleton, and Murray (1972) have doubted that there is any mechanism by which the 2-3 percent or more ferric iron that is present in many red beds (including those of the Willwood) can be extracted diagenetically by clay minerals. Thus, there is no substantive evidence to contradict the assumption that Willwood coloring agents were transported to the site of deposition by streams and were hydrated or dehydrated there prior to lithogenesis.

Krynine (1949, p. 62) has observed that the preservation of red color requires only the dominance of oxidizing over reducing conditions. The relative oxidation/reduction potential (Eh) can be controlled by the supply of gaseous O_2 *versus* organic matter to be decomposed. Both of these constituents are readily available at the sedimentary interface in a fluviatile regime.

Krynine (1949) observed that red soils were formed by a dominance of hematite or turgite and that yellow or brown soils reflect a dominance of limonite. Limonite can be derived from ferrous carbonate. This mineral (siderite) commonly forms in association with other low-Eh minerals, such as pyrite, under reducing conditions. When soluble FeO is derived by the action of humic acids on feldspars (Hager, 1928), it can be converted to siderite by the reaction:

$$I- \quad FeO + O_2 + 2CO_2 \longrightarrow FeCO_3 + O_2 + CO_2$$
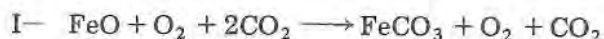
Siderite is soluble in waters that contain dissolved CO_2, so that in this state (see Tomlinson, 1916), or as FeO, iron may be transported in solution to the site of deposition. Ferrous carbonate readily oxidizes to limonite ($2Fe_2O_3 \cdot 3H_2O$) when CO_2 is removed from the system:

$$II- \quad FeCO_3 + H_2O \longrightarrow Fe(OH)_2 + CO_2,$$

and

$$4Fe(OH)_2 + O_2 + H_2O \longrightarrow (2Fe_2O_3 \cdot 3H_2O)$$
$$+ 2H_2O$$
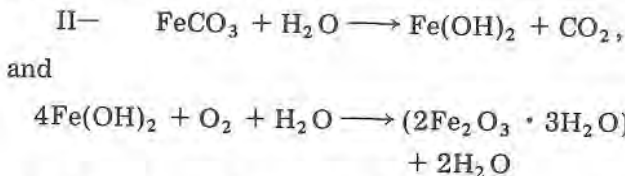
The limonite is then available to dehydrate into one of several ferric oxyhydrates or hematite, or to remain as an essentially insoluble precipitate.

Similarly, hematite can be derived from ferrous carbonate in the presence of calcium ions:

$$\text{III}- \quad 4FeCO_3 + 4Ca + 3O_2 \longrightarrow$$
$$2Fe_2O_3 + 4CaCO_3$$
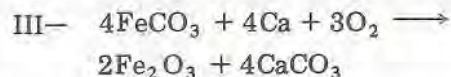
This equation is probably of importance in the association of calcium carbonate nodules with red mudstones in the Elk Creek facies of the Willwood Formation.

In the presence of organic carbon and poorly aerated waters, hematite may return to the ferrous state, *e.g.*:

$$\text{IV}- \quad 2Fe_2O_3 + 2C \longrightarrow 4FeO + CO_2 + C$$
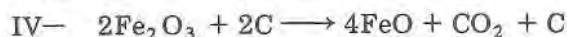
or, in the presence of oxygen, remain in the dehydrated ferric state:

$$\text{V}- \quad Fe_2O_3 + C + O_2 \longrightarrow Fe_2O_3 + CO_2$$
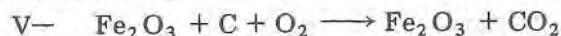
It is therefore possible to derive most ferric minerals necessary for the formation of variegated beds from compounds present at the site of deposition. These compounds may have arrived originally in solution or as detrital grains.

Sinclair and Granger (1911) and others have attributed the red color of some mudstones to a low Fe^{++}/Fe^{+++} ratio. This may be true in the sense that this ratio reflects the dominant oxidation state of the contained iron; however, the red coloring must result from the presence of at least some ferric oxide or oxyhydrate.

Dorsey (1926) believed that a more meaningful reason for the red color of mudstones is the dehydration of most ferric oxyhydrates to turgite or hematite. In support of his contention, he offered several examples of non-red rocks with relatively high ferric iron percentages. Similarly, chemical evidence from mudstones of the Sand Creek facies shows that those mudstones with the highest content of ferric iron are not red, but yellow (Fig. 16).

Van Houten (1964) observed that if red and associated non-red sediments were derived from the same source and initially had the same composition, the deficiency of red color in the non-red beds must have resulted from the reduction and dissolution of some iron oxides. In 1968, Van Houten emphasized the importance of aging of more-or-less-ubiquitous brown, amorphous ferric oxide to goethite and hematite in some tropical soils.

Neasham (1967, p. 66) noted that lavender Willwood mudstones commonly occur above red or maroon mudstones and that this association may have resulted from the accumulation of organic matter in the upper part of a red bed. The lavender bed represents an incipient "A" horizon of a developing alluvial soil profile. In 1970, Neasham observed that purple mudstones had low percentages of free Fe, Mn, and Al relative to red mudstones. He believed that this phenomenon might be due to the alteration of the upper parts of red mudstones " . . . through sesquioxide mobilization within a predominantly oxidizing and low organic matter environment." Neasham thought that this evidence was consistent with conditions resulting from a rising water table within elevated oxidizing areas.

Hager (1928) has shown that, in purple slates, the ferrous/ferric iron ratio is higher than in red slates or red shales. This evidence corroborates the evidence of Neasham (1970) that lavender beds can result from the partial reduction of iron compounds in red beds.

Chemical profiles of varicolored mudstones presented by Neasham (1970) and Neasham and Vondra (1972) have demonstrated the strong likelihood that the concentration of some chemical constituents in some variegated beds and their mobilization in others is related to ancient soil-forming processes. The percent weights of free iron, aluminum, and manganese and of organic carbon are particularly important to soil-forming processes in tropical areas today.

Geochemical analyses of mudstones of the Sand Creek facies exhibit fairly consistent ratios of free iron, free manganese, and organic carbon (Figs. 16-18). Mottled purple and orange mudstones in the Sand Creek facies have abnormally high organic carbon and free manganese contents. Class A gray mudstones also have high concentrations of organic carbon, and are invariably underlain by mottled purple and orange mudstones.

Robinson (1949) observed that oxides of manganese commonly accumulate near the surface in soils of poorly drained regions. The mottled purple and orange mudstone—Class A gray mudstone couplets of the Sand Creek facies may in part be analogous to the A_0 and A_1 soil horizons of Mohr and Van Baren (1954). The Class A gray mudstone represents an organic-rich eluviated zone, essentially leached of free iron. The underlying mottled purple and orange mudstone contains a significant, but smaller, percentage of organic carbon and contains a variable, but consistently high, percentage of free iron.

Van Houten (1948) and Neasham (1970) re-

lated color mottling in Willwood mudstones to bioturbation or to intermediate oxidation conditions. The evidence for bioturbation would be strengthened were it not that red and gray beds in the Sand Creek facies are almost never mottled. Moreover, those mudstone beds that preserve burrow casts are only rarely mottled.

Patterns similar to the irregular, anastomosing orange mottles in several purple beds of the Sand Creek facies were believed by Van Houten (1968) to occur in beds that:

> " . . . accumulated slowly on extensive lowlands with seasonal lakes and swamps where tropical soils formed and were preserved under conditions of variable drainage."

Mohr (1944) observed that mottling in some Indonesian soils may be due to an intermediate stage in the removal of ferric oxides in the zone of weathering, and possibly reflects poor drainage. In 1954, Mohr and Van Baren referred to this intermediate stage as "transitional amphibious weathering" and observed that it commonly occurs in soils that are submerged during the rainy season but oxygenated during the dry season. Conversely, Duchaufour (1972) and Meyer (1976) have noted that a shallow water table can cause mottling at the bottom of a horizon (hydromorphy).

The mottled mudstones of the Sand Creek facies are probably analogues of the amphibious soils of the Indonesian tropics. The geochemical data from the mottled purple and orange mudstones analyzed in this study are consistent with this hypothesis and suggest that the purple color is related to the high concentrations of organic carbon in these beds. The high organic carbon content indicates that the amphibious soils formed on a surface that was accumulating organic ground litter.

Willwood red beds probably formed in a climate typified by seasonal rains that alternated with relatively dry periods (see Mohr and Van Baren, 1954, p. 309-310). Krynine (1936) has observed that alternating periods of sheet flooding and thorough drying out of alluvium are common in the "seasonally humid tropics." Seasonal dryness is also a factor in calcium carbonate precipitation (see below). The absence of any plinth formation (see e.g., Sanchez and Boul, 1975; Abbot et al., 1976), the unaltered nature of most Willwood detrital feldspar grains, and the relative paucity of kaolinite in Willwood mudstones indicate an absence of lateritic weathering in either Willwood sediment source areas or at the sites of deposition of the Willwood mudstones. The fewer red beds in the Sand Creek

facies indicate that the Sand Creek—No Water Creek area maintained higher water tables than did much of the Elk Creek facies in early Eocene times. This might have resulted from more absolute rainfall in the southeastern Bighorn Basin (an idea that is supported below) or from more frequent rainfall.

Neasham (1970) and Neasham and Vondra (1972) attributed the Willwood red beds to the differential drying of alluvial fines that were stranded by the relocation of streams away from alluvial ridges. Red beds are among the most laterally persistent of Willwood mudstones, and it is not likely that alluvial ridges would dominate the floodbasin at the expense of lower terrain. This is particularly true in that these ridges are not seen in deposit geometries.

I believe that red Willwood mudstones are more symptomatic of alternating wet and dry climatic conditions than of the topographic positions of these deposits at one stage in their histories. These climatic conditions were felt differently in different parts of the Bighorn Basin because of the differential uplift of the basin borderlands.

Willwood red beds lack the genetic and tectonic attributes that were applied to red bed fluviatile environments in the Rock Springs Uplift area and Piceance Creek Basin by Roehler (1965, 1974). That author (1965) recognized eight intertonguing "lithofacies" in rocks of earlier Eocene through early middle Eocene age in the Rock Springs Uplift area. The characteristics of these "lithofacies" (red bed fluviatile, non-red bed fluviatile, paludal, recurrent lacustrine, shallow lacustrine, deep lacustrine, evaporite, and mud flat) were believed by him to reflect climate, tectonics, and topography. The red bed fluviatile facies is

> " . . . diagnostic of well-drained upland areas adjacent to mountain fronts or local topographic highs . . . " and " . . . uniformly gave way basinward to drab gray and green colors . . . ", (Roehler, 1965, p. 141).

The distribution of red and variegated mudstones in the Willwood Formation is apparently not controlled by proximity to the surrounding mountains. The greatest proportions and thicknesses of red Willwood mudstones are found in the central, not the peripheral, parts of the Bighorn Basin.

CALCIUM CARBONATE NODULES

Wortman (in Osborn and Wortman, 1892)

was the first to notice the multitude of small, brown, "earthy" calcareous nodules that litter many exposures of Willwood mudstones in the Elk Creek facies of the central Bighorn Basin (Fig. 19). Sinclair and Granger (1911, p. 107) observed that these nodules " . . . strew the badland slopes in countless numbers . . . ."

Many workers have suggested that these nodules have resulted from ground water activity and weathering processes under the present semiarid to arid erosion cycle. Several lines of evidence contradict this suggestion.

Some colored mudstones rarely have $CaCO_3$ nodules exposed at the surface and never possess them *in situ* in the Elk Creek facies (*e.g.*, gray and green mudstones). Neasham and Vondra (1972, p. 2173) have recorded the *in situ* occurrence of $CaCO_3$ nodules in red beds, and I have found them also in orange mudstones. This differential occurrence of the nodules in colored mudstones and the lack of differential mineralogical and textural attributes of clastics in color-differentiated mudstones are important to any explanation of nodule origins.

The deposition of calcium carbonate is controlled by the pH of the surrounding medium. When the pH increases, $CaCO_3$ may be precipitated. The increase in pH may be caused by the removal of CO_2 from solution, an effect that can be achieved by a decrease of atmospheric CO_2 pressure, agitation and aeration, or an increase in temperature.

Tarr (1921) and Weeks (1953) have studied the origins of certain fossil-bearing calcium carbonate concretions that occur in marine shales. Both authors conclude that the concretions are syngenetic and probably formed during or only shortly after deposition of the confining sediment. Weeks (1953, p. 162) observed that:

 " . . . an alkalinity adequate for rapid carbonate deposition from calcium-ion rich waters may be locally created by the ammonia that evolves rapidly as soon as proteinaceous (nitrogen-bearing) organic matter begins to decompose."

Although this argument was made with reference to a marine mode of origin, the association of calcium carbonate nodules as encrustations on fossil bone in Willwood and other fluviatile rocks is not an uncommon one (see, *e.g.*, Rose, Bown, and Simons, 1977) in the Elk Creek facies.

Schiebout (1974) suggested that carbonate nodules in the Paleocene Black Peaks Formation were formed by periodic flooding with "carbonate laden waters," and that this flooding was succeeded by drying out of the alluvium to form red beds. She also observed $CaCO_3$ encrustations on bones.

Mohr (1944) has observed that in areas of soil formation in the Indonesian tropics, $CaCO_3$ nodules normally do not develop in areas where relatively even-spaced rainfall exceeds about 1,000 mm per year. Krynine (1949) noted that 95 percent of present-day red soils have formed at temperatures above 60° F and rainfall of more than 1,000 mm. Because calcium carbonate is soluble, it usually remains in solution under such wet conditions and is then carried out of the system by the relatively consistent downward movement of water beneath the depositional interface. In areas of periodic rainfall, however, calcium carbonate nodules have formed even if precipitation rates have reached 1,400 mm per year. Areas of the East Indies with periodic but strong eastern monsoons that are spaced by relatively dry periods have developed large concentrations of $CaCO_3$ nodules deep in the soil profiles (beneath the development of red beds). Mohr and Van Baren (1954) documented the change in color of the A horizon of soils, due to a strong drought, from yellowish-brown to reddish-brown or red in parts of Indonesia that undergo distinct wet and dry periods.

Varicolored Willwood mudstones possess geochemical profiles like those expected for incipient alluvial soils. In analogy with soil-forming conditions in parts of Indonesia, it is likewise logical to relate the presence of $CaCO_3$ nodules to processes of soil formation under alternating wet and dry conditions. The *in situ* restriction of the nodules to red or orange Willwood mudstones is thereby explained.

Significantly, the basically drab Bitter Creek section of the Wasatch Formation ("Main Body") currently under study by Savage *et al.* (1972) does not contain variety 1 calcium carbonate nodules. These structures abound, however, in much of the dominantly red mudstones of the younger and superposed Cathedral Bluffs Member of the Wasatch.

The source of the calcium in these nodules in Willwood rocks is unknown, but there was probably no lack of exposed Paleozoic carbonate rock on the basin margins in early Eocene time. Warner (1965) determined that proximity to exposed limestone source rocks was an important factor in the derivation of calcium ions for $CaCO_3$ cement in sandstones of the Duchesne River Formation.

Carbonate rocks probably contributed to nodule development in the Willwood sequence, but calcium is also readily available from the weathering of felsic igneous rocks, and oxygen and carbon dioxide are abundant in the atmosphere and in some ground waters. Calcium is also a common interlayer element that can be freed by the weathering of calcium-rich clays (*e.g.*, mixed-layer smectites). Grim (1953) has observed that illite and montmorillonite (the dominant Willwood clay minerals) are commonly associated with pedological environments that permit calcium, potassium, and magnesium ions to remain in the weathered soil profile.

The absence of variety 1 calcium carbonate nodules in the Sand Creek facies is remarkable in view of their abundance in the Elk Creek facies. The differential occurrence of these structures is probably attributable to different amounts and spacings of rainfall in different areas of the basin in early Eocene times. The Sand Creek—No Water Creek Area is situated in the extreme southeastern corner of the Bighorn Basin and, in early Eocene time, was dominated by the rising southern Bighorn Mountains. It is probable that rainfall was greater in this marginal area than in the central part of the basin, an inference that is also supported by the fewer number of red beds in the Sand Creek facies.

Mudstone beds of the Sand Creek facies are slightly coarser in mean grain size than are most mudstones of the central basin Elk Creek facies. It is possible that a slight increase in permeability affected the mobility of $CaCO_3$ dissolved in ground water. Colored mudstones of the Sand Creek facies are also paler than their counterparts in the Elk Creek facies. Krumbein and Sloss (1963) have attributed paler colors, in some instances, to a general increase in mean grain size.

FERRIC IRON NODULES AND CONCRETIONS

The consistently correlated occurrences of indurated aggregates of ferric iron and sediment in varicolored Willwood mudstones is also important to an understanding of the genesis of these rocks. The origin of the ferric iron cement is probably the same as that of more finely dispersed ferric iron compounds in the colored mudstones. Miller and Folk (1955) have attributed hematite cement to the solution of ferrous iron during the weathering of parent rock in sediment provenance areas.

Mohr (1944) reported the association of $CaCO_3$ and ferric oxide concretions (or nodules; see Pettijohn, 1957) in soils of warm, damp climates that undergo periodic dry intervals. Robinson (1949, p. 90) observed that the deposition of iron oxides is commonly

"... marked where there is a fluctuating water table in a fairly permeable profile as in many sandy soils in low-lying flats."

Many ferric iron nodules of the Sand Creek facies also contain very large concentrations of free manganese compounds (*e.g.*, varieties 3, 8, and 9, Fig. 20). Manganese compounds are commonly concentrated in soils of poorly drained areas (see above; also Robinson, 1949; Soil Survey Staff, 1951). Poorly-drained areas are often typified by reducing chemical conditions. If one prefers a detrital hematite source for the iron in variegated beds and indurated structures, Carrol (1958) has observed that Fe_2O_3 in clays may be reduced by bacterial activity on organic matter (see equation IV, above). If the sediments later dry out, Fe_2O_3 may reappear as nodules.

There is some evidence that varying chemical conditions in Willwood alluvium affected the nature of ferric oxyhydrate precipitation in the presence of vertebrate fossil material. At fossil localities 44, 55, and 111, the iron encrustation on the fossils is yellow-brown (probably limonite), whereas elsewhere it is red (probably hematite). Equations I-III (above) demonstrate that both compounds may be derived from siderite.

Van Houten (1944, p. 183) states:
"Under swamp conditions, ferric hydroxide can be precipitated from ferrous carbonate solutions by oxidation and hydration or by activity of organisms. In the presence of carbonic acid or decaying matter, iron may be precipitated as ferrous carbonate. This may be oxidized to ferric hydroxide or remain as a carbonate in the presence of much organic material."

If these iron compounds were originally deposited on the bones as ferrous carbonate, it is an easy matter to derive either the limonite encrustations encountered at localities V-73044, V-73055, and V-73111 (equation II) or the hematite encrustations that occur everywhere else on these bones in the Sand Creek facies. A second explanation, the dehydration of limonite to hematite, takes place more rapidly in warm, moist climates than in hot, dry climates (Hager, 1928).

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The presence of ferric oxide nodules in mudstones of the Sand Creek facies that are similar to structures forming in tropical soils today invokes the probability that the Willwood structures were, similarly, formed by pedogenetic processes. The Sand Creek facies was typified by poorly-drained areas or fluctuations of the water table during sediment deposition. The paucity of variety 2-6 and 8-10 structures in the Elk Creek facies suggests that better drainage existed where these beds were deposited.

CYCLIC UNITS

Solution of the Markov Analysis for beds of the Sand Creek facies using variable 4 x 4 matrices defines a colored mudstone—sandstone cyclothem in the order sandstone, mottled purple and orange mudstone, drab mudstone, red-orange mudstone or sandstone. In two sections, red-orange mudstones are commonly overlain by mottled purple and orange mudstones. Solution for 8 x 8 variable matrices produced meaningless results.

As noted above, some of the colored mudstones (e.g., mottled purple and orange mudstones) owe their color to fluctuations of the water table, a process that could affect the mudstones differentially depending on the hydrated iron compounds developed under surface weathering conditions. The Markov Analysis might therefore be affected by the superposition or alteration of geochemical states in a way that cannot be eliminated as a variable from the analysis.

The discrete units recognized in this study are essentially the same as those utilized by Neasham (1970) and Neasham and Vondra (1972) for the middle and upper parts of the Antelope Creek— Tatman Mountain section and for the Meeteetse— Tatman Mountain section. Those authors grouped orange mudstones with red mudstones in these sections (Vondra, 1976, oral communication), and did not differentiate mottled purple and orange mudstones in the lower part of the Antelope Creek—Tatman Mountain section, units which certainly occur in those rocks. Carbonaceous shale, represented by only two units in the Sand Creek facies and lumped with DRAB, composes about 18 percent of the lower Antelope Creek—Tatman Mountain section.

Sandstones in the Elk Creek facies are dominantly overlain by red mudstones or by drab mudstones. Neasham and Vondra (1972) believe the red mudstone/sandstone couplet could be attri-

buted to "Improved drainage and lower water tables in the alluvial ridge and natural levee areas . . ." In the Sand Creek facies, sandstones are principally overlain by MPOP and the same is generally true for RO mudstones. It is expected that, in fluviatile sections where sandstones are characterized by erosional lower contacts, the units subjacent to sandstones will vary. However, in both the Sand Creek and Elk Creek facies, sandstones are much more frequently underlain by DRAB or RO (red) mudstones than by any other unit. The sandstone/DRAB couplet is understandable because runoff will naturally re-establish a channel in low-lying areas of the floodplain that are likely to be characterized by higher water tables and reducing conditions. The sandstone/RO (red) couplet may be explained by occasional very dry periods between flood and channel relocation stages. This interpretation is further corroborated by the very high incidence of red beds in the Elk Creek facies. It is unlikely that runoff will re-establish on alluvial ridge and natural levee sediments that owe their red color to lower water tables and improved drainage.

It is desirable to define the areal and stratigraphic dispersion of cyclic deposits. Slanska (1976) has shown that the lateral extent of fluviatile cyclothems may not be great. Neasham and Vondra (1972) observed a greater proportion of red beds near the top of the Willwood section than at lower levels. In general, however, the Sand Creek and Elk Creek facies cyclothems are quite similar. The major differences that do exist between these two units (nodules, bed geometries and thicknesses, proportions of colored mudstones) are not apparent in comparisons of Markov analyses.

Willwood color cyclothems are apparently not restricted to a single floodbasin. Because these cyclothems probably reflect general climatic and tectonic conditions, they are allocyclic (sensu Beerbower, 1964) in that the effects of these conditions are not restricted to a single sedimentary prism or facies within the Willwood body of sediment.

CLASS A GRAY MUDSTONES AND TAPHONOMY

The occurrence of about 90 percent of the fossil vertebrate specimens in the Sand Creek facies in Class A gray mudstones is suggestive of the mode of origin of fossil concentrations in the Willwood Formation in general. The occurrence of the fossils in situ in a particular kind of mudstone

is perhaps less significant than is the fact that these distinctive Class A gray beds *invariably* overlie mottled purple and orange mudstones in the Sand Creek facies. This association suggests that the mode of origin of the mottled purple and orange units has affected the probability of fossil concentrations in superjacent units.

The genesis of mottled purple and orange mudstones has been related to incipient soil-forming processes in areas of variable drainage. Alluvial soils form relatively rapidly in comparison to most bedrock soils; nevertheless, any soil formation is accompanied by intervals of non-deposition. Müller (1950) has observed that accumulations of fossil shells in the German Muschelkalk (Triassic) indicate periods of interrupted sedimentation. In view of the persistent association of fossil concentrations with incipient soil horizons in the Sand Creek facies, it seems likely that the same condition is responsible for these accumulations.

Articulated skeletal material is rarely encountered in Willwood mudstones. The remains consist almost entirely of jaws, teeth, phalanges, vertebrae, and a few articular ends of long bones. Most of these elements are broken, the teeth are often fractured, and the bone surfaces are occasionally weathered or cracked. A few bones have been gnawed, presumably by rodents.

This evidence is consistent with the gradual accumulation of the remains on the surface of the ground. The paucity of complete long bones and ribs suggests the likelihood of scavenging activity by carnivorans. There is no convincing evidence that these concentrations are of scatological origin (Mellett, 1974), rather than simple lags produced by intervals of non-deposition. The occurrence of the remains of both large and small mammals in approximately equal stages of preservation argues against a scatological interpretation.

Voorhies (1969) has suggested that Late Tertiary depositional regimes apparently favored concentrations of transported remains to a greater extent than did Early Tertiary regimes. He observed that many small postcranial elements (*e.g.*, vertebrae, sacra, ribs, phalanges, and carpals) are winnowed out by hydraulic sorting in streams. Vertebrae, phalanges, and occasional carpal and tarsal bones are the most common complete postcranial bones in Willwood mudstones: this indicates little or no sorting by stream action. The fossils in most Willwood mudstones probably represent, for the most part, the remains of animals that lived or frequented and died on the alluvial floodbasin.

The idea that the fossils may have been carried a significant distance by thalweg- or meander-belt-controlled streams is contradicted by three lines of evidence in addition to the relative frequencies of different postcranial bones. (1) There is no evident mean increase in size of fossil specimens laterally as the apron of a channel sandstone is approached. Such an increase would be expected if skeletal elements of different sizes were deposited on the flood basin by streams during high water. Conversely, Class A gray mudstones become increasingly sandy as the proximal sandy apron of the channel is approached, and rarely contain any fossils whatsoever. (2) Overbank mudstones comprise, volumetrically, the bulk of Willwood rocks and yield in excess of 98 percent of known vertebrate fossils from the formation. Only mudstone units of certain colors possess large concentrations of fossils. If these concentrations were the result of overbank flooding, one would expect them to occur in the mudstones irrespective of their colors. (3) Sandstones comprise nearly 22 percent of the Sand Creek facies, yet are virtually barren of fossils. Very few specimens of any provenance are water worn. The few teeth that have lost all or most of their enamel were probably ingested by crocodilians (Fisher, 1976, oral communication).

The fossil concentration processes at work during the deposition of the Sand Creek facies, therefore, contrast with the taphonomic models outlined for later Tertiary and Quaternary rocks and faunas in northeastern Nebraska (Voorhies, 1969) and East Africa (Behrensmeyer, 1975). Fossil deposits on soil surfaces in Willwood rocks probably constitute attritional mortalities (*sensu* Voorhies, 1969) as evidenced by the relatively high percentage of remains of small (short-life-span) mammals. Nevertheless, the recovery of a large number of juvenile dentitions of *Hyracotherium* at UW locality V-73022d and of *Hyracotherium* and *Ectocion* at UW locality V-73024 (Campbell Quarry) suggests the possibility of at least some controlled mortality of young individuals.

Similar concentrations, perhaps in unrecognized Class A gray mudstones, have been noted by earlier workers. Jepsen (1930a) and Van Houten (1944, p. 179 and 184) encountered fossil concentrations or "pockets" developed in gray Willwood mudstones. Sinclair and Granger (1911, p. 117) observed that fossils often occur at the contacts of "red" and "blue" strata in Bighorn Wasatch (= Willwood) rocks, and recorded a peculiar abundance of fossils " . . . at or near the contact of a stratum of bluish-green shale resting on a red shale

band . . . '' in badlands of the Wind River Formation on Beaver Rim (1911, p. 91). Gazin (1952, p. 7) and Lillegraven and Winterfeld (1976, oral communications) have reported similar rich concentrations of fossils in the Knight Formation near La Barge and Big Piney, and in the Fort Union Formation in the eastern Rock Springs Uplift area, respectively.

Bed "A" of Rohrer (1964a, 1964b) and Rohrer and Gazin (1965) is a particularly persistent and at least locally fossiliferous gray-purple mudstone and sandstone complex that outcrops in the Sheep Mountain — Tatman Mountain area of the central Bighorn Basin and may be related genetically to the Class A gray mudstones of the Sand Creek facies. The wide distribution of Bed "A" and the possible overlap of the local range zones of the tapiroids *Homogalax* and *Heptodon* in Bed "A" are suggestive of soil development and an interval of no deposition.

Class A gray mudstones were encountered with less frequency in rocks of the Elk Creek facies than in those of the Sand Creek facies. However, more than thirty fossil localities known to me in the Elk Creek facies are physically associated with purple mudstones. The richest of these are probably localities UMMP-RB-10 and UW-fl-76-7, each of which has yielded more than 200 mandibular and maxillary specimens in a single day. YPM locality 45 is a complex of extremely rich sites dispersed over approximately two sections in the Elk Creek facies west of Worland. More than 2,500 specimens have been recovered from these sites, and they remain highly productive. The fossils occur largely as surface lag concentrations on a sequence of alternating orange and gray mudstones rich in variety 1 calcium carbonate nodules. Similar and nearly as rich localities occur at "Moo Cow Hollow" and at "Kraus Flats," also west of Worland in the Elk Creek facies.

The orange and gray mudstones that yield the fossils are alternating beds between 3 and 9 meters in thickness. The individual orange beds in the sequence are commonly about 1 meter thick and the gray beds are 6-30 cm thick. Approximately 17 specimens were recovered *in situ* at these localities in 1975 and 1976. All were weathering from gray mudstones. An additional 80 matrix-enclosed specimens were obtained, all derived from gray mudstones. The fossils from these localities are often encrusted by varity 1 calcium carbonate nodular material (about 15-25 percent of all specimens).

Simpson (1937a) and Van Houten (1945) have concluded that most Early Tertiary mammalian fossils have been found at surface localities where

" . . . the mammal remains are rare, as far as known, and are so sparsely scattered through the matrix that only occasional finds or concentration from long weathering and wind erosion leads to any production." (Simpson, 1937a, p. 29)

Sinclair and Granger (1911) believed that the Bighorn Wasatch (= Willwood) fossils are most abundant in red beds. These viewpoints have been reflected in techniques employed by collectors in the Willwood Formation for more than eighty years.

Enormous lag concentrations do exist on Willwood exposures; however, re-collection of some of the richest of these lags, the discovery of new concentrations, and examination of the rocks suggest that the fossils are largely derived from gray mudstones and that these gray mudstones are abnormally rich in fossil vertebrate remains. Concentrations of vertebrate fossils are only very rarely encountered *in situ* in true red, orange, or purple, as opposed to gray, mudstones.

Van Houten (1945, 1948) believed that most Willwood fossils from drab sediments are concentrated in small pockets or quarries and represent small, forest-dwelling animals. On the other hand, he believed fossils from "red beds" to be generally scattered throughout the matrix and to be principally those of terrestrial ungulates and carnivores.

The difference between surface-collected and quarry-collected material in Willwood rocks is not as dramatic as Van Houten assumed. Most of the forms that Van Houten considered to be arboreal are relatively small in body size and would be easier to find by washing quarry matrix than by surface prospecting. It is clear that the mammals Van Houten has listed as prevalent in "red beds" or at surface localities are also the largest elements in the fauna, *e.g.*:

Coryphodon	*Phenacodus*
"*Sinopa*"	*Hyracotherium*
Homogalax	*Didymictis*
Lambdotherium	*Oxyaena*,

or are the most abundant in any Willwood beds, *e.g.*:

Hyracotherium	ischyromyids (especially specimens of
Hyopsodus	ally specimens of
	incisors).

Surface nodular litter often obscures productive beds from the eye of the collector. Moreover, weathering of interbedded variegated and gray

mudstones often makes the whole sequence appear to be colored. Where very large concentrations of fossil mammals appear to occur in colored mudstones in the Elk Creek facies (*e.g.* YPM localities 45, 175, 185; UW field localities 75-5, 76-8), they are invariably derived from gray beds. As noted on p. 45, purple beds also occasionally possess large concentrations of vertebrate fossils.

SEDIMENTARY ENVIRONMENT

The pigmenting iron minerals in Willwood rocks were probably derived from the decomposition of ferromagnesian minerals in the source areas (see, *e.g.*, Van Houten, 1948; Krynine, 1949). The relocation of these minerals to the site of deposition (by either solution or mechanical transportation) was followed by their differential oxidation, reduction, hydration, or dehydration in response to geochemical conditions on the floodplain. There is abundant evidence which relates these geochemical conditions to incipient soil-forming processes. There is no evidence that the iron minerals in Willwood rocks were formed by dehydration due to increased heat and pressure after burial (see, *e.g.*, Crosby, 1891; Barrell, 1908), or that they reflect interstratal alteration due to aging of ferromagnesian minerals (Walker, 1967a, 1967b, 1974, 1976). In the absence of significant textural and compositional differences in the clastic fractions of Willwood colored mudstones, no way is known by the present author in which either the cyclic deposition or *in situ* post-lithogenic cyclic alteration of these minerals can be accomplished.

The presence of orange mottling in many of the purple beds, the concentration of free iron and manganese compounds in these beds, the concentration of organic carbon in mottled purple and orange and Class A gray beds, and the association of fossil vertebrate remains with Class A gray mudstones clearly support color origins consistent with pedogenesis.

The differential coloration of mudstones and the occurrences of nodules and concretions indicate that Willwood soils were developed under alternating wet and dry conditions similar to those operative in some present-day tropical and subtropical areas subject to monsoons.

The paucity of red beds, the absence of calcium carbonate nodules, and the relative abundances of gray and purple beds in the Sand Creek facies indicate that moister conditions prevailed during the deposition of those rocks than during the deposition of the Elk Creek facies. If, as at present, the southern Bighorn Mountains faced, or were proximal to, the windward side of the basin, then most rain fell in the upland border areas of the basin, such as the eastern part of the Sand Creek—No Water Creek area.

Mackin (1937, 1947) suggests that, for most of the Eocene, the ranges surrounding the Bighorn Basin probably stood at a maximum of 900-1500 meters above the basin floor. Mackin (1937) and Van Houten (1952) believed that the Willwood Formation was probably deposited in a warm, humid, lowland environment, not more than 300-450 meters above sea level. Dorf (*in* Van Houten, 1949) has observed that the known Willwood flora is closely related to the early Eocene Wilcox flora of the Gulf Coast region, a flora representative of warm, humid lowland environments.

High mountains surrounding the Bighorn Basin, particularly on the windward side, would certainly have affected the climate by the creation of a basinward rain shadow. The presence of upper Polecat Bench and lower Willwood conglomerates along the east front of the Beartooth Mountains (see, *e.g.*, Pierce, 1965; Bredall, 1971) and of "Wasatch" conglomerates along the east front of the central and northern Bighorn Mountains (see, *e.g.*, Brown, 1948, 1958; Hose, 1954) indicates that these regions were active or were already elevated in early Eocene time. The Absaroka volcanic pile, bordering the central-western and southwestern Bighorn Basin, began to accumulate in late early Eocene time (Jepsen, 1939; Hay, 1956). The Absarokas lie atop the truncated Washakie Range (Love, 1939). It is unlikely that the Washakie Mountains were a formidable barrier to westerly storms, particularly if quartzite cobbles were transported southeastward across this region at about the time of the beginning of Willwood deposition as suggested by Love (1960; oral communication, 1975) and Love and Reed (1968).

The major drainage of the Wind River Basin was eastward in Paleocene times (Love, McGrew and Thomas, 1963; Keefer, 1965; Courdin and Hubert, 1969; McGrew, 1971; Rocky Mountain Association of Geologists, 1972), and the major drainage out of the Bighorn Basin was probably to the southeast (Love, 1960; Love, McGrew, and Thomas, 1963; my unpublished data), over the site of the present-day Owl Creek Mountains. This drainage probably joined the major east-flowing Wind River Basin streams.

The Owl Creek deformation was probably initiated during the Paleocene with the development of low, west-northwest-trending folds (Keefer, 1965). However, the principal episodes of overthrusting and structural elevation of the range probably did not occur until post-Fort Union time (Tourtelot and Nace, 1946; Tourtelot and Thompson, 1948; Keefer and Love, 1963), and the central and eastern Owl Creek Mountains may not have risen until post-Indian Meadows time (Keefer and Troyer, 1956; Keefer, 1965).

This schedule of orogenic activity is consistent with a reversal of the major Bighorn Basin drainage to the northwest in late "Gray Bull" and early "Lysite" time, the development of drier conditions as a result of higher borderlands, and the concomitant up-section evolution from dominantly variegated to dominantly red and purple mudstone suites observed by Neasham (1970).

VERTEBRATE FAUNA

INTRODUCTION

FOSSIL LOCALITIES

Eighty vertebrate fossil localities were discovered in the Sand Creek facies by prospecting exposed rock, flats developed at the bases of badland hills, and anthills. Ten of these sites were developed further by the screen washing of weathered matrix, and seven localities were successfully quarried. With the exception of the Banjo Quarry, discovered by E.L. Simons in 1972 (YPM locality 370; UW locality V-73016a), these are the only continuously productive fossil vertebrate quarries found in Willwood rocks since collecting operations began in the Bighorn Basin in 1880.

The development of these localities has resulted in the recovery of approximately 3,400 catalogued specimens, of which about 90 percent are gnathic remains. An additional estimated 6,000 teeth and 900 postcranial bones (mostly fragmentary) have been recovered but not catalogued. All specimens from the Sand Creek facies that are discussed in this report are housed in the paleontology collections of The Geological Museum, University of Wyoming, Laramie.

Class A gray beds are the most important fossil-producing beds in the Sand Creek facies and yielded 90 percent of the fossils described in this report. Because of their abnormally rich vertebrate fossil content, these units constitute zonules in the strict stratigraphic sense (American Commission on Stratigraphic Nomenclature, 1961), and are biostratigraphic units. Insofar as the Willwood collections from each Class A gray bed in the Sand Creek facies comprise

"... a sample of the general fauna of the

formation, coming from a definite horizon in the local section and from a definite geographic position ..."

these collections are *faunules* in the sense of Williams (1903, p. 131; see also Tedford, 1969, p. 686).

Class A gray beds proved to be so distinctive that it was possible to reconnoiter large areas of the Sand Creek—No Water Creek Area, estimate the productivity of the exposures, and plan collecting efforts for several days in advance. The lateral fossil productivity for some of these beds exceeds 3,400 meters. All but one of the screen wash sites (excluding anthills) and all but two of the small mammal quarries were developed on Class A gray mudstones.

Approximately 7,500 kg of matrix from these beds were screen washed for fossils in 1974-75, a figure that will be increased in succeeding seasons. The principal technique was to shovel weathered matrix from the surface of a bed into burlap bags. The matrix was soaked briefly in water, and the resulting mud was sieved in a slurry through fine screens. No kerosene preparation is necessary for weathered matrix. The concentrate obtained by this method was about 80 percent vertebrate fossils.

The richest wash sites (Slick Creek Quarry, Wadi Kraus Quarry) yielded approximately 7 teeth and one jaw fragment per bag of matrix (about 15-20 kg), and the richest quarry sites yielded about 6 mandibular or maxillary specimens per worker per day (Wadi Kraus Quarry). The Supersite Quarry bed yielded about one jaw and 14 teeth per cubic foot of matrix taken at random from the best exposures of this bed along strike for about 150 meters. If this bed is equally rich in the subsurface,

Table 2. Synopsis of vertebrate fossil localities — Sand Creek Facies

Locality	Name	Meters/feet above base of Willwood	Type of occurrence	Methods
V-73016a =YPM 370	Banjo Quarry	69.8/229	SS-Exc.	S,W,Q
V-73016b =YPM 370	Banjo Anthills	64.0/210	AH-Exc.	S,W
V-73016c	Banjo CAG	61.3/201	CAG-F	S
V-73017	Camp	64.0/210	SI-F	S
V-73019	Canal	8.5/28	SI-P	S
V-73020a,b	Purple Valley #1	97.3/319	CAG-G, AH	S,W
V-73021	Banjo Flats #1	?	SI-P	S
V-73022	Slick Creek Q. Beds	45.7/150	CAG-Exc.	S,W,Q
V-73023	—	31.1/102	CAG-G	S
V-73024	Campbell Quarry	48.2/158	MPO-Exc.	S,W,Q
V-73025	—	24.4/80	SI-P	S
V-73026	—	24.4/80	SI-P	S
V-73027	Stonehenge Q. Beds U of Wyo. Quarry	29.6/97	CAG-Exc.	S,Q
V-73028	East Fork Crossing	18.3/60	SI, CAG-F	S
V-73029	—	?	SI-P	S
V-73030	Sand Creek Divide	129.6/425	CAG-P	S
V-73031	—	?	SI-P	S
V-73032	Hilltop	?45.7/?150	CAG-G	S
V-73033	—	33.5/110	CAG-F	S
V-73034	Two Head Hill Q. Beds	33.5/110	CAG-Exc.	S,W,Q
V-73035	—	39.9/131	CAG-F	S
V-73036	—	?36.0/?118	SI-F	S
V-73037	Supersite Q. Beds	33.5/110	CAG-Exc.	S,W,Q
V-73038	—	40.9/134	CAG-F	S
V-73039	—	23.2/76	SI-P	S
V-73040	—	?	SI-P	S
V-73041	—	<30/<100	CAG-P	S
V-73042	—	~24/~80	SI-P	S
V-73043	—	?	CAG-P	S
V-73044	Wadi Kraus Q. Beds	56.7/186	CAG-Exc.	S,W,Q
V-73045	—	45.7/150	SI-P	S
V-73046	Marconi Road Loc.	75.3/247	CAG-Exc.	S,W
V-73047	—	?	CAG-P, SI, P	S
V-73048	—	62.8/206	SI-P	S
V-73049	Purple Valley #2	87.8/288	CAG-F	S
V-73050	—	65.5/215	SI-P	S
V-73051	Purple Valley #3	87.8/288	CAG-F, SS	S
V-73052	Purple Valley #4	97.3/319	CAG-G, AH	S
V-73053	—	39.0/128	CAG-F	S
V-73054	—	112.8/370	CAG-P	S
V-73055	Lost Yale Site	118.6/389	CAG-G, AH	S
V-73056	—	?	CAG-P, SI	S
V-73057	Rattlesnake #1	?	CAG-P	S
V-73058	Rattlesnake #2	?	CAG-P	S
V-73059	—	~4.3/~14	SI-P	S
V-73060	—	39.0/128	SI-P	S
V-73061	—	?	SI-P	S
V-73062	—	27.1/89	CAG-P	S
V-73063	—	45.7/150	CAG-P	S
V-73066	—	31.1/102	MPO-Exc.	S
V-73067	*Thryptacodon* Site	~25.9/~85	MPO-Exc.	S
V-73076	*Tinimomys* Hills	29.6/97	CAG-Exc.	S,W

Locality	Name	Meters/feet above base of Willwood	Type of occurrence	Methods
V-73077	—	33.5/110	CAG-F	S
V-73078	—	~45.7/~150	CAG-G	S
V-73080	—	45.7/150	CAG-F	S
V-73081	—	76.5/251	CAG-P	S
V-73082	Oilspud Site	87.8/288	CAG-Exc., AH	S
V-73083	—	~80.8/~265	CAG-P	S
V-73084	—	118.6/389	CAG-G	S
V-73085	—	22.9/75	CAG-P	S
V-73086	Lantern Hill	61.3/201	CAG-P	S
V-73087	—	94.2/309	SI-P	S
V-73088	Banjo Flats #2	?	SI-P	S
V-73089	Banjo Flats #3	?	SI-P	S
V-73090	Bown Bonanza	?	CAG-Exc.	S
V-73091	—	?	SI-P	S
V-73092	—	?	SI-P	S
V-73095	—	<10.0/<33	SI-P	S
V-73096	—	~20.0/~65	SI-P	S
V-73098	—	?	SI-P	S
V-73105	—	15.2/50	SI-P	S
V-73110	—	39.6/130	SI-P	S
V-73111	—	112.8/370	CAG-P, AH	S
V-73124	—	179.9/590	CAG-F	S
V-73125	Big "W" Site	179.9/590	CAG-Exc.	S
V-73126	—	179.9/590	CAG-P	S
V-73127	—	179.9/590	CAG-F	S
V-73128	Lower Sand Creek Divide	?	CAG-F	S
V-73129	Mary's Hill	80.5/264	SS-Exc.	S
V-73130	Oil Well Locality	30.5/100	CAG-P	S

CAG = occurrence in Class A gray mudstone
MPO = occurrence in mottled purple and orange mudstone
SS = occurrence in sandstone or in sandy mudstone
AH = occurrence in anthills
SI = surface interval locality, provenance of fossils uncertain

Q   = quarry
W   = screen washing
S   = surface prospecting
Exc = excellent productivity
G   = good productivity
F   = fair productivity
P   = poor productivity

an assumption that is in part corroborated by the recovery of numerous fossils over an irregular outcrop pattern, a section of the bed 10 cm thick, 30 cm wide and 150 meters long might be expected to yield 150 jaw specimens and 2,100 teeth. Clearly, the paleontological potential of Class A gray mudstones is enormous.

Numbered localities that are used in the text designate geographic areas, and a single Class A gray mudstone may be the source of fossils for several numbered localities. For example, numbered localities V-73033, 73034, 73037, and 73077 were developed in different areas on the same bed, but are separated by areas of poor exposure. The systematic and analytical treatment has lumped samples by their provenance beds in those cases where the tracing of beds has demonstrated the productive horizons to be in identity. For the utility of future, more refined studies, and in case of possible error in correlating beds, all fossils were catalogued by geographic locality.

The relative stratigraphic positions of nearly all the Sand Creek facies fossil localities are depicted on the graphic sections (Figs. 2-4) and in Table 2.

STRATOPHENETIC TECHNIQUES

The synthesis of stratigraphic and paleontologic data for Willwood rocks, when coupled with a still-badly-needed review of Wasatchian faunas in general, has the potential to become the first reliable biostratigraphic zonation of the continental early Eocene. These studies are especially important in the Bighorn Basin, where rich early Eocene faunules are supplemented by well-documented Paleocene vertebrate assemblages. Moreover, the Early Tertiary section of the Bighorn Basin includes the type occurrences of the Clarkforkian, "Sand Coulee" and "Gray Bull" faunas. The elucidation of the relationships and significance of potential equivalents of these faunas outside the Bighorn Basin must begin with a clear

Figure 23. Relative representation of the orders of mammals in all collections from the Sand Creek facies. The number of degrees in each sector was calculated from the minimum number of individuals of each species in the order necessary to account for the total number of identifiable specimens. The minimum number of individuals was determined separately for each taxon and was based on the greatest frequency of either left or right P^4_4, M^1_1, and M^2_2 (where distinguishable), and M^3_3.

picture of the successive early Eocene faunal composition within that basin.

Simpson (1949) suggested that, in sections where there are no major gaps in the fossil record, the paleontological evidence can prove continuity of origin of species. Mayr (1942) believed that species tend to arrive allopatrically and, once established, usually remain allopatric. These tenets are expressed today in the concepts of phyletic gradualism and punctuated equilibria in organic evolution.

Gingerich (1974c, 1976a) has documented what is apparently relatively slow *in situ* evolution involving changes in tooth size in stratigraphically successive populations of *Hyopsodus*, *Haplomylus*, and *Pelycodus* from the Willwood Formation of the Bighorn Basin. Schaeffer, Hecht, and Eldredge (1972), Eldredge (1974), and Eldredge and Gould (1974) presented arguments favoring punctuated equilibria or allopatry as the principal method of speciation in many organisms.

It is doubtless futile to attempt to convincingly falsify either hypothesis on existing empirical evidence, and the biologic and paleontologic data appear to be versatile enough to accommodate either or both. Eldredge and Gould (1974) admit to some "short term" gradualism in the guise of directional selection, but they believe it unlikely that a population would submit to environmental change requiring linear directional evolution for a long period of time without changing its place of residence.

Eldredge (1974) presented three minimal requirements for a test of phyletic gradualism in samples of fossil organisms. (1) The sample must span a considerable segment of geologic time. (2) The sample must be derived from all available geographic areas and must approximate, as much as possible, the original configuration of the depositional basin. (3) The phylogenetic relationships among these samples must be "... adequately and realistically grasped ...." When these requirements are satisfied, the student then selects characters that are variable in the sample and determines whether or not progressive changes in these character states emerge when viewed against stratigraphic position. If enough points are used and a progression is found, the model is then consonant with phyletic gradualism.

Matthew (1915a) and Simpson (1937c) first recognized that progressive size changes had occurred in populations of Clarkforkian, "Sand Coulee," and "Gray Bull" mammals of the Bighorn

Basin. The stratigraphic paleontologic studies of *Hyopsodus*, *Haplomylus*, and *Pelycodus* by Gingerich (1974c, 1976a), when here supplemented by similar and corroborative treatments of these taxa in the Sand Creek facies, meet the requirements of Eldredge (1974) perhaps as closely as is presently possible for samples of fossil vertebrates. These studies (Figs. 25, 32, and 34) clearly demonstrate the progressive directional evolution of size-dichotomous or size-trichotomous populations of these mammals. The interbasinal dispersion and identity of the paleontologic species of some of the mammals, *e.g.*, *Hyopsodus* and *Pelycodus*, remain in doubt. The difficulty in assigning established names to the groups that have emerged from these stratigraphic plots results from ignorance of the relative stratigraphic contexts of the type materials. Many of these types were collected outside the Bighorn Basin and may have occurred in rocks deposited at different rates. However, it does seem likely that there are enough named taxa to accommodate the existing correlatable variation.

It is unfortunate that most samples of early Eocene fossil vertebrates have been obtained (often necessarily) from scattered outcrops without good stratigraphic control. Moreover, few published fossil vertebrate localities in these rocks yield large enough samples of even common taxa to provide reliable estimates of biometric variation for the species at their respective stratigraphic positions.

If paleontologic species are difficult to distinguish on characters other than size differences, the relative contemporaneity of samples is critically important. This is especially true for species that exhibit progressive size changes up section. The experimental statistical treatment of several samples of fossil mammal teeth from different stratigraphic levels of the Sand Creek facies has demonstrated that the use of histograms, scatter diagrams, standard deviations, and coefficients of variation of tooth dimensions derived from pooled samples of teeth from widely disparate stratigraphic or geographic positions is often of no reliable utility in the diagnosis of paleontologic species.

Simpson (1942, p. 175) asked:

"If a fossil can only be identified when its horizon is known, what becomes of the whole basis of paleontological correlation of horizons by the identification of their fossils?"

It is not circular reasoning to identify fossils by their horizon-specific characters and to correlate these horizons by their fossils if the stratigraphic positions can be determined independently of the fossils. Because there can be no evolution without time, the use of relative stratigraphic positions of fossil samples for identification purposes is valid. This technique can now be used with greater precision for early Eocene mammals than the arbitrary separation of samples into ill-defined subage components (*e.g.*, "Gray Bull," "Lysite," and "Lost Cabin").

SYSTEMATIC PALEONTOLOGY — CLASS MAMMALIA

Subclass Allotheria Marsh, 1880

ORDER MULTITUBERCULATA Cope, 1884

Superfamily Taeniolabidoidea Granger and Simpson, 1929

Family Eucosmodontidae (Jepsen, 1940)

Genus *Neoliotomus* Jepsen, 1930a

Neoliotomus ultimus (Granger and Simpson, 1928)

REFERRED SPECIMENS: UW numbers 6577 (Fig. 39a), 6578, 6579, 6976, 7015, 10428 (Fig. 39a), 10429, 10430 (Fig. 39b), 10431, 10433 (Fig. 39a), 10434, 10435

DESCRIPTION: A large eucosmodontid multituberculate occurs at nine localities in the Sand Creek—No Water Creek section. These specimens, all isolated or associated teeth, represent $I^1/1$, P^3, P^4_4, M_{1-2} and in virtually every respect conform well with comparable teeth of *Neoliotomus ultimus*.

The upper incisor has a much larger maximum cross-sectional diameter than has the lower and, although the tooth has been considerably worn, the enamel along the venter of the crown is posteriorly restricted relative to the lower incisor. The buccal and lingual enamel cover approximately one third and one quarter of the mediolaterally compressed crown of the tooth, respectively.

P^3 is single-rooted as in eucosmodontids (Jepsen, 1940) and possesses three equisized cusps, two near the buccal margin of the tooth and one lingual to these at its anterior midline. P^4 has nine midline cusps (one more than noted by Jepsen, 1930a, for *N. coventus*), all approximately equal in size, and a large anterolabial cusp situated much as in P^4 of ?*Anconodon* sp. (Jepsen, 1940, Pl. II, Fig. 5, 5a; see Fig. 56b, this paper) and *Liotomus marshi*.

The lower incisors possess crowns with heavily enameled venters, the enamel covering 50 percent and 30 percent of the labial and lingual surfaces, respectively. Very faint fasciculate ribbing occurs on the labial enameled surface of the best preserved of the lower incisors.

P_4 is relatively low crowned as in *Eucosmodon* and *N. coventus* and possesses 14 serrations. P_4 is slightly longer than that in the type of *N. ultimus*, but its length is well within the expected range of variation for this tooth and is considerably less than that in *N. coventus*.

M_1 is somewhat smaller than in the type of *N. ultimus* and in referred specimens from the Four Mile fauna (McKenna, 1960), but morphologically conforms well with those specimens. M_1 possesses six buccal and four lingual cusps, with the anterior of the buccal series and posterior of the lingual array the smallest and largest cusps, respectively. The enamel of these cusps along the median furrow is highly plicated.

M_2 has five external cusps, the last of which is narrowest and anteroposteriorly elongate. There are two principal lingual cusps, and, as in M_1, the medial margins of all cusps are plicated.

Measurements (mm): (UW 10430) $P^4L = 8.00$, $P^4W = 3.23$; (UW 10433) $P_4L = 12.00$, $P_4W = 4.00$; (UW 10428) $M_1L = 6.58$, $M_1W = 3.10$; (UW 6577) $M_2L = 3.58$, $M_2W = 3.15$.

OCCURRENCE: In the Sand Creek Basin, *N. ultimus* is known from sites between the 60 and 319 foot levels (localities V-73028 and V-73020, respectively). West of the Bighorn River the discovery of *N. ultimus* at Yale locality 119 (ca. 350 foot level)[*] in 1972 is the highest occurrence of this species in the Willwood Formation known to me (although the relative positions of localities in the Clark's Fork Basin are unknown). The species also occurs in the Four Mile fauna of northwestern Colorado (McKenna, 1960) and is questionably present in the "Wasatch" Formation of the Powder River Basin (Delson, 1971).

Superfamily Ptilodontoidea (Gregory and Simpson, 1926)

Family Ectypodontidae Sloan and Van Valen, 1965

Genus *Parectypodus* Jepsen, 1930a

Parectypodus, species "A" Van Valen and Sloan, 1966

REFERRED SPECIMENS: UW numbers 6547-6551, 6553-6555, 6556 (Fig. 39c), 6557-6561, 6562 (Fig. 39d), 6563-6565, 6569-6576, 6963, 10376, 10432, 10436, 10439-10442, vials of isolated teeth, and one jaw fragment

DESCRIPTION: Dr. R.E. Sloan kindly identified the few small ectypodontid specimens sent for his examination in 1973 and 1974[†]. The remainder of the sample was identified using the specimens he designated for comparison. Because the bulk of the No Water multituberculate sample had not been collected at the time of my original correspondence with Dr. Sloan, it is possible that some specimens of the referred sample belong to a different species. However, the absence of other morphotypic P_4 specimens in the size range for *P.* sp. "A" in the No Water sample (P_4 is common) seems to decrease this likelihood. As far as is known, specimens of *P.* sp. "A" in the No Water collection constitute the largest known sample of this species.

P_4 consistently possesses 11 serrations at the top of the crown; however, the penultimate serration is not confluent with the lingual ridge, and the posterior two serrations commonly do not have counterparts among the labial ridges. The anterobuccal margin of the crown of P_4 is some-

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[*] Foot levels for Willwood localities in the central Bighorn Basin are derived from sections measured by myself, Neasham and Vondra (1972), or Meyer and Radinsky (unpublished). The studies of D. Schankler (oral communication, 1976) and myself indicate that the latter section is much too thin (see under CORRELATION).

[†] See Note added in press, p. 151.

Table 3. Measurements (mm) of No Water *Parectypodus* sp. "A" (209 feet of section; more than fifty damaged teeth could not be accurately measured)

	N	OR	X̄
P_4L	5	2.60—2.90	2.73
P_4W	5	0.80—1.00	0.90
M_1L	5	1.66—2.00	1.80
M_1W	5	0.83—1.00	0.94
M_2L	3	0.91—1.00	0.96
M_2W	3	0.77—0.91	0.86
P^4L	4	2.31—2.37	2.34
P^4W	4	0.90—1.05	1.01
M^1L	4	2.10—2.33	2.25
M^1W	4	1.04—1.20	1.14
M^2L	4	0.96—1.00	0.98
M^2W	4	0.90—1.06	0.97

what more distended than on the anterolingual side, though the anterior height of the crown is not as great as that noted for genus *Parectypodus* by Sloan (1966, p. 310).

M_1 possesses a cusp formula of 8:4 (three instances) or 7:4 (two instances) and has a posterointernal cusp that is occasionally partitioned. This contrasts with an M_1 cusp formula of 6:4 or 5 in *P. lovei*, the most closely comparable species (but see Krishtalka and Black, 1975, p. 289). The internal cusps are plicated or nearly twinned on the medial side, in contrast to the sharp, unicuspidate labial array.

M_2 consistently has a formula of 4:2 with medially plicated internal cusps as in M_1 and with a raised posterolabial cristid giving the appearnace of a fifth labial cusp (Fig. 39d).

P^4 (Fig. 39c) has a variable cusp formula of 7:1, 2, or 3. This formula is 8:3 in one specimen if the high posterior cusp, well removed from cusp seven, is counted. The anterobuccal cusp consistently occurs beneath cusp one of the lingual array, and buccal cusps two and three (when present) occur anterior to lingual cusp three.

M^1 is the most variable tooth in cusp formulae, and the degree of the variation suggests that a second species may have been inadvertently included in this sample. The formula is 7:10:5 (N=2), 8:10:5 (N=1), or 8:9:5 (N=10). The extra cusps, when present, do not occur as partitionings or twinned cusps.

M^2 has a formula of 1:3:3 (N=4). The buccal cusp is the smallest, and the medial and lingual cusps are roughly equal in size, but with the posteromedial cusp slightly isolated posteriorly from its medial counterparts.

OCCURRENCE: *Parectypodus* sp. "A" was originally reported from the Four Mile fauna (Sloan, 1966, p. 313; McKenna, 1960, Fig. 13b) and has since been reported from the Powder River local fauna (Delson, 1971), the Golden Valley Formation of North Dakota, and Mutigny, France (Sloan, 1974, written communication). In the No Water section, *P.* sp. "A" was found at only seven sites distributed between the 110 and 319 foot levels (localities V-73037 and V-73020, respectively).

Genus *Ectypodus* Matthew and Granger, 1921
Ectypodus Cf. *tardus* (Jepsen, 1930a)

REFERRED SPECIMENS: UW numbers 6566-6568, 6575, 10437, 10438

DISCUSSION: These specimens fall well outside the measurements for *Parectypodus* sp. "A" (above) but conform well in size and morphology with the admittedly heterogeneous Four Mile sample referred by McKenna (1960) to *Ectypodus tardus*. P_4 possesses 10 serrations in three specimens and 11 serrations in one specimen. McKenna (1960, p. 36) recorded a variable 9-11 serrations on P_4 in the Four Mile sample. M_2 has a cusp formula of 5:2, contrasting with that of 4:2 in the type of *E. tardus* (Jepsen, 1930a, p. 121).

Measurements (mm): P_4L = 3.40-3.46 (N=2), P_4W = 1.17-1.24 (N=2); M_2L = 1.15, M_2W = 1.07. Several additional damaged specimens of P_4 were not measured.

OCCURRENCE: *E. tardus* is positively known only from the Willwood and Four Mile faunas. Krishtalka, *et al.* (1975) have tentatively referred some of the Shotgun Member multituberculate sample to this species. In the No Water section, *E. tardus* occurs at only four sites, and these are between the 134 and 229 foot levels (localities V-73038 and V-73016a, respectively).

ectypodontid, sp. indet.

REFERRED SPECIMEN: UW 6552

DISCUSSION: UW 6552 is a right P^4 of a very small ectypodontid, fully 25% smaller than that tooth in the *Parectypodus* sp. "A" sample. The tooth has a cusp formula of 6:4 and therefore apparently has one too few lingual cusps for reference to genus *Parectypodus* (see Sloan, 1966, p. 310). The three largest cusps in the buccal locus are situated almost directly opposite their lingual counterparts and the most posterior cusp in either the lingual or buccal array is largest. The fourth buccal cusp is quite small and occupies a position intermediate between the second and third buccal cusps but well removed toward the external margin of the tooth.

Measurements (mm): P^4L = 1.79, P^4W = 0.80.

OCCURRENCE: UW 6553 was found at the Banjo Quarry at the 229 foot level in the No Water section.

Subclass Theria Parker and Haswell, 1897
Infraclass Metatheria Huxley, 1880
ORDER MARSUPIALIA Illiger, 1811
Family Didelphidae Gray, 1821
Genus *Peradectes* Matthew and Granger, 1921
Peradectes chesteri (Gazin, 1952)

REFERRED SPECIMENS: UW numbers 6989, 9570, 9604, 9605 (Figs. 39e, 40b), 9612, 9615, 9628, 9643, 9657, 9658, 9673, 9677, 9687, 9705, 9731, 9742 (Fig. 40a), 9754, 10126-10128, 10133, 10379

DISCUSSION: Setoguchi (1973) suggested the synonymy of *Peradectes protinnominatus* McKenna (1960) with *Peratherium chesteri* Gazin (1952) and noted that the type of the latter species is probably *Peradectes*. My comparisons of the type of *Peratherium chesteri* with McKenna's referred lower dentitions of *Peradectes protinnominatus* convince me that Setoguchi's assessment is correct, and I follow his new combination here.

Peradectes chesteri is represented in the No Water collection by seven fragmentary lower jaws and about forty upper and lower teeth. A mandibular fragment preserving M_{1-4} (Fig. 39e) is, to my knowledge, the most complete serially associated lower dentition of Wasatchian *Peradectes*.

The upper molars of No Water *P. chesteri* are comparable in every way with those referred to *P. "protinnominatus"* by McKenna (1960). The metacone is slightly larger than the paracone on M^{1-3}, but, as McKenna noted, this discrepancy is well within the known range of variability for *Peradectes*. M^1 possesses a faint paraconule and no metaconule; M^{2-3} retain a faint metaconule and a weak or absent paraconule. Stylar cusp "C" is weakly developed in M^{1-3}, about as in the Four Mile specimens. Stylar cusps "B" and "D" are well developed.

The hypoconulid on the lower molars is closely appressed to the entoconid but does not project posteriorly as in *Peratherium* and is also situated somewhat more labially than in that genus. The entoconid is less acute and is posteriorly farther removed from the metaconid than in *Peratherium*. In the latter genus, the entoconid is typically an acute spire that is close to the metaconid, as in many soricids, but without the distinct entocristid common to many of those insectivores.

P. chesteri seems to be a plausible derivative of Tiffanian *P. elegans*, or a close relative thereof, and differs from it principally in size (*P. elegans* is larger). The species may have given rise to later *Peradectes*-like didelphids collectively grouped under the genus *Nanodelphys* (but see below). Measurements of No Water *Peradectes chesteri* are presented in Table 4.

Matthew and Granger (1921) named *Peradectes* from two superbly preserved lower jaws and a maxillary fregment preserving M^{1-4}. Among the generic characters they noted for the upper molars were subequal paracones and meta-

cones and the presence of "rudimentary" conules. McGrew (1937) based his type of *Nanodelphys minutus* on a maxillary fragment preserving M^{2-3}. He did not, at that time, compare *Nanodelphys* with *Peradectes*, but did note the absence of paraconules and metaconules, the presence of roughly equisized paracones and metacones, and the absence of the "median stylar cusp" (stylar cusp "C") on the type upper molars (see also McGrew, 1939). From my comparisons, stylar cusp "C" is present in the type of *N. minutus* and is about equal in size with that cusp in *P. chesteri*.

Setoguchi (1973) reviewed the North American Tertiary didelphids and suggested (p. 31) that *Peradectes* could be separated from *Nanodelphys* by the possession of a "distinct stylar cusp C on upper molars" (also noted by McKenna, 1960, p. 41, in *Peradectes chesteri*). In 1975, Setoguchi noted that *Peradectes* and *Nanodelphys* lower molars were separable from those of *Peratherium* in talonid construction, in particular by the close posterobuccal relationship of the hypoconulid to the entoconid. The lower molars of the two former genera are, as observed by Setoguchi, difficult to distinguish. From my comparisons, I believe that they are indistinguishable on a consistent basis.

Lillegraven (1976) remarked that roughly equisized para- and metacones and reduced or absent conules and stylar cusp "C" were good characters for separting *Nanodelphys* and *Peratherium*. He did not compare *Nanodelphys* with *Peradectes*.

Setoguchi (1973, p. 39) proposed two lineages of American Tertiary didelphids. The first was composed of the many species of *Peratherium* and was divided into two sub-lineages of time-ascendant species separated by size of individuals. His second lineage constitutes the *Peradectes—Nanodelphys* complex with the addition of an undescribed new genus. In brief, the *Peradectes—Nanodelphys* lineage is typified by (1) subequal paracones and metacones on the upper molars, (2) reduction or loss of stylar cusp "C" and the para- and metaconules, and (3) a close appression of the hypoconulid with the entoconid but with the hypoconulid raised and situated more to the labial side than in *Peratherium* species.

The distinctions between *Peradectes* and *Nanodelphys* are somewhat less convincing. The lower molars are virtually indistinguishable from one another except that those referred to *Nanodelphys* are, like the upper molars, typically smaller. The upper molars appear to be separable only by the presumed less well developed stylar cusp "C" and conules in *Nanodelphys*. As noted by Matthew and Granger (1921) the stylar cusps are weak and the conules "rudimentary" in Tiffanian *Peradectes elegans*. The same is true for Wasatchian *P. chesteri*. Lillegraven (1976) noted that stylar cusp "C" and the molar conules may be "greatly reduced or absent" in *Nanodelphys californicus*. Because the median stylar cusp and the conules are weak or "rudimentary" in *Peradectes* and are "greatly reduced" in some species (including the type) of *Nanodelphys*, the criteria for distinguishing these two genera are not convincing.

OCCURRENCE: These specimens constitute the first *Peradectes* known from the Bighorn Basin. The genus is known but undescribed from the central-basin Willwood, and will probably appear in washed samples from some of the richer localities in the lower part of the section. In the No Water Creek sections, *P. chesteri* occurs in faunules between 97 and 390 feet above the base of the Willwood Formation. Where found, the species is a rare element of the fauna.

P. chesteri is also known from the Four Mile fauna of the Sand Wash Basin, Colorado under the appellation *Peradectes protinnominatus* (McKenna, 1960; Setoguchi, 1973) and the type of the species was recovered from "Upper Knight" beds, north of Big Piney, Wyoming (Gazin, 1952; Setoguchi, 1973).

Genus *Peratherium* Aymard, 1850
Peratherium macgrewi, sp. nov.

ETYMOLOGY: *macgrewi* — for Dr. Paul O. McGrew, in recognition of his many contributions to Tertiary stratigraphy and mammalian paleontology and in appreciation of his generous support of this project

HOLOTYPE: UW 9564, fragment of right ramus with P_{2-3}, M_{1-2} (Figs. 39f, 40d), collected by T.M. Bown

HYPODIGM: Type and UW numbers 7036, 7043, 9607, 9614, 9669, 9693, 9719, 9756, 10129 (Fig. 40c)

LOCALITY: Lower Willwood Formation (early Eocene), UW locality V-73034 (Two Head Hill quarry beds), sec. 1, T.46N., R.92W., Washakie County, Wyoming

DIAGNOSIS: Smallest Eocene species now referred to *Peratherium.* Largest molars in hypodigm 45-50 percent smaller than in smallest specimens referred to *P. marsupium* (Troxell, 1923; Simpson, 1928); 16-32 percent smaller than smallest specimens referred to *P. knighti* (McGrew, 1959; Setoguchi, 1973; Lillegraven, 1976); 50 percent smaller than smallest of penecontemporary *P. comstocki* (Cope, 1884; Simpson, 1928); 11 percent smaller than *Peratherium* sp. "A" (Cray, 1973); 45 percent smaller than smallest *Peratherium* sp. "B" (Cray, 1973). Hypoconulid situated directly behind the entoconid and expanded posteriorly as in *P. marsupium, P. comstocki* and *P. knighti,* not "intermediate between the median and internal positions" as in *P.* sp. "A", *Peradectes,* and *Nanodelphys.* Bases of molar metaconids terminate abruptly posterior to paraconid, not attenuated anteriorly as in *P. knighti,* resulting in relatively more acute trigonid basins. Paraconids of M_{2-3} relatively closer to metaconids than in *P. knighti,* similar to the condition in some *Peradectes.*

DESCRIPTION: *Peratherium macgrewi* is represented in the No Water collection by composite dentitions that comprise P_2-M_3 and M^{1-3}. The holotype is the most complete specimen and serially preserves P_2-M_2 in the lower jaw (Figs. 39f, 40d). P_2 is a small double-rooted premolariform tooth that is slightly taller than P_3. The protoconid is sit-

uated somewhat anterior to the transverse midline of the tooth and is connected to a faint paraconid by a short anteriorly-sloping cristid. There is no metaconid. The protoconid is connected to the heel of the tooth by a transversely narrow but long and posterolingually sloping postvallid. A short but transversely broad posterobasal cusp defines the posterior margin of the tooth. This cusp is highest labially and slopes lingually. Cingulids are absent.

Table 4. Measurements (mm) of No Water didelphids

	Peradectes chesteri (293 feet of section)			*Peratherium macgrewi,* sp. nov. (222 feet of section)		
	N	OR	X̄	N	OR	X̄
P_2L	—	—	—	3	1.00—1.09	1.05
P_3L	—	—	—	3	1.00	1.00
M_1L	5	1.34—1.43	1.37	3	1.33—1.43	1.37
$M_{2,3}$L	10	1.33—1.50	1.39	10	1.39—1.56	1.43
M_4L	3	1.24—1.29	1.27	—	—	—
P_2W	—	—	—	3	0.49—0.57	0.53
P_3W	—	—	—	3	0.50—0.55	0.52
M_1W	5	0.72—0.82	0.76	3	0.77—0.79	0.78
$M_{2,3}$W	10	0.71—0.90	0.82	10	0.82—0.91	0.86
M_4W	3	0.71—0.76	0.74	—	—	—
M^1L	4	1.50—1.56	1.53	1	1.62	1.62
M^{2-3}L	12	1.28—1.50	1.37	2	1.30—1.51	1.40
M^1W	4	1.50—1.66	1.58	1	1.90	1.90
M^{2-3}W	12	1.56—1.82	1.70	2	1.68—1.89	1.79

P_3 is shorter (less tall) than P_2 but otherwise conforms with that tooth in morphology.

M_1 is fully molariform and equal in length to M_2 but narrower transversely. The paraconid is somewhat anteriorly and medially removed from the metaconid, in contrast to the condition in M_{2-3}. This has resulted in a slightly shorter paracristid that is aligned less obliquely to the tooth row and more in parallel with the long axes of the molars. The lingual opening of the trigonid basin is consequently broader than on M_{2-3}. The M_1 protoconid and hypoconid have relatively larger and more rounded labial bases than on M_{2-3}. This has resulted in a relatively deeper and more sharply defined hypoflexid on unworn M_{2-3}.

The metaconids of M_{1-3} are as tall as the protoconids on unworn teeth and are not attenuated anteriorly, as are molars of *P. knighti.* This condition has resulted in relatively deeper and more acute lingual openings of the trigonid basin.

The M_{1-3} entoconid is a high spire that is taller than the hypoconid on unworn teeth but less broad at the base.

The entoconid is positioned about equidistant between the metaconid and the hypoconulid, somewhat closer to the former cusp than in species of *Peradectes*, and with a deep and acute valley separating the trigonid and talonid moieties of the tooth.

The hypoconulid on M_{1-3} is a low platform that projects posteriorly from the posterolingual corners of the molars. Precingulids and postcingulids are well developed on M_{1-3}, and a faint ectocingulid, fading across the bases of the protoconid and hypoconid, crosses the base of the hypoflexid on M_1.

M^{1-2} possess parastyles as well as stylar cusps "B", "C" and "D"; stylar cusp "C" is better developed than in faunally associated *Peradectes chesteri*. The M^2 stylar shelf is transversely much broader than in associated *P. chesteri* and some *Peratherium knighti*, especially the parastylar shelf. The metacone is significantly larger than the paracone on M^{1-2}, and the labial base of the latter cusp has been depressed lingually with respect to the paracone in *Peradectes* upper molars. The M^{1-2} para- and metaconules are small but more distinct than in *Peradectes*. These teeth are relatively broader with respect to length in *Peratherium macgrewi* than in *Peradectes chesteri*.

DISCUSSION: *Peratherium macgrewi* is the smallest described species of Eocene didelphid now referred to *Peratherium*. *P. comstocki* alone shares a Wasatchian antiquity among North American forms and is considerably larger. From my comparisons, a Bridgerian specimen referred to *Peratherium innominatum* (McGrew, 1959) actually represents a species of *Peradectes*, as suggested by Setoguchi (1973) for the type of this species. The Bridgerian specimen (UW 984) is closely comparable in size to *P. macgrewi*.

OCCURRENCE: Didelphids are rare elements of the Willwood fauna. The specimens of *Peradectes* and *Peratherium* described above and a new undescribed genus (Bown and Rose, 1979) constitute the largest sample known from Willwood rocks as well as the only new specimens documented from the Bighorn Basin Wasatchian since 1930. Undescribed Willwood *Peradectes* and *Peratherium*, including specimens of *Peratherium macgrewi* and *Peradectes chesteri* from Banjo Quarry, are present in the small No Water collection at the Yale Peabody Museum.

P. macgrewi is known only from the Sand Creek facies of the Willwood Formation where it occurs between the 97 and 319 foot levels, inclusive. Because of the relative scarcity of this taxon, its absence in the rich faunules between the 319-390 and at the 590 foot levels is of doubtful significance.

Infraclass Eutheria Gill, 1872
ORDER PROTEUTHERIA (Romer, 1966)
Superfamily Palaeoryctoidea (Winge, 1917)
Family Palaeoryctidae (Winge, 1917)
Subfamily Didelphodontinae Matthew, 1918
Genus *Didelphodus* Cope, 1882b
Didelphodus absarokae (Cope, 1881)

REFERRED SPECIMENS: UW numbers 9579, 9655, 9747, 9749, 9750, 9842, 9851, 9852, 9940, 9943 (Fig. 40e), 9966, 10304, 10362, 10447, 10464

DISCUSSION: The upper molars are slightly larger than many of *D. absarokae* in the American Museum and Yale Peabody Museum collections, but do not differ significantly from these teeth in the type rostrum. The M^1 para- and metaconules are distinct and there is no mesostyle; however, minute cuspules occur on the labial margin of the ectoflexus.

OCCURRENCE: Only fifteen specimens of *Didelphodus* exist in the No Water collection, and most of these are isolated teeth. This paucity is surprising in view of the relative abundance and variety of microfaunal elements at several localities. *D. absarokae* (in one of its several and possibly valid subspecies or "mutations"; see Matthew, 1918; White, 1952; Van Valen, 1966; Rich, 1971) is a rare but persistently present faunal component of several well sampled central basin Willwood localities, especially in the 800 - 1,500 foot levels.

In the No Water Creek section, *D. absarokae* is known from nine localities in the 110-319 foot interval. *D. absarokae* or a closely allied form occurs in the Golden Valley

Table 5. Measurements (mm) of teeth of *Didelphodus absarokae*

	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W	P^4L	P^4W	M^1L	M^1W	M^2L	M^2W
UW 9579													3.25	5.05
UW 9749	3.21	2.12												
UW 9750	3.57	2.28												
UW 9943									3.32	3.91	3.74	4.31	3.42	5.00
UW 10304			3.55	2.28			3.00	2.00	3.55	3.85				
UW 10362	3.63	1.93												

Formation of North Dakota, in the Powder River "Wasatch" faunas (Delson, 1971), in the Four Mile faunas of the Sand Wash Basin, Colorado, in the Bitter Creek faunules of the northwestern Washakie Basin, in the New Mexican Almagre facies of the San José Formation, in the faunas of the Lysite Member of the Wind River Formation, and in the early Eocene of the Paris Basin, France (Rich, 1971).

Superfamily Apatemyoidea (Matthew, 1909) Scott and Jepsen, 1936

Family Apatemyidae Matthew, 1909

Genus *Apatemys* Marsh, 1872

Apatemys sp.

REFERRED SPECIMENS: UW numbers 8908, 8997, 8999 (Fig. 41a), 9571 (Fig. 41b), 9574, 9599, 9622, 9630-9633, 9634 (Fig. 40f), 9725, 10243, 10415, 10416

DESCRIPTION: *Apatemys* sp. is documented in the No Water collection by seven lower jaws, one maxillary fragment, and nine teeth, which represent P_4 - M_3 and M^2. The root and enameled posterolingual margin of the enlarged lower incisor are preserved in one specimen.

P_4 is double rooted in the only specimen of this tooth, and has a poorly defined posterolingual basin with no distinct talonid cusps. A well defined labial fossa is present beneath the fourth premolar and extends anteriorly beneath the alveoli for P_3 and P_2 (may also be P_1 or $\overline{C}$) and is nearly confluent with the latter alveolus.

The crowns of M_{1-3} show no consistent differences when compared with their counterparts in *A. bellus* or *"Teilhardella" chardini*. An accessory anterolabial cusp is present on the trigonids of two M_1 specimens and is absent on three others. The position of the posterior mental foramen is beneath the M_2 hypoflexid in two specimens and beneath the posterior M_1 root and anterior M_2 root in one specimen each.

DISCUSSION: Apatemyids are rare faunal elements of the Bighorn Basin Willwood Formation. The specimens listed above average somewhat smaller in mean tooth size than samples of Bridger Formation *A. bellus* and are slightly larger than comparable teeth in the type of *"Teilhardella" chardini* (Table 6). West (1973b) believed the latter taxon to be a synonym of *A. bellus*. The diagnostic characters provided by Jepsen (1930a) for the type of *"T." chardini* are certainly not diagnostic in the specific sense, but rather indicate only the affinity of the specimen with other early and middle Eocene apatemyids. The only notable feature of *"T." chardini* appears to be its distinctive small size.

West (1973b) reviewed the North American Eocene and Oligocene apatemyids and synonymized all previously recognized Wasatchian and Bridgerian species with Marsh's (1872) *Apatemys bellus*. I believe these synonymies are premature. The specimen sample size for the family as a whole is too small for meaningful statistical treatment and for correlation of parts of this sample by age or locality.

West (1973b, p. 13) has noted that the t-tests run by

him "indicate the probability of all specimens being drawn from a single population. . . ." But the specimens obviously were not drawn from a single population, as they were from temporally and geographically disparate localities. Whether or not the specimens could have been drawn from a single species population had they been found together is meaningless.

The high coefficients of variation for the *Apatemys bellus* samples (as divided by West, 1973b) are likewise not important. Because time-transgressive size and morphologic trends are noted for many species of fossil mammals, the separation of the apatemyid sample into Tiffanian, Wasatchian and middle Eocene components and the ensuing individual statistical treatment of these samples is without utility. If we assume that the fauna-dependent boundaries between these land mammal ages are reliably determined, there is still no reason to suppose *a priori* that character evolution or size trends within the group are affected one way or another on either side of a faunal boundary. It is unfortunate that the poor stratigraphic data that accompany most apatemyid specimens do not allow more refined and reliable interpretations of size and morphologic trends.

Considering the relative uniformity in molar size among Bridger Formation *Apatemys* specimens I have measured, it is difficult for me to believe that the type of *"Teilhardella" chardini* and *Apatemys* sp. (YPM 23476) were conspecific. Moreover, using the criteria of West and acknowledging the lack of precise stratigraphic data, I find his sample of M_1 in Tiffanian and Wasatchian *A. bellus* separable into four size groups. The separation of these groups may be due to speciation, differential stratigraphic sampling, or sampling bias.

Early Wasatchian apatemyids appear to have had no clear predilection for one or two roots supporting the fourth

Table 6. Measurements (mm) of No Water *Apatemys* sp. (293 feet of section)

	N	OR	$\overline{X}$
P_4L	1	1.00	1.00
M_1L	5	1.55—1.83	1.67
M_2L	5	1.54—2.20	1.71
M_3L	2	1.64—1.80	1.72
P_4W	1	0.78	0.78
M_1W Tri	5	0.87—1.08	0.98
M_1W Tal	5	0.96—1.23	1.11
M_2W Tri	5	0.95—1.65	1.15
M_2W Tal	5	0.92—1.52	1.15
M_3W Tri	2	1.16—1.24	1.20
M_3W Tal	2	1.07—1.10	1.09
M^2L	1	1.57	1.57
M^2W	1	1.76	1.76

premolar (see Jepsen, 1934; Simpson, 1954; McKenna, 1960), but it seems evident that there was a trend toward the loss of one root in middle Eocene specimens that culminated in the single rooted P_4 of "*Steblinius*" and *Sinclairella*. Root loss in apatemyids is often correlated with a decrease in the complexity of the P_4 talonid; *i.e.*, specimens with a double-rooted P_4 tend to have a well-developed posterolingual basin, and those with a single root have simpler basins with less well defined talonid cusps. A few exceptions do exist, notably Torrejonian *Jepsenella*, which does not have a well-defined P_4 talonid basin.

Simpson (1954) and West (1973b) have suggested that the number of P_4 roots may only represent variation of an almost vestigial tooth and therefore be of no systematic value. If the variable P_4 root and crown morphology in *Apatemys* is related to the vestigial nature of the tooth, it seems odd that the presence of P_4 should have persisted in the apatemyid lineage for more than twenty million years.

From my comparisons, the number of roots and development of the talonid basin of P_4, tooth size, the development of the M_1 paraconid and accessory anterolabial trigonid cusp, the amount of lingual distension of the molar metaconids, the relative development of the talonid cusps on M_{1-3}, and the relative oblique *versus* transverse orientation of the molar postvallid surfaces may prove to be of systematic value in the study of apatemyids, once larger and stratigraphically documented samples are available.

OCCURRENCE: *Apatemys* sp. is known at a few localities in the 97-390 foot interval, inclusive. In the central basin Willwood, *Apatemys* occurs at levels higher than 1,600 feet above the base of the Willwood Formation. West (1973b) has adequately documented the other known occurrences of North American apatemyids.

Superfamily Pantolestoidea Cope, 1887

Family Pantolestidae Cope, 1884

Genus *Palaeosinopa* Matthew, 1901

Palaeosinopa Cf. *lutreola* Matthew, 1918

REFERRED SPECIMENS: UW numbers 7917, 8995, 9588

DISCUSSION: The No Water specimens are much smaller than comparable teeth of *P. simpsoni, P. didelphoides,* and *P. veterrima,* and are larger than those of *Propalaeosinopa diluculi*. Morphologically, the two M^1 specimens conform in every way with first upper molars of *P. didelphoides* and *P. veterrima* but are proportionally less broad transversely with a L/W ratio of 0.90. This ratio is about 0.70 in M^1 of *P. didelphoides*.

The fragmentary lower jaw (UW 7917) here tentatively referred to *P. lutreola* possesses teeth that are definitely larger than those in the type but considerably smaller than in *P. didelphoides,* the next largest Wasatchian species, and smaller than specimens referred by McKenna (1960, p. 43) to Cf. *P. didelphoides*. McKenna believed that the small Four Mile specimens probably represent an undescribed

form. It is likely that the intermediate sizes of both No Water and Four Mile *Palaeosinopa* specimens reflect their low stratigraphic occurrences; both samples may simply be drawn from early populations of *P. didelphoides*. No known samples, however, are large enough to document this likelihood stratigraphically, and the No Water specimens are referred to *P.* Cf. *lutreola,* the form they most closely approximate in size. The paraconid is as strongly developed on M_{1-2} as in some *P. veterrima,* but not markedly more so than in *P. didelphoides* or *P. lutreola*.

Upper molars of *P. lutreola* are not positively known from other Wasatchian faunules. Delson (1971, p. 326) referred two second upper molars from the Powder River Basin local fauna to this taxon. The specimens at hand conform in relative size to what might be expected for their first upper molar counterparts.

Measurements (mm): $M^1 L = 4.00$ (N=2), $M^1 W = 4.50$ (N=2), $M_1 L = 3.71, M_2 L = 4.14$.

OCCURRENCE: These three specimens are the only record of *Palaeosinopa* and the Pantolestidae from the No Water Creek sections, where they occur at the 97, 102, and 110 foot levels. The genus is extremely rare near the base of the section in the central-basin Willwood but is encountered with somewhat greater frequency in localities above the 600 foot level.

P. lutreola has been reported as well from the Powder River "Wasatch" Formation and "Lost Cabin" faunules in the Wind River Basin.

Superfamily Leptictoidea (Gill, 1872)

Family Leptictidae Gill, 1872

Subfamily Leptictinae (Gill, 1872)

Genus *Prodiacodon* Matthew, 1929

Prodiacodon tauricinerei (Jepsen, 1930a)

REFERRED SPECIMENS: UW numbers 7004, 7014, 7021, 7027, 7034, 7046, 9567 (Fig. 41d), 9575-9577, 9591, 9598, 9606, 9609, 9637, 9639, 9642, 9644, 9647, 9648, 9650, 9651, 9654, 9656, 9660, 9661, 9668, 9670, 9679, 9680, 9686, 9691, 9708, 9727, 9734, 9745, 9746, 9753, 9837, 10159 (Fig. 42a), 10311 (Fig. 41c), 10325, 10413, 10418-10420, 10446

DESCRIPTION: The lower premolars are four in number and increase in size posteriorly. P_{1-2} are not as procumbent as in the type of *P. tauricinerei,* and P_2 is relatively broader than in that species, possessing four cusps, rather than three as in the type. The largest of these is anteriorly situated and supports a second, smaller cusp on its posterior face. A third cusp occurs in the middle of the P_2 heel, well below the second. The most posterior cusp is smallest and is developed on the posterolingual border of the heel.

P_3 has only four cusps, not five as in the type of *P. tauricinerei,* with the second from anterior cusp the tallest. A third cusp is present on the posterior face of the largest

cusp, and a small but transversely wide shelflike cusp defines the posterior margin of the P_3 heel.

P_4 is the longest tooth in the lower dental series. When unworn, this tooth possesses a metaconid equal in height to the protoconid. The paraconid is consistently very large, but varies in relative size and is always considerably less tall than the protoconid and metaconid. The P_4 heel possesses three cusps. The hypoconid and entoconid become attenuated with wear, and the hypoconulid, always distinct, is smaller than the hypoconid or the entoconid and projects posteriorly from the heel of the tooth.

Statistically, the lower molars increase in size through M_{1-2-3}, but M_1 is larger than M_2 on several specimens. The molars are typified by high trigonids that are generally, but not invariably, relatively higher than in species of *Palaeictops*. The molar talonids possess either three or four cusps; a small mesoconid is evident on some unworn teeth. The heel of M_3 is invariably attenuated with a strong posteriorly projecting hypoconulid. A small entoconulid is occasionally present on the anterior part of the entocristid adjacent to the talonid notch.

P^3 is longer than P^4, and the latter tooth is longer than any of the upper molars. $P^4 - M^3$ possess long precingula and small but distinct hypocones. The conules on these teeth are somewhat removed medially from the para- and metacones, and the ectoflexus is trongest on M^2 and M^3. M^2 is broader transversely than M^1, and M^3 is as broad or nearly as broad as M^2.

DISCUSSION: Novacek (1977) has recently reviewed the Early Tertiary Leptictidae, and his revised concept of the systematics of that family is followed here. The No Water lepticid sample is a large and morphologically heterogeneous one; however, diagnostic teeth in this sample indicate that the whole of the collection is most closely referable to *Prodiacodon tauricinerei* Jepsen (1930a). In his emended diagnosis of *Palaeictops*, Novacek noted that the P_4 paraconid is well developed and that the lower molars are typified by low trigonids relative to the condition in *Prodiacodon*. However, his diagnosis of *Prodiacodon* included the observation that the lower molars of that genus exemplify "sharp cusps" associated with high, anteroposteriorly compressed trigonids. In a subsequent passage, Novacek (1977) remarked that the paraconids are "always present on P_4" in *Prodiacodon*, but he failed to note the development of this cusp relative to that in *Palaeictops*.

Table 7. Measurements (mm) of lower teeth of *Prodiacodon tauricinerei* (493 feet of section)

	P_3L	P_3W	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W
UW 7004			2.89	1.49						
UW 7021					2.11	1.62	2.20	1.65		
UW 7046							2.28	1.64		
UW 9567					2.10	1.64	2.30	1.76	2.57	1.58
UW 9575					2.29	1.71	2.22	1.84	2.53	1.57
UW 9576							2.31	1.86		
UW 9598					2.18	1.57				
UW 9637					2.16	1.70				
UW 9647			2.98	1.60	2.32	1.67				
UW 9648							2.36	1.65	2.60	1.88
UW 9651					2.12	1.53				
UW 9654							2.25	1.59		
UW 9656							2.46	1.77		
UW 9660			2.57	1.40					2.43	1.40
UW 9668							2.25	1.57		
UW 9670					2.10	1.66				
UW 9680					2.36	1.75	2.38	1.83		
UW 9691			2.73	1.48						
UW 9708							2.29	1.61		
UW 9727					2.38	1.61	2.42	1.75		
UW 9734					2.17	1.80	2.17	1.83		
UW 9746			2.75	1.41	2.45	1.62				
UW 9837							2.16	1.77	2.64	1.65
UW 10159	2.80	1.10	2.79	1.66						
UW 10311			2.75	1.48	2.43	1.58				
UW 10325	2.69	1.10								
UW 10413							2.32	1.73		
UW 10418							2.30	1.81	2.64	1.74
UW 10419							2.52	1.84		

Table 8. Measurements (mm) of upper teeth of *Prodiacodon tauricinerei* (493 feet of section)

	P^3L	P^3W	P^4L	P^4W	M^1L	M^1W	M^2L	M^2W	M^3L	M^3W
UW 9591	2.57	1.96								
UW 9609			2.39	2.55						
UW 9639	2.52	1.92								
UW 9642					2.28	3.20				
UW 9644	2.76	1.83								
UW 9651			2.25	2.83						
UW 9661			2.45	2.86			2.40	3.34		
UW 9679			2.44	2.65	2.18	3.23			1.67	2.66
UW 9686					2.31	3.13				
UW 9745			2.22	2.60						
UW 10413			2.38	2.70						
UW 10446	2.60	1.93								
UW 10420							2.23	3.43		

Leptictids in the No Water collection vary considerably in trigonid height and in development of the P_4 paraconid. If Novacek meant to imply that *Prodiacodon* is typified by a relatively small P_4 paraconid in association with molar trigonids that are high relative to the condition in *Palaeictops*, then some of the No Water sample exhibits crossing characters. Moreover, Novacek believed that the molar paraconids are higher than the protoconids in *Prodiacodon*. This is certainly not true for the type of the genus, for *P. tauricinerei* or for any specimens in the No Water collection, with the possible exception of some extremely worn teeth.

The No Water leptictids differ from *Palaeictops* in the possession of transversely aligned and relatively anteroposteriorly compressed upper molars with acute cusps. The upper molars and P^4 have long precingula and have conules that are removed medially from the paracone and metacone relative to the condition Novacek has observed for *Palaeictops*. The lower teeth differ specifically from those teeth in *Palaeictops bicuspis* in the retention of an anterior accessory cusp on P_3 and from *P. multicuspis* in the possession of a shorter (less tall) P_3 and in the absence of the several accessory cusps on P_{2-3}.

OCCURRENCE: *Prodiacodon tauricinerei* was found at twenty-one localities in the Sand Creek—No Water Creek area. These localities are distributed between the 97 and 590 foot levels, inclusive (localities V-73027 and V-73125, respectively).

Novacek (1977, Table 1) recorded the occurrence of this species in the "Wasatch" Formation of the Powder River Basin, at localities along Bridger Creek in the Wind River Formation of the Wind River Basin, in the Big Piney fauna of the northern Green River Basin (see Gazin, 1952, 1965), in the Bitter Creek sequence of the northwestern Washakie Basin, at East Alheit pocket in the Four Mile Creek area of northwestern Colorado, and at Arroyo Blanco in the San José Formation of the San Juan Basin, New Mexico.

ORDER INSECTIVORA Bowdich, 1821
Superfamily Erinaceoidea Gill, 1872
Family Erinaceidae Fischer Von Waldheim, 1817
Genus *Leipsanolestes* Simpson, 1928a
Leipsanolestes Cf. *siegfriedti* Simpson, 1928a

REFERRED SPECIMENS: UW 9568 (Fig. 41e), 9751

DESCRIPTION: *Leipsanolestes* Cf. *siegfriedti* is considerably larger than *L. simpsoni*, sp. nov. (infra) and compares favorably in size and morphology with AMNH 56317, a specimen of *L. siegfriedti* from the Powder River Basin "Wasatch" Formation (Krishtalka, 1976a).

The molars in UW 9568 decrease in size posteriorly; however, M_2 is not as greatly reduced relative to M_1 as in *Litolestes*, the Tepee Trail erinaceid, and *L. simpsoni*. The molars lean lingually and are sharply exodaenodont on the buccal side. The M_1 paraconid is dorsally flattened and transversely elongate, rather less cuspidate than in *L. simpsoni* or the Tepee Trail specimen, and the M_{2-3} paraconids are reduced to broad and long shelves with no distinct cusp.

The shelf on M_3 is anteroposteriorly the longest of these structures on the molars. The M_{1-2} hypoconulids are better developed than in *L. simpsoni* or other *L. siegfriedti*, but are not quite so pronounced as in *Litolestes notissimus*. The M_{1-2} hypoconulids are medially situated between the hypoconids and entoconids as in *Litolestes notissimus* and most *Leipsanolestes siegfriedti*, and are not appressed to the entoconids as in *L. simpsoni*, some *L. siegfriedti*, and *Entomolestes grangeri*.

Measurements (mm): (UW 9568) $M_1L = 1.57$, $M_1W = 1.22$, $M_2L = 1.50$, $M_2W = 1.16$, $M_3L = 1.47$, $M_3W = 1.04$; (UW 9751) $M_2L = 1.41$, $M_2W = 1.18$.

OCCURRENCE: *Leipsanolestes* Cf. *siegfriedti* is known from only two specimens, and these are from sites that fall at the 229 and 288 foot levels (localities V-73016b and

73051, respectively). The species is best known from a late Paleocene locality near Bear Creek, Montana (Simpson, 1928), but also occurs at Reculusa Blowout, a locality in the "Wasatch" Formation of the Powder River Basin.

Leipsanolestes simpsoni, sp. nov.[*]

ETYMOLOGY: Named for Dr. George G. Simpson, in recognition of his outstanding contributions to Early Tertiary mammalian paleontology

HOLOTYPE: UW 9616, fragmentary right ramus with P_4 - M_2 (Fig. 42b), UW locality V-73041, lower Willwood Formation (early Eocene), sec. 24, T.46N., R.92W., Washakie County, Wyoming

HYPODIGM: type only

DIAGNOSIS: P_4 - M_2 approximately 20 percent smaller than in *L. siegfriedti*. P_4 shorter and narrower than M_1, more so than in *L. siegfriedti*. P_4 paraconid separated from the protoconid by a deep valley as in *Entomolestes grangeri*. M_1 larger in relation to M_2 than in *L. siegfriedti* and developed about as in *Litolestes ignotus*, *L. notissimus*, and the Tepee Trail erinaceid. M_1 paraconid more cuspidate and less shelflike than in *L. siegfriedti* and paralleling that in the Tepee Trail specimen.

DESCRIPTION: P_4 is a premolariform-semimolariform tooth with a strong paraconid and metaconid. The paraconid is a shorter but broader based cusp than the metaconid, is relatively more removed from the metaconid than in *Litolestes*, and is separated from the protoconid by a deep transverse valley (much as in *Entomolestes grangeri*). The P_4 metaconid is large and is situated immediately lingual to the protoconid as in *Leipsanolestes siegfriedti*, not posterolingual to this cusp or small as in *Litolestes* or the Tepee Trail erinaceid (AMNH 88288). The P_4 talonid basin is very short and is about one fourth as wide as the trigonid. A small but distinct cristid obliqua connects the posterior face of the metaconid with the posterolingual margin of the tooth. The P_4 talonid possesses no distinct cusps. P_4 is shorter and narrower than M_1, more so than in *L. siegfriedti*, and with the heel much narrower than the trigonid, *contra Litolestes*. P_4 - M_2 are about 20 percent smaller than comparable teeth of *Leipsanolestes siegfriedti*, and P_4 possesses a strong descending anterolabial cingulid.

M_1 is much larger than M_2 in contrast to *Entomolestes grangeri* and some *L. siegfriedti*, and these teeth are relatively developed as in *Litolestes* and in the Tepee Trail specimen. The M_1 paraconid is a little less shelflike in *L. simpsoni* than in *L. siegfriedti* and is also developed about as in the Tepee Trail erinaceid. The M_2 paraconid is anteroposteriorly compressed against the metaconid relative to M_1. The molar hypoconids exhibit much more dorsal flattening due to wear than do the entoconids, which re-

main tall. The M_{1-2} hypoconulids are smaller than in *Litolestes* but are distinct and closely appressed to the entoconids as in *Entomolestes grangeri*, not medial as in *Litolestes* M_{1-2} or the M_1 in *Leipsanolestes siegfriedti*. M_{1-2} possess weak, shelflike cingulids beneath the hypoflexids.

DISCUSSION: *Leipsanolestes simpsoni* is prevented from inclusion in the ancestry of *Entomolestes* by the relatively reduced M_2 and the anteriorly projecting M_1 paraconid, both of which are certainly derived characters. In *Entomolestes*, curiously, it is the M_2 that has an anteriorly expanded paraconid. *L. simpsoni* appears to be more derived than *L. siegfriedti* by the greater reduction of the P_4 talonid basin and in the reduction in size of M_2 relative to M_1. In the latter character, *L. simpsoni* resembles *Litolestes ignotus*, but the species is readily separable from that taxon on the basis of the smaller P_4 with a reduced heel, the lingual rather than posterolingual P_4 metaconid, and the position and development of the M_{1-2} paraconids and hypoconulids.

Measurements (mm): UW 9616 (type); P_4L = 1.18, P_4W = 0.81, M_1L = 1.43, M_1W = 0.97, M_2L = 1.19, M_2W = 0.91.

OCCURRENCE: *L. simpsoni* is represented solely by the type specimen, which was recovered from UW locality V-73041 at the 75 foot level.

Family Adapisoricidae Schlosser, 1887

Subfamily ?Dormaaliinae Quinet, 1964

Genus *Scenopagus* McKenna and Simpson, 1959

Cf. *Scenopagus* sp., probably new

REFERRED SPECIMENS: UW numbers 9595, 9611, 9638 (Fig. 42c), 9662, 9699, 9713, 9720, 9729

DESCRIPTION: Cf. *Scenopagus* sp. possesses teeth that are slightly smaller than those in *S. curtidens*.

Five fragmentary lower jaws in the No Water collection are believed to preserve M_{1-3} of this species, but, unfortunately, no specimen preserves P_4 associated with the lower molars. The trigonid of M_1 on these referred lower molars is narrower than the talonid, and the trigonids of M_{2-3} are broader than the talonids, as in *S. edenensis*, and the paraconids of M_{1-3} are shelflike, although more cuspidate than in *S. edenensis*, *S. curtidens*, or *S. priscus*.

A fragmentary maxilla and three isolated upper teeth are referred to Cf. *Scenopagus* on the basis of size, occlusal relationships with the referred lower dentitions, and morphology. UW 9638 (Fig. 42c) preserves associated P^{3-4}, M^2 that are closely comparable to those teeth in AMNH 56035 (a specimen of *S. edenensis*). In some respects, however, the teeth of UW 9638 are more primitive. P^3 forms an essentially isoceles triangle in occlusal outline with the base oriented anteriorly. The protocone is a minute cusp on a small lingual shelf, and the tooth is dominated by a high paracone. A faint metacone is present on the postparacrista, but is absent in AMNH 56035. Small para- and metastyles

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[*] This species has been subseqeuntly referred to a new genus by Bown and Schankler, in press.

exist at the anterobuccal and posterobuccal margins of the tooth, respectively.

P^4 and M^2 are constructed almost exactly the same as in AMNH 56035, but they are smaller and have slightly more acute cusps, and P^4 in the No Water specimens possesses a distinct metacone on the postparacrista that is not seen in *S. edenensis* (see McKenna and Simpson, 1959). Krishtalka (1976a) has noted that the premolarization of P^4_4 is a trend in adapisoricids. If Cf. *Scenopagus* represents an early species of this genus, as is strongly suggested by the morphology of the known cheek teeth, P^4 in some early Eocene *Scenopagus* was semimolariform.

Measurements (mm): M_2L = 1.41-1.62 (N=4), M_2W = 1.00-1.15 (N=4), M_3L = 1.37-1.58 (N=3), M_3W = 0.92-1.00 (N=3), P^3L = 1.19, P^3W = 1.00, P^4L = 1.35-1.55 (N=2), P^4W = 1.45-1.77 (N=2), M^1L = 1.62, M^1W = 2.00, M^2L = 1.39-1.48 (N=2), M^2W = 1.82-1.87 (N=2).

OCCURRENCE: Cf. *Scenopagus* sp. was recovered at seven localities within the 97 and 389 foot levels, inclusive. This primitive species is not known to occur elsewhere.

Genus *Macrocranion* Weitzel, 1949
Macrocranion nitens (Matthew, 1918)

REFERRED SPECIMENS: UW numbers 7057, 8996, (Fig. 42d), 9640, 9641, 9690

DISCUSSION: Krishtalka (1976a) has recently reviewed the Early Tertiary North American adapisoricids and has recommended the synonymy of *Entomolestes nitens* Matthew with *Macrocranion* Weitzel, a view that is tentatively endorsed here. No Water specimens of lower teeth of *M. nitens* do not differ appreciably from those in the type, which is also from the Willwood Formation. A solitary upper molar (UW 9641, an M^1) mirrors its counterpart in upper dentitions from the Wind River Formation.

Measurements (mm): P_3L = 0.81, P_3W = 0.53, P_4L = 1.48-1.60 (N=2), P_4W = 0.96-1.00 (N=2), M_1L = 1.55, M_1W = 1.25, M_2L = 1.70, M_2W = 1.30, M^1L = 1.65, M^1W = 2.10.

OCCURRENCE: *Macrocranion nitens* has been found at five localities between the 97 and 389 foot levels of the Sand Creek facies (UW localities V-73027 and V-73055, respectively). Krishtalka (1976a) has adequately documented other occurrences of this species.

Plagioctenodon, gen. nov.

ETYMOLOGY: Gr. *plagios* = oblique + Gr. *cteno* = comb + Gr. *odontos* = tooth; in allusion to the oblique orientations of the P_4 and molar talonids

TYPE: *Plagioctenodon krausae*, sp. nov. and only known species

DIAGNOSIS: same as for the type species

Plagioctenodon krausae, sp. nov. *

ETYMOLOGY: for M.J. Kraus, collector of the type and first specimens and discoverer of the type locality

HOLOTYPE: UW 9682, fragment of right ramus with P_{2-4} (figs. 42e, 43a), UW locality V-73044 (Wadi Kraus Quarry), lower Willwood Formation (early Eocene), Sand Creek facies, sec. 4 T.46N., R.91W., Washakie County, Wyoming

HYPODIGM: Holotype and UW numbers 6974, 6999, 7005, 7035, 7047, 7048, 8583-8586, 8993, 9000, 9572, 9585, 9587, 9589, 9592, 9597, 9600, 9603, 9610, 9613, 9618, 9620, 9623, 9624 (Fig. 43b), 9627, 9635, 9649, 9653, 9666, 9674, 9675, 9683, 9684, 9688, 9689, 9692, 9695, 9697, 9700, 9701, 9704, 9706, 9711, 9714, 9715, 9718, 9721-9723, 9726, 9728, 9740, 9741, 9743, 9752, 9782, 10448, 10451-10454

DIAGNOSIS: Molars decrease in size posteriorly as in *Adapisorex* (Adapisoricinae; see Russell, Louis, and Savage, 1975), *"Leptacodon" jepseni*, and *Mckennatherium ladae*. P_4 paraconid arises relatively high on anterior face of protoconid as in *"L." jepseni* and some "adapisoricids," not low as in *M. ladae* and most nyctitheriids. P_4 with well developed heel in contrast to *Talpavus*. Trigonids of M_{2-3} compressed relative to trigonid of M_1 as in *"Leptacodon" jepseni* and *L. tener*. P_{2-3} not separated by diastema as in *Nyctitherium* and more procumbent than in *L. munusculum*, *"L." jepseni*, and *Nyctitherium*. P_2 double-rooted as in *M. ladae* but considerably taller than P_3 in contrast to that species, nyctitheriids, and *"L." jepseni*. P_3 with a greater paraconid—protoconid notch than in *"L." jepseni*. Hypoconulid not appressed to entoconid on M_1 as in *"L." jepseni*. P^4 - M^3 much as in *Nyctitherium*, but P^4 shorter anteroposteriorly than M^1. P^4 talon shorter than in *N. velox* and molar protocones with steeper and less excavated posterior borders.

DESCRIPTION: The rami of *P. krausae* possess at least double anterior mandibular foramina. The anterior moiety is situated beneath the posterior root of P_3 and is preceded by a small anterodorsally extended sulcus. The posterior component opens beneath the anterior root of P_4 and is situated slightly higher on the ramus than is its anterior counterpart.

P_2 is large, sectorial, and procumbent, is two-rooted as in *Saturninia*, *Cryptotopos*[†], and *Nyctitherium*, and is much taller than P_3 as in *Amphidozotherium*. In *"Leptacodon" jepseni*, the closest form to *Plagioctenodon* in terms of the morphology of P_4 - M_3, P_2 is single-rooted, is much shorter (less tall) than P_3, and is not noticably procumbent as in *Amphidozotherium*. A small paraconid arises high on the anterior face of the P_2 protoconid and projects ante-

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* The hypodigm of *P. krausae* presented here has been subdivided into several forms by Bown and Schankler, in press.

† Sigé (1976, Mém. du Mus Nat. d'Hist. Natur., Sér. C, t. 34, p. 44) has regarded *Cryptotopos* Crochet to be a synonym of *Saturninia* Stehlin.

riorly from it. The protoconid slopes posteriorly down a long postvallid surface to a small posterobasal cusp that makes up the heel of the tooth. P_2 in *"Leptacodon"jepseni* is essentially unicuspidate. P_2 possesses neither a metaconid nor cingulids. The protoconid of P_3 is considerably shorter than that of P_2, but otherwise these premolars are closely comparable. The P_3 paraconid is larger than that in P_2, and the tooth is somewhat broader transversely. A faint cristid connects the posterior margin of the apex of the protoconid with a transversely broad shelf that makes up the heel of P_3.

P_4 is the most diagnostic tooth in *Plagioctenodon* and possesses a paraconid high on the anterior face of the protoconid as in *"L."jepseni* and unlike known nyctitheriids (excepting some *Nyctitherium, contra* Krishtalka, 1976b). This cusp is shelflike, oriented anterolingually—posterolabially, and, in some specimens, separated from the protoconid on the labial side by a shallow inflection often accompanied by an anterolabial cingulid. The tooth is semi-molariform and has a tall metaconid and conspicuous talonid basin as in nyctitheriids and early adapisoricids. This basin may be variably relatively narrow or broad transversely. When narrow, the peripheral cusps, if well developed at all, are restricted to the hypoconid and entoconid, and the cristid obliqua is long but faint (*e.g.*, UW 9624, Fig. 43b). In those specimens with a relatively wide talonid basin, the hypoconulid is usually distinct and the cristid obliqua is more strongly developed (*e.g.*, UW 9692), similar to *Nyctitherium*.

The molars decrease in size posteriorly. The trigonid of M_1 is less anteroposteriorly compressed than those of M_{2-3} because of the slight anterolingual rotation of the shelf-like paraconid. The M_1 metaconid is often extended anteriorly, while on M_{2-3} this cusp is normally steeper on the anterior (paraconid) side. The molar entoconids are taller

than the hypoconids, but the latter cusps do not become completely flat with wear. The hypoconulids are distinct but small on M_{1-2} and are generally situated medially between the hypoconid and entoconid on M_1, but are more closely associated with the entoconid on M_2. M_{1-3} have well developed precingulids, but the conspicuous ectocingulids seen in many specimens of *Nyctitherium* are absent.

P^4 is a large tooth, but is not anteroposteriorly longer than M^1 as it is in *Nyctitherium velox*. The tooth possesses a small parastyle and a large, labially inflected metastylar shelf. Conules and the hypocone are absent, but the metacone is tall and sectorial and is connected to the metastylar shelf by a long, curving postmetacrista. The P^4 talon is considerably shorter than that in *Nyctitherium*, and the posterior face of the protocone is steeper and less excavated. P^4 possesses a very small lingual precingulum.

M^1 is larger than M^2 and M^2 is larger than M^3. All of the upper molars have medial anteroposterior vespiform constrictions, but M^1 is stoutest at the midline. M^{1-3} have a well developed and anteriorly attenuated parastylar shelf and have a smaller but distinct metastylar shelf as in *Leptacodon*. These teeth possess well developed conules. The paraconule is lingual to the metaconule and is somewhat taller than it. The postparaconule and premetaconule cristae are very long and connect their respective conules to the anterior and posterior margins of the para- and metastylar shelves, respectively. The molar para- and metacones are tall spires and do not possess well developed postparacone and premetacone cristae (centrocristae). The upper molars have large precingula and a strong shelflike talon. A small hypocone is invariably present on M^{1-3}.

DISCUSSION: *Plagioctenodon* appears to be most closely related to another enigmatical form, *"Leptacodon"jepseni* (McKenna, 1960), among known erinaceid and soricoid insectivores. Krishtalka (1976b) advocated the removal of *"L." jepseni* from genus *Leptacodon* and the Nyctitheriidae, citing the high origin of the paraconid and the short talonid of P_4, the flattening of the molar hypoconids in increasingly senile stages of wear, and the poor development of the M_{1-2} hypoconulids. He suggested that *"L." jepseni* was more closely affined with the erinaceomorph than with the soricimorph insectivores.

Russell, *et al.* (1975) placed *"L."jepseni* in the Adapisoricidae, a view that is followed here for both that species and for *Plagioctenodon*. Nevertheless, neither species appears to be closely related to the *Litolestes—Leipsanolestes* complex of erinaceomorphs: both of the latter forms possess much blunter cusps, among many other differences.

"Leptacodon" jepseni and *Plagioctenodon krausae* certainly differ from advanced nyctitheriids in the construction and placement of the P_4 paraconid, but this cusp also arises at a higher point on the protoconid than it does in some adapisoricids (*e.g.*, *Mckennatherium ladae*). The placement of this cusp on the P_4 of *Nyctitherium* is higher than suggested by Krishtalka (1976b) for most members of the Nyctitheriidae. The P_4 talonid is extremely narrow in *Plagioctenodon* and in *"L." jepseni* and is indeed short,
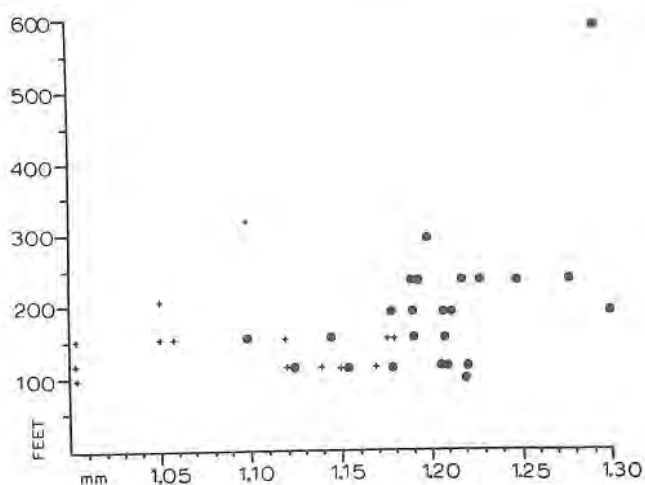
Figure 24. Stratigraphic plots of P_4 (+) and M_1(·) in *Plagioctenodon krausae*. Abscissa is tooth length in millimeters; ordinate is the distance above the base of the Willwood Formation in feet.

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more so than in *M. ladae*, and with the cristid obliqua oriented somewhat more obliquely in contrast with the relatively anteroposterior development of this cristid in *M. ladae*. The variability in P_4 talonid construction in *Plagioctenodon* is suggestive of the relative development in a cline between *Nyctitherium* and *Talpavus*, but without the extreme talonid reduction characteristic of the latter genus.

M_1 is characterized by a shelflike paraconid that is anteriorly somewhat more removed from the metaconid in *Plagioctenodon* and *"L." jepseni* than in *M. ladae* and is developed about as in *Leptacodon tener*. The hypoconid in *Plagioctenodon* molars may become flattened by wear as occasionally occurs in *M. ladae*, but the entoconids are high and acute as compared with those in the latter species.

The M_{1-2} hypoconulids of *P. krausae* are smaller than

Table 9. Measurements (mm) of lower teeth of *Plagioctenodon krausae* (493 feet of section)

	P_3L	P_3W	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W
UW 6974									1.09	0.65
UW 6999			1.05	0.59	1.37	0.90	1.21	0.96		
UW 7005									1.13	0.68
UW 7048					1.20	0.95				
UW 8584							1.23	0.90		
UW 8993							1.22	0.92		
UW 9000									1.15	0.71
UW 9583							1.19	0.81		
UW 9585							1.22	0.88		
UW 9586							1.19	0.83	1.05	0.56
UW 9587			1.12	0.84						
UW 9592					1.37	0.91	1.31	0.89	1.29	0.71
UW 9597							1.30	1.00	1.14	0.70
UW 9600			1.10	0.73	1.37	1.00				
UW 9610							1.18	0.90		
UW 9613							1.22	0.80	1.10	0.59
UW 9618							1.10	0.90		
UW 9620			1.18	0.66	1.28	0.87				
UW 9623							1.19	0.88	1.12	0.66
UW 9624			1.12	0.63	1.16	0.88	1.16	0.85		
UW 9627									1.17	0.77
UW 9635					1.28	0.89	1.22	0.82		
UW 9649							1.12	0.87		
UW 9666							1.22	0.90		
UW 9674							1.20	0.75		
UW 9675			1.00	0.68						
UW 9682	0.82	0.48	1.15	0.82	P/2 L = 0.95, P/2 W = 0.42					
UW 9683					1.30	0.92	1.19	0.85		
UW 9684									1.14	0.75
UW 9688					1.23	0.97	1.15	0.97		
UW 9689			1.14	0.65	1.24	0.84				
UW 9692			1.17	0.66	1.24	0.84	1.21	0.86		
UW 9695					1.31	0.94				
UW 9697			1.00	0.60						
UW 9700					1.21	0.81				
UW 9704									1.10	0.69
UW 9706							1.18	0.78	1.08	0.68
UW 9711							1.21	0.94		
UW 9714					1.30	0.95				
UW 9718									1.07	0.60
UW 9721					1.30	0.92				
UW 9722							1.15	0.87		
UW 9723			1.06	0.56						
UW 9726									1.00	0.57
UW 9743							1.25	0.92		
UW 9752			1.05	0.65	1.31	0.76				

in most nyctitheriids and appear to be slightly smaller than those in unworn molars of *Mckennatherium ladae*. The P₄ talonid in *Plagioctenodon* and in *"L."* *jepseni* (*contra* Krishtalka, 1976b) is not relatively shorter than that in genus *Leptacodon* (see, *e.g., L. munusculum*). With respect to the diagnostic characters which Krishtalka has noted for the Nyctitheriidae *versus* the Adapisoricidae, I make the following notes:

1 — The M_{2-3} molar trigonids do not appear to me to be distinctly or consistently compressed relative to M_1 in taxa Krishtalka (1976a) believes to be adapisoricids (see, *e.g., Macrocranion tupaiodon*), although, as noted by that author, they are thus compressed in *"Leptacodon" jepseni*. The paraconid on M_1 in *Leptacodon tener* (a nyctitheriid) is clearly medial and more removed from the metaconid than on M_{2-3} in this species.

2 — The P₄ paraconid on one of the earliest adapisoricids (*sensu* Krishtalka, 1976b), *Mckennatherium ladae* (*e.g.*, AMNH 35955), arises considerably lower on the anterior face of the protoconid than in the type of *"L." jepseni* and at a height about equal to that in *Leptacodon tener* (a nyctitheriid).

3 — If *Adapisorex* is not an adapisoricid (Krishtalka, 1976a, p. 7), then nothing is.

"Leptacodon" jepseni and *Plagioctenodon* undoubtedly are genera distinct from *Leptacodon* and the nyctitheriids, as well as from the earliest known adapisoricids (*Mckennatherium, Scenopagus, Macrocranion*). The crossing specializations apparent in early nyctitheriid and adapisoricid stocks (as these taxa are conceived by Krishtalka, 1976a, b) and evident in the specimens examined by me suggest that the diagnostic characters offered by Krishtalka have added some clarity to the assessment of the relationships of these animals but remain inadequate to diagnose these groupings consistently and fully.

OCCURRENCE: *Plagioctenodon krausae* was found at fourteen localities spanning the 97 through 590 foot interval. The taxon is unknown at present from elsewhere.

Cf. *Plagioctenodon krausae*

REFERRED SPECIMENS: UW numbers 9608, 9696, 9698, 9709, 9712, 9737

DISCUSSION: These six specimens differ from *P. krausae* in having lower fourth premolars that are larger in relation to M_1 and in having somewhat larger cheek teeth in general. The P₄ talonid is typically better developed than in most *P. krausae* (but see above), with strong hypoconid and entoconid cusps and a faint hypoconulid. P₄ is not clearly separable from that tooth in *Nyctitherium velox*, but P₂ and P₃, apparently each two-rooted (only alveoli are preserved), were not separated by a diastema as in *N. velox* (see Robinson, 1968, Fig. 1).

Measurements (mm): P₄L = 1.27-1.40 (N=6), P₄W = 0.78-0.94 (N=6), M_1L = 1.43-1.48 (N=2), M_1W = 1.07-1.12

(N=2), M_2L = 1.40-1.41 (N=2), M_2W = 1.07-1.15 (N=2).

OCCURRENCE: Cf. *Plagioctenodon krausae* is known only from the Supersite Quarry (110 foot level) and Banjo Quarry (229 foot level).

Plagioctenoides, gen. nov.

ETYMOLOGY: in reference to the superficial similarities of this genus to *Plagioctenodon*

TYPE: *Plagioctenoides microlestes*, sp. nov. and only known species

DIAGNOSIS: same as for the type species

Plagioctenoides microlestes, sp. nov.

ETYMOLOGY: Gr. *mikros* = small + Gr. *lestes* = plunderer or predaceous

HOLOTYPE: UW 9694, fragment of left ramus with P₃₋₄ (Fig. 43c), UW locality V-73037 (Supersite Quarry), lower Willwood Formation (early Eocene), sec. 35, T.47N., R.92W., Washakie County, Wyoming

HYPODIGM: Holotype and UW numbers 9667, 9676, 9707, 9724, 10394

DIAGNOSIS: Diminutive erinaceomorph with P₃ very small as in *Saturninia* and single rooted as in *Amphidozotherium* (Filhol, 1877; Crochet, 1974) and *Macrocranion nitens* (*e.g.* Russell, Louis and Savage, 1975), not double rooted as in most nyctitheriids, *Plagioctenodon*, and *"Leptacodon" jepseni*. Hypoconid only distinct cusp on P₄ talonid as in some *Plagioctenodon* and P₄ paraconid very small and arising high on anterior face of protoconid as in that genus and *"L." jepseni*. Molar cusps tall and acute, hypoconid a spire that projects far buccally. Molar hypoconulids closely appressed to entoconids. M_3 longer in relation to M_2 than in *Plagioctenodon* and many nyctitheriids. M_1 paraconid expanded anteriorly with paraconids of M_{2-3} closer to metaconids as in *Plagioctenodon* and molar entocristids very long, relatively more so than in most nyctitheriids and adapisoricids. Molar talonids longer than trigonids and with strongly oblique cristids obliqua. Premolars decreasing in size posteriorly through P_{1-2-3}, as judged from alveoli.

DESCRIPTION: The lower teeth in this taxon average 15-20 percent smaller than in *Plagioctenodon* or *"Leptacodon" jepseni*. P₁ and P₂ are not preserved in the hypodigm, but the alveoli for these teeth are preserved in UW 9676 and suggest that both teeth were single rooted and larger than P₃ or of equal size. It is also possible that P₂ was very large and double rooted as in *Plagioctenodon*. P₃ is single rooted and is bicuspidate with a strong convex and anteriorly sloping cristid connecting the protoconid with a small paraconid. There is no metaconid. A small posterobasal cusp defines the posterior border of the P₃ heel and is located at the base of a long, convex postvallid surface.

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This heel is relatively shorter than that in *Plagioctenodon* or "*L.*" *jepseni,* and the tooth closely resembles that in some early didelphids.

P_4 is constructed much as in the latter taxa with the paraconid arising high on the anterior face of the protoconid. The talonid is sharply defined by cristids, but with the hypoconid being the only well developed cusp. The cristid obliqua is variably connected lingually with a cristid extending posteriorly from the metaconid (UW 9707) as in *Cryptotopos* Crochet (1974) and abuts the face of the postvallid surface labially to the cristid extending posteriorly from the metaconid (UW 9694, Fig. 43c), or abuts the medial part of the face of the postvallid with the posterior metaconid cristid becoming confluent with the entocristid (UW 9676). P_4 possesses a tiny anterolabial cingulid, but good pre-, post-, ecto-, and entocingulids are lacking.

The trigonid of M_1 has a paraconid that is distinctly removed anteriorly from the metaconid, resulting in a large and conspicuous trigonid notch. A strong labial precingulid and an anterior ectocingulid are present and are similarly developed to those in *Nyctitherium.* The molar cusps are tall and trenchant, and the configuration of the lower molars is exodaenodont with strongly oblique cristids obliqua and hypoconids that project far buccally beyond the trigonids. M_{1-3} are characterized by very long entocristids, and the heels of these teeth have hypoconulids that are strongly appressed to the entoconids as in many soricids. M_3 is nearly as long as M_2, but is considerably narrower and possesses a large posteriorly projecting hypoconulid that is lingually associated with the entoconid. The upper teeth are unknown.

Measurements (mm):

UW No.	Loc.	P_3L	P_3W	P_4L	P_4W			
9667	34							
9676	55	0.61	0.39	1.06	0.68			
9694	37	0.50	0.32	0.80	0.46			
9707	37			0.82	0.43			
9724	22	0.49	0.40	0.95	0.68			
10394	37			0.84	0.49			
		M_1L	M_1W	M_2L	M_2W	M_3L	M_3W	
9667	34			1.00	0.75	0.92	0.62	
10394	37	1.00	0.63					

DISCUSSION: One specimen of this insectivore (UW 9676) is somewhat larger than the others and occurs considerably higher in the section than other specimens in the hypodigm. This specimen may represent a second species of *Plagioctenoides,* or it may reflect an increase in mean size of individuals of this taxon through time.

Plagioctenoides possesses a "primitive" adapisoricid-like P_4 with the development of small and high paraconids and talonids that are relatively unreduced in relation to described species of *Scenopagus.* P_{1-2} were probably single rooted teeth as in *Scenopagus* (Krishtalka, 1976a), but the single-rooted P_3 contrasts with the retention of two roots as in other known Early Tertiary North American adapisoricids and parallels, to this extent at least, developments in *Amphidozotherium,* but without the peculiar crown morphology evident in that taxon.

OCCURRENCE: This small insectivore was recovered from four localities at the 110, 150, and 389 foot levels. The species has not been recognized in other collections.

adapisoricid, indeterminate

REFERRED SPECIMENS: UW 8998 (Fig. 43e), 9716, 9730 (Fig. 43d), 9738, 10450 (Fig. 43d)

DISCUSSION: A fifth apparent adapisoricid is represented in the No Water collections by a fragmentary left ramus preserving P_4-M_1 and by jaw fragments and isolated teeth preserving M_2 and P^4-M^2. If this species is an adapisoricid, it is quite primitive in the retention of a strong paraconid and well developed talonid on P_4. This talonid, narrower than the high trigonid, supports distinct hypoconid and entoconid cusps that surround a deep basin, much as in *Mckennatherium ladae.* The P_4 paraconid, however, is smaller and is situated higher on the anterior face of the protoconid than in that taxon or than in species of the nyctitheriid *Leptacodon.* The paraconids of the molars are reduced to a shelf as in *Scenopagus,* but the notch between the paracristid and the metaconid is at about the same level as the talonid notch, as in *Macrocranion nitens.*

The upper teeth, if correctly referred, are *Scenopagus*-like but with a distinct metacone on the P^4 postparacrista as in Cf. *Scenopagus* (above) and with somewhat sharper cusps.

Measurements (mm): P_4L = 1.67-1.72 (N=2), P_4W = 0.93-1.06 (N=2), M_1L = 1.93, M_1W = 1.40, P^4L = 1.92, P^4W = 2.08, M^1L = 1.84, M^1W = 2.28, M^2L = 1.70, M^2W = 2.50.

OCCURRENCE: This species occurs at five localities between the 110 and 319 foot levels, inclusive (localities V-73037 and 73020, respectively) and is currently unknown from elsewhere.

Superfamily Soricoidea Gill, 1872
Family Nyctitheriidae Simpson, 1928a
Genus *Pontifactor* West, 1974
Pontifactor Cf. *bestiola* West, 1974

REFERRED SPECIMENS: UW numbers 9681, 9732, 9733, 10449 (Fig. 44a), 10455, 10456 (Fig. 44a)

DISCUSSION: Several upper teeth in the No Water collection appear referable to *Pontifactor bestiola*, an enigmatical taxon, apparently closely related to *Nyctitherium* and placed by West (1974) in the Nyctitheriidae. The No Water specimens average somewhat smaller than those of the type material, but morphologically they conform fairly well with the Bridger sample.

P^4 possesses a small but distinct bump on the postparacrista in the vicinity of the metacone, and this cusp is supported by a long and curving postparacrista connected to a buccally projecting metastylar shelf. The P^4 parastyle is well developed but this tooth has no conules or hypocone.

M^1 is larger than M^2 and has a much shallower ectoflexus. Both teeth, however, are nearly dilambdodont and have postpara-and premetacristae that are labially confluent with a strong mesostyle, resulting in the development of an ectoloph somewhat less well developed than in the type of *P. bestiola*. M^2 possesses a small stylocone on one specimen (UW 9733).

West (1974) and Krishtalka (1976b) discussed the possibility that AMNH 15103 (from the Willwood Formation) represents an early Eocene species of *Pontifactor*. It seems unlikely that *Plagioctenodon* represents the lower dentition of *Pontifactor* if the upper and lower dentitions comprising AMNH 15103 are, indeed, properly associated. M_{1-2} of *Plagioctenodon* possess a relatively small hypoconulid and no mesoconid. Moreover, the upper teeth referred to *P. krausae* occlude well with lower teeth referred to that taxon and are more numerous in the quarry samples. *Plagioctenodon* is the most abundant insectivore in the No Water collection. PU 17671, a nearly complete but undescribed palate, conforms most closely with specimens of *Pontifactor* in the No Water collection.

Measurements (mm): $P^4L = 1.28$, $P^4W = 1.38$, $M^1L = 1.24$-1.40 (N=5), $M^1W = 1.65$-1.82 (N=5), $M^2L = 1.12$-1.15 (N=2), $M^2W = 1.61$-1.75 (N=2).

OCCURRENCE: *Pontifactor* Cf. *bestiola* is known from three localities occurring between the 150 and 229 foot levels, inclusive. The type material of *P. bestiola* was recovered from the Henry's Fork Divide in beds above the Lone Tree White Marker (Bridger "D" of Matthew, 1909; West, 1974). AMNH 15103 is from an unknown locality in the Willwood Formation described by Matthew (1918) as in the "middle Gray Bull beds." PU 17671 appears to represent a species of *Pontifactor* or a closely related genus from near the base of the Willwood Formation.

ORDER PRIMATES Linnaeus, 1758
Suborder Prosimii Illiger, 1811
Infraorder Plesiadapiformes Simons and Tattersall *in* Simons, 1972
Superfamily Microsyopoidea (Osborn and Wortman, 1892) VanValen, 1969, p. 295
Family Microsyopidae Osborn and Wortman, 1892
Subfamily Microsyopinae (Osborn and Wortman, 1892)
Genus *Microsyops* Leidy, 1872
Microsyops wilsoni Szalay, 1969a

REFERRED SPECIMENS: UW numbers 6802, 6803, 6905, 6964, 6984, 6985, 6993, 6997 (Fig. 44e), 7086, 7093, 7100-7107, 7111, 7112 (Fig. 44d), 7120, 7146, 7154, 7160, 7172-7174, 7176, 7177, 7180, 7192, 7194 (Fig. 44c), 7195, 7202, 7209, 7218, 7222, 7230, 7235, 7236, 7239, 7242, 7280, 7283, 7289, 7292, 7315, 7320, 7327, 7916, 8800, 8801, 8805, 8810, 8820 (Fig. 44d), 8822, 8823, 8826, 8828, 8829, 8834, 8838 (Fig. 44d), 8853, 8855, 8857, 8869, 8873, 8885, 8912, 8916-8919, 8933, 8945, 8949, 10132 (Fig. 44b), 10222, 10239, 10244

DISCUSSION: *Microsyops wilsoni* is the most common microsyopid in the No Water fauna. Measurements of the teeth of *M. wilsoni* in this collection conform well with those of the species from the "lower Gray Bull" and East Alheit Quarry described by Szalay (1969a). This species has recently been reviewed by Bown and Rose (1976). As noted by them, *M. wilsoni* differs from *M. alfi* and *M. angustidens* by virtue of its smaller size and in the retention of a relatively more transverse postprotocrista. The species further differs from *M. alfi* in the possession of a small metacone on P^4 and no metaconid on P_4, and from *M. angustidens* in the lack of the P_4 metaconid.

P^4_4 are the most variable teeth in *M. wilsoni*. This may be due to the slight diastemata which separate these teeth from the adjacent P^3_3. Szalay (1969a) has noted a progressive molarization of P^4_4 through the *Microsyops* lineage. Such a trend is evident for Eocene microsyopines, but not for Paleocene forms. *Plesiolestes* and *Palaechthon* possess premolariform—semimolariform P^4 with a well developed metacone. *Plesiolestes* and some *Torrejonia* have strong metaconids on P_4; however, this cusp is smaller or may be absent in *Palaechthon* and is usually absent in *Palenochtha* and *Navajovius*. The last two genera retain only a very small metacone on P^4.

I am unable to find consistent differences between specimens of *Plesiolestes* and of *Palaechthon*, with the exception of a normally well developed metaconid on P_4 in the former genus. Bown and Gingerich (1972) and Bown and Rose (1975) have noted the occurrence of a mutable P_4 metaconid in various microsyopid genera. This condition appears to have persisted among the microsyopids from the middle Paleocene to the early Eocene. *Microsyops wilsoni* lacks a P_4 metaconid; however, several specimens in the No Water collection have variably developed postero-

Table 10. Numerical data for No Water *Microsyops wilsoni* (measurements in millimeters; 330 feet of section)

	N	OR	X̄	S	CV
P_3L	1	1.27	1.27	—	—
P_3W	1	1.05	1.05	—	—
P_4L	14	2.34—2.93	2.66	0.13	5.2
P_4W	14	1.39—1.95	1.78	0.13	7.3
M_1L	16	2.54—3.00	2.79	0.12	4.5
M_1W	16	1.91—2.28	2.10	0.13	6.3
M_2L	36	2.56—3.00	2.80	0.12	4.4
M_2W	36	1.81—2.43	2.23	0.13	6.1
M_3L	9	2.63—3.28	3.00	0.19	6.5
M_3W	9	1.67—1.96	1.85	0.10	5.5
P^4L	3	2.22—2.92	2.61	0.35	13.6
P^4W	3	2.82—3.24	3.05	0.21	6.9
M^1L	9	2.54—2.83	2.70	0.09	3.5
M^1W	9	3.18—3.55	3.35	0.11	3.4
M^2L	13	2.58—2.96	2.74	0.10	3.7
M^2W	13	3.23—3.95	3.68	0.19	5.1
M^3L	9	2.17—2.60	2.32	0.16	7.0
M^3W	9	2.90—3.30	3.06	0.12	4.1

internal ridges lingual and posterior to the protoconid on the lower fourth premolar (Fig. 44d).

The absence or relative development of these ridges does not correlate with the stratigraphic occurrences of the specimens: some P_4 specimens from low in the section possess well defined ridges, while others from considerably higher faunules have none. The presence of posterointernal ridges is often correlated with a thickening of the enamel in the metaconid region but without the development of a cusp. This has the effect of broadening the tooth transversely and results in a high coefficient of variation for P_4W, relative to the other cheek teeth. The talonid basins of M_{1-2} are relatively broader in relation to the trigonid than in *Plesiolestes* and *Palaechthon*, but are also relatively narrower with respect to the conditions in *M. alfi* and *M. angustidens*. The broadening of the talonid basins with respect to the trigonids is a characteristic trend of Eocene microsyopid evolution.

M. wilsoni, then, is a plausible derivative of *Palaechthon* (see Bown and Gingerich, 1973) or of a late Paleocene descendant of that genus. *M. alfi* and *M. angustidens* are probable descendants of *M. wilsoni* (as noted by Szalay, 1969a), having developed a premolariform—semimolariform P_4 with the formation of a metaconid. *M. alfi* diverged from *M. wilsoni* and *M. angustidens* in the loss of the P^4 metacone.

Bown and Gingerich (1972, 1973) have offered arguments that support the inclusion of *Plesiolestes*, *Palaechthon*, and *Navajovius* in the Microsyopidae. Bown and Rose (1976) have recently presented more detailed arguments and information regarding the phylogenetic relationships of the microsyopids to the plesiadapoid and paromomyid primates. Szalay (1975a, 1976) has criticized the conclusions of Bown and Gingerich and believes that those authors chose to "... disregard the basicranial evidence available for the microsyopids and paromomyiforms ..." (1975a, p. 100; 1976, p. 366; footnotes). This is incorrect.

Among the Paromomyiformes (*sensu* Szalay, 1973), only *Phenacolemur* (*e.g.*, Szalay, 1972) and *Plesiadapis* (*e.g.*, Szalay, 1971; Gingerich, 1971, 1974) have known well preserved basicrania, as Szalay (1975a) acknowledges. Well preserved skull material that preserves the basicranium (including the ear region) is unknown for all taxa discussed by Bown and Gingerich (*Plesiolestes*, *Palaechthon*, *Navajovius*), as well as for *Palenochtha*, *Tinimomys*, and *Micromomys* which, together, constitute much of Szalay's suborder Paromomyiformes. Dental evidence clearly documents the much closer affinities of these last six genera to the Eocene microsyopids (Bown and Gingerich, 1972, 1973; Bown and Rose, 1976) than to either plesiadapoids (including *Plesiadapis*) or paromomyids *sensu stricto* (*Paromomys*, *Ignacius*, and *Phenacolemur*; Bown and Rose, 1976). The dental remains strongly suggest the subdivision of the Plesiadapiformes (=Paromomyiformes of Szalay, 1973) into three superfamilies; the Plesiadapoidea, Paromomyoidea, and Microsyopoidea.

The Microsyopoidea are possessed of much more generalized dentitions than plesiadapoids or paromomyoids. It is therefore more logical to assume that *Plesiolestes*, *Palaechthon*, and *Navajovius* retained the generalized bullar construction of *Microsyops* rather than bullae reminiscent of those in *Plesiadapis* or *Phenacolemur*. Simply because Szalay maintains there is a closer relationship between his Paromomyini and Palaechthonini (Szalay, 1968a, 1969a) than the dental anatomy supports does not prove that the two tribes possessed a similar basicranial construction.

Bown and Gingerich, therefore, did not ignore the basicranial evidence; rather, they found none of this evidence pertinent to the hypothetical basicranial anatomy in *Plesiolestes*, *Palaechthon*, and *Navajovius* other than what little might be inferred from the anatomy of their closest dental relatives, the Eocene microsyopids. It is, again, most logical to assume that the unknown basicranial anatomy of the Palaechthonini will more closely approximate that of dentally similar *Microsyops* than of dentally disparate *Plesiadapis* or *Phenacolemur*.

Szalay (1968a, 1969a) has noted the dental similarities shared by mammals he considers to be in Palaechthonini and those he believes to be microsyopids. It is these and other similarities that formed the basis for the investigations by Bown and Gingerich (1972, 1973) and Bown and Rose (1976). Szalay, however, has repeatedly denied the primate status of the microsyopids on the basis of the basicranial and bullar anatomy of *Microsyops*. Whether or not the

ordinal position of the microsyopids is best based on the bullar structure alone is debatable; in any case, I see nothing in the bullar anatomy of *Microsyops* that suggests other than that this anatomy is simply very generalized. Interestingly, however, Szalay has ignored the fact that basicrania preserving ear regions are wholly unknown for his Palaechthonini. This being the case, I am unable to determine by what criteria Szalay (1968a) allocated the Palaechthonini to the Paromomyidae other than by the ill-defined taxonomic association of genera of Palaechthonini and Paromomyini in works published for nearly half a century.

It is indeed possible that the microsyopoids are not primates in the phylogenetic sense. The phylogenetic relationships of the microsyopoids to the plesiadapoids and paromomyoids and, indeed, the relationship of the Plesiadapiformes to other prosimians is debatable. I believe the dental evidence supports the close relationship of taxa placed by Bown and Rose (1976) in the Plesiadapiformes. If the systematic position of the Microsyopoidea needs revision in the light of future discoveries, the dental similarities shared by palaechthonines (*sensu* Szalay, 1968a, 1969a) and microsyopids *sensu lato* will, in the contradictory absence of specimens of palaechthonine auditory regions, necessitate the close association of taxa now included in both groupings.

Szalay (1976) also criticized Bown and Gingerich (1973) for comparing *Plesiolestes* with *Microsyops latidens*, rather than with earlier and more generalized *Microsyops* species such as *M. alfi* or *M. wilsoni*. No false parsimony was intended by these comparisons; rather, *M. latidens* was represented by more complete materials in the Yale collection. Because the metaconid on P_4 is mutable in development between *Plesiolestes* and *Palaechthon* (Bown and Rose, 1976), it makes little difference whether *Plesiolestes* is compared with *M. angustidens* or *M. latidens* or if *Palaechthon* is compared with *M. wilsoni*. The latter comparison was made by Bown and Rose (1976) and was briefly discussed above. Moreover, the angle formed by the pre- and postprotocristae of the upper molars in *Palaechthon* and *M. wilsoni* is quite similar in both taxa and lends added comparative support to the contentions of Bown and Gingerich.

The supposition that the upper fourth premolars of *M. wilsoni* are wholly premolariform (*e.g.*, Szalay, 1969a, 1976) is a misconception. As discussed by Bown and Gingerich (1973) and Bown and Rose (1976), upper fourth premolars referred to *M. wilsoni* and figured by Szalay (1969a) belong to *Tetonius*, an anaptomorphine tarsiiform primate. Gingerich and I succeeded in distinguishing several upper fourth premolars of *Microsyops* (presumably *M. wilsoni*) from the East Alheit Quarry sample in the American Museum collection. All of these possess a small but distinct metacone and are identical with P^4 in serially associated upper dentitions of *M. wilsoni* from the lower Willwood Formation of the Bighorn Basin (Bown and Rose, 1976, Fig. 2e; Fig. 44b, this paper).

OCCURRENCE: *M. wilsoni* was recovered from several localities in the Sand Creek facies, between the 14 and 390 foot levels, inclusive. The species also occurs in lower Willwood faunules of the Elk Creek and Antelope Creek badlands but is not known to occur in faunules more than 450 feet above the base of the Willwood Formation. *M. wilsoni* was first described from samples in the Four Mile collection from northwestern Colorado and the Willwood Formation of the Bighorn Basin (type). Delson (1971) has also recorded the occurrence of this species at localities in the "Wasatch" Formation of the Powder River Basin, Wyoming.

Subfamily Uintasoricinae Szalay, 1969b
Genus *Niptomomys* McKenna, 1960
Niptomomys doreenae McKenna, 1960

REFERRED SPECIMENS: UW numbers 6897 (Fig. 44f), 6898 (Fig. 45b), 6899-6904, 6906, 7031, 7094, 7121-7124, 7125 (Fig. 45a), 7126-7128, 7150-7152, 7155, 7157, 7158, 7161, 7167-7169, 7182, 7183, 7198, 7200, 7205, 7226, 7229, 7268, 7720, 7913, 8804, 8811, 8860, 8864-8867, 8875, 8881, 8884, 8903 (Fig. 45c), 8909, 8923, 8934, 8941, 8948, 9410 (Fig. 45e), 9411, 10003, 10207, 10241, 10375, 10393, 10425

DESCRIPTION: The recovery of many well preserved dentitions of *Niptomomys doreenae* from the No Water Creek Willwood exposures permits, for the first time, description of P_2 and P^3. A specimen from the Clarks Fork Basin (PU 19550; Fig. 45d) preserves alveoli for two teeth anterior to P^3 and underlines the affinity of the genus to microsyopids in general (as suggested by Russell, Louis and Savage, 1967; Russell, *in* Szalay, 1969b; and Szalay, 1969b) and to *Navajovius* in particular (Bown and Rose, 1976).

P_2 (Fig. 45c) is known from a single specimen in which the tooth has become dislodged from its alveolus but is preserved in association with a dentary preserving P_3-M_2. P_2 is single rooted and roughly equisize with P_3. The crown is blunt, as is that of P_3, and possesses a single cusp situated somewhat anterior to the transverse midline of the tooth.

P_3 is now known from seven specimens. Three of these are from the No Water area, one from the Clark Fork Basin, one from the Bighorn Basin "Lysite" equivalent (Bown and Gingerich, 1972); and two specimens are from the Sand Wash Basin of Colorado. In every specimen, this tooth is single rooted with a blunt crown and a single poorly defined cusp located as in P_2 above.

P_4 is known in twenty-eight specimens from the No Water fauna. A metaconid is present in all the specimens; however, the cusp is not always distinct, and may appear as a fold on the lingual side of the postvallid, posterolingual to the protoconid. A small paraconid is variably present on the anterolingual margin of the protoconid. The talonid is never well basined, but is composed of a deep transverse valley between the back of the postvallid surface and a relatively higher transverse posterior shelf. This shelf occasionally supports small but well defined hypoconid and entoconid cusps. Cingulids are normally absent, but

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may occur on the labial surface of the talonid, posterior to the hypoflexid. In occlusal view, the crown of P_4 is normally long anteroposteriorly with the transverse breadth roughly equal when measured anteriorly or posteriorly. A few specimens, however, are ovoid in occlusal view with somewhat shorter anteroposterior lengths, and two specimens are very narrow in trigonid breadths but have relatively broad talonids. These latter varieties are accompanied by a slight distension of the crown enamel on the posterolabial side as in *Tetonius* and *Absarokius*, but to a lesser degree than in those forms.

M_1 and M_2 are characterized by trigonids that are relatively narrow transversely and talonids that are much broader. The paraconid is distinct on M_1, and is lingual and close to the metaconid. A small paracristid shelf extends labially from the paraconid, squaring off the tooth anteriorly. On M_2, the paraconid is absent or connate with the metaconid. A minor paracristid shelf is retained at the anterior margin of the tooth and slopes labially. The entoconids of M_{1-2} are normally displaced lingually relative to the metaconids, resulting in talonid basins that are expanded both lingually and labially with respect to the trigonids. The talonids are much more broadly basined than in anaptomorphines, and more closely approximate those in *Omomys* (see Gazin, 1958) or *Pelycodus*. Hypoconulids are usually distinct on M_{1-2} and are always closer to the entoconids than to the hypoconids. Cingulids are normally absent on M_{1-3}, but a weak shelf may occur beneath the hypoflexid.

M_3 lacks a paraconid and has a talonid basin that is relatively less broad than on M_{1-2}. The M_3 entoconid is attenuated anteroposteriorly relative to M_{1-2}, and an enlarged hypoconulid closes the talonid basin posteriorly and projects behind the entoconid. With the exception of the protoconid, the molar cusps, when observed in occlusal view, are dispersed around the peripheries of the tooth crowns. M_1 is always the longest and broadest tooth when the molars may be measured serially in a dentary. M_3 is longer than M_2 but narrower transversely.

From alveoli preserved in PU 19550 (Fig. 45d), the upper canine was double rooted, with the roots aligned anteroposteriorly, suggesting a labiolingually compressed crown. P^2 was smaller than the canine and was also double rooted, with the same alignment of the roots.

The P^3 is preserved in two specimens. It has two roots and may be round in occlusal view with a single anteromedial cusp and no cingula (Fig. 45d), or is somewhat oval in outline with a small lingual shelf and with lingual and precingula (Fig. 44f). In the former specimen, the crown of P^3 is relatively smaller than in the latter, causing a slight diastema between P^3 and P^4. There is no diastema in the P^3 specimen with the larger crown and lingual shelf.

P^4 is normally longer than M^1 in specimens that preserve these teeth serially. In a few specimens, P^4 and M^1 are about the same size. The paracone is the largest cusp and is succeeded in size by the protocone. There is no metacone, but a high cristid connects the paracone to the metastylar

area as in *Tetonius* and *Tetonoides*. A small parastylar cusp is invariably present at the anterior margin of the tooth, opposite the paracone. This cusp is always much better developed than in *Niptomomys* from the Sand Wash Basin (McKenna, 1960). The enamel of the anterolabial margin of P^4 is distended superiorly. This feature is often seen in the P^4 of progressive *Tetonius*, a tooth with which the fourth upper premolar in *Niptomomys* is closely comparable.

M^1 is normally larger than M^2, and M^2 is larger than M^3. Styles are absent on the upper molars, and the postparacrista is normally longer than the premetacrista. Occasional specimens possess somewhat obliquely oriented postpara- and premetacrista, resulting in a slightly invaginated centrocrista as in *Ignacius*; however, facets 3 and 4 (Crompton, 1971) are never as transversely aligned as in *Ignacius*. The upper molar basins are broad and deep as in omomyines, not relatively narrow as in anaptomorphines. Considerable variation exists, however, and specimens of upper molars from the lower part of the No Water section possess smaller angles formed by the preprotocrista—protocone—postprotocrista than do upper molars from higher faunules. Para- and metaconules are well developed on all the upper molars. M^3 is relatively longer anteroposteriorly in relation to breadth than are M^{1-2} and resembles closely the last upper molar in *Microsyops* species. A small hypocone is variably developed on the talon shelf, posterior to the protocone. The protocone may be separated from the hypocone or talon shelf by a steep postprotocrista or may be connected with the talon by an incipient postprotocingulum. In specimens with a postprotocingulum, the structure originates from the postprotocrista about one quarter of the way from the protocone to the metaconule. Most specimens which possess the postprotocingulum occur relatively high in the No Water section.

DISCUSSION: Bown and Gingerich (1972) described a mandibular specimen of *Niptomomys doreenae* and determined that the lower dental formula in known specimens of that taxon was 1.1.3.3., as in *Navajovius*. New specimens from the No Water Creek faunules support that assessment. From comparisons based on those new specimens, *N. doreenae* appears to have been most recently related to *Navajovius* among known Paleocene microsyopids.

The teeth of both forms are minute and include an enlarged and procumbent anterior incisor with a lanceolate crown (Simpson, 1935; Szalay, 1969b; Bown and Gingerich, 1972; Bown and Rose, 1976). In both species, the lower canine and P_2 are single rooted, and P_2 is larger than the canine and P_3 in *Navajovius*, a characteristic of many microsyopids. P_3 is small and double rooted in *Navajovius*. In *Niptomomys*, P_2 and P_3 are roughly equal in size, and P_3 retains a single root like P_2. P_4 is similar in both forms, that in *Navajovius* requiring only the development of a metaconid to conform with P_4 in *Niptomomys*.

The lower molars of *Navajovius* differ from those of *Niptomomys* in the possession of talonids that are relatively narrower transversely, and of M_{2-3} trigonids which possess paracristid shelves that terminate lingually in a small flat-

Table 11. Numerical data for No Water *Niptomomys doreenae* (measurements in millimeters; 493 feet of section)

	N	OR	$\overline{X}$	S	CV
P_2L	1	0.47	0.47	—	—
P_2W	1	0.39	0.39	—	—
P_3L	3	0.46—0.64	0.54	.09	16.9
P_3W	3	0.35—0.46	0.40	.05	13.8
P_4L	28	1.13—1.57	1.33	.09	7.2
P_4W	28	0.76—1.10	0.96	.08	8.4
M_1L	32	1.21—1.43	1.31	.05	4.4
M_1W	32	1.00—1.26	1.11	.06	6.1
M_2L	20	1.03—1.35	1.20	.09	7.4
M_2w	20	0.93—1.17	1.06	.06	6.3
M_3L	10	1.10—1.39	1.26	.09	7.8
M_3W	10	0.83—0.96	0.90	.04	5.1
P^3L	2	0.64—0.78	0.71	—	—
P^3L	2	0.51—0.74	0.63	—	—
P^4L	8	1.27—1.41	1.35	.05	4.1
P^4W	8	1.58—1.85	1.72	.08	4.8
M^1L	13	1.10—1.41	1.30	.09	7.0
M^1W	13	1.41—1.86	1.66	.11	6.6
M^2L	10	1.10—1.25	1.17	.04	4.0
M^2W	10	1.48—1.64	1.55	.05	3.3
M^3L	3	0.87—0.94	0.90	.03	4.2
M^3W	3	1.14—1.22	1.18	.04	3.3

tened paraconid. In *Niptomomys,* the paraconid is absent or may have fused with the metaconid.

The upper canine and P^2 in *Navajovius* are two rooted and possess labiolingually compressed crowns (Simpson, 1935, Fig. 4). The same was probably true for the corresponding teeth in *Niptomomys,* where four anteroposteriorly aligned rooted alveoli occur anterior to P^3 (Fig. 45d). The most anterior two roots are larger than the posterior pair and suggest the presence of a large and double-rooted canine followed by a slightly smaller doubled-rooted P^2. Because these alveoli are aligned anteroposteriorly and because there are no lingual roots to complement the labial array, I conclude that the $\underline{C}$ and P^2 in *Niptomomys* probably had labiolingually compressed crowns as in *Navajovius.*

The P^4 of both genera possesses a strong postparacrista extending posteriorly from the apex of the paracone. In *Navajovius,* this crista encounters a minute metacone before reaching the posterolabial margin of the tooth. *Niptomomys* P^4 does not have a metacone. The parastyle is well developed

in *Navajovius* and in No Water *N. doreenae,* less so in Four Mile specimens. The P^4 of *Niptomomys* is more robust than that of *Navajovius,* largely due to labial enamel distension and medial rounding of the base of the paracone.

The upper molars of *Niptomomys* and *Navajovius* do not differ significantly. *Navajovius* does not possess the postprotocingulum characteristic of some specimens of *Niptomomys.* Moreover, the angle defined by the preprotocrista—protocone—postprotocrista is smaller in *Navajovius,* but, as noted above, this condition is variable in *Niptomomys* and may, in a general way, be correlated stratigraphically. UW 6898 (Fig. 45b) has a trigon angle that conforms well with that in *Navajovius.*

The above dental comparisons seem to me to be consistent with the hypothesis the *Niptomomys* is a close relative, if not a descendent, of *Navajovius.* The latter interpretation was advocated by Bown and Rose (1976). *Navajovius* is close also in known dental morphology to *Microsyops wilsoni,* particularly in the development of P^4_4 and the upper molars; however, *Navajovius* has a reduced M_3, possesses weaker hypoconulids, and has better developed M_{2-3} paraconids: these are characteristics more typical of the Uintasoricinae than of the Microsyopinae (Bown and Rose, 1976).

The occurrence of *Navajovius ?mckennai* Szalay (1969a) in deposits of Wasatchian age in New Mexico does not preclude the genus from ancestral affinity to *Niptomomys.* Rather, it removes this ancestry to a Paleocene species of *Navajovius* for which *N. kohlbaasae* is suitable.

From my comparisons, it seems likely that *N. ?mckennai* is a species of *Niptomomys.*

Uintasorex Matthew (1909) was regarded by Bown and Rose (1976) as a possible descendent of *Niptomomys.* Savage (1972, personal communication) noted the presence of an uintasoricine specimen from the late Wasatchian of the Washakie Basin, Wyoming, in which the teeth between the incisor and P_4 possess pointed crowns. These crowns are taller, less rounded, and generally unlike those of $\overline{C}$, P_{2-3} in *N. doreenae,* but are similar to those in *Navajovius,* which indicates the probability of at least two Wasatchian uintasoricine lineages. Except for the incisor and P_4, the antemolar dentition of *U. parvulus* is unknown.

Lillegraven (1976) described a new species, *U. montezumicus,* from the late middle Eocene of California. His diagnosis concisely summarizes the principal differences between samples of *U. parvulus* and *U. montezumicus.* In addition to these differences, however, I note that P_4 in *U. montezumicus* normally possesses a larger paraconid than in *U. parvulus* and that P^4 has no distinct parastyle as in *N. doreenae.* Teeth of *U. montezumicus* are also slightly smaller than those of *U. parvulus.* The M_1 paraconid of *U. montezumicus* varies in development from near that in *U. parvulus* where the cusp is close to but somewhat anteriorly separated from the metaconid, to the close appression with the metaconid described by Lillegraven in his diagnosis. The paraconids of M_{2-3} are absent as in most *U. parvulus* and many *N. doreenae,* giving the trigonids of

these teeth a somewhat paramyid-like construction. The relatively taller P_4 with a well developed paraconid and well basined talonid in *U. montezumicus* is an interesting departure from the structure of this tooth in *N. doreenae* and *U. parvulus*. On one P_4 specimen (UCMP 109472), the talonid is developed nearly as well as on the molars. At least one lineage of uintasoricines, then, paralleled the molarization of P_4 evident in Eocene microsyopines.

OCCURRENCE: *N. doreenae* is known from several localities in the lower Willwood Formation of the Bighorn Basin, and a single specimen is associated with post-"Gray Bull" faunas (Bown and Gingerich, 1972). In the No Water Creek section, *N. doreenae* was found at faunules between 97 and 590 feet above the base of the Willwood Formation. The species also occurs in early Wasatchian faunules of the Sand Wash Basin of Colorado, and probably occurs in Wasatchian rocks near Bitter Creek, Wyoming. ?*Navajovius mckennai* from the Almagre facies of the San José Formation of New Mexico may also represent a species of *Niptomomys*.

Microsyopidae, *incertae sedis*

Genus *Tinimomys* Szalay, 1974

Tinimomys graybulliensis Szalay, 1974

EMENDED HYPODIGM: PU 17899 (holotype), PU 17898, YPM uncatalogued specimen, UW numbers 6893 (Bown and Rose, 1976, Fig. 6), 6894 (Bown and Rose, 1976, Fig. 7), 6895, 6911, 6912, 7118, 7721, 8955, 8956 (Fig. 45f), 8957, 8958, 8962, 8963, 9565, 9748

DISCUSSION: *Tinimomys graybulliensis* was named by Szalay (1974) for a maxillary fragment preserving P^4-M^2 and a dentary fragment with P_{3-4}. Bown and Rose (1976) rediagnosed the taxon and documented several new and more complete specimens of the lower dentition. Subsequent finds from the No Water Creek area do not alter their diagnosis.

A second maxillary specimen (UW 8956, Fig. 45f) was recovered in 1975. This specimen is slightly larger and less worn than the type and likewise possesses a well developed cingular hypocone on P^4-M^2 and a strong pericone on M^{1-2}. *Tinimomys* and late Paleocene *Micromomys* Szalay (1973) resemble Torrejonian *Palenochtha* more than any other primate known to me. Bown and Rose (1976, Table 1) have noted the crossing characters *Palenochtha* shares with microsyopines and uintasoricines. The same is true of *Tinimomys* and *Micromomys*, and it now seems probable that these three genera constitute a third subfamily of Paleocene—Eocene microsyopids. The only major differences between the known upper cheek teeth of *Palenochta* and those of *Tinimomys* are the development, in the latter genus, of small conules and a larger metacone on P^4 and the extension of the cingulum lingually, coupled with the development of the cingular hypocone on P^4-M^2 and of the pericone on M^{1-2}.

Table 12. Numerical data for hypodigm of *Tinimomys graybulliensis* (measurements in millimeters; about 283 feet of section)

	N	OR	$\overline{X}$	S	CV
P_3L	4	0.73—1.00	0.88	.11	13.0
P_3W	4	0.52—0.65	0.58	.05	10.2
P_4L	11	1.13—1.45	1.32	.09	6.9
P_4W	11	0.87—1.11	0.96	.07	7.6
M_1L	7	0.91—1.13	1.06	.07	7.5
M_1W	7	0.90—1.05	0.95	.05	5.9
M_2L	4	0.97—1.09	1.04	.05	5.7
M_2W	4	0.83—1.00	0.92	.07	7.6
M_3L	3	1.48—1.55	1.53	.04	2.6
M_3W	3	0.81—0.95	0.88	.07	7.9
P^4L	2	1.33—1.39	1.36	—	—
P^4W	2	1.74—1.93	1.84	—	—
M^1L	2	1.07—1.10	1.09	—	—
M^1W	2	1.72—1.76	1.74	—	—
M^2L	2	0.97—1.00	0.99	—	—
M^2W	2	1.56—1.67	1.62	—	—

P_3 of *Tinimomys* is somewhat smaller and lower crowned than its counterpart in *Palenochtha*; in both genera, this tooth is two rooted. The *Tinimomys* P_4 is somewhat hypertrophied, and the trigonid has been lengthened anteriorly, relative to P_4 in *Palenochtha*. The construction of the P_4 talonid basin is identical in the two genera. M_{1-2} in *Tinimomys* do not differ appreciably from those in *Palenochtha*. *Palenochtha* molars lack an entocristid and a strong lingual cingulum, and the entoconid is closer to the metaconid relative to M_{1-2} in *Tinimomys*.

Palenochtha is a plausible ancestor for *Micromomys* and *Tinimomys* and a perhaps less plausible antecedent for *Navajovius*. The relationships among the small microsyopid genera might best be visualized by the inclusion of *Palenochtha*, *Micromomys*, and *Tinimomys* in the Uintasoricinae and the recognition of two uintasoricine tribes. The Micromomyini Szalay (1974) is available for one of these, with the inclusion of *Palenochtha*.

OCCURRENCE: *Tinimomys graybulliensis* is currently known only from early Wasatchian faunules of the Bighorn Basin, Wyoming, and is not now known to occur at localities less than 97 feet above nor more than 380 feet above the Polecat Bench Formation—Willwood Formation contact (UW locality V-73027, No Water Creek area, and UW locality V-73070, South Fork Elk Creek drainage). The small size of *Tinimomys* specimens may have affected their

recovery by surface collecting at higher levels in the Willwood and where concretions litter surface outcrops.

Superfamily Paromomyoidea (Simpson, 1940)

DISCUSSION: Bown and Rose (1976, p. 110-111) have rediagnosed the family Paromomyidae. Because this family is here deemed to be a grouping of forms distinct from the Plesiadapoidea and Microsyopoidea at the superfamilial level, the name Paromomyoidea is adopted to indicate this distinction. The Paromomyoidea contains but one family as does the Microsyopoidea, and the diagnosis of the Paromomyidae presented by Bown and Rose (1976) also serves as a diagnosis for the Paromomyoidea.

Family Paromomyidae Simpson, 1940
Genus *Ignacius* Matthew and Granger, 1921
Ignacius graybullianus Bown and Rose, 1976

REFERRED SPECIMENS: UW numbers 7091, 7092, 7109, 7116 (Fig. 46a), 7117, 7189, 7220, 7269, 8809, 8907 (Fig. 46c), 8954 (Fig. 46b), 9629, 10005, 10006, 10296

DISCUSSION: Bown and Rose (1976) resurrected Matthew and Granger's (1921) *Ignacius* for three species of middle Paleocene to late Eocene paromomyids referred by other authors to *Phenacolemur* (following Jepsen, 1934, and Simpson, 1935). *I. graybullianus* was erected as a new and the largest known species based on specimens in the Yale collection. Additional specimens of this very rare species were recovered in 1974 and 1975 from lower Willwood exposures in the Sand Creek — No Water Creek area. These new specimens conform well in size and morphology with the type and referred material at Yale. A solitary specimen of M_3 is somewhat smaller than those studied by Bown

and Rose (1976) and a referred P_4 (UW 7116) is somewhat shorter and markedly narrower than other known specimens.

There was no P_3 in either UW 7116 or 8907 (Figs. 46a, 46c), a condition that could not be positively ascertained by Bown and Rose (1976) on then-available mandibular material. A broad shelf composes the dorsal part of the ramus in the diastema between the incisor and P_4. This shelf is terminated lingually by a sharply keeled ridge.

I. graybullianus possesses a double anterior mandibular foramen; the anterior moiety is smaller and is situated just beneath the labial anteroposterior midline of the dentary and ventral to the posterior root of P_4. Its posterior complement is located at the labial midline of the dentary, beneath the hypoflexid of M_1. This mandibular foramen is also paired in *Phenacolemur praecox* and *P. citatus*. The anterior opening is usually situated beneath the diastema just in front of the anterior root of P_4, but may occur as far anteriorly as the labial alveolar border of the enlarged incisor. The posterior foramen of *P. praecox* and *P. citatus* is normally much smaller than its anterior counterpart, in contradistinction to the condition in *Ignacius*, and is developed beneath the posterior root of P_4 or the anterior root of M_1.

Part of the enlarged lower incisor of *I. graybullianus* is preserved in UW 8907 (Fig. 46c). This tooth appears to be relatively more robust than in *Phenacolemur pagei* and *P. jepseni*, but is otherwise similarly constructed.

Rose and Gingerich (1976) recently described cranial material of *I. graybullianus* from the lower Willwood Formation of the Clarks Fork Basin, and that specimen serves to underline the generic distinctiveness of *Ignacius* and *Phenacolemur*.

OCCURRENCE: *I. graybullianus* is known only from the lower Willwood Formation of the Bighorn Basin. In the Sand Creek—No Water Creek area, the species is known to occur at localities between 90 and 229 feet above the Willwood—Polecat Bench contact (localities V-73096 and

Table 13. Measurements (mm) of No Water *Ignacius graybullianus*

	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W	M^1L	M^1W	M^2L	M^2W
UW 7091			2.06	1.88								
UW 7092											2.28	3.00
UW 7109					2.16	2.00						
UW 7116	1.65	1.34	2.00	1.96	2.16	2.11						
UW 7117									2.16	2.70		
UW 7189					2.00	1.91						
UW 7220					2.15	1.80	2.90	1.58				
UW 7269							2.73	1.75				
UW 8809											1.81	2.78
UW 8907			2.00	1.98	2.10	1.90						
UW 8954									2.16	2.94	2.00	2.92
UW 10005					2.17	1.95						
UW 10006			2.08	1.72								
UW 10296							2.70	1.70				

73016a, respectively). However, in the valleys of Tenmile, Elk, and Antelope creeks, southwest of the town of Basin, *I. graybullianus* is known through a much thicker interval. There the species has its lowest recorded occurrence at Yale locality 341 and is last collected at levels coincident with Yale locality 158. My sections indicate that locality 341 is about 360 feet above the contact of the Willwood with the Polecat Bench (see also Gingerich, 1976, Fig. 2). Yale locality 158 is at least 800 feet above this contact.

Genus *Phenacolemur* Matthew, 1915c
Phenacolemur simonsi Bown and Rose, 1976

REFERRED SPECIMENS: UW numbers 6792-6794, 6795 b (Fig. 46f), 6796, 6797 (Bown and Rose, 1976, Fig. 2d), 6798, 7089, 7133-7135, 7136 (Fig. 46e), 7162, 7190, 7208, 7211, 7215, 7322 (Fig. 46e), 9404, 10215-10219, 10221, 10223, 10224, 10228, 10232 (Fig. 47b), 10233-10235, 10237, 10238, 10240, 10242, 10245, 10330

DESCRIPTION: Quarry and washing techniques have added significantly to the hypodigm of *P. simonsi*; however, the species unfortunately remains known largely from isolated teeth. The type (YPM 30666), UW 7136 (Fig. 46e), and UW 7215 are the only known specimens preserving two or more associated teeth. The new sample of No Water *P. simonsi*, however, permits description of the upper medial incisor, P^3, and P_4.

I follow Gingerich (1974, 1975a) in recognizing that paromomyids possessed upper medial incisors closely resembling those of plesiadapoids (Fig. 47). This contention is borne out by faunal associations: two sizes of plesiadapoid-like upper medial incisors occur at several localities which also yield *P. simonsi* and *P. praecox*. Plesiadapoid cheek teeth, however, are unknown in the No Water Willwood faunules, and it therefore seems logical to assign these incisors to the closest plesiadapiform counterpart of the plesiadapoids, the Paromomyoidea. The two incisor types are too small and too large, to represent *Ignacius* and are assigned, respectively, to *P. simonsi* and to *P. praecox*.

Upper medial incisors in *Phenacolemur* possess relatively longer crowns thatn those in *Chiromyoides* (Gingerich, 1973, Fig. 2; 1975b, Figs. 5-8) or *Saxonella* (Russell, 1964, Plate 8, Fig. 6d), and approximate the proportions in *Plesiadapis*. In both *Plesiadapis* and *Phenacolemur*, the apex of the crown possesses one or two distinct cusps, the anterocone and laterocone (Gingerich, 1976b, p. 6), situated apically (ventrally) and medial to a large third cusp, the posterocone (Fig. 47). *Phenacolemur* typically retains two apical cusps while *Plesiadapis* commonly has only one. The posterocone, massive in *Plesiadapis*, *Chiromyoides*, and *Saxonella*, is distinctly smaller and more acute in *Phenacolemur* and is more distinctly separated from the laterocone. This has the effect of making the crown appear less curved in lateral view. Upper medial incisors of *P. simonsi* were distinguished from those of *P. praecox* on the basis of size.

P^3 in *Phenacolemur simonsi* is supported by two labial roots and one lingual root, has a nearly complete but faint cingulum, and has but two cusps, the paracone and a shorter metacone. With the exception of the cingulum, the tooth is virtually identical to P^3 in *P. praecox*, and *P. pagei* and is only referred to *P. simonsi* by virtue of its small size. This tooth is known only in UW 10234 and measures 1.70 mm (L) by 1.65 mm (W).

Deciduous lower fourth premolars of *P. simonsi* and *P. praecox* were recovered in wash samples from several localities (Fig. 46f). The teeth were assigned to *Phenacolemur* on the basis of the filled protocristid valley of the trigonids in association with peripherally situated cusps, an anteriorly inclined postvallid, and the possession of talonids that are deeply basined, squared posteriorly, and have no hypoconulid. As with the incisors, the sample of *Phenacolemur* dP_4 is separable into two size ranges compatible with *P. simonsi* and *P. praecox*. *P. simonsi*: $dP_4 L = 1.81 - 1.85$ mm (N=2); $dP_4 W = 1.18 - 1.27$ mm (N=2). Measurements of other cheek teeth of *P. simonsi* fall within the observed size ranges given by Bown and Rose (1976).

OCCURRENCE: In the No Water Creek area, *P. simonsi* occurs at localities between 95 and 390 feet above the base of the Willwood Formation (localities V-73027 and 73055, respectively). In the Elk Creek section, *P. simonsi* occurs at UW locality V-73073 and at Yale localities 341 and 358, about 360-375 feet above the Willwood—Polecat Bench contact. The absence of *P. simonsi* in the rich faunules above the 400 foot level both in the Elk Creek section (Yale localities 290, 296) and in the Worland area (UW locality V-73125) strongly suggests that *P. simonsi* is restricted to the lower 400 feet of the Willwood. *P. simonsi* also occurs in early Eocene rocks of the Sand Wash Basin, Colorado (Bown and Rose, 1976).

Phenacolemur praecox Matthew, 1915c

REFERRED SPECIMENS: UW numbers 7084, 7085, 7087, 7088, 7090, 7108, 7113, 7129-7132, 7137, 7138, 7145, 7147-7149, 7153, 7163, 7178, 7186, 7187, 7191, 7193, 7196, 7197, 7203, 7206, 7207, 7213, 7219, 7245, 7248, 7254, 7282, 7288, 7294, 7312, 7321, 7323, 7324, 7328, 7908, 7914, 8802 (Fig. 47a), 8803, 8807, 8808, 8813, 8815, 8821, 8824, 8831, 8836, 8837, 8854, 8868, 8874, 8876, 8886, 8891, 8906, 8913, 8921, 8928, 8931, 8932, 8936, 8953 (Fig. 48b), 10220, 10225-10227, 10229 (Fig. 46f), 10230, 10231, 10236, 10338, 10372, 10373 (Fig. 46d, 48a), 10412

DISCUSSION: Bown and Rose (1976), acknowledging Simpson (1955), believed that *Phenacolemur praecox* and *P. citatus* are very closely related species but are nonetheless distinct in proportions and morphology of P_4. Gingerich (1974b) suggested that the teeth of closely related sympatric fossil species could be differentiated biometrically. He used first molars, which he and Leutenegger (1971) had demonstrated to commonly be the least variable of the cheek teeth in many primates.

Bown and Rose (1976) and Ramaekers (1975) were unable to differentiate mixed samples of M_1 in referred samples of *P. praecox* and *P. citatus*, but the former authors and Simpson (1955) reported success with P_4. Bown and Rose recorded an observed range of 3.30-4.10 mm for P_4L in *P. praecox* and of 2.60-3.10 mm for referred specimens of *P. citatus* (the type does not preserve this tooth). Excluding the diminutive *P. simonsi*, the No Water *Phenacolemur* sample straddles these ranges (P_4L = 2.91 - 3.34 mm), connecting the lower limits of the observed range for P_4L in *P. praecox* with the upper limits of this range for *P. citatus*. The inclusion of these measurements with those of the earlier known hypodigm of the *P. praecox*—*P. citatus* complex strongly suggests these samples may not be really distinct after all and that only one, albeit highly variable, species is represented.

Because the No Water sample does not approach the mean for P_4L in *P. praecox* (*sensu* Bown and Rose, 1976) but just reaches the lower limits of its range, an alternative interpretation would be to extend the observed range for P_4L in *P. citatus* and retain the taxon as valid. Such a move would be arbitrary. One of the criteria used by Bown and Rose (1976) in the separation of the *P. praecox* P_4 sample was the relative degree of anterobasal enamel distension.

Table 14. Numerical data for No Water *Phenacolemur praecox* (measurements in millimeters; 295 feet of section

	N	OR	$\overline{X}$	S	CV
P_4L	20	2.91−3.34	3.12	.13	4.4
P_4W	20	1.83−2.41	2.06	.15	7.6
M_1L	21	2.35−2.65	2.53	.09	3.7
M_1W	21	1.97−2.41	2.16	1.2	5.7
M_2L	20	2.30−2.71	2.48	.12	5.1
M_2W	20	1.77−2.41	2.18	.16	7.4
M_3L	11	3.36−3.69	3.54	.09	4.5
M_3W	11	1.88−2.89	2.12	.27	12.9
P^3L	1	−	2.66	−	−
P^3W	1	−	1.68	−	−
P^4L	7	2.39−2.69	2.51	.11	4.4
P^4W	7	2.64−3.07	2.85	.14	5.2
M^1L	19	2.27−2.68	2.45	.11	4.7
M^1W	19	2.69−3.38	3.12	.20	6.6
M^2L	7	2.45−2.73	2.60	.11	4.3
M^2W	7	3.10−3.45	3.35	.12	3.6
M^3L	5	2.41−2.78	2.65	.15	5.9
M^3W	5	2.40−2.95	2.69	.22	8.1

One of us (T. M. B.) believed this distension was correlated with the larger size of lower fourth premolars referred to *P. praecox*. The No Water sample of P_4 runs the gamut from little or no anterobasal enamel distension (*e.g.*, UW 7084, 8813, 10236a), as in typical *P. pagei*, to a degree of thickening as great as that on the most typical of *P. praecox*, *sensu lato* (*e.g.*, UW 7085, 7288, 8824, 10236b). Both P_4 morphologies commonly occurred together at several localities.

The numerical data for pooled UW, YPM, and AMNH (excluding Four Mile) samples of *P. praecox* yield these results:

	N	OR	$\overline{X}$	S	CV
P_4L	64	2.20-4.10 mm	3.14	.3184	10.141
M_1L	69	2.20-3.20 mm	2.60	.2096	8.064

Simpson (1955, p. 422) remarked that P_4 in *P. pagei* was statistically larger than that in *P. praecox*. This is true only when the *P. praecox*—*P. "citatus"* sample is pooled, as above. The upper limit of the range of P_4L in *P. praecox*, however, is markedly higher than that for *P. pagei*, and M_{1-3} are relatively much larger than in the latter species. The unusual hypertrophy of P_4 in *P. pagei* with respect to the molars may contradict the possibility that the Tiffanian species is in the ancestry of *P. praecox*, even though the two species are otherwise very close in comparable dental anatomy.

OCCURRENCE: *P. praecox* occurs at localities from 95 to 390 feet above the base of the Willwood Formation in the Sand Creek—No Water Creek area (UW localities V-73027 and 73055, respectively). *P. praecox* is known at levels less than 100 feet and more than 1,400 feet above the Willwood—Polecat Bench contact west of the Bighorn River; the high levels represent Willwood "Lysite" localities (so-called; *e.g.*, YPM locality 193). A probable new species of *Phenacolemur*, most closely resembling *P. simonsi*, and a possible species of *Ignacius* are represented in the Yale Peabody Museum Bighorn Basin "Lysite" collection (Bown, unpublished data). *P. praecox* has also been documented from the Golden Valley Formation of North Dakota (West, 1973d), Powder River Basin "Wasatch" (Delson, 1971; Bown, unpublished data), Wind River Formation (Guthrie, 1967, 1971), Bitter Creek fauna (Gazin, 1962) and the Sand Wash Basin of Colorado (Ramaekers, 1975). *P. praecox* probably also occurs in the Niland Tongue of the "Wasatch" Formation in the northern Red Desert and Great Divide Basins (Pipiringos, 1955; Bown, unpublished data).

<div align="center">

Infraorder Tarsiiformes Gregory, 1915

Family Omomyidae (Trouessart, 1879)

Subfamily Anaptomorphinae (Cope, 1883)

Genus *Tetonoides* Gazin, 1962

</div>

EMENDED DIAGNOSIS: Teeth smaller than in typical *Tetonius*, about equisize with those of *Teilhardina belgica*

or *T. americana*. Lower dental formula $\overline{2}\ \overline{1}\ \overline{3}\ \overline{3}$, where determinable. P_{3-4} quadrate in occlusal outline and P_3 commonly with well developed metaconid and normally with strong paraconid in contrast to *Tetonius* and *Teilhardina*. Paraconids and metaconids very strong on P_4 in relation to last two genera and P_4 shorter than or roughly equal in height with M_1, not taller as in *Tetonius* and *Teilhardina*. P_3 -M_3 with stronger ectocingulids than in last two genera. P_4 with raised heel with respect to protoconid as in *Tetonius*, not low as in *Teilhardina*. M_3^3 commonly larger with respect to M_2^2 than in *Tetonius* and *Teilhardina*, and P^4 smaller with respect to M^1 than in *Tetonius*. M^{1-3} with well developed lingual cingula as in early *Tetonius* and in contradistinction to *Teilhardina belgica*. P_4 with unbasined heel and narrower M_{1-2} talonids, in contrast to *Anemorhysis*.

Tetonoides tenuiculus (Jepsen, 1930a)

EMENDED DIAGNOSIS: Comparable teeth larger than in unique specimen of *Anemorhysis sublettensis*. P_4 relatively broader with respect to M_1 than in the latter species and P_4 with a stronger metaconid and normally a distinct protocristid. Heel of P_4 unbasined and without distinct hypoconid and entoconid as is present in *A. sublettensis*. P_{3-4} with less molarized trigonids than in *Tetonoides pearcei*.

REFERRED SPECIMENS: UW numbers 6907 (Fig. 48c), 6965, 7096, 7097, 7098 (Fig. 48d), 7139-7144, 7170, 7175, 7179, 7181, 7199, 7201, 7212, 7214, 7217, 7225, 7227, 7246, 7281, 7295, 7329, 7694, 7707, 7912, 7915, 8812, 8819, 8835, 8870, 8871, 8922, 8961 (Fig. 48f), 10374, 10424

DISCUSSION: Szalay (1976) recently reviewed the omomyid primates and recommended the synonymy of *Tetonoides* Gazin (1962) with *Anemorhysis* Gazin (1958). This synonymy was also advocated by Bown (1974) who stressed that the latter genus was, in terms of the dentition, the most generalized of the known omomyids (see also Bown, 1976). Restudy of the large No Water collection of anaptomorphines now convinces me that Gazin's (1962) erection of the new genus *Tetonoides* was warranted. *Tetonoides* is more generalized than *Anemorhysis*, a form which has divergently begun the molarization of the P_4 talonid.

Szalay recognized three, presumably time-transgressive species of *Anemorhysis*, *A. tenuiculus*, *A. musculus*, and *A. sublettensis*, and differentiated these species on the basis of size and occurrence of P_2 and the degree of molarization of P_4. He believed that P_2, large where known in *A. tenuiculus* (including, in the construct of Szalay, "*Tetonoides pearcei*"), was vestigial in *A. musculus* and absent in *A. sublettensis*. *A. musculus* (*sensu* Szalay, 1976) is positively known only from the type, a lower jaw preserving only M_3. It is obviously impossible to know the morphology of P_4 in this specimen. Though the P_2 alveolus is quite small, it is important that among Bighorn Basin specimens of *Tetonius homunculus* the size of the P_2 or its alveolus

may very nearly 200 percent in a single sample. With all respect to Gazin (1952) and Szalay (1976, p. 228), there is no extant comparative evidence regarding the presence or development of the crown or root of P_2 in *A. sublettensis*. Therefore, the evidence of P_2, as currently known, is of no utility in distinguishing Szalay's concept of species of *Anemorhysis*.

In his re-diagnosis of *A. sublettensis*, Szalay (1976) remarked (p. 228) that the species also differs from "*A.*" *tenuiculus* in possessing a "...more slender P_4...", and noted (page 218) that this P_4 "...has become relatively less robust and what might be described as premolariform." From my comparisons, the P_4 in *A. sublettensis*, although relatively narrower than that in *Tetonoides tenuiculus*, is equally if not more molarized. The metaconid is better developed in *Tetonoides tenuiculus*, but the paraconids are equally formed in the two taxa, and P_4 in the type of *A. sublettensis* possesses a well-basined heel with distinct hypoconid and entoconid cusps. In this respect, the tooth is more molariform than that of *T. tenuiculus* and is unlike that of other omomyids. If one presupposes the phylo-

Table 15. Numerical data for No Water *Tetonoides tenuiculus* (measurements in millimeters; 500 feet of section

	N	OR	$\overline{X}$	S	CV
P_3L	4	1.39—1.52	1.46	.06	4.4
P_3W	4	1.06—1.15	1.11	.04	3.9
P_4L	5	1.45—1.67	1.54	.08	5.2
P_4W	5	1.28—1.51	1.38	.08	6.2
M_1L	9	1.69—1.97	1.84	.10	5.4
M_1W	9	1.48—1.90	1.64	.14	8.5
M_2L	20	1.70—2.00	1.85	.07	4.2
M_2W	20	1.51—1.92	1.74	.12	7.1
M_3L	6	1.89—2.11	2.03	.08	4.2
M_3W	6	1.31—1.50	1.41	.07	5.4
P^3L	3	1.48—1.66	1.55	.09	6.2
P^3W	3	1.87—2.00	1.96	.07	3.8
P^4L	6	1.43—1.61	1.55	.06	4.1
P^4W	6	2.20—2.52	2.31	.12	5.4
M^1L	5	1.60—2.00	1.79	.16	9.1
M^1W	5	2.52—3.05	2.81	.22	7.8
M^2L	5	1.58—1.85	1.72	.11	6.7
M^2W	5	2.75—3.40	3.09	.24	8.0
M^3L	2	1.22—1.34	1.28	—	—
M^3W	2	2.16—2.50	2.33	—	—

genetic interpretation Szalay placed on the relative development of P_2 and P_4, respectively, for his species of *Anemorhysis*, one must assume he has referred dentitions preserving M_{1-3} to *A. tenuiculus* on a purely stratigraphic basis. This useage, as well as his diagnosis of the species, is perplexing.

The No Water *Tetonoides* sample contains specimens approximating both the P_4 in holotypic *Tetonoides pearcei* (*e.g.*, UW 8959, Fig. 48e) and the Golden Valley and Gray Bull referred specimens of *T. tenuiculus* (*e.g.*, UW 7098, Fig. 48d). Moreover, other specimens of P_4 in the No Water sample are intermediate in size and morphology, varying primarily in the size of the paraconid (the most distinctive attribute of P_4 in the type of *Tetonoides pearcei*) and in the strength of the ectocingulid. Upper dentitions, although slightly larger in mean size, are identical in morphology to the type of *T. tenuiculus* (PU 13027).

OCCURRENCE: *Tetonoides tenuiculus* occurs at levels between 90 and 590 feet above the base of the Willwood Formation in the No Water Creek area (localities V-73027 and 73125, respectively). Southwest of the town of Basin, in the drainages of Elk and Antelope creeks, the species is known from 200 to 500 feet above this contact. *T. tenuiculus* occurs at localities in the Golden Valley Formation of South Dakota (Jepsen, 1963), the Powder River Basin "Wasatch" Formation, and the Sand Wash Basin, Colorado.

Tetonoides pearcei Gazin, 1962

REFERRED SPECIMEN: UW 8959 (Fig. 48e)

DISCUSSION: A single lower jaw with P_3-M_2 is referred to Gazin's original species on the basis of the stronger P_3 paraconid and P_{3-4} metaconids.

OCCURRENCE: This specimen of *Tetonoides pearcei*, the first described from the Willwood Formation, was found at locality V-73125, at the 590 foot level.

Genus *Teilhardina* Simpson, 1940

EMENDED DIAGNOSIS: Lower dental formula $\overline{2}$ $\overline{1}$ $\overline{3-4}$ $\overline{3}$. Canine relatively larger than in *Tetonius* or *Tetonoides*. P_{3-4} considerably longer than wide and P_3 never with distinct metaconid or paraconid in contrast to most *Tetonoides tenuiculus*. P_4 essentially premolariform but with minor paraconid and metaconid. Heel of P_4 not raised with respect to protoconid as in *Tetonoides* and, to a lesser degree, *Tetonius*. P_4 less exodaenodont than in *Tetonoides* and *Tetonius*, and labial enamel not distended as in *Tetonius*. Trigonid cusps more peripheral than in *Tetonius* or *Tetonoides*. Paracone of P^{3-4} situated more anteriorly than in *Tetonius*. M^3_3 reduced relative to M^2_2 about as in *Tetonius*, more so than in *Tetonoides*.

Teilhardina americana Bown, 1976

REFERRED SPECIMENS: UW numbers 6896 (holotype), 6917, 7095

DISCUSSION: Only two additional specimens in the No Water collection of anaptomorphines appear referable to *Teilhardina*; both are isolated teeth. UW 6917, a right P^3, differs from that tooth in *Tetonius* in its small size and from *Tetonius* and *Tetonoides* in the possession of a more anteriorly situated paracone. UW 7095, a left M_1, has broadly splayed trigonid cusps, a more open trigonid between the metaconid and paraconid, and cusps that are more peripherally placed around the margin of the tooth. Moreover, the trigonid cusps are less bulbous in *Teilhardina* than in *Tetonius* or *Tetonoides* (see also Szalay, 1976, p. 176). In these characters, UW 7095 more closely resembles M_1 in *T. americana* than in either *Tetonoides tenuiculus* or *Tetonius homunculus*.

Measurements (mm): $P^3L = 1.42$, $P^3W = 1.85$, $M_1L = 1.95$, $M_1W = 1.46$.

Although typically believed to be an omomyine (see *e.g.*, Russell, *et. al.*, 1967; Simons, 1972), Bown (1976) and Szalay (1976) have recently demonstrated the anaptomorphine affinities of *Teilhardina*. The genus appears to be plesiomorphic for the Omomyidae in the occasional retention of P_1, a tooth found in no other tarsioid (see *e.g.*, Simons, 1961; Quinet, 1966; Szalay, 1976). However, Bown (1976) has argued that the morphology of P_4 and the relative reduction in size of M^3_3 in *Teilhardina* are probably derived conditions, relative to these teeth in *Tetonoides* and the ancestral omomyid condition.

Szalay (1976) allied Gazin's (1958) *Chlororhysis* with *Teilhardina* in the tribe Teilhardinina and unified this association on the basis of presumed shared premolariform fourth premolars, unreduced P_2 and lower canine, and unenlarged incisors. Szalay believed *Chlororhysis* to be ". . . dentally possibly one of the most primitive omomyids in North America." I do not share that view. The type of *Chlororhysis knightensis* (USNM 21901) does not preserve enough of the alveolar border of the jaw anterior to the canine to give any estimate whatsoever as to the relative size of the anterior incisor. Bown and Gingerich (1972) have shown that the foreshortened views obtained by oblique breakage across alveolar boundaries may lead to confusion with respect to the interpretation of size and number of anterior lower teeth. The example of the type of *C. knightensis* is even less explicit in that only a tiny part of the lingual alveolar border is preserved for either of the incisors. The allegation of Szalay (1976, p. 178) that ". . . the two incisors were not so large as those in either *Anemorhysis* or *Tetonius* . . ." simply cannot be substantiated for any specimen currently referred to *Chlororhysis*. The canine in the latter genus is, if anything, relatively smaller than that in CM 12190, the only specimen of *Tetonius* that preserves this tooth. The crown of the canine in the type of *Chlororhysis* is slightly taller and relatively more slender than that in CM 12190, but the range of

variation in this tooth is unknown, and it is not very useful now to use these possibly variable differences as generic diagnostic criteria. It is interesting that the tall, slender canine in the type of *Chlororhysis* is most similar in morphology to that in YPM 27791, a specimen of *Absarokius abbotti* (Bown and Gingerich, 1972, Fig. 3a, c) and a probable descendant of *T. homunculus*.

The "unreduced" P_2 in the type of *Chlororhysis*, deemed significant in the diagnosis of Szalay's Teilhardinina, is actually less than the mean size for this tooth in the Yale Willwood sample of *Tetonius*. Many specimens of P_2 in *Tetonius* are both absolutely and relatively larger (*e.g.*, YPM 25017). The second lower premolar in CM 12190 (Szalay, 1976, Figs. 22, 23, 26) is unusually small when compared with the rest of the Willwood sample.

The remaining diagnostic character of the Teilhardinina, premolariform fourth premolars, is, as Szalay (1976, p. 196) himself states, a characteristic of *Tetonius* as well as *Chlororhysis*. In all respects, possibly excluding its small size, the type of *Chlororhysis knightensis* conforms well with Willwood *Tetonius homunculus*. A few specimens of *Tetonius* (*e.g.*, UW 7165, 8830) match the small size of USNM 21901 but occur from near the base of the Willwood Formation and are surely much older than Gazin's type as determined by the comparative faunal associations. I regard the type of "*Chlororhysis*" to be structurally intermediate between advanced *Tetonius homunculus* and *Absarokius abbotti* although the teeth are much smaller than in any known specimens of the latter taxon.

UCMP 46705, a right dentary with P_4 - M_3, was tentatively assigned to "*Chlororhysis*" by Szalay (1976, p. 181). Although P_4 is slightly taller than in the type and referred specimens of *Loveina zephyri*, I refer this specimen to that taxon on the basis of the P_4 - M_3 trigonid construction, the broad and deeply basined M_{1-2} talonids, and the relatively unreduced M_3. *Loveina* is a pivotal genus, closely related to *Tetonoides* (Bown, 1974) and probably critical to an understanding of the anaptomorphine—omomyine dichotomy.

OCCURRENCE: *Teilhardina americana* occurs at only two localities in the report area, at intervals 110 and 150 feet above the base of the Willwood Formation. Gingerich and Rose (1976, oral communications) have noted the probable presence of *T. americana* in recent UMMP collections in the Willwood of the Clarks Fork Basin. The known geographic range of the species is the Bighorn Basin.

Genus *Tetonius* Matthew, 1915c

EMENDED DIAGNOSIS: Teeth typically larger than in *Teilhardina, Tetonoides*, or *Anemorhysis*. Dental formula ?2/2, 1/1, 3/3, 3/3. Canine relatively smaller than in *Teilhardina*. P_2 - P_4 anteroposteriorly compressed and inflated with short heels and pronounced posterolingual and labial distension of enamel. Lingual cingulids commonly developed on posterior incisor through P_3 and occasionally on P_4. P_{3-4} more rectangular in occlusal outline with respect to

Tetonoides and only rarely possess strong ectocingulids. Paraconids and metaconids generally small on P_4 but with tendency to decrease in size in younger faunules. P_4 always taller than M_1 as in *Teilhardina*, but with elevated heel in comparison to protoconid, as in *Tetonoides*. M_3^3 relatively reduced as in *Teilhardina*, not comparatively large as in *Tetonoides*. Trigonid cusps typically less peripheral in occlusal view, and with broader bases, than in *Teilhardina*. Paracone of P^{3-4} situated centrally in early samples, placed more anteriorly in younger samples, but without distinct metacone.

Tetonius homunculus (Cope, 1882a)

REFERRED SPECIMENS: UW numbers 7110, 7164, 7165? (Fig. 49a), 7171 (Fig. 49d), 7184, 7188, 7204, 7210, 7216, 7223, 7224, 7228, 7271, 7325, 7910 (Fig. 49b), 7911, 7919, 8830 (Fig. 49c), 8901, 8910, 8960 (Fig. 49a), 9412, 10146, 10247, 10355-10357

DISCUSSION: The small size of the No Water *Tetonius* sample has made it difficult to assess its significance when compared with much larger Willwood samples from elsewhere in the Bighorn Basin (largely at Yale). The No Water sample is quite heterogeneous, both in size and morphology, and many teeth are more generalized in their structure than any I have studied in collections from central basin localities. Many of the isolated molar teeth were allocated to *T. homunculus* strictly on the basis of their relative large size with respect to samples of *Tetonoides* or, more rarely, *Teilhardina americana* from the same localities.

In a few instances, collections from some of the richer quarries (*e.g.*, Supersite, Banjo, Slick Creek) permitted distinctions based on the dental association of large or small molars with premolars of characteristic *Tetonius* or *Tetonoides* morphologies (see diagnosis, above). The neat assessment of the No Water anaptomorphines has, however, suffered from curious samples obtained at a few localities (*e.g.*, V-73125). Furthermore, Bown (1974) noted the tendency for a general increase in *Tetonius* tooth size up section. This increase is associated with a loss in the relative expression of the ectocingulid, metaconid, and paraconid of P_4. These trends were noted primarily in *Tetonius* collections from the lower part (600 feet) of the Willwood Formation. Higher samples are less consistently correlated, but similar and continued developments must have played a role in the derivation of P_4 in *Absarokius* (Bown and Gingerich, 1972). If these trends may be inferred down section for the hypothesized basal Willwood sample of *Tetonius* P_4, a situation approximating that in the No Water sample is reached. In these specimens, P_4 is characterized by strong ectocingulids and a well developed metaconid. The teeth are distinguished from those of *Tetonoides* by the relatively weak paraconids and the strong buccal enamel distension characteristic of this tooth in *Tetonius*. This latter character, as well as the compressed P_4 heel, distinguishes these teeth from P_4 in *Teilhardina*. The lower fourth premolars referred to *Tetonius* are, however, mar-

kedly narrower with respect to length than in other *Tetonius* samples.

Three specimens of *Tetonius* P$_4$ are figured to illustrate sample variation. I am unable to confidently assign UW 7165 (Fig. 49a) to *Tetonius* or *Tetonoides*. The specimen differs from *Teilhardina americana* in the possession of a relatively broader P$_4$ in association with (1) a greater degree of buccal enamel distension. (2) a more anteroposteriorly compressed P$_4$ heel, (3) a relatively shorter M$_1$ talonid basin, (4) more bulbous M$_1$ trigonid cusps, and (5) a relatively broader M$_1$ than that in *T. americana*. These differences are very minor, however, and taken singly could well be expected in the range of variation for either *Tetonoides tenuiculus* or *Tetonius homunculus*. In spite of its small dimensions, I have referred the specimen to *T. homunculus* because of the reduced P$_4$ paraconid, tall protoconid (taller than M$_1$ trigonid), and relative buccal exodaenodonty. This specimen and three others referred to *T. homunculus* are from the 110 foot level above the base of the Willwood Formation (Supersite Quarry).

UW 8830, a right P$_4$ (Fig. 49c), was found at the 319 foot level associated with *T. tenuiculus* which, at that locality, is much smaller and quite distinct. UW 8830 conforms very well with samples of *Tetonius homunculus* P$_4$ from the base of the Willwood in the central basin sections (see Bown, 1974, Fig. 5a) and has a minor ectocingulid and moderately well developed paraconid and metaconid cusps.

UW 8960 (Fig. 49a) was recovered at locality 125 (W), 590 feet above the base of the Willwood. This specimen is of interest in that the P$_4$ is very small in relation to M$_1$, yet is buccally exodaenodont and has no ectocingulid. The small P$_4$ size in this lower jaw is unusual for a specimen at this stratigraphic level. The P$_4$L is beneath the range for that tooth observed by Szalay (1976, p. 200); however, the M$_1$ measurements are slightly above the mean given by Szalay for that tooth. Szalay (1976) referred McKenna's (1960) "Cf. *Anemorhysis minutus*" and other similar Four Mile specimens to *Tetonius* sp. These specimens as well are abnormally small, but differ from the No Water Willwood specimens in lacking as well developed paraconid and/or metaconid cusps on P$_4$.

Varying cheek tooth morphology in the basal Willwood anaptomorphine samples has blurred generic distinctions among *Tetonoides*, *Teilhardina*, and *Tetonius*. This is certainly to be expected if we agree that all these animals shared a common ancestor not far removed in time from the early Wasatchian. Unfortunately, anaptomorphine dental samples are far too small, and the specimens too fragmentary, for a confident assessment of the phylogenetic relationships to emerge in the near future. Review studies will not add much more than is now known without the recovery of large, stratigraphically controlled samples of specimens that serially preserve antemolar as well as cheek teeth. The virtually identical P$_4$-M$_3$ of *Tetonius* and *Pseudotetonius* are shown to be completely misleading when the antemolar arrays are compared (Bown, 1974). Similar differing antemolar specializations might well be

Table 16. Numerical data for No Water *Tetonius homunculus* (measurements in millimeters; 480 feet of section)

	N	OR	$\overline{X}$	S	CV
P$_2$L	1	—	1.06	—	—
P$_2$W	1	—	0.86	—	—
P$_3$L	2	1.56—1.84	1.70	—	—
P$_3$W	2	1.37—1.70	1.53	—	—
P$_4$L	6	1.60—2.00	1.78	.17	9.7
P$_4$W	6	1.30—2.00	1.73	.29	17.1
M$_1$L	11	1.92—2.34	2.15	.13	6.4
M$_1$W	11	1.70—2.13	1.90	.14	7.6
M$_2$L	11	1.92—2.26	2.09	.11	5.7
M$_2$W	11	1.71—2.16	1.95	.13	6.7
M$_3$L	3	2.07—2.15	2.12	.04	2.0
M$_3$W	3	1.40—1.53	1.44	.07	5.2
P^{3}L	2	1.80—1.94	1.87	—	—
P^{3}W	2	2.36—2.47	2.41	—	—
P^{4}L	2	1.84—1.86	1.85	—	—
P^{4}W	2	2.82—2.88	2.85	—	—
M^{1}L	5	1.91—2.10	1.99	.07	3.8
M^{1}W	5	2.76—3.35	3.06	.25	8.4
M^{2}L	6	1.85—2.00	1.92	.06	3.4
M^{2}W	6	3.14—3.67	3.38	.21	6.4
M^{3}L	4	1.18—1.38	1.27	.08	6.5
M^{3}W	4	2.27—2.53	2.38	.10	4.5

expected in the variety of small anaptomorphines that are collectively called *Tetonoides*.

OCCURRENCE: *Tetonius homunculus* is sparsely represented at localities between 110 and 590 feet above the base of the Willwood Formation in the study area. Specimens of this taxon that fall within the central basin sample range (Yale collection) first occur at 186 feet. The species has not been found at the well-sampled University of Wyoming Quarry Beds (locality 27, 97 foot level), but the significance of this absence is unknown. Specimens referred to *Tetonius homunculus* occur associated with *Teilhardina americana* at localities V-73037 and 73022 and with *Tetonoides tenuiculus* at localities V-73016b, 73020, 73022, 73037, 73044, 73055, and 73125. West of the Bighorn River, *T. homunculus* occurs from about 200 to at least 1,200 feet above the base of the Willwood Formation (Yale locality 249). The species is known to occur in association with *Absarokius* in the Bighorn Basin. *Tetonoides* and *Tetonius* occur together at several localities in the central basin within the 200-500 foot interval (UW localities V-73001, 73002, 73070, 73073; Yale localities 215W,

358, 363), and may occur together at higher levels (e.g., Yale locality 376).

Tetonius homunculus is also known from early Wasatchian rocks in the Powder River Basin, Laramie Basin (Eaton and Bown, unpublished data), and Washakie and greater Green River basins, Wyoming, and the Sand Wash Basin, Colorado. The species is not positively known from early Wasatchian rocks (Indian Meadows Formation) in the Wind River Basin.

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Infraorder Lemuriformes Gregory, 1915

Family Adapidae Trouessart, 1879

Subfamily Notharctinae Trouessart, 1879

Genus *Pelycodus* (Cope, 1875)

Pelycodus ralstoni* Matthew, 1915c

</div>

REFERRED SPECIMENS: UW numbers 6961, 6962, 6966-6972, 6977-6980, 6983, 6986-6988, 6990, 6991, 6994-6996, 6998, 7000, 7001, 7003, 7006-7008, 7010, 7012, 7016, 7018-7020, 7022-7026, 7029, 7032, 7033, 7037-7040, 7042, 7045, 7049, 7051-7055, 7058-7062, 7063 (Fig. 49e), 7064, 7065, 7066 (Fig. 50a), 7067, 7068 (Fig. 50b), 7069-7083, 7099, 7156, 7159, 7166, 7185, 7221, 7231-7234, 7237, 7238, 7240, 7241, 7243, 7244, 7247, 7249-7253, 7255-7267, 7270, 7272-7279, 7284-7287, 7290, 7291, 7293, 7296-7311, 7313, 7314, 7316-7319, 7326, 7918, 8373, 8376, 8377, 8806, 8814, 8816-8818, 8825, 8832, 8833, 8839-8841, 8842 (Fig. 49f), 8843-8852, 8856, 8858, 8859, 8861-8863, 8872, 8877-8880, 8882, 8883, 8887-8890, 8900, 8902, 8904, 8905, 8920, 8924-8927, 8929, 8930, 8935, 8937-8940, 8942-8944, 8946, 8947, 8950-8952, 9123, 9200, 10326, 10346, 10404, 10410; jaw fragments and vials of teeth

DISCUSSION: *Pelycodus* is the most abundant primate in the Willwood Formation. The No Water sample, here referred to *P. ralstoni* with the exception of a few specimens, is extremely heterogeneous both in size and morphology. P_4 -M_3 may vary as much as 40 percent in size; however, this variability is well correlated with the stratigraphic occurrence of specimens (Fig. 25). In mean size of cheek teeth, No Water *P. ralstoni* falls well below samples assigned to this species from the Powder River (Delson, 1971) or Sand Wash basins (McKenna, 1960). Interestingly, the No Water sample coincides well with the stratigraphic record of *Pelycodus* species documented by Gingerich (1976, Fig. 7; this paper, Fig. 25), with the exception of six specimens from the 590 foot level. Here, a solitary large individual falls within the upper part of the range for *P. trigonodus*, but the remaining specimens lie considerably beneath the lower end of the observed range for *Pelycodus* at this level (590-600 feet) in the Elk Creek section. Barring possible stratigraphic complications (discussed below under COR-

* Gingerich and Simons (1977, Contribs. Mus. Paleont. Univ. Michigan, v. 24, p. 245-279) have recently reviewed the phylogeny of North American adapids. In their classificatory scheme, some of the specimens here referred to *P. ralstoni* probably belong to *Pelycodus mckennai*.
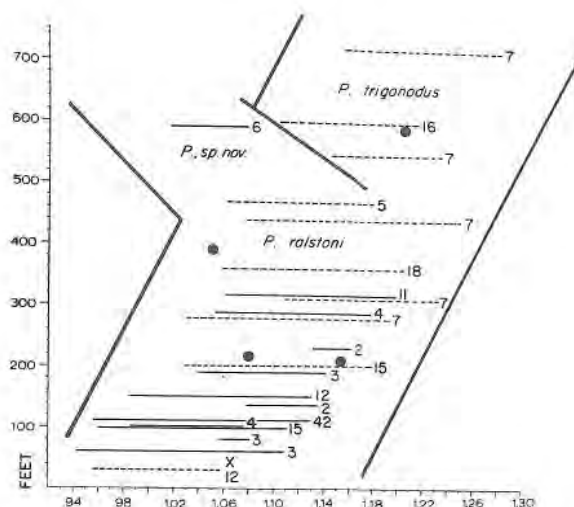
Figure 25. Stratigraphic plots of M_1 in *Pelycodus* from the Willwood Formation. Solid lines are observed ranges of measurements on specimens in the No Water collection; dashed lines are observed ranges of measurements on specimens in the Yale collection (from Gingerich, 1976a); solid circles represent individual specimens in the No Water collection; numbers show sample size at each interval; abscissa is log (L x W)M_1; ordinate is distance in feet above the base of the Willwood Formation. The lowest sample of 12 specimens, designated by x at the bottom of the column, is the "Clark Fork" sample noted by Gingerich (1976a).

RELATION), two distinct possibilities exist to explain this discrepancy. An extension of the observed range for *P. trigonodus* at this level offers one solution, but would blur whatever size distinctions exist between that species and *P. ralstoni*. *Pelycodus* samples in the 300-600 foot level (Gingerich, 1976, Fig. 7) show three marked decreases in mean size and observed size range for M_1. If this trend, not now represented for most of this interval by specimens, were continued at either of the two lower shifts of the mean, the sample at UW locality V-73125 would coincide with the trend at the 590 foot level. The recovery of a solitary M_1 at the 390 foot level, however, suggests that the shift of the mean size of M_1 began considerably lower (if change was gradual). The small specimens found at the 590 foot level represent either a decrease in mean size of *P. ralstoni* or a new *Pelycodus* species.

In accordance with the data presented by Gingerich (1976) and the "specific characters" given by Matthew (1915c) for *P. ralstoni*, I have found that specimens available to me that occur above the 440 foot level of Gingerich (1976) more closely approximate Matthew's size criteria for *P. trigonodus* than do *Pelycodus* teeth found beneath this level. The sample of *Pelycodus* with small teeth from the 590 foot level south of Worland constitutes a decrease in mean size of individuals, separating *P. trigonodus* from a probable new species; this supports a trend otherwise only apparent in the single specimen from locality 55 (390 foot level).

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Earlier workers (*e.g.*, Cope, 1875; Osborn 1902; Loomis, 1906; Matthew, 1915c), hampered by small sample sizes, made few attempts to separate species of *Pelycodus* on other than size differences. Matthew (1915c) gave measurements of 11-14 mm for M_{1-3} of *Pelycodus ralstoni*. The mean of the No Water sample referred to this species is 12.3 mm, well within this range. *Pelycodus trigonodus* was believed to possess M_{1-3} lengths of about 15 mm. UW 8892 (Fig. 50c), here assigned to *P. trigonodus*, is the only No Water specimen to closely approximate these dimensions (length M_{1-3} = 14.6 mm). McKenna (1960) considered *P. trigonodus* a possible synonym of *P. ralstoni*, and advanced the hope that a biostratigraphic study of the Willwood Formation would clarify the relationship of these species. Although such studies have been and are now being undertaken, the status of *P. trigonodus* remains in doubt. Kelley and Wood (1954) believed that the species of *Pelycodus* tend to ". . . intergrade almost continuously." Biometric data for *P. trigonodus* and *P. ralstoni*, whose stratigraphic point of separation is still unclear, tend to support this contention. I provisionally regard these species as distinct until a clearer understanding of their biostratigraphy evolves. Additional collecting in the 350-600 foot level (poorly exposed in the No Water area) should aid in solving this problem; however, if gradual, stratigraphically controlled size differences prove to consistently separate large samples of these groupings as now recognized, their synonymy is not warranted.

My attempts to discern two morphologic species in the No Water and correlative samples of *Pelycodus* were futile. Matthew (1915c) suggested that P_4 of *P. ralstoni* was ". . . smaller and less compressed than in *P. trigonodus*." The relative buccal-lingual compression of P_4 is quite variable in *Pelycodus*. Lower fourth premolars that are long anteroposteriorly are commonly narrow in the buccal-lingual dimension, and short lower fourth premolars are often relatively broad. In the absence of correlative size or other morphologic distinctions, the shape of P_4 in early Wasatchian *Pelycodus* has no taxonomic validity. P_4 breadth in the No Water *Pelycodus* sample is often related (but not always) to the strength of development of the metaconid. Several specimens (*e.g.*, UW 7033, 7234) do not possess this cusp, while most others (*e.g.*, UW 7063, Fig. 49e) have a well developed metaconid.

Gazin (1962) noted the presence of a tall, anteriorly situated entoconid in M_{1-2} of *P. praetutus*. Moreover, the entoconids in this species are often lingually removed from the remainder of the talonid basin. Several No Water specimens of *P. ralstoni* have entoconids situated far to the lingual side, expanding the talonid buccal-lingually as in *P. praetutus*, but none possess anterior entoconids or well separated M_2 paraconids and metaconids as in that species. *P. praetutus* is also apparently unique among *Pelycodus* species in specializations of the premolar series. The type of this species (USNM 22262) possesses a double-rooted P_3 as in other *Pelycodus*, but anterior to the front alveolus for this tooth are three alveoli, the first two of which are small in relation to the most anterior. This suggests that *P. praetutus* had lost the first premolar (as in *Protoadapis*) or that

this tooth and P_2 were single rooted. Gazin (1962) also referred YPM 14697 to *P. praetutus*, and this specimen clearly possesses a double-rooted P_2, as do all dentally comparable *Pelycodus* dentaries known to me. If the second lower premolar in the type of *P. praetutus* was similarly double rooted, then that tooth must have been equally large as, or larger than, P_3, and preceded by a relatively enormous P_1 or a very small canine. In either case, the antemolar dentition of *P. praetutus* appears to differ from that known in other *Pelycodus* species.*

M_3 in *Pelycodus* is normally widest buccal-lingually at the trigonid. However, several specimens of No Water *P. ralstoni* and central basin *P. ralstoni* and *P. trigonodus* have a wider anterior talonid lobe than trigonid. As far as is known, the relative trigonid *versus* talonid breadth of M_3 in *Pelycodus* is not correlatable with other morphologic characters of the cheek teeth. Loomis (1906) and Kelley and Wood (1954) noticed differences in the formation of the posterior talonid lobe of M_3 in *P. frugivorus* and *P. jarrovii*. In many specimens, the third talonid lobe is formed by apparent partitioning of the hypoconulid into two or three small cusps which square off the posterior margin of the tooth (also seen to some extent in *Plesiadapis*). Other M_3 specimens have an elliptical posterior margin with only one cusp or even no distinct cusps. Both of these varieties and an intermediate condition (UW 7063, Fig. 49e) exist in the No Water collection of *P. ralstoni*, and these divergent morphologies could not be correlated with other cheek tooth variables.

Distinct hypocones and mesostyles do not occur in *P. ralstoni*, but are known in *P. frugivorus* (*e.g.*, AMNH 15022; see also Osborn, 1902). In any case, the development of these structures has been gradual, as may be seen in the highly variable *P. trigonodus* sample in the Yale collection. Here, and in specimens of No Water *P. ralstoni*, the postprotocingulum may be elevated posteriorly (*e.g.*, UW 7276) or not (*e.g.*, UW 7068, Fig. 50b), and M^{1-2} may possess an inflected ectocingulum (*e.g.*, UW 7068, Fig. 50b) or not (*e.g.*, UW 7066, Fig. 50a). As can be seen from the examples above and other specimens, these variables do not consistently correlate with each other, with morphologic variables in faunally associated lower teeth, or with molars that are relatively more or less triangular in occlusal view (see Matthew, 1915c, p. 436). The development of the lingual cingulum on the upper molars is likewise variable and apparently random.

Thus, the anagenetic change in size in successive populations of Willwood *Pelycodus* (Gingerich, 1976a) was seemingly accompanied by gradual morphologic change first expressed as increases in the morphologic variability of the dental samples. The development of the hypocone and mesostyle of the upper molars are not, then, absolute characters useful in generic or specific distinction, but rather are present in a greater or lesser degree within the population variability of all named species of *Pelycodus*.

* Gingerich and Simons (1977; see footnote, p. 80) have placed both *Pelycodus tutus* and *P. praetutus* in a new genus, *Copelemur*.

OCCURRENCE: Specimens assigned to *P. ralstoni* were found at numerous localities between the 80 and 390 foot levels in the No Water section (UW localities V-73025 and 73111, respectively). Gingerich (1976a) has allocated a Clarkforkian sample to *P. ralstoni*; if these specimens occur in Polecat Bench as opposed to Willwood rocks, they probably represent the oldest known occurrence of the species. The Clarkforkian sample approximates the mean size for M_1 in *P. ralstoni* lower jaws from the lowest levels of the No Water section (Fig. 25) and for M_1 in the unusually small specimens from the 590 foot level. No Water samples of M_1 from the 110 through 390 foot levels average somewhat larger in size. Samples of M_{1-3} approaching the size of *P. ralstoni* ($\overline{X}$ M_{1-3} L = 12.3 mm) are rare above the 500 foot level in the Elk Creek-Buffalo Basin sections, and no specimens from comparable or higher levels are as small as those from UW locality V-73125 (590 foot level).

P. ralstoni is known from several Wasatchian faunas outside the Bighorn Basin. Jepsen (1963) and West (1973d) have reported the species from the Golden Valley Formation of North Dakota, and it is believed to occur as well in the Powder River Basin "Wasatch" (Delson, 1971), the northwestern Washakie Basin (Bitter Creek Wasatch; Savage, 1976, personal communication), and the Sand Wash Basin of Colorado (Four Mile fauna; McKenna, 1960). Dorr (1952) assigned a fragmentary lower jaw preserving only M_3 from Hoback locality #2 to *P. ralstoni* (?).

Pelycodus trigonodus Matthew, 1915c

REFERRED SPECIMENS: UW 8892 (Fig. 50c), 10445

DISCUSSION: A fragmentary mandible and two teeth are alone referred to *P. trigonodus*. The teeth in UW 8892 are absolutely larger than any others referred to *Pelycodus* in the No Water collection and dwarf those of six faunally associated specimens here referred to a new, undescribed species. The No Water *P. trigonodus* specimens fall in the uppermost part of the size range for M_1 in this species noted by Gingerich (1976a) for the 600 foot level. M_3 (Fig. 50c) is typified by a posteriorly squared talonid.

OCCURRENCE: *P. trigonodus* is presently known to occur only at the 590 foot level in the No Water section (UW locality V-73125). The species (as defined statistically by Gingerich, 1976a) is found at least as high as the 1,200 foot level in Willwood localities marginal to Schuster Flats, northwest of Worland (Bown, unpublished data).

Elsewhere, *P. trigonodus* has been reported only by Gazin (1962; 1965) from Wasatchian faunules at Bitter Creek, in the Red Desert, and near Elk Mountain, and by Prichinello (1971) for early Eocene deposits in the Laramie Basin.

Pelycodus sp., probably new

REFERRED SPECIMENS: UW numbers 8893-8899, 8911, 8915, 10352, 10354

DISCUSSION: These eleven specimens from the 590 foot level of the Willwood Formation record a marked decrease in mean tooth size of *Pelycodus* individuals accompanied by the appearance of a specimen of the large *P. trigonodus*. Because these specimens depart from the gradual increase in size noted for *P. ralstoni* at lower levels, this sample is tentatively assigned to a new but unnamed species.

Pelycodus sp. is morphologically indistinguishable from *P. ralstoni* and differs from that species only in its abnormally small size with respect to its stratigraphic position. This species differs from *P. trigonodus* in its much smaller mean tooth size and in the retention of untwinned hypoconulids on M_3 and the resultant lack of squaring of the M_3 heel.

Measurements (mm): P_4L = 3.74, P_4W = 2.91, M_1L = 3.35-3.94 (N=5), M_1W = 2.97-3.18 (N=5), M_2L = 3.51=4.00 (N=5), M_2W = 3.32-3.54 (N=5), M_3L = 4.42-4.95 (N=4), M_3W = 3.02-3.19 (N=4), P^4L = 3.25-3.38 (N=2), P^4W = 4.25-4.35 (N=2), M^1L = 3.72, M^1W = 4.75, M^2L = 3.45-3.54 (N=2), M^2W = 5.56-5.78 (N=2), M^3L = 2.54-2.87 (N=2), M^3W = 4.37-4.42 (N=2).

ORDER RODENTIA Bowdich, 1821

Dr. Mary R. Dawson is currently studying the collection of No Water rodents. She (1976, written communication) has identified the mandibular and maxillary specimens as follows:

Family Ischyromyidae Alston, 1876
Genus *Paramys* Leidy, 1871
Paramys excavatus Loomis, 1907a

REFERRED SPECIMENS: UW numbers 8322, 8324-8327, 8329-8332, 8334, 8336, 8337, 8339-8341, 8485, 8966, 8968-8971, 8974, 8976, 8978, 8979, 8981, 8982, 8984, 8987, 8988, 8990, 8991

OCCURRENCE: *P. excavatus* is known from the 50-590 foot levels of the Sand Creek facies of the Willwood Formation.

Paramys sp. nov., near *P. francesi* Wood, 1962

REFERRED SPECIMEN: UW 8973

OCCURRENCE: A single specimen of this species was recovered at locality V-73020, at the 319 foot level.

Genus *Reithroparamys* Matthew, 1920
Reithroparamys, sp. nov., near *R. atwateri* (Loomis, 1907a)

REFERRED SPECIMENS: UW numbers 8333, 8977, 8983, 8992

OCCURRENCE: Four specimens of this species were recovered from localities V-73033, 73034, 73051, and 73055, between the 110 and 389 foot levels of the Willwood Formation.

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Genus *Franimys* Wood, 1962

Franimys, near *F. amherstensis* Wood, 1962

REFERRED SPECIMEN: UW 8323

OCCURRENCE: A single specimen of this species was found at locality V-73023 at the 102 foot level.

Identification of the isolated teeth of No Water Rodentia may expand this fauna and will certainly expand the recorded occurrences of taxa in the Sand Creek facies.

ORDER TILLODONTIA Marsh, 1875
Family Esthonychidae Cope, 1883
Genus *Esthonyx* Cope, 1874
Esthonyx grangeri Simpson, 1937c

PROBABLE SYNONYM: *E. latidens* Simpson, 1937c

REFERRED SPECIMENS: UW numbers 7422, 7429, 7436 (Fig. 50f), 9286 (Figs. 50d, e), 9292, 9302, 10007, 10301

DESCRIPTION: Simpson (1937c) noted that *E. grangeri* differs from *E. bisulcatus* in the overall larger teeth and in the heavier jaw construction, the presence of a relatively more molarized P_4, and the stronger development of the P^4 metacone in association with a very small hypocone. Gazin (1953, p. 28-29) added that the "... less striking development of styles and cingula of the upper cheek teeth ... " was also probably significant. UW 9286, a maxillary fragment preserving P^{3-4} and several other associated upper and lower teeth, exemplifies most of these characters and, with the comparable referred material, is therefore assigned to *E. grangeri*. All No Water specimens are somewhat smaller than most *E. grangeri* in the American Museum collection, but the teeth are considerably larger than associated samples of teeth here referred to *E. bisulcatus*.

P^3 is a triangular tooth with blunt cusps. The protocone is absent or minimally developed, and the paracone dominates the tooth. The metacone is a small but distinct cusp in the middle of the postparacrista. A large metastyle is present, equal in size to the metacone but situated lower on the postparacrista at the posteroexternal margin of the tooth. The metastyle is an anterolingually-posterobuccally oriented cusp which causes the postparacrista to become obliquely deflected posterobuccally behind the metacone. A faint buccal cingulid and precingulid are present. The buccal cingulid is strongest and somewhat raised where it meets the precingulid at the anterior extent of the preparacrista. No distinct parastyle is present.

P^4 is a very large, semimolariform tooth with a prominent metacone that is equal in height to the protocone, somewhat smaller than the paracone, and well separated from the latter cusp in contrast to most *E. bisulcatus*. The parastylar area is greatly enlarged, more so than the metastylar area, and is separated from the preparacrista by a deep valley. Small para- and metastyles are present,

but these are not distinct cusps. Rather, they are raised areas on the prepara- and postmetacristae and the buccal cingulum. A small precingulum is situated immediately beneath the anterior face of the protocone, and a strong shelflike talon exists beneath, and posterior to most of the postprotocrista.

M^1 is longer anteroposteriorly but narrower transversely than M^2. In both upper molars, the parastylar shelves are more extended buccally than the metastylar shelves. These stylar shelves are relatively less broad than in *E. bisulcatus*, but otherwise the upper molars of both species are similarly constructed.

P_4 is a stout, rectangular, semimolariform tooth. Except for its larger size in *E. grangeri*, it strongly resembles P_4 in *E. bisulcatus*. Simpson (1937c) and Gazin (1953) noted that the molarization of P_4 in *E. grangeri* is well advanced and suggested that it is more so than in penecontemporary species of *Esthonyx*. The cusps on the cheek teeth in *E. grangeri* (and *E. "latidens"*) do appear stouter and more bunodont and perhaps reflect less relative hypsodonty than the relatively narrower, more gracile teeth of *E. bisulcatus*. A distinct entoconid and a relatively higher, more pronounced entocristid are present on most P_4 in *E. grangeri* and are lacking or are less well developed in even unworn teeth of *E. bisulcatus*. Gazin (1953, p. 29) suggested that *E. grangeri* lower molars lack a metastylid but, this cusp appears to me to be equally formed in the type of *E. grangeri*, the referred and comparable No Water specimens of this species, and all specimens of *E. bisulcatus* examined by me. In *E. grangeri*, the M_1 paraconid on unworn teeth appears to be farther removed anteriorly from the metaconid than in *E. bisulcatus*.

DISCUSSION: The M^1 in the No Water sample referred to *E. grangeri* compares closely in size and in the W/L proportion (1.25) to that recorded by Simpson (1937c) for *E. latidens* (1.22). Simpson noted a greater width to length proportion for *E. grangeri* (1.45), but neither he (1937c) nor Gazin (1953) figured or described M^1 for this species. Simpson (1937c, p. 11) mistakenly observed that M_1 was unknown in *E. grangeri* (that tooth was figured by him, 1937c, p. 8); at the time of his writing, it was M^1 that was unknown. Consequently, the estimated W/L ratio described by that author for M^1 in *E. grangeri* was based on alveoli. Curiously, Van Valen (1963) remarked that M^1 in "Clark Fork *Esthonyx*" is "considerably less transverse than M^2." I know of no specimens certainly referable to *E. latidens* that preserve M^2. The specific characters of *E. latidens*, then, consist only of its intermediate size between *E. grangeri* and *E. bisulcatus* and in the low W/L ratio for M^1, a tooth not earlier represented by a complete crown in *E. grangeri*. I believe these distinctions are insufficient to support specific distinction, and I believe *E. latidens* to be a junior synonym of *E. grangeri*. The small tooth size in the No Water sample of *E. grangeri* bridges that earlier observed for *E. "latidens"* and the lower limits of the range for *E. grangeri* and may well reflect stratigraphic differences.

OCCURRENCE: *Esthonyx grangeri* was recovered at eight localities in the report area. These sites span the 28 through 319 foot levels, inclusive. Elsewhere, *E. grangeri* is known only from the lower levels of the Willwood Formation and possibly also the upper part of the Polecat Bench Formation in the Clark's Fork Basin.

Esthonyx bisulcatus Cope, 1874

PROBABLE SYNONYM: *E. spatularius* Cope, 1880

REFERRED SPECIMENS: UW numbers 7423-7428, 7430-7435, 7437-7442, 7443 (Fig. 51b), 7444-7447, 7448 (Figs. 51a, c), 7449, 7450, 9285, 9287, 9288-9291, 9293-9296, 9298-9301, 9303-9306, 10458-10461

DESCRIPTION: A superb mandible of *E. bisulcatus* (UW 7448; Figs. 51 a,c), preserving all of the lower dentition excepting right I_{2-3}, P_2, and left I_3, /C, and P_2, forms the basis for the description of the lower teeth of this species. The upper dentition is represented only by isolated teeth and a few maxillary fragments preserving M^{1-2} or M^{2-3}. Unfortunately, in no instance for this species were upper and lower dentitions found in positive association.

The lower jaw is shallower and is considerably narrower than in *E. grangeri* or *E. acutidens*. The jaw is deepest at a point beneath the anterior root of M_3 (20.1 mm, labial side) and becomes increasingly shallow anteriorly (10.0 mm beneath the canine, labial side). The jaw possesses a double anterior mandibular foramen. The anterior moiety is largest beneath the anterior root of P_3 and is preceded by a shallow, anteriorly extended sulcus. The posterior opening is situated at the same level beneath the anterior root of P_4. Both openings occur at the midline of the jaw, about equidistant from the alveolar margins of the cheek teeth and the inferior border of the mandible. The symphysis is fused and robust and extends back beneath the posterior margin of P_3, only slightly farther than in *Megalesthonyx* but about as in other *E. bisulcatus* (e.g., Gazin, 1953, Fig. 2b; Rose, 1972).

I_1 is considerably smaller than I_2 and appears to have been slightly larger than I_3 (represented only by alveoli). I_1 and I_2 are gently curved, convex anteriorly, and only slightly procumbent, seemingly less so than in AMNH 4275 (Gazin, 1953, Fig. 2a). Both I_{1-2} are posteriorly flattened and somewhat spatulate. The canine is a tall, semi-erect tooth, about equally as robust as I_2, but with a shorter crown. The tooth is excavated on the lingual side and has antero- and posterolingual furrows extending ventrally down the crown. I_1 - /C appear to have been closely set together in the ramus.

Small diastemata separate the canine from P_2 and the latter tooth from P_3. P_2 is preserved only by rooted alveoli, but the tooth was clearly two rooted and with the roots oriented posterolingually-anterobuccally, as in other known species of *Esthonyx*.

P_3 - M_3 conform well in morphology with those of other specimens referred to *E. bisulcatus*. P_3 lacks a paraconid, metaconid, and entoconid, but possesses a strong hypoconid. P_4, unlike the molars, lacks a metastylid and has a less well developed entoconid and entocristid than in *E. grangeri*. Most of the lower cheek teeth fall in the lower end of the observed range of measurements for San José and "Gray Bull" *E. bisulcatus* given by Gazin (1953, p. 19-20), and no specimens reach the distinctly large upper end of the range noted by that author for "Gray Bull" *E. bisulcatus*.

P^3 (UW 9288) and P^4 (e.g., UW 7446) do not possess a metacone, in contrast to these teeth in *E. grangeri*. Certain upper molars (e.g., UW 7433a) have a greatly inflated metastylar area in contrast to more typical specimens (e.g., UW 7443, Fig. 51b). In this respect, some of the upper molars are reminiscent of those in *E. acutidens* (e.g., AMNH 4808; Gazin, 1953, Fig. 7).

DISCUSSION: This small species of *Esthonyx* might well be referred to *E. spatularius* of Cope (1880) rather than to *E. bisulcatus* because of the relatively small size of the cheek teeth. However, Simpson (1937c) and Gazin (1953) have both noted that the observed size ranges of teeth accorded to these species overlap. The cheek teeth in No Water *Esthonyx*, excluding specimens of *E. grangeri*, vary in size from smaller than those of the type (AMNH 4809) and referred (AMNH 16065) lower dentitions of *E. spatularius* to well within the lower limits of the observed range for teeth of *E. bisulcatus* (see Gazin, 1953; Delson, 1971). Because no other characters appear to consistently distinguish these named species, I regard *E. spatularius* to be a junior synonym of *E. bisulcatus*.

OCCURRENCE: *E. bisulcatus* was recovered at localities between the 60 and 590 foot levels, inclusive. Elsewhere,

Table 17. Measurements (mm) of teeth of *Esthonyx grangeri* (291 feet of section)

	P_3L	P_3W	P_4L	P_4W	M_1L	M_1W	P^3L	P^3W	P^4L	P^4W	M^1L	M^1W	M^2L	M^2W
UW 7436											9.95	12.43	8.77	13.00
UW 9286			9.86	7.18	9.85	8.00	8.55	8.57	9.86	12.48				
UW 9292	6.92	5.45	8.78	7.00										
UW 9302			9.16	7.00										
UW 10301					11.30	8.60								

Table 18. Measurements (mm) of lower teeth of *Esthonyx bisulcatus* (530 feet of section)

	P_3L	P_3W	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W
UW 7426					7.14	5.28				
UW 7430	5.26	3.40			7.35	6.17	7.67	6.16		
UW 7433					7.55	5.44				
UW 7438			6.78	4.43	6.75	5.00				
			6.86	4.83						
UW 7439									9.83	4.68
UW 7441									9.00	4.76
UW 7442			6.94	5.40	6.86	5.78	7.00	6.07	8.61	4.35
UW 7444					x	5.00	6.40	5.81		
UW 7447			6.23	4.16						
UW 7448	5.60	3.42	6.73	4.65	7.05	5.80	7.42	6.00	8.88	4.71
	5.62	3.68	6.75	4.53	7.00	5.67	7.50	6.00	8.75	x
UW 7449			6.74	4.68	7.25	6.00	8.00	6.00		
UW 7450	5.18	3.77	6.88	4.51					x	4.37
UW 9291							7.35	5.84		
							7.60	5.24		
UW 9295									9.20	4.81
UW 9296					6.80	5.36				
UW 9303									10.00	4.95
UW 9305			6.78	4.44						

the species has been reported from the Four Mile, Powder River Basin "Wasatch," Wind River Basin "Lysite," Indian Meadows Formation (Denison, 1937), "Red Desert" (Gazin, 1962), "west of Elk Mountain" (Gazin, 1962), Tipton Butte (Gazin, 1965), Little Bitter Creek (McGrew and Roehler, 1960), Laramie Basin, and possibly the Dad early Eocene faunas. The type of *E. bisulcatus* is from the San José Formation of New Mexico.

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ORDER CREODONTA Cope, 1875

Family Oxyaenidae Cope, 1877

Subfamily Oxyaeninae Trouessant, 1885

Genus *Oxyaena* Cope, 1874

Oxyaena sp., near *O. transiens* Matthew, 1915a

</div>

REFERRED SPECIMENS: UW numbers 9757, 9759 (fig. 51d), 9778, 9782, 9790 (Fig. 51e), 9791, 9819, 9822, 9824, 9868, 9878, 9890, 9897-9900, 9908, 9922, 9923, 9932, 9936, 9937, 9956, 9961, 9964

DISCUSSION: *Oxyaena* is well represented in the No Water collection; however, earlier treatments of this genus (*e.g.*, Matthew, 1915a; Denison, 1938) do not readily lend themselves to specific identification of other than relatively complete dental remains. An excellent review by Van Valen (1966) is more useful, but does not discuss in detail either *O. transiens* or *O. gulo*, the forms most likely represented by the material at hand. It seems unlikely that the observed ranges of measurements of the lower molars given by Matthew (1915a) and Denison (1938) are meaningful for specific distinction alone, especially when there is little reliable stratigraphic control for any of the type specimens of Willwood oxyaenids. The specific diagnostic characters given by Matthew (1915a) on the whole do reflect observable differences in the type materials of *O. transiens* and *O. gulo* and are therefore more useful than the brief treatments accorded these taxa by Denison.

The No Water *Oxyaena* sample is quite heterogeneous in size, and, as with some of the condylarths and as inferred from the descriptions of Matthew (1915a), this size variability appears to be readily correlatable with the occurrence of the specimens in the measured stratigraphic sections. The largest teeth are found high in the section. Specimens of *Oxyaena* sp. from UW locality V-73051 (288 foot level; *e.g.*, UW 9790, 9791) are larger than those from locality V-73034 (110 foot level; *e.g.*, UW 9782), and specimens that are intermediate in size are normally found at intermediate points in the section.

From my comparisons of Bighorn Basin oxyaenids in the American Museum collection, I have concluded that the lengthening of the M_1 trigonids with respect to their breadth does appear to be a progressive character (noted by Matthew, 1915a, and used by Denison, 1938) that is probably of some utility in the study of the progressive evolution of the genus, if any faith may be placed in the original locality data. Specimens of *Oxyaena* sp. from the lower part of the No Water section generally have smaller teeth and have trigonids that are about as long as wide. UW 9793, a specimen of *Oxyaena* Cf. *intermedia*, was recovered from about the 900 foot level just outside the area of this report. In that specimen, the teeth are fully 25-30 percent larger than in *Oxyaena* sp. or *O. transiens* from the 590 foot level, and possess molars with trigonids 25 percent longer than wide.

Specimens of *Oxyaena* sp., near *O. transiens* vary in

Table 19. Measurements (mm) of upper teeth of *Esthonyx bisulcatus* (530 feet of section)

	P^3L	P^3W	P^4L	P^4W	M^1L	M^1W	M^2L	M^2W	M^3L	M^3W
UW 7433a							7.53	10.68	6.22	10.20
UW 7440					7.26	10.20	7.63	11.33		
UW 7443							7.14	11.00		
UW 7445							7.65	11.85		
UW 7446			5.87	7.78						
UW 9287					6.81	9.20	7.39	11.47		
							7.12	10.90		
UW 9288	6.67	6.27								
UW 9293							8.15	12.15	6.62	11.30

size from that of *Dipsalidictides* to that of small *O. gulo*. This size is generally smaller than that of *O. gulo*, however, and is essentially intermediate between that of *O. aequidens* ($M_{1-2}L$ = 26.6 mm) and that of *O. transiens* ($M_{1-2}L$ = 22.5 mm), as given by Denison (1938). These specimens differ from *Dipsalidictides*, *O. aequidens*, and *O. transiens* in having M_1 trigonids that are slightly longer than wide, as in *O. lupina*. M_1 is distinctly smaller than M_2, as in *O. transiens*, *O. lupina*, *O. forcipata*, and *O. gulo*, and unlike *Dipsalidictides* and *O. aequidens*. P^3 (one specimen) has a protocone as in most *Oxyaena* and *contra Dipsalidictides* and the type of *O. transiens*. The M_2 trigonid is variable and may be longer than wide, equally long and wide or, slightly wider than long and with a large heel as in *O. transiens*. The anterobasal cusp on P_4 is small as in *O. transiens* and *O. gulo*. The No Water species clearly has smaller teeth than most *O. gulo* and in *O. intermedia*, *O. forcipata*, *O. lupina*, *O. ultima*, and *O. pardalis*.

In most of these characters, the specimens at hand appear to be intermediate in development between the types of *O. transiens* and *O. gulo*. Van Valen (1966, p. 79) considered *O. gulo* to be a probable subspecies of *O. transiens*.

OCCURRENCE: *Oxyaena* sp. is known from localities between the 89 and 590 foot levels, inclusive. *O. transiens* and *O. gulo*, species that most closely approximate the No Water form, are known only from the lower levels of the Willwood Formation, but may also occur in the Four Mile fauna of northwestern Colorado (see McKenna, 1960, p. 94).

Genus *Dipsalidictides* Denison, 1938

Dipsalidictides amplus (Jepsen, 1930b)

REFERRED SPECIMEN: UW 9771 (Fig. 52a)

DISCUSSION: Denison (1938 p. 167) transferred Jepsen's (1930b) *Dipsalidictis amplus* to a new genus, *Dipsalidictides*, following the synonymy of the type of *Dipsalidictis*

Table 20. Measurements (mm) of lower teeth of *Oxyaena* sp., near *O. transiens* (501 feet of section)

	P_3L	P_3W	P_4L	P_4W	M_1L	M_1TrL	M_1TrW	M_2L	M_2TrL	M_2TrW
UW 9757								15.40	10.20	9.70
UW 9759	7.90	4.30	10.50	5.70	10.40	6.00	6.00			
UW 9778								12.90	6.80	7.40
UW 9782	7.40	3.90	11.20	5.70	9.80	6.40	5.90	11.90	x	x
UW 9790					10.90	7.40	6.70	14.00	8.70	8.30
UW 9791					12.50	7.90	7.00			
UW 9819								x	7.40	8.30
UW 9822								x	9.70	9.70
UW 9824			11.60	5.80						
UW 9868								x	9.20	9.00
UW 9878					x	7.70	7.10			
UW 9897			10.30	5.60	10.00	6.20	6.10			
UW 9899								x	7.80	8.40
UW 9922	7.60	4.30								
UW 9923			11.30	5.20						
UW 9932								x	x	7.30
UW 9956								x	7.60	7.70
UW 9961								x	8.10	7.50

with *Oxyaena*. Denison believed that *Dipsalidictides* was distinguishable from *Oxyaena* principally on differences of the upper cheek teeth. UW 9771, a fragmentary right ramus with P_{3-4}, M_2, differs from species of *Oxyaena* and resembles *Dipsalidictides* in the possession of a relatively slender P_{3-4} with more trenchant protoconids, in the presence of a prominent anterobasal cingular fold on P_4, and in the development of a less robust mandibular symphysis. As noted by Van Valen (1966), P_4 closely resembles that tooth in *Prototomus mordax*. The trigonid of M_2 in UW 9771 is only slightly wider than long.

Measurements (mm): P_3L = 7.4, P_3W = 3.8, P_4L = 10.4, P_4W = 5.0, M_2L = 12.5, M_2LTr = 6.8, M_2WTr = 6.9.

OCCURRENCE: This solitary specimen of *D. amplus* was recovered at locality V-73034, at the 110 foot level of the Willwood Formation. The only other known specimen, the type, was collected from "lower Gray Bull" (Sand Coulee) beds in the Clark's Fork Basin.

Subfamily Palaeonictinae Denison, 1938
Genus *Palaeonictis* Blainville, 1842
Palaeonictis Cf. *occidentalis* Osborn, 1892

REFERRED SPECIMENS: UW numbers 9783, 9850

DISCUSSION: Two fragmentary teeth, a right P^4 and a left P_4, are tentatively referred to this taxon. The teeth are much larger than faunally associated specimens of *Oxyaena* and compare favorably with the type of *P. occidentalis* Osborn (1892) in comparable features. P^4 differs from that tooth in *Oxyaena* by the relatively taller cusps, the conspicuous notch separating the metacone from the paracone, the nonanteroposterior orientation of the metacone, and the anterior inclination of the tall parastylar cusp.

P_4 differs from that tooth in *Oxyaena* by the relatively taller and more slender protoconid, the relatively great width of the anterobasal part of the tooth, and the development of a broad posterointernal shelf.

Measurements (mm): P^4L = 16.30, P_4L = 12.90 (est.), P_4W = 9.20 (est.)

OCCURRENCE: *P.* Cf. *occidentalis* was found at localities V-73039 and 73034, at the 74 and 110 foot levels, respectively. The species is otherwise known only from the lower Willwood Formation, elsewhere in the Bighorn Basin.

Family Hyaenodontidae Leidy, 1869
Subfamily Hyaenodontinae (Leidy, 1869)
Tribe Proviverrini (Schlosser, 1886)
Genus *Arfia* Van Valen, 1965
Arfia opisthotoma (Matthew, 1901)

REFERRED SPECIMENS: UW numbers 9762, 9767, 9781, 9803, 9807, 9810, 9820, 9821, 9823, 9844, 9854, 9856, 9862, 9869, 9875, 9876, 9882, 9883, 9891, 9894, 9906, 9907, 9909-9911, 9915 (Fig. 52b), 9929, 9930, 9947, 9950, 9958, 9967

DISCUSSION: Van Valen (1965) raised Matthew's (1901) *Sinopa opisthotoma* and his (1915a) *Sinopa shoshoniensis* to generic rank with the designation of *Arfia*. These species differ from other proviverrines in the combination of vertically rugose enamel on the premolars, the relatively reduced metaconid on M_3, the enlarged M_3 trigonid (relative to M_{1-2}), and the absence of a metacone and presence of a short metastylar area on P^4. From my comparisons of hyaenodontines pursuant to this study, I agree with Van Valen in the recognition of *Arfia* as a distinct genus and one of the most common hyaenodontines in the lower Willwood Formation.

The No Water sample of *Arfia* possesses all the distinguishing characters of the genus insofar as these may be compared with preserved teeth. However, the largest M_{1-3} in the No Water collection, when combined as a composite dentition ($M_{1-3}L$ = 27 mm), are about equisize with *A. opisthotoma* (M_{1-3} L = 31 mm) or *A. shoshoniensis* (M_{1-3} L = 28 mm). The measurements conform reasonably well with those taken from a sample from the "Wasatch" Formation of the Powder River Basin referred by Delson (1971) to *A. shoshoniensis*. Moreover, P_{3-4} in the No Water sample typically possess distinct anterobasal cusps, though these are less cuspidate than in *Tritemnodon*. Matthew (1915a) noted that neither *A. opisthotoma* nor *A. shoshoniensis* possesses these cusps, even though they are faintly developed in the type of the latter species (Matthew, 1915a, Fig. 65) and in referred dentitions of *A. opisthotoma* in the American Museum collection. M_{1-3} increase in length posteriorly, and the trigonids increase in size (wider, longer, and taller) with respect to the talonids from the first to the last lower molar.

I can find no consistent differences distinguishing dentitions of *A. shoshoniensis* and *A. opisthotoma*, except perhaps the more transversely oriented paracristid on M_3 of

Table 21. Measurements (mm) of upper teeth of *Oxyaena* sp., near *O. transiens* (501 feet of section)

	P^3L	P^3W	P^4L	P^4W	M^1L	M^1W	M^2L	M^2W
UW 9890	10.80	8.40						
UW 9900			13.10	10.80	x	12.70		
UW 9923			13.00	x	12.80	x		
UW 9964							x	14.80

Table 22. Measurements (mm) of lower teeth of *Arfia opisthotoma* (582 feet of section)

	P_2L	P_2W	P_3L	P_3W	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W
UW 9762					9.10	3.70			8.90	4.60	9.90	x
UW 9767									9.20	4.60		
UW 9781							7.90	4.50				
UW 9803							7.00	3.90				
UW 9807							6.80	3.50				
UW 9810							7.90	4.60				
UW 9820							7.00	3.80	7.90	4.60		
UW 9821											9.35	5.50
UW 9823							7.10	3.80				
UW 9844									8.50	4.50		
UW 9854			7.20	3.20								
UW 9862			7.50	3.45	8.70	3.80						
UW 9869							7.80	4.40				
UW 9882									9.00	4.60		
UW 9883									8.65	4.90		
UW 9891									8.45	4.60		
UW 9906	6.20	x	6.70	3.30	7.60	3.80	6.60	3.60				
					7.85	3.80						
UW 9907					8.60	3.85						
UW 9910							6.00	3.40				
							6.20	3.20				
UW 9911											8.90	5.10
UW 9929									8.00	4.20		
UW 9930											8.60	4.90
UW 9947									8.15	4.70		
UW 9958							6.90	3.70				
UW 9967									8.50	4.60		

the type of *A. shoshoniensis* (mentioned by Matthew, 1915a, p. 74). Van Valen (1965) also questioned the validity of *A. shoshoniensis*, and the range of morphologic variation in the No Water sample appears to include both species, suggesting that they are probably synonymous.

OCCURRENCE: *A. opisthotoma* was recovered at nineteen sites between the 8 and 590 foot levels, inclusive (localities V-73095 and 73124, respectively). This species has also been reported from the "Wasatch" Formation of the Powder River Basin (in the form of *A. shoshoniensis*). The type material of both named species was discovered in the Willwood Formation of the Bighorn Basin.

Genus *Prototomus* Cope, 1874

Prototomus sp.

REFERRED SPECIMENS: UW numbers 9779, 9814, 9864, 9880, 9895, 9931, 9941

DISCUSSION: Seven specimens in the No Water collection are referable to this genus, but the material is so fragmentary that a specific designation cannot confidently be given. This genus was reviewed by Van Valen (1965, 1966), who recognized four species, *P. multicuspis*, *P. vulpecula*, *P. mordax*, and possibly *P. secundaria*, from early Wasatchian rocks of the Bighorn Basin. *Prototomus* sp. is considerably

smaller than the type and referred specimens of *P. multicuspis* and *P. vulpecula* and does not possess the curiously reduced M_3 of *P. mordax*. The heels of M_{1-3} are narrowly basined and are narrower than the trigonids as in *Tritemnodon*. The trigonids are relatively very tall with respect to the talonids, more so than in typical *P. multicuspis* or *P. vulpecula*. The molar metaconids are large and relatively unreduced in comparison with the paraconids, and the molars appear to increase in size posteriorly through M_{1-3}, although the material is too fragmentary to positively ascertain this character. The molar talonids are elongate posteriorly, with a well developed hypoconulid and hypoconid, but often with an ill defined entoconid. A small cusp (?entoconulid) is occasionally present on the entocristid, just anterior to the entoconid. The premolars and any positively referable upper teeth are, unfortunately, unknown.

Table 23. Measurements (mm) of upper teeth of *Arfia opisthotoma* (24 feet of section)

	P^4L	P^4W	M^1L	M^1W
UW 9894	7.90	7.30	7.10	9.40
UW 9915	7.90	7.25	7.25	9.30
			6.80	9.10

Prototomus sp. most closely resembles figures and descriptions of *P. secundaria* (see Matthew, 1915a, p. 82; McKenna, 1960, p. 91; Van Valen, 1966); however, I was unable to compare this sample with specimens of that species.

Measurements (mm): depth of jaw beneath M_2, labial side = 11.30; M_1L = 6.30, M_1W = 3.90, M_2L = 6.60-6.70 (N=2), M_2W = 3.90 (N=1), M_3L = 7.00-7.50 (N=3), M_3W = 3.65-3.90 (N=3).

OCCURRENCE: *Prototomus* sp. was recovered at six localities between the 110 and 319 foot levels of the Willwood Formation. The sample most closely resembles *P. secundaria*, a species tentatively reported from the Four Mile fauna, the type which is from the San José Formation of New Mexico. A closely related species was believed by Matthew (1915a) to occur in the "Upper Gray Bull Beds" of the Bighorn Basin.

Genus *Tritemnodon* Matthew, 1906
Tritemnodon sp.

REFERRED SPECIMENS: UW numbers 9777, 9785, 9796, 9798, 9805, 9809, 9818, 9835, 9846 (Fig. 52d), 9865 (Fig. 52c), 9881, 9905, 9933

DISCUSSION: Teeth of *Tritemnodon* sp. in the No Water collection are considerably smaller than those in *T. strenua* or *T. bians* and are somewhat smaller than in *T. whitiae*. Because this small size may reflect stratigraphic differences and because I can find no consistent morphological distinctions between teeth in the sample at hand and those in the type of *T. strenua*, I refrain from naming a new species.

P_3 is a long, low, very narrow tooth with a long diastema anterior to it and a very short diastema separating it from P_4. The width of P_3 is about one-third the length, or less. The protoconids of P_{3-4} are acute, and lean posteriorly. P_4 possesses a distinct anterobasal cusp and a trenchant heel that slopes anterolingually. The hypoconid is the only distinct cusp on the P_4 talonid, and this basin is wholly open on the lingual side. M_1 is considerably smaller than

M_2, and M_3 is generally smaller than M_2, but may be nearly as large. The trigonid of M_2 is much larger than that of M_1. The paraconid is generally larger than the metaconid on M_2, but may be equal in size with the metaconid or even slightly smaller on M_1.

A small metacone is present on P^4. The paracone and metacone are connate on M^{1-3}, about as in *Prototomus*, not separated as in *Proviverra*, and the paracone is larger than the metacone. The metacone is considerably reduced on M^3, more so than in *Proviverra*. These characters are consistent with those given for *Tritemnodon* by Matthew (1906, 1915a) and Van Valen (1965), and adequately serve to distinguish this form from both *Proviverra* and *Prototomus*.

OCCURRENCE: *Tritemnodon* sp. was found at localities between the 89 and 590 foot levels, inclusive. Specimens this small do not occur in other early Wasatchian faunules, but the species is morphologically closest to *T. strenua*, a form that has also been reported from other localities in the Willwood Formation of the Bighorn Basin, at sites "West of Elk Mountain," and at La Barge (Gazin, 1952, 1962), and from the Lysite and Lost Cabin members of the Wind River Formation. The type specimen of *T. strenua* was recovered from the San José Formation of New Mexico.

Cf. *Tritemnodon* sp.

REFERRED SPECIMENS: UW numbers 9830, 9884, 9903, 9921, 9945

DISCUSSION: These five fragmentary specimens suggest the presence of a very small species of *Tritemnodon* in the No Water collection. Preserved teeth indicate a size range about 10-16 percent smaller than in *Tritemnodon* sp. (above), a sample that possessed considerably smaller teeth than in described species. The P_4 morphology is consistent with that observed for *T.* sp. and *T. strenua*, and M_2 is considerably larger than M_1 and has a much larger trigonid. The metaconid is slightly larger than the paraconid on M_2, apparently a primitive trait for the genus (Van Valen, 1965, p. 642). A single upper molar (UW 9921) is hesi-

Table 24. Measurements (mm) of teeth of *Tritemnodon* sp. (501 feet of section)

	P_3L	P_3W	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W	P^4L	P^4W	M^1L	M^1W	M^2L	M^2W	M^3L	M^3W
UW 9785									6.00	3.00								
UW 9796									6.20	3.20								
UW 9798											5.80	5.35	6.05	7.50				
UW 9818									5.90	4.60	5.60	5.30	6.40	7.50			4.40	7.35
UW 9846	5.00	1.40	5.80	2.00	5.20	2.40												
UW 9865									6.40	4.50	6.60	5.95	6.90	8.00			4.80	7.90
											6.40	5.70	6.80	8.00				
UW 9881					5.00	2.50	6.30	3.80										
UW 9905	5.70	1.80	5.80	x	x	2.70	7.00	4.00										
					x	2.80												
UW 9933													6.40	x	6.60	x		

tantly included in this sample. This tooth conforms morphologically with that in *T.* sp. and *T. strenua*, but is likewise much smaller. M_3 is not preserved, but rooted alveoli for this tooth indicate that it was about the size of M_2 or slightly smaller, but not so small as in species of *Prolimnocyon.*

Measurements (mm): depth of jaw beneath M_2, labial side = 6.00; P_4L = 4.85, P_4W = 1.40, M_1L = 4.00-4.60 (N=3), M_1W = 2.10-2.40 (N=3), M_2L = 4.35-4.53 (N=2), M_2W = 2.87-2.93 (N=2), M^1L = 4.50, M^1W = 4.20.

OCCURRENCE: Cf. *Tritemnodon* sp. was recovered at five localities, spanning the 110-590 foot interval, and is unknown from elsewhere.

Subfamily Limnocyoninae Wortman, 1902

Tribe Limnocyonini (Wortman, 1902)

Genus *Prolimnocyon* Matthew, 1915a

Prolimnocyon atavus Matthew, 1915a

REFERRED SPECIMENS: UW numbers 9815, 9816, 9833, 9839, 9917, 9938, 9939

DISCUSSION: *Prolimnocyon* was believed to be a synonym of *Prototomus* by McKenna (1960). Van Valen (1966) did not accept this synonymy, and both that author and I regard the latter genus to be a hyaenodontine. The affinities of the genus were reviewed by Van Valen (1966), and other treatments of the morphology of *Prolimnocyon* have been given by Denison (1938), McKenna (1960), Guthrie (1967b), and Delson (1971).

Teeth of *P. atavus* from the No Water Creek area are much smaller than in the type specimen and specimens from the Four Mile fauna (see measurements in Van Valen, 1966, p. 71, and Delson, 1971, p. 334), and closely approximate those in a referred sample from the Powder River Basin (Delson, 1971). No Water *P. atavus* resembles the type material in possessing a two-rooted M_3 and a distinct metaconid on M_3, and differs from *Proviverra mordax* in the greater reduction of M_3 relative to M_2. P_4 in UW 9815 has a stronger anterobasal cusp than in the type specimen of this species.

Measurements (mm): depth of jaw beneath M_2, labial side = 10.00; P_4L = 4.55, P_4W = 2.40, M_1L = 4.30-4.90 (N=2), M_1W = 2.40-2.80 (N=2), M_2L = 5.40-5.85 (N=3), M_2W = 3.00-3.35 (N=3), M_3L = 2.85-3.00 (N=3), M_3W = 1.50-1.55 (N=3).

OCCURRENCE: *P. atavus* was recovered from six localities within the 110-590 foot interval. Elsewhere, this species has been reported from the "Wasatch" Formation of the Powder River Basin and may occur in the so-called "Wind River" Formation of the Laramie Basin (Eaton and Bown, unpublished collection). Denison (1938) noted the occurrence of this species in the San José Formation of New Mexico.

ORDER MESONYCHIA Van Valen, 1969

Van Valen (1969) proposed Mesonychia and Arctocyonia as new names for mesonychid and arctocyonid mammals, respectively, and elevated these names to subordinal ranks to replace his (1966) suborders Mesonychoidea and Arctocyonoidea. He refrained, however, from raising these taxa to ordinal rank, a treatment advocated recently by McKenna (1975a). I believe the peculiar dental specializations achieved by the mesonychids and, less certainly, the arctocyonids warrant their ordinal separation from the Condylarthra (see, *e.g.*, Van Valen, 1966) and from the Creodonta (see, *e.g.*, Simpson, 1945), and recognize Van Valen's names as ordinal categories, following McKenna (1975a).

Family Mesonychidae Cope, 1875

Genus *Pachyaena* Cope, 1874

Pachyaena Cf. *gracilis* Matthew, 1915a

REFERRED SPECIMENS: UW numbers 9761, 9794, 9841, 9847, 9858, 9863, 9871, 9872

DISCUSSION: A small species of *Pachyaena*, indistinguishable from *P. gracilis* but represented only by isolated teeth and tooth fragments, occurs at seven localities in the Sand Creek-No Water area. In size, these teeth fall in the *Dissacus-P. gracilis* range but differ from *Dissacus* in the presence of relatively large P_4 paraconids and the absence of distinct metaconids on the lower molars. This species could be referable to *P. ossifraga* of Cope (1874), but the tooth dimensions are slightly smaller than those recorded by any author for *P. gracilis*, and that species possesses somewhat smaller teeth than any recorded for *P. ossifraga*.

Measurements (mm): P_3L = 16.90, P_3WTr = 8.30, P_3WTa = 8.10, P_4L = 18.0, P_4WTr = 8.10, P_4WTa = 7.40, P^4L = 12.30 (est), P^4W = 12.20 (est).

OCCURRENCE: *Pachyaena* Cf. *gracilis* was found at seven localities between the 76 and 319 foot levels. Elsewhere, this species is known from a locality west of Elk Mountain in the Fossil Basin (Gazin, 1962) and may occur in the New Fork fauna (Gazin, 1952). *P. ossifraga* occurs in the Bitter Creek faunules (Gazin, 1962, 1965), and either *P. gracilis* or *P. ossifraga* is a component of the Four Mile fauna.

ORDER ARCTOCYONIA Van Valen, 1969

Family Arctocyonidae Murray, 1866

Subfamily Oxyclaeninae Matthew, 1937

Genus *Thryptacodon* Matthew, 1915a

Thryptacodon Cf. *antiquus* Matthew, 1915a

REFERRED SPECIMENS: UW numbers 7389-7411, 7412 (Fig. 53b), 7413 (Fig. 53a), 7414-7420, 7421 (Fig. 53c, d), 9307-9333, 9959, 9997-9999, 10001, 10002, 10305, 10333, 10382, 10398, 10466-10468

DISCUSSION: The seventy-three specimens of *Thrypta-codon* in the No Water collection probably constitute the largest sample of the genus from early Wasatchian rocks. The specimens evidence a great deal of variability, principally in tooth size, which strongly suggests that two species may be included in the No Water sample. Matthew (1915a) did not give adequate criteria for the separation of P_4^4-M_3^3 in samples of *T. antiquus* and *T. olseni*, but did note that the latter species possesses larger teeth. When lengths are plotted against widths for M_{1-2}, there is some tendency for the sample to separate into two groups; however, this distinction was not so clear for other cheek teeth. The sample is not large enough to plot tooth size against stratigraphic occurrence and achieve meaningful results, but the plot for M_2 (Fig. 26) clearly shows that UW 7411 (locality V-73024) and UW 9307 (locality V-73034) are abnormally larger than other specimens from the same levels. UW 7390, 7400, and 9311 are slightly larger in mean size than the remainder of the M_2 specimens from lower levels (80-150 feet), but are much smaller than UW 7411 or UW 9307, from the 158 and 110 foot levels, respectively. This size discrepancy between teeth in individual specimens from the same locality appears to be greater than that expected in a single sample from one paleontologic species. Moreover, M_1 and M^2 in separate specimens from locality 67 (80 foot level) differ in size by 10-15 percent and 15-20 percent, respectively. Some morphological differences appear to exist between the largest and the smallest specimens, but these distinctions are blurred in teeth that are intermediate in size.

The larger specimens, typified by UW 7412 and 7413 (Figs. 53b, a), are closely comparable in morphology to *T. antiquus*, but the teeth are generally smaller than in either the AMNH Willwood sample or the Four Mile sample of teeth of this species. The smaller specimens, typified by UW 7421 (Figs. 53c, d), are well beneath the range in size for all previously described Willwood *Thryptacodon*, have smaller teeth than in *T. demari*, *T. australis*, and Torrejonian

T. pseudarctos (Simpson, 1928a), and closely approximate in size those of Lysite *T. loisi* (Kelley and Wood, 1954), and Tiffanian *T. belli* (Gazin, 1956). The small specimens, however, differ from *T. loisi* in having more rectangular lower molars, in the relatively good development of the hypoconulid on M_2, and in having the M_2 metaconid about equal in size with the protoconid. The lower jaw of *T.* Cf. *antiquus* is shallower (8.5-10.4 *vs.* 13.8 mm) and more slender than in *T. antiquus* and approximates the relative condition in *T. australis* (Simpson, 1935). The entoconulids vary from weak bumps on the entocristid to development about as in *T. antiquus*. The labial border of M^2 is generally not so deeply notched at the ectoflexus as in *T. australis*, *T. antiquus*, or *T. olseni*, but this character is variable and of doubtful diagnostic value. On some of the smallest specimens, M^2 is relatively longer with respect to width (more square) than in *T. antiquus*, and in this character the teeth parallel those of *T. olseni*. The larger specimens, in contrast, usually have a relatively smaller L/W ratio.

A sample about three times as large as the existing one is needed to confidently assess and interrelate the observed stratigraphic, biometric, and morphologic variation in No Water *Thryptacodon*. The genus possesses little morphologic variation that has been consistently and meaningfully correlated among existing samples in earlier studies. There appear to be more than enough named species to accommodate what variation does exist and may be correlatable. Simpson (1937c, p. 11) suggested that a small subspecies of *T. antiquus* may occur in the "Sand Coulee" and a larger subspecies in the "Gray Bull." Since the No Water sample is apparently size dichotomous and most teeth in that sample are substantially smaller than those in the AMNH Willwood collection of *Thryptacodon*, this viewpoint cannot be substantiated with the specimens at hand.

OCCURRENCE: *Thryptacodon* Cf. *antiquus* was recovered at 38 localities, spanning the 7 to 389 foot levels of the Willwood Formation. The type of *T. antiquus* was recovered from the lower Willwood Formation of the Clarks Fork Basin, and this species has also been reported from the Four Mile and La Barge-Big Piney faunas and doubtfully occurs in the New Fork tongue of the "Wasatch" Formation (Gazin, 1965) and in so-called "Lysite Beds" in the Bighorn Basin (Van Houten, 1945).

Genus *Chriacus* Cope, 1883
Cf. *Chriacus* sp.

REFERRED SPECIMEN: UW 9893

DISCUSSION: A solitary left upper molar is questionably referable to this genus and resembles *C. gallinae* more closely than it does any other taxon known to me. The tooth is relatively broader transversely than in the type of *C. gallinae* and possesses a very broad basal cingulum that is not restricted to the posterolingual border of the crown as in *C. gallinae* and *C. pelvidens*, but is continuous around the lingual margin of the tooth between the anterior and posterior midlines of the crown as in an Almagre specimen
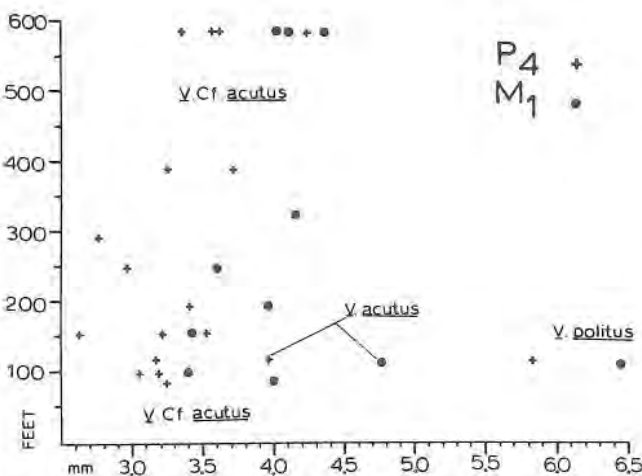

Figure 26. Stratigraphic plots of *Thryptacodon* M_2. Abscissa is tooth length in millimeters; ordinate is feet above the base of the Willwood Formation.

(AMNH 48006, figured by Delson, 1971) and about as in AMNH 56326 from the Powder River local fauna. A faint hypocone is present on the posterolingual extremity of this cingulum. The specimen may warrant specific distinction from *C. gallinae*, the only other described Wasatchian species of *Chriacus*.

Measurements (mm): upper molar, L = 4.95, W = 6.90.

OCCURRENCE: UW 9893 was recovered from locality V-73038, at the 134 foot level of the Willwood Formation.

Chriacus occurs in Torrejonian (*C. pelvidens*) and Wasatchian (*C. gallinae*) deposits of the San Juan Basin of New Mexico. McKenna (1960) also reported several fine specimens of the latter species from the Four Mile fauna of northwestern Colorado. Delson (1971) reported this genus in the "Wasatch" Formation of the Powder River Basin. If the allocation to *Chriacus* is correct, UW 9893, extends the range of this rare oxyclaenine into the Wasatchian of the Bighorn Basin.

Table 25. Measurements (mm) of lower teeth of *Thryptacodon* Cf. *antiquus* (382 feet of section)

	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W
UW 7389							6.00	3.92
UW 7390					6.13	5.00	6.08	4.00
UW 7392					6.00	4.66		
UW 7394			6.17	4.73				
UW 7396			5.89	4.05	5.81	4.39		
UW 7397					5.80	4.89		
UW 7399	5.40	3.05	5.92	4.42				
UW 7400	5.08	2.95			5.89	5.06		
UW 7404							5.42	3.38
UW 7408					5.92	4.67	5.82	3.68
UW 7409			5.88	4.18	5.57	4.42		
UW 7410					5.70	4.52	5.78	3.74
UW 7411					6.45	5.16		
UW 7413					5.75	4.91	5.65	3.85
UW 7414	5.00	2.87	6.40	5.00	5.62	4.66		
UW 7415					6.00	4.83		
UW 7416	5.00	2.87						
UW 7417					5.92	5.05	5.86	4.25
UW 7418					5.63	4.42	6.00	3.24
UW 7420					5.81	4.70	6.00	3.80
UW 7421			5.76	4.10	5.47	4.40	5.60	3.25
					5.48	4.32		
UW 9307					6.34	5.08		
UW 9308	5.24	2.88						
UW 9310					5.48	4.12		
UW 9311					5.91	4.89		
UW 9313					6.11	5.00	6.24	4.00
UW 9314							6.29	3.45
UW 9315					5.90	4.95		
UW 9316							5.61	3.70
UW 9317					5.74	4.73	6.28	3.87
UW 9318			5.61	4.12	5.60	x		
UW 9320					6.07	5.15	5.76	3.61
UW 9322					6.09	4.85		
UW 9323					5.75	5.00	6.00	3.67
UW 9328							5.72	3.28
UW 9329							5.67	3.58
UW 9330							5.74	3.58
UW 9331	5.31	3.33						
UW 9997			5.73	4.00				
UW 9998	5.00	2.82						
UW 9999			5.66	4.00				

Table 26. Measurements (mm) of upper teeth of *Thryptacodon* Cf. *antiquus* (342 feet of section)

	P^4L	P^4W	M^1L	M^1W	M^2L	M^2W	M^3L	M^3W
UW 7389	5.12	5.18						
UW 7390					5.35	6.77		
UW 7391					6.08	7.57	4.37	5.42
UW 7393					5.78	7.34	4.42	5.55
UW 7395	5.25	5.44						
UW 7400	5.07	5.49						
UW 7402			5.67	6.90				
UW 7403							4.32	5.43
UW 7404	4.38	4.55						
UW 7405			6.13	7.45	5.58	6.15		
UW 7407	x	5.26						
UW 7412			6.28	7.28	5.95	8.00	4.51	5.63
UW 7414							4.73	5.38
UW 7416	4.75	x	5.91	7.30	5.51	6.67		
UW 7419			5.24	6.44	5.25	6.73	4.00	5.48
UW 7421	4.65	5.00	5.30	5.91	5.33	6.53	3.70	5.00
	4.37	4.65	5.15	6.00				
UW 9309	5.00	5.12						
UW 9311					6.00	6.60		
UW 9317			5.74	6.00	.5.22	6.61		
UW 9317a					6.16	7.52		
UW 9320a			5.17	6.28				
UW 9321					5.57	6.92	4.43	x
UW 9325					5.61	7.00		
UW 9332					5.85	7.00	4.47	5.51
UW 9333							4.35	5.52
UW 10465					5.75	7.52		

ORDER CARNIVORA Bowdich, 1821

Suborder Fissipeda Blumenbach, 1791

Superfamily Miacoidea Simpson, 1931

Family Miacidae Cope, 1880

Subfamily Viverravinae Matthew, 1909

Genus *Didymictis* Cope, 1875

Didymictis protenus (Cope, 1874)

REFERRED SPECIMENS: (large variety), UW numbers 9772 (Fig. 53e), 9849, 9866, 9867, 9873, 9874, 9951, 10345; (small variety), UW numbers 9763, 9773, 9786 (Fig. 53f), 9787, 9806, 9834, 9840, 9857, 9888, 9912, 9968, 9971, 10344

DISCUSSION: Two populations of *Didymictis* are probably present in the No Water collections and, on a consistent basis, are separable only on tooth size. The large variety averaged 35 percent larger in P_4L, 24 percent larger in M_1L and about 15 percent larger in M_2L than the small variety. The absolute measurements recorded for specimens of *Didymictis protenus* are relatively less clinal than those recorded here for most of the other fossil mammals, and a distinct size dichotomy has emerged. In that both large and small individuals are sometimes found at the same localities, the size dichotomy is not strictly an artifact of the stratigraphic positions of localities.

Simpson (1937c) described the variability in samples of *Didymictis* teeth from "Clark Fork," "Sand Coulee," and "Gray Bull" horizons in the Bighorn Basin and concluded, as I have in this study, that the "Clark Fork" to "Lost Cabin" specimens do not form a single, continuous linear sequence. This evidence contradicts an earlier conclusion of Matthew (1915a). The smaller specimens in the No Water sample fit just within the lower limit of Simpson's observed range for M_2 in *D. protenus curtidens*, or beneath that observed range. The observed range for M_1L, however, is clearly beneath that observed by Simpson for *D. protenus*

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curtidens. The sample of large specimens conforms well with the observed range for M_2L in the latter subspecies, but falls again into the very lowest limit of the observed range for M_1L in that taxon. Because Simpson's (1937c) separation of his *Didymictis* sample into two stratigraphic collections ("Clark Fork" vs. "Sand Coulee" and "Gray Bull") could and probably did include specimens occurring through more than 1,200 feet of section, his refinement is believed by me to be too coarse and to involve too few specimens to consistently separate samples of *Didymictis* teeth on a stratigraphic and size basis. Simpson (1937c, p. 14) remarked: "As a considerable span of time is represented, it is reasonable to suppose that progressive changes did take place and that the range of variation is due in part to such changes, and not purely to contemporaneous fluctuation." I further agree with Simpson that no consistent morphologic basis exists, or at least is known, by which $P_4^4 - M_2^2$ may be separated into two or more groups for samples of *D. protenus.*

The key to species of *Didymictis* presented by Matthew (1915a) is unrealistic for use in the distinction of species in the absence of morphological differences because all of the observed ranges for tooth dimensions given by that author for M_{1-2} either overlap or appear to be arbitrarily separated. Moreover, no attempt was made to test time-transgressive size changes. A clearer picture of evolution in Bighorn Basin *Didymictis* will undoubtedly emerge once larger and stratigraphically controlled samples are available. *D. protenus,* in one of its plethora of named subspecies and mutations, is adequate to contain the No Water sample of *Didymictis.* According to the scheme of Matthew (1915a, p. 20), the No Water sample spans the observed ranges of measurements in the *D. haydenensis-D. protenus leptomylus* samples.

Measurements (mm): Large variety: depth of jaw beneath M_1 = 15.0; P_4L = 10.60, M_1L = 10.20-10.50 (N=3), M_2L = 7.75, P^4L = 9.90-10.00 (N=2), P^4W = 11.00, M^1L = 7.80-8.00 (N=3), M^1W = 10.40-11.50 (N=2), M^2L = 4.35-4.80 (N=3), M^2W = 8.20. Small variety: depth of jaw beneath M_1 = 10.3; P_4L = 7.80-8.20 (N=3), M_1L = 8.10-8.90 (N=5), M_2L = 6.20-6.90 (N=4), M^1L = 6.60, M^1W = 8.70, M^2L = 4.20, M^2W = 6.50.

OCCURRENCE: *D. protenus* was recovered from several localities between the 60 and 319 foot intervals, inclusive. This species, in one form or another (*D. protenus protenus, D. protenus leptomylus, D. protenus curtidens, D. protenus lysitensis, D. protenus proteus*), probably occurs in "Clark Fork" through "Lysite" horizons in the Bighorn Basin and has been reported as well from the Powder River Basin, Bitter Creek, "west of Elk Mountain" (Gazin, 1962), Wind River Lysite Member, Four Mile, Sand Butte (Gazin, 1965), Laramie Basin, and Dad (Gazin, 1965) faunas, and may be present also in the Golden Valley, Huerfano (Farisita-Robinson, 1966; Osborn, 1897), and "Cuchara" (Robinson, 1963) faunas.

Genus *Viverravus* Marsh, 1872

Viverravus Cf. *acutus* Matthew, 1915a

REFERRED SPECIMENS: UW numbers 9652, 9768-9770, 9795, 9797, 9801, 9811-9813, 9828, 9829, 9831, 9832 (Fig. 54a), 9836, 9843, 9853, 9861, 9870, 9885, 9889, 9902, 9916, 9924-9926, 9944, 9948, 9953, 9955, 9957, 9963, 9965, 9972, 10313, 10417

DISCUSSION: Matthew (1915a) referred the *Viverravus* sample from the Bighorn Basin to two species, *V. acutus* and *V. politus,* and these have remained the only two recognized species of *Viverravus* in early Wasatchian faunas in general. *V. acutus* includes the smallest specimens described by Matthew ($M_{1-2}L$ = ~7.5 mm); however, only a composite of the largest M_1 and M_2 of the small variety of *Viverravus* in the No Water collection equals this range, in spite of an almost certain stratigraphic overlap of the two samples. The Four Mile sample, allocated by McKenna (1960, p. 95) to *V. acutus,* closely compares in tooth dimensions with Matthew's collection. McKenna (1960, p.96) suggested that two or more unnamed subspecies of *V. acutus* are probably involved in the Bighorn Basin sample used by Matthew, that from younger beds (*e.g.,* AMNH 15181) being the largest. Because the teeth in McKenna's *V. acutus,* as well as the type material from the "Sand Coulee" bed, have larger dimensions than teeth in the No Water sample, a sample that spans 510 feet of section, it is apparent that the species of *Viverravus* are not so simply resolved.

Stratigraphic plots of P_4L and M_1L, although hampered by a paucity of specimens, suggest the presence of three *Viverravus* groups in the No Water collection (Fig. 27). *V. politus* is clearly distinct from the remainder of the specimens, and UW 9919 and 9963 appear to be abnormally large in the dimensions of P_4 and M_1 when their
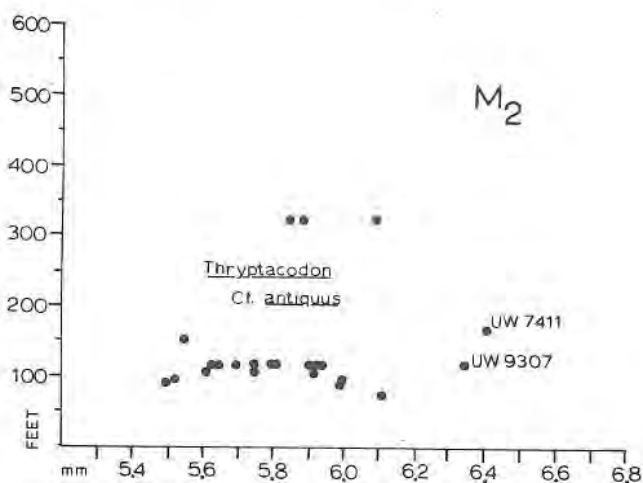

Figure 27. Stratigraphic plots of P_4 (+) and M_1 (·) in No Water specimens of *Viverravus.* Abscissa is tooth length in millimeters; ordinate is distance in feet above the base of the Willwood Formation.

stratigraphic provenance is considered. Although the sample is small enough to be affected by the vagaries of collecting in the field, it seems improbable that UW 9919 and 9963 represent the upper end of the size range for these teeth in the small variety. These two specimens lie within the size range for *V. acutus* given by McKenna (1960) for the Four Mile sample.

The small variety of *V.* Cf. *acutus* is represented by fourteen unbroken P_4 that may be placed in stratigraphic context and ten unbroken M_1. Both teeth appear to increase in size upward through the section but, admittedly, this could be an illusory affect of collecting bias. It seems possible that the small size of teeth in the main No Water *V. acutus* and *Didymictis protenus* samples may reflect ecological separation from populations that were characterized by larger tooth size, a suggestion also offered by Simpson (1937c) for faunas in the "Clark Fork"-"Gray Bull" transition in general.

OCCURRENCE: *V.* Cf. *acutus* occurs at twenty localities in the Sand Creek facies, between the 80 and 590 foot levels, inclusive. *V. acutus* has been reported from the Four Mile and Bitter Creek faunas and may occur in the Dad, Golden Valley, Table Rock, and Sand Butte faunas as well.

Viverravus politus Matthew, 1915a

REFERRED SPECIMENS: UW numbers 9776 (Fig. 54b), 9879, 9904

DISCUSSION: Teeth from these specimens conform well in morphology and size with comparable ones of *V. politus*.

Measurements (mm); depth of jaw beneath M_1 = 8.40; P_4L = 5.84, P_4W = 2.21, M_1L = 6.49, M_1W = 3.66, M_2L = 5.83-5.84 (N=2), M_2W = 3.14-3.30 (N=2).

OCCURRENCE: *V. politus* was found at three localities between the 110 and 319 foot levels of the Willwood Formation, inclusive. This species is unknown in early Wasatchian faunules outside the Bighorn Basin.

Subfamily Miacinae Trouessart, 1885
Genus *Uintacyon* Leidy, 1871
Uintacyon massetericus (Cope, 1882)

REFERRED SPECIMENS: UW numbers 9765, 9766, 9780, 9784, 9792, 9827, 9850, 9860, 9886, 9892, 9896, 9901, 9913 (Fig. 54c), 9914, 9920, 9927, 9928, 9935, 9946, 9952, 9954, 9960, 9962, 9969

Table 27. Measurements (mm) of lower teeth of *Viverravus* Cf. *acutus* (510 feet of section)

	P_3L	P_3W	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W
UW 9768			3.76	1.65				
UW 9769			3.28	1.47				
UW 9801			3.09	1.37				
			3.24	1.24				
UW 9811					4.00	x	3.00	x
UW 9812			3.47	1.55				
UW 9813							2.87	1.67
UW 9828			3.57	1.45	4.14	x		
UW 9829			3.60	1.55	4.07	x	2.84	1.55
UW 9831			3.34	1.55	4.33	2.40		
UW 9832	2.71	1.25	3.57	1.54	4.13	x		
UW 9836							2.82	1.66
UW 9843	2.30	1.00	2.79	1.23	x	1.77		
UW 9853					4.22	2.66	3.55	2.07
UW 9861			3.29	1.51	4.09	x		
UW 9870							2.68	1.68
UW 9885							2.83	1.56
UW 9916			3.18	1.36				
UW 9924	2.33	1.10	3.28	1.42				
UW 9925	2.57	1.23	3.67	1.50				
UW 9926			2.68	1.19	3.52	2.08		
UW 9948							2.70	1.63
UW 9953	2.36	1.00	3.00	1.35	3.67	2.17		
UW 9972					3.47	x		

DISCUSSION: A small specees of *Uintacyon* is represented by these specimens. The preserved lower molars have more trenchant heels than in *Miacis* or *Vulpavus*, and the lower carnassial appears to be better developed than in *Vulpavus*. A very small anterobasal cusp is present on a few P_4 specimens, but this cusp is not nearly as large as in *Miacis*, and is developed (when present at all) about as in referred lower jaws of *U. massetericus* in the AMNH collection. The molars compare most favorably with those of *U. massetericus rudis* of Matthew (1915a; *e.g.*, AMNH 4250, 16855). The M_3 is typically less reduced than in early Wasatchian *Miacis*.

The UW sample of *U. massetericus* is likewise separable into two groups on the basis of depth and general robustness of the lower jaw. The lower cheek teeth are of approximately the same size in both groups, suggesting that this trait may be sexually dimorphic. The sample with deep jaws (depth beneath M_2, labial side = 10.40-10.50, N=3) conform well with measurements obtained from specimens of *U. massetericus*, especially *U. m. rudis*, in the American Museum collection. Those specimens with shallower and narrower jaws (depth beneath M_2, labial side = 8.35-8.60) resemble *U. jugulans* (Matthew, 1909b) in this respect, but, as in *U. massetericus*, the No Water specimens retain a two-rooted M_3 with a well developed and trenchant heel.

The distinctions given by Matthew (1915a) are of little use in separating species of "Gray Bull" *Miacis* from those of *Uintacyon* in the P_4-M_3 series, and, because neither genus is known from pre "Gray Bull" faunas, it is possible that some mixing of characters is to be expected in the earliest samples of these closely related genera. UW 9901 possesses a small anterobasal cusp on P_4 as in *Miacis exiguus*

(*e.g.*, AMNH 15717, the paratype). UW 9901, however, possesses more trenchant M_{1-3} heels than in *M. exiguus*. The size and contour of the lower jaw in the gracile *U. massetericus* closely resemble those in *Miacis exiguus*.

OCCURRENCE: Specimens of *U. massetericus* were found at sixteen localities in the Sand Creek facies. These sites are located between the 60 and 590 foot levels, inclusive. The type of *U. massetericus* was recovered from the lower Willwood Formation (probably "Upper Gray Bull" of Matthew, 1915a), and *U. m. rudis* is known in "Sand Coulee" beds (Matthew, 1915a). This species has also been reported from the Wind River Lysite Member; however, those specimens appear to me to be more advanced than in typical *U. massetericus* and may be closer to *U. asodes*.

Cf. *Vassacyon* sp.

REFERRED SPECIMENS: UW numbers 9877, 10427

DISCUSSION: Two specimens, a left ramal fragment preserving M_2 and the heel of M_1 and a lower molar (?M_3), are questionably referred to *Vassacyon*. M_2 is about 50 percent larger than in the largest *U. massetericus* and ?M_3 is about 45 percent larger. The heels of M_{1-3} are relatively trenchant as in *Uintacyon* and *Vassacyon*.

Measurements (mm): depth of jaw beneath M_2 = 17.10; M_2L - 6.10, M_2WTr = 4.35, ?M_3L = 5.00, ?M_3WTr = 3.65.

OCCURRENCE: Cf. *Vassacyon* sp. was recovered at localities V-73051 and V-73082 at the 288 foot level of the Sand Creek section.

Table 28. Measurements (mm) of lower teeth of *Uintacyon massetericus* (530 feet of section)

	P_4L	P_4W	M_1L	M_1WTr	M_2L	M_2WTr	M_3L	M_3WTr
UW 9765	4.90	2.10	x	x	4.10	2.60		
UW 9780					4.20	2.70		
UW 9784	5.40	x						
UW 9792	5.25	2.35						
UW 9827					3.70	2.65	3.40	2.15
UW 9850			6.00	3.85				
UW 9860			5.90	3.85				
UW 9886					3.85	2.55		
UW 9892	5.40	2.25						
UW 9896	4.90	2.10						
UW 9901	4.90	2.20	5.80	3.95				
UW 9913	4.85	2.35	6.00	4.00	4.10	2.85		
UW 9914	5.10	x	5.90	3.80				
UW 9927	5.00	2.40	x	x	4.00	2.85		
UW 9928					3.80	2.75		
UW 9935	4.90	2.10						
UW 9946					4.40	3.10		
UW 9954					3.70	2.70		
UW 9960					3.80	2.65		
UW 9962	5.30	2.10						
UW 9969	5.30	2.20			4.40	2.90		

Genus *Oödectes* Wortman, 1901

Oödectes Cf. *herpestoides* Wortman, 1901

REFERRED SPECIMENS: UW numbers 9774, 9775

DISCUSSION: Two specimens of a very small miacine were recovered from locality V-73034. The lower molars possess acutely trenchant heels with the trigonids considerably broader than the talonids, much broader than in *Miacis* and about as in lower jaws of *Oödectes* in the American Museum Collection. The jaw is relatively deep, deepest beneath M_1 as in *O. herpestoides*. The measurements of M_{2-3} and all other morphologic characters of these teeth conform best with those exemplified by Wortman's taxon.

Measurements (mm): depth of jaw beneath M_2, labial side = 5.90-6.30 (N=2); M_2L = 3.55, M_2WTr = 1.90; M_3L = 2.40-2.50 (N=2), M_3WTr = 1.50-1.70 (N=2).

OCCURRENCE: Both specimens were recovered at locality V-73034 (110 foot level). This taxon is a very rare component of the lower Willwood fauna. Robinson (1966) reported the occurrence of *O. herpestoides* in the Huerfano Formation of southern Colorado. The type is from the lower Bridger Formation of southwestern Wyoming (Gazin, 1976).

miacine, indet.

REFERRED SPECIMENS: UW numbers 9799, 9817

DISCUSSION: Two specimens record the presence of a very large miacine in the No Water collection. UW 9817 resembles *Vassacyon* in the possession of a well developed and basined heel on M_1, but differs from that genus in the presence of a large anterobasal cusp and a relatively long bicuspidate talonid crest on P_4, as in *Miacis*, but in that animal, P_4 has a raised posterior margin. The mandibular symphysis is robust and extends posteriorly beneath the middle of P_4. The combination of these few but distinctive characters with the large tooth and jaw size is unique among miacids known to me.

Measurements (mm): depth of jaw beneath M_1, labial side = 17.50; P_4L = 8.40-9.50 (N=2), P_4W = 3.30-4.00 (N=2).

OCCURRENCE: These specimens were found at UW locality V-73027 and along the line of section at about the level of locality V-73030, at the 97 and 425 foot levels, respectively.

ORDER CONDYLARTHRA Cope, 1881

Family Phenacodontidae Cope, 1881

Genus *Phenacodus* Cope, 1873

Phenacodus primaevus Cope, 1873

REFERRED SPECIMENS: UW numbers 7453, 7454, 7458, 7460 (Fig. 54e), 7461, 7463, 7464, 7466, 7469-7474,

7475 (Fig. 54f), 7477-7481, 9272, 9273 (Fig. 54d), 9274, 9276, 9280, 9282, 9283, 10000, 10130, 10331, 10335, 10343

DISCUSSION: West (1976) has recently reviewed the phenacodontid condylarths. He and several previous authors (*e.g.,* Kelley and Wood, 1954; Robinson, 1966; Guthrie, 1967a, 1971; West, 1973a) have attempted the speciation of early Eocene *Phenacodus* principally on size differences. Guthrie (1967a) noted that the morphological characters given by Granger (1915) for use in the speciation of *P. "copei"* and *P. vortmani* were correlated with size and that complete intergradation in those characters exists. West (1976) remarked on the intergradation of size and morphologic characters for populations of large *Phenacodus* in general. Guthrie (1967a) synonymized *P. copei* with *P. vortmani* and was followed in this by West (1976), who also included *P. robustus, P. hemiconus,* and *P. intermedius* in *P. primaevus*. Although great morphologic variation exists in the sample of large *Phenacodus* from rocks of early Eocene age, this variability, as noted by the authors above, is difficult to correlate, and no satisfactory distinction of two or more paleontologic species of large *Phenacodus* in the No Water collection could be made using size and/or morphology in conjunction with stratigraphic position. Although *Phenacodus* is relatively rare in the Sand Creek facies, a large, stratigraphically documented sample of large *Phenacodus* specimens exists in the Yale Peabody Museum collection. This sample should be studied with the purpose of attempting morphological correlation by the positions of specimens in the stratigraphic column. As noted by Simpson (1937c, p. 17) for *Phenacodus primaevus primaevus, P. p. hemiconus,* and *P. intermedius:*

" . . . the segregation vaguely suggested by a single character is not positively correlated with groupings suggested by other characters and the whole series takes on the appearance of an indivisible but highly variable and very flat (in statistical terms platykurtic) distribution. It is highly unlikely that such a distribution belongs to a single species."

On page 18 he (1937c) remarked further:

"It does not follow that they are synonymous, for the fact that they cannot be fully distinguished does not prove that they are the same thing."

I follow this viewpoint and believe that *P. primaevus* (as conceived by West, 1976) actually represents at least two species or populations that simply cannot be consistently distinguished on the existing morphologic and stratigraphic evidence. Specimens assigned by earlier workers to *P. intermedius* or *P. primaevus hemiconus* are normally smaller than those assigned to *P. robustus* or *P. primaevus primaevus,* and specimens designated *P. p. hemiconus* commonly have more rugose enamel on the lower molars than in any of the other three groups.

The upper molars in the No Water sample, particularly M^1, are extremely variable in occlusal outline. UW 7475 (Fig. 54f) is much narrower transversely and hence more square than are other M^1 here assigned to *P. primaevus.*
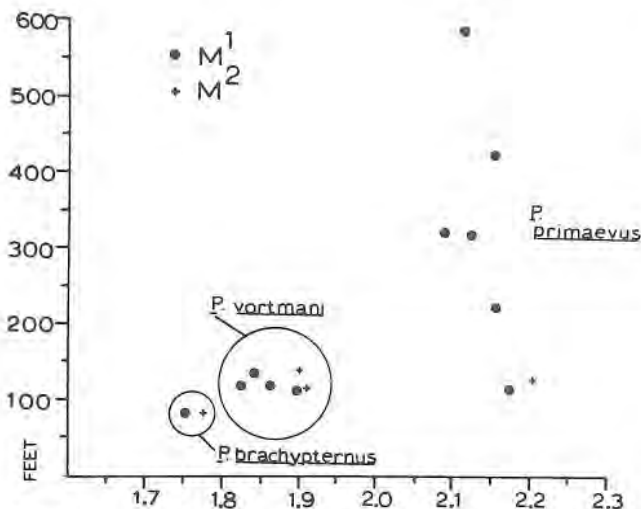
97

Figure 28. Stratigraphic plots of M^{1-2} in No Water *Phenacodus*. Abscissa is log $(L \times W)M^{1-2}$; ordinate is distance in feet above the base of the Willwood Formation.

M_2 appears to decrease in length up section (Fig. 29), a trend that is less apparent for the overall size of M^1 (Fig. 28). Admittedly, the No Water sample is statistically small. The data of West (1976, Fig. 40) suggest a general decrease in mean size of M_1 in *P. primaevus* up section from the "Gray Bull" to the "Lost Cabin"; however, the observed range of measurements of "Gray Bull" *P. primaevus* encompasses the observed ranges of all other of his *Phenacodus* samples.

OCCURRENCE: *P. primaevus* in one of its several and

possibly valid forms was found at localities between the 80 and 590 foot levels of the Willwood Formation, inclusive. The occurrence of this species (including *P. robustus*, *P. intermedius*, and *P. p. hemiconus*) has been adequately summarized by West (1976, Table 1).

Phenacodus vortmani (Cope, 1880)

REFERRED SPECIMENS: UW numbers 7451, 7459, 7462, 7467, 7468 (Fig. 55c), 9275 (Fig. 55b), 9278, 10008, 10396 (Fig. 55a)
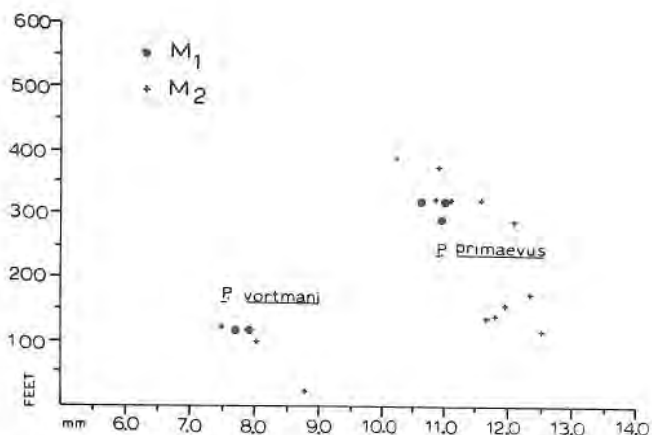

Figure 29. Stratigraphic plots of M_{1-2} in No Water specimens of *Phenadodus*. Abscissa is tooth length in millimeters; ordinate is distance in feet above the base of the Willwood Formation.

Table 29. Measurements (mm) of lower teeth of *Phenacodus primaevus* (510 feet of section)

	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W
UW 7453					11.00	10.10	11.10	9.00
UW 7454	10.90	7.50						
UW 7458	x	7.80	11.15	9.45				
UW 7464					11.70	10.00	12.30	9.20
UW 7466					11.80	9.90		
UW 7470	12.50	8.00						
UW 7471					10.30	8.90		
UW 7472	12.00	8.15						
UW 7473	11.10	7.00						
UW 7474					11.35	9.10		
UW 7475							11.10	8.20
UW 7477	x	6.90	10.75	8.10	11.00	9.50		
UW 7480	12.65	x			12.30	11.60		
UW 7481					12.90	12.10		
UW 9272					12.50	10.90		
UW 9273			11.10	8.75	12.10	10.00		
UW 9274					12.00	11.10		
UW 9276	11.70	7.00			11.70	10.00	11.90	8.80
	10.20	6.50			11.00	8.90		
UW 9282	9.60	6.20						
UW 10000							12.40	9.60

Table 30. Measurements (mm) of upper teeth of *Phenacodus primaevus* (510 feet of section)

	M^1L	M^1W	M^2L	M^2W	M^3L	M^3W
UW 7456					8.35	9.90
UW 7460			11.50	14.20	9.00	13.00
UW 7461	11.00	13.50	11.00	x		
UW 7463	11.00	13.40				
UW 7469	11.00	13.65	x	15.20		
UW 7471					8.38	10.27
UW 7475	10.60	11.80			8.90	10.90
UW 9280	10.00	13.70				
UW 9283	10.00	12.35				
UW 9284	10.00	13.40				

DISCUSSION: Delson (1971) implied that Simpson's (1935a) Tiffanian *P. matthewi* and *P. vortmani* may be shown (with more complete material) to intergrade and form a single lineage, and, hence, he did not accept McKenna's (1960) assignation of certain Four Mile *Phenacodus* specimens to *P. matthewi*. West (1976) gave no characters in his diagnoses of *P. matthewi* and *P. vortmani* that adequately serve to distinguish these closely related forms. The morphologic characters of *P. matthewi* (M_{2-3} entostylid, distinct paraconid, stout and shallow jaw) and its tooth size (intermediate between *P. vortmani* and *P. brachypternus*), as given by Simpson (1935a), do not effectively separate currently known samples that are potentially referable to one of these two species. Because *P. vortmani* (Cope, 1880) has precedence over *P. matthewi* Simpson (1935a), I assign the No Water sample to *P. vortmani*.

Guthrie (1967a) believed *P. copei* to be a synonym of *P. vortmani* and suggested that the tooth size discrepancies between these forms were stratigraphically controlled by a decrease in mean tooth size in individuals of *P. copei* up section. Judging from known material, this interpretation seems possible, even likely, but remains to be substantiated by detailed stratigraphic studies. *P. vortmani* is rare in the Sand Creek facies, and specimens in the No Water collection show little morphologic or size variation.

OCCURRENCE: Specimens of *P. vortmani* were found at eight localities in the Sand Creek facies between 14 and 128 feet above the base of the Willwood Formation, inclusive. The occurrence of this species elsewhere has been adequately documented by West (1976, Table 1), and *P. vortmani* also occurs in the Cooper Creek fauna of the Laramie Basin (my unpublished data).

Phenacodus brachypternus Cope, 1882a

REFERRED SPECIMENS: UW numbers 7465 (Fig. 55d), 9279, 10490

DISCUSSION: Three specimens were assigned to *P. brachypternus* on the basis of a very elongate P_4 in UW 9279 and the distinctively small size of all referred teeth. So far as I

am able to determine from studies of dentitions in the American Museum, Yale, and University of Wyoming collections, M^{1-3}_{1-3} are morphologically indistinguishable from those teeth in *P. vortmani*.

OCCURRENCE: *P. brachypternus* is known from only three localities in the Sand Creek facies. Two of these sites could not be correlated with the stratigraphic sections, and the other site is at the 74 foot level. West (1976, Table 1) has listed the occurrences of most other specimens of this species. A very small specimen of *P. brachypternus* occurs in the Cooper Creek fauna of the Laramie Basin (my unpublished data).

Genus *Ectocion* Cope, 1882b
Ectocion Cf. *osbornianus* Cope, 1882b

REFERRED SPECIMENS: UW numbers 7957, 9334-9403, 9413-9478, 10267 (Fig. 56a), 10268 (Fig. 56c), 10269 (Fig. 56b), 10270 (Fig. 55e), 10271-10274, 10327, 10328, 10332, 10347

DISCUSSION: Granger (1915) recognized four species of "Clark Fork"—"Lost Cabin" *Ectocion* (*E. parvus, E. ralstonensis, E. osbornianus, E. superstes*) and believed that these species formed a continuous evolutionary sequence marked primarily by a gradual increase in mean tooth size. Simpson (1937c) recognized the divisions of Granger (1915) and was able to show more convincingly the tendency for increase in size of M_1. In a later paper (Simpson, 1943), he attempted to document this clinal increase in size as a series of ascending stages or subspecies. West (1976) synonymized *E. ralstonensis* with *E. osbornianus*, preferring to draw a morphological separation between the earliest Eocene *Ectocion* group (*E. ralstonensis*—*E. osbornianus*) and late Paleocene samples of *Ectocion*. West (1976, p. 50) noted that *E. osbornianus* possesses a P_4 that is more molarized than those of early Tiffanian *E. montanensis* or *E. wyomingensis*. However, West recognized *Gidleyina* Simpson (1935b) to be a synonym of *Ectocion* and (1976, p. 58) separated "Lost Cabin" *E. superstes* from early Wasatchian *E. osbornianus* on the presence of a relatively long P_3 and larger tooth size in the former species.

The observed range for M_1L in the No Water sample of *Ectocion* (6.00-7.40 mm) closely fits that for Simpson's (1943) *E. osbornianus complens* (6.10-7.20 mm) from the "Sand Coulee" beds. The stratigraphic plot of Log (L x W) M_1 of the No Water *Ectocion* sample (Fig. 30) shows some tendency for separation into two and possibly three groups. The same plot for M_2 (Fig. 31) could separate these teeth into four closely knit but distinct groupings were it not for crossings of the size range for M_2 and M_1 when serially associated specimens of these teeth were correlated with each other. In other words, some mandibular specimens preserving M_{1-2} have an M_1 that falls into group B (Fig. 30) while the associated M_2 is a member of group C (Fig. 31), and *vice versa*. Plots of P_4 and M^{1-2} (not figured here) do, however, corroborate a threefold distinction (A, B-C, and D) for the No Water sample, but these divisions are so
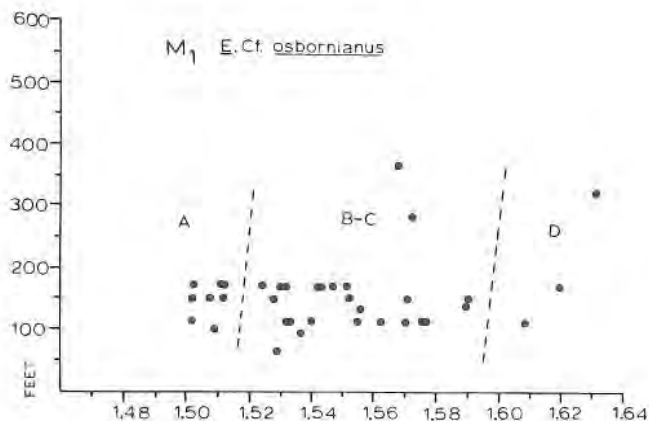
Figure 30. Stratigraphic plots of M_1 in specimens of No Water *Ectocion*. A, B-C, and D are divisions discussed in the text; abscissa is log (L x W)M_1; ordinate is distance in feet above the base of the Willwood Formation.
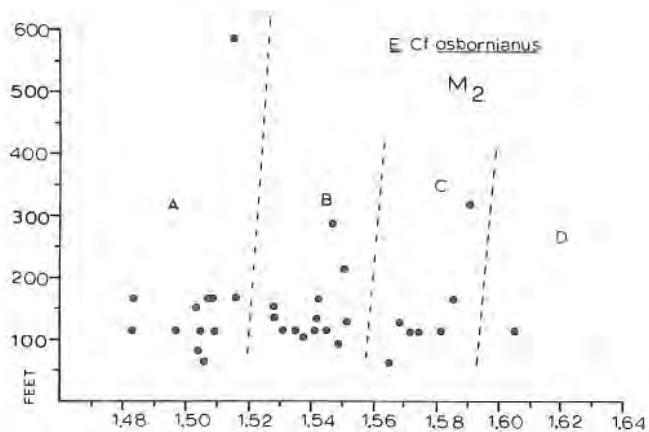

Figure 31. Stratigraphic plots of M_2 in No Water specimens of *Ectocion*. A, B, C, and D are divisions discussed in the text; abscissa is log (L x W)M_2; ordinate is distance in feet above the base of the Willwood Formation.

close that they may be more random than real. They may be regarded as real divisions if supported by plots of other specimens from the 0-400 foot levels and specimens from the 400-600 foot levels that exist in the Yale and University of Michigan collections. I agree with West (1976) that known samples of *Ectocion* do not support the separation of *E. ralstonensis* from *E. osbornianus*.

A number of good deciduous dentitions (see Figs. 56 a, c) of *E. Cf. osbornianus* were recovered from locality V-73024 (Campbell Quarry). These specimens conform in every way (including eruption sequence) with those described by West (1971).

OCCURRENCE: *E. Cf. osbornianus* was recovered from 54 localities between the 14 and 590 foot levels of the Willwood Formation. West (1976, Table 1) has documented other occurrences of this species.

Family Hyopsodontidae (Trouessart, 1879)
Subfamily Hyopsodontinae Trouessart, 1879
Genus *Hyopsodus* Leidy, 1870
Hyopsodus sp.

REFERRED SPECIMENS: UW numbers 7580-7676, 7677 (Fig. 57a), 7678-7693, 9119-9122, 9124-9177, 9178 (Fig. 56d), 9179, 9180, 9184-9196, 10319, 10329, 10349, 10380, 10383, 10384, 10389, 10403, 10405, 10414

DISCUSSION: Gazin (1968) reviewed the species of *Hyopsodus* and recognized three valid species from the "Gray Bull" faunal zone and its equivalents. These are *Hyopsodus loomisi*, *H. miticulus*, and possibly *H. wortmani*. Because of incomplete or nonexistent stratigraphic documentation of the samples available to him, however, Gazin was forced to the conclusion that the *Hyopsodus* sample could be separated into size-distinct groupings by sub-provincial age faunal groupings. Some of these groupings (*e.g.*, *H. miticulus*), Gazin believed to be distinct throughout Wasatchian time in three states. Gingerich (1974c, 1976a) has convincingly demonstrated the existence of more-or-less continuous shifts in mean size of M_1 when samples of this, the least variable tooth, are viewed in their stratigraphic contexts.
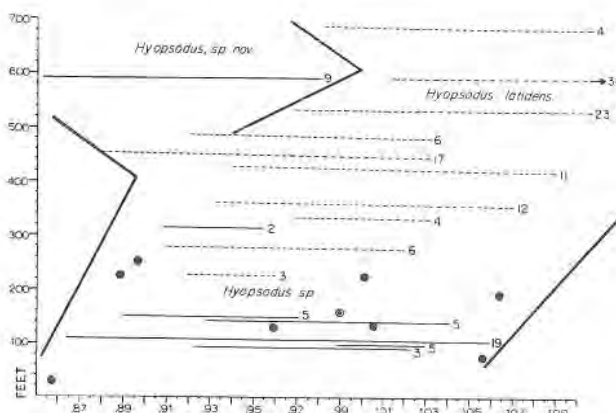

Figure 32. Stratigraphic plots of M_1 in *Hyopsodus* from the Willwood Formation. Solid lines are the observed ranges of measurements on specimens in the No Water collection; dashed lines are the observed ranges of measurements on specimens in the Yale collection; solid circles represent individual specimens from the No Water sample; the open circle represents an individual specimen from the Yale sample (after Gingerich, 1974c; 1976a); numbers indicate sample sizes at their respective levels; abscissa is log (L x W)M_1; ordinate is distance in feet above the base of the Willwood Formation.

M_{1-2} of *Hyopsodus* in the No Water collection variously fit or overlap the observed ranges of these teeth in *H. wortmani*, *H. simplex*, *H. minor*, and *H. loomisi* as defined by Gazin (1968); however, the No Water specimens are certainly much older than the types of *H. wortmani* or *H.*

minor and may be older than the type of *H. simplex* (see Loomis, 1905, p. 420). Gingerich (1974c, 1976a) attempted to take into account the stratigraphic and geographic discrepancies of the type material of Wasatchian *Hyopsodus* and designated established names for the Yale collection samples available to him where this was possible. He believed *H. latidens* and *H. loomisi* to comprise the bulk of the "Gray Bull" sample and recognized a new species of very small *Hyopsodus* at about the 900 foot level of the Willwood Formation.

H. latidens is based on a left mandibular fragment preserving M_{2-3} from the Indian Meadows Formation of the Wind River Basin. The relationship of this form to Bighorn Basin samples of *Hyopsodus* remains to be documented; however, from the evidence of associated faunas it is almost certain that Indian Meadows and lower Willwood time overlapped to some extent. There is no valid basis, so far as I can determine, for synonymizing *H. latidens* under *H. miticulus* (Gazin, 1968, p. 14). The type of *H. miticulus*, misplaced at least since 1907, is from the San José Formation of New Mexico and is likewise of uncertain relationship to Bighorn Basin samples of *Hyopsodus*. The associated fauna of the San José, however, suggests a somewhat younger age than that usually called "Gray Bull." The positive assignment of named species of *Hyopsodus* to samples from the Bighorn Basin will have to await the collection of stratigraphically documented samples from other basins. Even these, when available, will not substantially clarify this picture if such stratigraphically plotted samples deviate appreciably from the phylogenies of Gingerich (1974c, 1976a), and may as well reflect such other variables as sedimentation rates or ecological separation.

Only *H. powellianus* and *H. simplex*, with type specimens from the Bighorn Basin, may be applied with any reliability to the Willwood *Hyopsodus* sample on the basis of measurement data alone. *H. loomisi*, described by McKenna (1960) from the Four Mile area of the Sand Wash Basin, may be excluded from the No Water sample on morphological grounds. This species fits the size range for *Hyopsodus* teeth from the lowest levels of the Willwood Formation in the Yale (see Gingerich, 1974c, Fig. 1; 1976a, Figs. 4, 5) and University of Wyoming collections, but differs from these samples in lacking ectocingula on M^{1-2} and in having poorly separated protocone and hypocone cusps on these teeth. If these characters alone are sufficient to distinguish *H. loomisi* and are not simply variants of the sample, that species is not represented in the No Water collection. Consequently, the bulk of the No Water sample of *Hyopsodus* is assigned to *Hyopsodus* sp., pending clarification of specific terminology.

The teeth of *Hyopsodus* sp. are distinguished by their very small size (within the range of *H. loomisi*), by the presence of weak to strong ectocingula and well separated protocone and hypocone cusps on M^{1-2}, and by the normal absence of a hypocone on M^3. The latter character is variable, however, and does not serve adequately to distinguish the No Water sample from Four Mile specimens assigned by McKenna (1960) to *H. miticulus*.
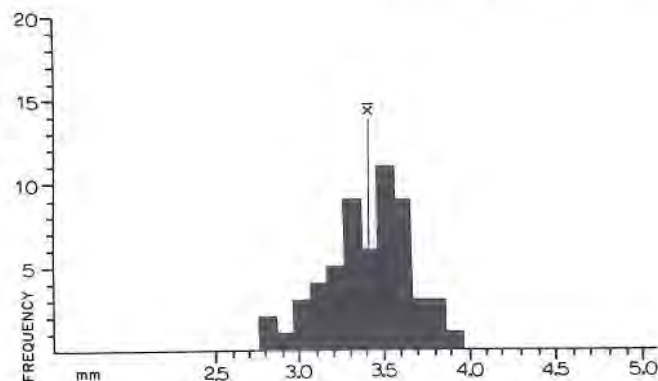

Figure 33A. Histogram of M_1 L in *Hyopsodus* sp. from the 28-390 foot interval of the Willwood Formation. Abscissa is length of M_1 in millimeters; ordinate is frequency of occurrence; $\overline{X}$ denotes sample mean.
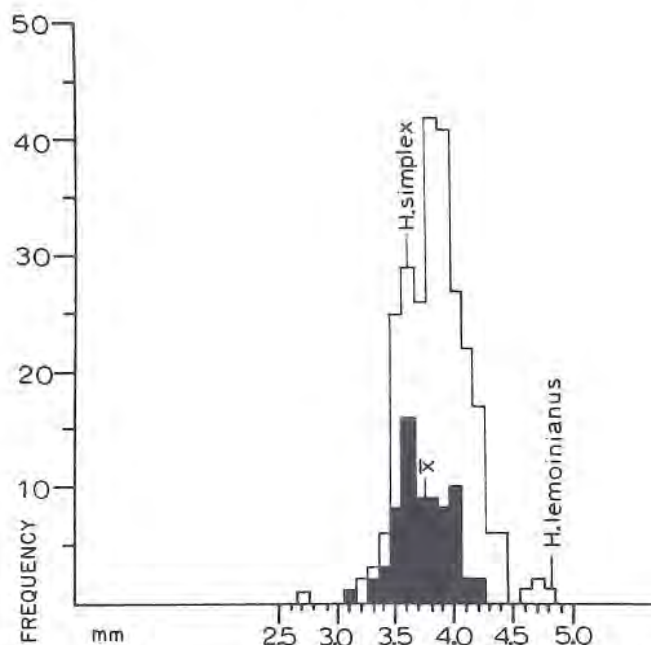

Figure 33B. Histograms of M_2 L in *Hyopsodus*. Unshaded area represents specimens in the Princeton and United States National Museum collections (from Gazin, 1968, fig. 2); shaded area represents specimens in the No Water collection; abscissa is length of M_2 in millimeters; ordinate is frequency of occurrence; $\overline{X}$ is sample mean for No Water collection; *H. simplex* and *H. lemoinianus* show the occurrence of the types of those species.

McKenna (1960) noted the mutual occurrence of *H. loomisi* and *H. miticulus* at six of his seven quarry sites in the Four Mile area. *H. loomisi* was unrecorded as a member of the fauna at Kent Quarry alone. Because the Four Mile quarries almost certainly overlap the No Water faunas and definitely overlap the combined "Sand Coulee" and "Gray Bull" faunas in age, the absence of two well documented and size segregated samples of *Hyopsodus* in the lower Willwood Formation is puzzling. This absence could be the

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result of several causes, taken separately or combined: (1) the picture of phylogeny in Willwood *Hyopsodus* offered by Gingerich does not adequately define relationships of *Hyopsodus* species elsewhere; (2) *H. loomisi* and *H. "miticulus"* (*sensu* McKenna, 1960) do co-exist in the Willwood Formation, but at a higher stratigraphic level than expected; (3) environmental and thereby faunal compositional differences are illustrated by these discrepancies and either *H. loomisi*, *H. "miticulus"* (*sensu* McKenna, 1960), or both are not present in known Willwood faunas. The second alternative is discussed further below. It is interesting that Four Mile specimens of M_1 assigned to *H. loomisi* and *H. "miticulus"*, respectively, in the UCMP collections do overlap slightly in terms of M_1 length and probably cannot be distinguished in terms of size alone.

Histogram plots for M_1 and M_2 in No Water *Hyopsodus* are provided in Fig. 33. The stratigraphic plots for M_1 are illustrated in Fig. 32.

OCCURRENCE: *Hyopsodus* sp. was recovered from 49 localities in the Sand Creek facies between the 28 and 390 foot levels, inclusive. Because of uncertain species assignation, the occurrence of this form in other faunas is unknown or unrecognized.

Hyopsodus, sp. nov.

REFERRED SPECIMENS: UW numbers 9105-9112, 9113 (Fig. 56e), 9114-9118, 9181-9183, 10339, 10341, 10350, 10351

DISCUSSION: Several specimens from two localities at the 590 foot level are tentatively assigned to a new but unnamed species. These specimens are separated from a sample designated *H. latidens* by Gingerich (1976a) on the basis of the very small size of M_1 with respect to stratigraphic position. Gingerich (*op. cit.*, Fig. 4) assigned a solitary member of this group to *H. simplex*, but noted that the specimen probably represents a new species. The stratigraphic plot of M_1 for this sample in relation to *Hyopsodus* sp. (above) and *H. latidens* (*sensu* Gingerich, 1974c, 1976a) is shown in Fig. 32. This sample, aside from small tooth size, also differs from *H.* sp. and the *H. latidens* sample of Gingerich in the lack of a hypocone on any preserved specimens of M^3 and in the absence or only very minimal development of ectocingula on M^{1-2}. It was on these same characters, as well as size, that McKenna (1960) distinguished *H. loomisi* from his sample of *H. "miticulus."* *H.*, sp. nov. does not, however, have the closely appressed protocones and hypocones on M^{1-2} that McKenna noted for *H. loomisi*. In studying the UCMP sample of *H. loomisi*, I find the last character to be variable and only vaguely discernible. The absolute measurements of the distances between the centers of these cusps on relatively unworn specimens of *H. loomisi* (*e.g.*, UCMP 60349) and those on *H.*, sp. nov. with the same or similar tooth dimensions does

not demonstrate any clear distinction between the two samples.

The possibility that *H. loomisi* occurs in the Bighorn Basin at the 500-900 foot levels cannot be ruled out on present evidence. McKenna's *H. "miticulus"* appear to have teeth that are too small to correspond well with *H. latidens* (as conceived by Gingerich, 1976a). Discussions by Gazin (1962, p. 62-63), Guthrie (1967a, p. 36-38), and Delson (1971, p. 350-351) are also pertinent.

OCCURRENCE: *H.*, sp. nov. was recovered from localities V-73124 and 73125 at the 590 foot level of the Willwood Formation. This species most closely resembles *H. loomisi*, a species known from the Four Mile fauna of northwestern Colorado and possibly the "Red Desert," Bitter Creek, and Golden Valley faunas.

Subfamily uncertain
Genus *Haplomylus* Matthew, 1915b
Haplomylus speirianus (Cope, 1880)

REFERRED SPECIMENS: UW numbers 6799-6801, 8345-8359, 8360 (Fig. 57b), 8361 (Fig. 57c), 8362-8372, 8374, 8375, 8378-8641, 8662-8684, 8685 (Fig. 57e), 8686-8799, 9001-9104, 9405-9409, 10318-10322, 10342, 10353, 10358 10361, 10363-10371, 10385-10388, 10390, 10400-10402, 10406, 10408, 10409, 10426

DISCUSSION: *H. speirianus* is the most abundant vertebrate fossil in the No Water collection. None of the more than 400 jaw specimens or more than 700 isolated teeth possess significant morphological differences when compared with "Sand Coulee" or "Gray Bull" specimens of this species in the AMNH collection. The *Haplomylus* sample in the American Museum, Yale Peabody Museum, and University of Wyoming collections is a morphologically homogeneous one, and, aside from minor size differences, dental specimens from the lowest levels of the Willwood Formation compare closely with the highest known tooth samples from those rocks (ca. 900 foot level) and with teeth examined in the Four Mile and certain Green River Basin collections.

Stratigraphic plots of M_1 in No Water *H. speirianus* (Fig. 34) demonstrate that the size of this tooth gradually increased through time as noted by Gingerich (1976a, Fig. 6) and that apparently only one species is represented. Simpson (1937c) noted the presence of some abnormally large specimens of *H. speirianus* or a close relative associated with "Clark Fork" faunas in the northern Bighorn Basin. Gingerich (1976a, p. 14-15) believed that these samples may have been obtained from higher faunules, but recently (Gingerich, 1976, oral communication) has acknowledged the occurrence of a very large species of *Haplomylus*, possibly distinct from *H. speirianus*, in the lowest levels of the Willwood Formation.
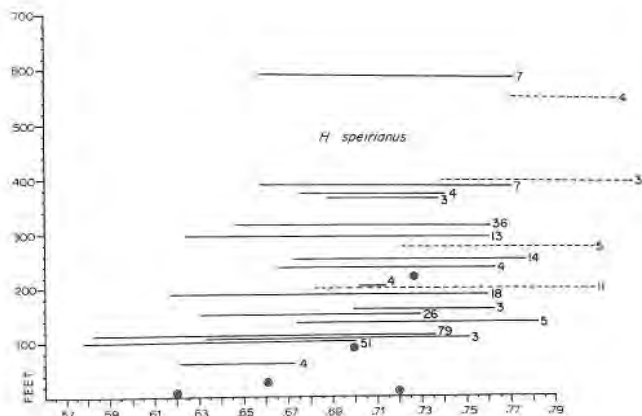
Figure 34. Stratigraphic plots of M_1 in *Haplomylus* from the Willwood Formation. Solid lines are observed ranges of measurements on specimens in the No Water collection; dashed lines are observed ranges of measurements on specimens in the Yale collection (from Gingerich, 1976a); numbers are sample sizes; solid circles represent individual specimens in the No Water collection; open circles represent individuals in the Yale collection; abscissa is log $(L \times W)M_1$; ordinate is distance in feet above the base of the Willwood Formation. The displacement in observed ranges of measurements between the University of Wyoming and Yale samples cannot be resolved by stratigraphic error, and is believed to reflect different measurement techniques.

As noted by McKenna (1960, p. 106):

"*Haplomylus* is more closely allied with the Paleocene shallow-jawed hyopsodonts than with *Hyopsodus*. Though similar in size to *Hyopsodus loomisi* . . ., the hypocones are of a different plan; P^4 is not as wide and possesses a metacone, there is no 'entostylid,' and M_3 has a narrow, projecting hypoconulid, to name but a few diagnostic features."

Haplomylus further differs from *Hyopsodus* in the possession of elongate P_{2-4} as in *Diacodexis*, but is clearly distinct from that genus in a number of characters, including the presence of a P_4 metaconid and the absence of M_{2-3} paracondis. In the structure of P_4 -M_3, *Haplomylus* shows some resemblances to *Phenacodaptes* and *Apheliscus*, but is perhaps most similar to Paleocene *Haplaletes*, as noted by several authors. The degree of differences in cheek tooth structure between *Haplomylus* and *Hyopsodus* is probably sufficient to remove the former genus from the Hyopsodontinae.

OCCURRENCE: *H. speirianus* was found at 52 localities between the 14 and 590 foot levels of the Sand Creek facies of the Willwood Formation. The species has also been reported from the Four Mile, Little Bitter Creek, Bitter Creek, "Red Desert," "west of Elk Mountain" (Gazin, 1962), Powder River "Wasatch," Laramie Basin, and Sand Butte (Gazin, 1965) faunas.

ORDER ?CONDYLARTHRA, *incertae sedis*
Family Pentacodontidae (Simpson, 1937a)
Genus *Apheliscus* Cope, 1875
Apheliscus Cf. *insidiosus* (Cope, 1874)

REFERRED SPECIMENS: UW numbers 6804, 6805, 7041, 7330, 7331 (Fig. 58d), 7332-7334, 7335 (Fig. 57d), 7336, 7337, 7338 (Fig. 58a), 7339, 7340 (Fig. 58c), 7341-7374, 7376-7388, 7909, 8642-8646, 8647 (Fig. 58b), 8648-8661, 9479-9499, 10131, 10191-10204, 10323, 10324, 10407

DISCUSSION: Cope (1875) erected *Apheliscus* for the type of his former New Mexican "Wasatch" *Prototomus insidiosus* (Cope, 1874). In 1918, Matthew referred AMNH numbers 15696 ("Upper Gray Bull"), 34, 44, 4201 ("probably from the Gray Bull"), 16925 ("Sand Coulee") and 15849 ("Clark Fork") to *A. insidiosus*, the type of which had, in the meantime, been lost. Simpson (1937c) designated AMNH 15849 the type of a new species, *A. nitidus*.

Comparable teeth from the No Water localities fall beneath the known size ranges for both *A. insidiosus* and *A. nitidus* and approximate the size of P^4 -M^1 in *A. wapitiensis* Van Valen (1967). Most of the No Water specimens closely match the morphology of comparable teeth of *A. nitidus* in that there is normally a well developed P^4 precingulum, the P^4 paracone is robust and strongly inclined posteriorly, and M^1 possesses a transversely narrow trigon basin. The P^4 protocone is not expanded as in *A. insidiosus*, and the M^1 is not as reduced relative to P^4 as in the type of *A. wapitiensis*. Van Valen (1967, p. 248) figured an isolated P^4 that he referred to *A. (Parapheliscus) bjorni*. This tooth is considerably larger than P^4 in *A. wapitiensis* or *A.* Cf. *insidiosus* and differs from most P^4 of *A.* Cf. *insidiosus* in the absence of the precingulum. Delson (1971) allocated a maxilla (AMNH 56329) to *A. nitidus*, but noted its distinctively smaller size. On the basis of the large tooth size range evident in the larger sample of *Apheliscus* teeth in the Four Mile collection, that author synonymized *A. wapitiensis* with *A. nitidus*. I agree with Delson's synonymy of these species. Only the smaller size of the type of *A. wapitiensis* serves to distinguish it from specimens of *A. nitidus*, and teeth tentatively referred to the latter species from both the Four Mile and No Water faunas bridge this size gap. Certain of the No Water specimens of upper teeth appear to differ consistently and significantly from the morphology of these teeth in *A. nitidus*; however, stratigraphic plots of P_4 and M_1 (Fig. 35) show no good tendencies toward separation into two or more groups and do not convincingly demonstrate changes in the mean size of these teeth up section. It is possible that UW 8653, an abnormally large specimen, denotes the presence of a second species of *Apheliscus* in this collection and that the remainder of the M_1 L plot suggests a mean decrease in the size of this tooth. The M_1 sample is too small, however, for a confident interpretation. Simpson (1937c) noted that the type of *A. nitidus* was recovered from "Clark Fork" beds. Wood (1967) suggested that this specimen was actually

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recovered from the "Gray Bull," but Gingerich (1976, written communication) believes an older horizon than "Gray Bull" is indicated. Because the type of *A. nitidus* is larger than most specimens elsewhere referred to this species, this specimen, if from faunules older than the "Gray Bull," suggests either that a decrease in mean tooth size was a trend in successive populations referred to *A. nitidus*, or that two species are represented. I believe the latter case to be the more probable, and hesitantly assign the No Water *Apheliscus* sample to *Apheliscus* Cf. *insidiosus*.
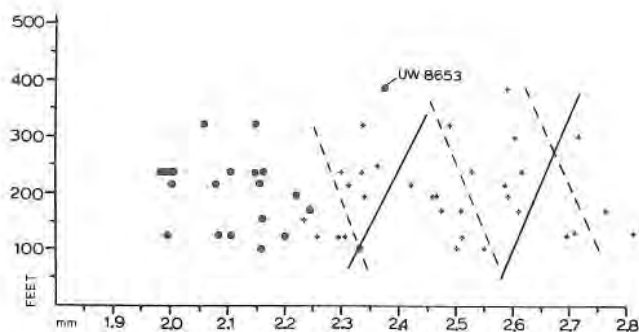
Figure 35. Stratigraphic plots of P_4 (+) and M_1 (·) in *Apheliscus* Cf. *insidiosus*. Abscissa is tooth length in millimeters; ordinate is distance in feet above the base of the Willwood Formation; solid and dashed lines separating groups of P_4 are discussed in the text.

The No Water sample of P_4 could be separated into four groups, in each of which tooth size decreases somewhat up section (the dashed lines, Fig. 35, separate these hypothetical groupings), or into three groups, in each of which tooth size increases up section (Fig. 35, solid lines).

The dP^{3-4} of *Apheliscus* Cf. *insidiosus* are represented by UW 7340 (Fig. 58c). dP^3 is a sectorial tooth with a transversely narrow crown dominated by a paracone that is situated slightly to the buccal side of the midline of the tooth. A long postparacrista connects this cusp to the posteromedial margin of the tooth. The tooth has no preparacrista, but terminates anteriorly in a small bulge at the anterolabial border of the crown. A protocone is absent, and the tooth is bordered lingually by a basal shelf that is broadest beneath the paracone and terminates immediately anterior to it. dP^4 resemdles M^1, but is less triangular and more trapezoidal in occlusal outline. The tooth has strong para- and metaconule cusps and well developed ecto- and postcingula. A small precingulum is developed beneath, and slightly lingual to, the paraconule, and merges with the ectocingulum to form a broad parastylar shelf. Unlike the condition in M^1, the preprotocrista is extremely short, and the postprotocrista is long and extends immediately posterior to the protocone, then turns obliquely (transversely) to merge with the metaconule.

dP_{3-4} are represented by UW 7331. dP_3 resembles the permanent P_4 in *Apheliscus*, but has a less squared and less well basined heel, a relatively lower protoconid (with respect to the length of the tooth), and a much better defined anterobasal cusp (nearly as tall as the posterobasal cusp). dP_4 is anteroposteriorly long and possesses a very sharply defined and medial paraconid that is well removed from the metaconid and is connected anterolabially to the base of the protoconid by a low paracristid. The trigonid notch is widely open lingually. The talonid is equally as long as the trigonid and is deeply basined. The hypoconid does not appear to be clearly distinguished from the postcristid on the posterolabial side; however, the tooth is damaged inferior to this cusp. The hypoconulid is tall and medial, and the entoconid is anteroposteriorly attenuated into the entocristid. The talonid notch is very short, and the hypoflexid is shallow. M_1 is preserved by rooted alveoli and appears to have been fully erupted. The trigonid of a fully formed M_2 is present in the crypt posterior and inferior to the roots of M_1.

OCCURRENCE: *Apheliscus* Cf. *insidiosus* was recovered at sites between the 60 and 390 foot intervals, inclusive, in the Sand Creek facies. This species, or a larger variant with nearly identical cheek tooth morphology, also occurs in lower Willwood faunules of the central Bighorn Basin.

ORDER PANTODONTA Cope, 1873b
Family Coryphodontidae Marsh, 1876
Genus *Coryphodon* Owen, 1845
Coryphodon sp.

REFERRED SPECIMENS: UW 9500-9508, 9509 (Fig. 58e), 9510-9563

DISCUSSION: *Coryphodon* is represented in the No Water collection by only the most meager material. Isolated teeth and one-tooth mandibular fragments do, however, represent nearly the entire dentition, and several elements of the postcranial skeleton were recovered. A solitary maxillary fragment preserves dP^{2-4} (Fig. 58e). dP^{2-3} resemble their permanent counterparts, but are smaller, more compressed transversely, have a more deeply inflected ectoflexus, and show little development of the protocones. The protocones are situated posterior to the transverse midlines of the teeth. dP^4 resembles M^1 in occlusal outline, but is also relatively compressed transversely, and the lingual margin of the tooth is less squared than in M^1. dP^{2-4} compare in virtually every way with those of *Coryphodon* sp. figured by Simons (1960, Fig. 4). As he notes, dP^4 resembles somewhat the M^1 in *Pantolambda* and *Caenolambda*.

A review of the species of *Coryphodon* is necessary before the No Water sample of this animal can be confidently assigned. The teeth are relatively small in relation to most of the specimens of *C. testis*, *C. lobatus*, and *C. cinctus* with which they were compared. However, the measurements compare rather closely with some specimens of *C. eocaenus*, although the size variability of several of the teeth might indicate that more than one population was sampled. M_3 in the No Water specimens retains an obliquely oriented hypolophid and a distinct entoconid as in *C.*

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Table 31. Measurements (mm) of lower teeth of *Coryphodon* sp. (576 feet of section)

	P_2L	P_2W	P_3L	P_3W	P_4L	P_4W	M_1L	M_1W	M_2L	M_2W	M_3L	M_3W
UW 9501							23.5	17.3				
UW 9504	21.1	14.2	21.7	14.9	21.0	16.8						
			21.0	15.6	21.6	16.1						
UW 9505					18.8	15.2	23.2	15.6				
UW 9510											32.5	25.8
UW 9511							33.3	23.9				
UW 9512			19.1	13.3	20.0	16.6			31.5	22.1	37.3	21.7
UW 9514											39.0	23.3
UW 9515							29.0	21.2				
UW 9518					21.3	18.6						
UW 9530					20.0	14.0						
UW 9535					24.9	19.0						
UW 9548							28.0	17.8				
UW 9556			19.7	13.9								
UW 9560					22.4	17.2						

Table 32. Measurements (mm) of upper teeth of *Coryphodon* sp. (245 feet of section)

	P^3L	P^3W	P^4L	P^4W	M^1L	M^1W	M^3L	M^3W
UW 9501			18.1	22.5			23.7	34.0
UW 9504							23.7	31.4
UW 9508	16.8	22.7						
UW 9518							25.8	38.8
UW 9519							28.0	36.0
UW 9546							28.2	38.0
UW 9550	16.6	20.0			22.7	30.3		
UW 9558							27.8	40.4

eocaenus (Simons, 1960). The entoconid, however, is less well separated from the hypoconulid than in *C. proterus*, and the cheek teeth and canines are much smaller. The M_3 entoconid is much more distinct than in UW 3355, a specimen referred by Simons (*in* Prichinello, 1971) to *C. eocaenus*, and the posterolingual part of the postcristid is less well developed. M_{1-2} apparently do not possess metastylids, cusps present on most specimens of M_3.

OCCURRENCE: *Coryphodon* sp. was found at 51 localities in the Sand Creek facies, between the 14 and 590 foot levels, inclusive. The specimens at hand appear to most closely resemble materials of *C. eocaenus*, a species known from elsewhere in the Bighorn Basin Willwood Formation and from the "Wind River" Formation of the Laramie Basin.

ORDER PERISSODACTYLA Owen, 1848
Family Equidae Gray, 1821
Subfamily Hyracotheriinae Cope, 1881c
Genus *Hyracotherium* Owen, 1840
Hyracotherium Cf. *angustidens* (Cope, 1875)

REFERRED SPECIMENS: UW numbers 7920-7923, 7924 (Fig. 59a), 7925-7956, 7958-8200, 8202-8283, 10312, 10314-10317, 10336, 10337, 10340, 10391, 10399

DISCUSSION: In the absence of consistently correlatable morphological differences in teeth of *Hyracotherium* in the No Water collection, the stratigraphic plots of M_1 (Fig. 36) and M^1 (unfigured) suggest the presence of two species in this sample. Kitts (1956) recognized two subspecies of *Hyracotherium angustidens* in the lower Willwood Formation, *H. a. grangeri* ("Sand Coulee") and *H. a. etsagicum* ("Gray Bull"). According to that author, *H. a. grangeri* is known only from "Sand Coulee" faunas while *H. a. etsagicum* also occurs in the Almagre facies of the San José Formation (New Mexico) and in the Indian Meadows Formation of the Wind River Basin. A third subspecies, *H. a. angustidens*, was recognized by Kitts (1956) in faunas from the Almagre facies and from the Powder River "Wasatch" Formation. These subspecies were believed to exhibit mean tooth size increase in the series *H. a. angustidens—H. a. grangeri—H. a. etsagicum;* however, the observed ranges for teeth of these groupings were arranged for samples that are temporally and geographically disparate.

P_4 and M_1 of No Water *Hyracotherium* are consistently

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smaller than those teeth in the Four Mile sample referred by McKenna (1960) to *H. angustidens* and do not, on the basis of the samples studied, overlap in L or W dimensions. These teeth in No Water *Hyracotherium* are also considerably smaller than teeth referred to either *H. a. grangeri* or *H. a. angustidens* by Kitts (1956), although these measurements do overlap somewhat. Because of the lack of stratigraphic control available at the time of Kitts' study, it is probable that his samples reflect artificial groupings that cannot presently be adequately correlated by size alone. The assignment of the No Water or, indeed, any sample of Bighorn Basin *Hyracotherium* to *H. angustidens* (the type of this species is from the Almagre facies) is questionable. This name, however, has come to embrace most specimens of *Hyracotherium* with small teeth from early Wasatchian faunules as well as some specimens from younger faunules (*e.g.*, the type). Because there are more than enough named species to accommodate the existing variation in *Hyracotherium* samples, the No Water sample is
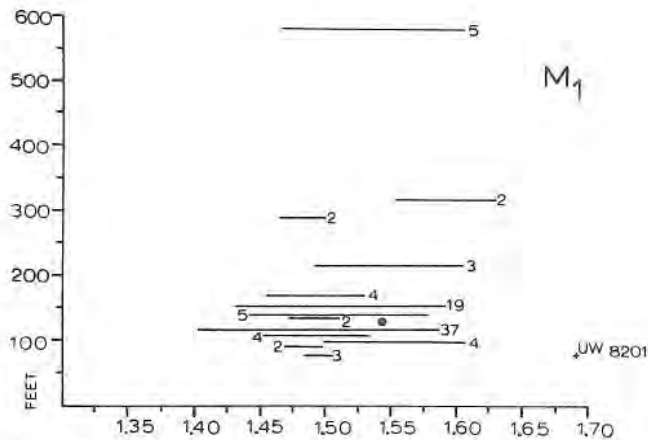
Figure 36. Stratigraphic plots of M_1 in jaws of *Hyracotherium* from the Sand Creek facies. Solid lines are observed ranges of measurements; numbers are sample sizes, the solid circle represents an individual specimen; abscissa is log $(L \times W)M_1$; ordinate is distance in feet above the base of the Willwood Formation.

tentatively referred to *H.* Cf. *angustidens*, pending the establishment of a more reliable and useful concept of this taxon.

OCCURRENCE: *H.* Cf. *angustidens* was recovered at seventy localities in the Sand Creek facies between the 14 and 590 foot levels, inclusive. Specimens referred to *H. angustidens* have been reported from the San José, Four Mile, Powder River "Wasatch," Indian Meadows Formation, "Red Desert," Bitter Creek, "west of Elk Mountain" (Gazin, 1962), and Laramie Basin faunas and possibly the "Cuchara" fauna.

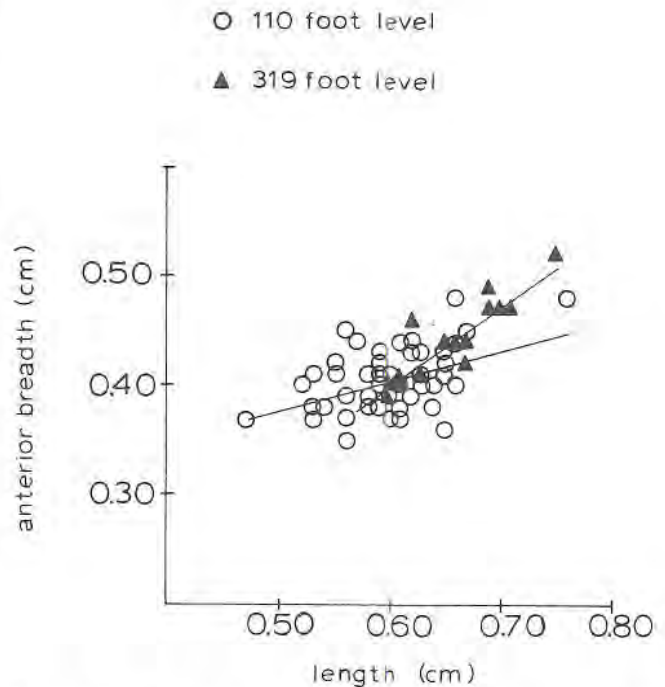### *Hyracotherium* sp.

REFERRED SPECIMEN: UW 8201 (Fig. 59b)

Figure 37. Scatter diagram of measurement distributions for P_4 in *Hyracotherium* Cf. *angustidens* from the 110 and 319 foot levels of the Willwood Formation (from J.L. Reitenbach, unpublished study).

DISCUSSION: This single specimen is far too large to be included with the remainder of the No Water *Hyracotherium* sample in *H.* Cf. *angustidens*. The M_1 dimensions (Fig. 36) as well as those of associated upper and lower teeth place this specimen in the upper end of the range noted by Guthrie (1967a, Fig. 31) for "Gray Bull" *H. angustidens*, but the specimen is clearly larger and distinct from contemporary and faunally associated specimens of *Hyracotherium*. UW 8201 differs from *Homogalax* in its smaller size, less robust cheek teeth, and lack of a significant protolophid on M_{1-3} or protoloph and metaloph on M^{1-3}. Specimens of *Homogalax protapirinus* from correspondingly low levels of the Willwood Formation in the Three Sisters—Gould Butte and Elk Creek areas are considerably larger and possess the peculiar morphology of that taxon.

OCCURRENCE: UW 8201 was found at UW locality V-73025, at approximately the 80 foot level of the Willwood Formation.

ORDER ARTIODACTYLA Owen, 1848
Family Dichobunidae Gill, 1872
Genus *Diacodexis* Cope, 1882a
Diacodexis Cf. *metsiacus* Cope, 1882a

REFERRED SPECIMENS: UW numbers 7482-7536, 7537 (Fig. 59e), 7538-7570, 7571 (Fig. 59c), 7572-7579, 9197-9199, 9201-9212, 9213 (Fig. 59d), 9214-9221, 9223-9270, 9996, 10306-10308, 10334, 10392, 10397, 10411

Table 33. Numerical data for P_4 and M_1 of *Hyracotherium* Cf. *angustidens* from selected levels of the Willwood Formation (measurements in millimeters; from Reitenbach, unpublished data)

Feet above Base	N	OR	$\overline{X}$	SD	CV
P_4L					
97	15	3.50—4.40	4.10	0.03	7.3
102	7	3.80—4.40	4.00	0.02	5.0
110	56	3.30—4.60	4.00	0.03	7.5
131	3	4.00—5.00	4.30	0.06	13.9
134	9	3.70—4.20	4.00	0.02	5.0
150	29	3.80—4.80	4.10	0.02	4.8
158	6	3.70—4.10	3.80	0.02	5.2
247	5	3.80—4.50	4.20	0.03	7.1
288	5	3.80—4.00	3.90	0.01	2.5
319	16	3.70—4.70	4.20	0.03	7.1
M_1L					
74	3	6.60—6.80	6.70	0.01	1.4
97	4	6.50—7.60	7.20	0.05	6.9
102	4	5.90—7.30	6.70	0.07	10.4
110	36	5.80—7.40	6.70	0.04	5.9
134	5	6.50—7.50	7.10	0.04	5.6
150	20	6.10—7.40	6.90	0.04	5.8
158	4	6.20—6.90	6.60	0.03	4.5
210	3	6.50—7.40	6.90	0.05	7.2

DISCUSSION: Sinclair (1914) recognized two species of *Diacodexis* in "Wasatch" (="Gray Bull") rocks of the Bighorn Basin: *D. chacensis* (including *D. metsiacus*) and *D. robustus*. Gazin (1952) and Guthrie (1967a) have convincingly demonstrated *D. chacensis* to be distinct from any known samples that have been referred to *D. metsiacus* on a size basis. Only *D. metsiacus* and *D. robustus* are valid for known Bighorn Basin collections of *Diacodexis*.

McKenna (1960) and Delson (1971) have referred samples to *D. metsiacus* that possess somewhat smaller teeth than in collections described by Guthrie (1967a) from the Lysite Member of the Wind River Formation. These specimens, however, conform well with measurements given by Granger (1914) for "Wasatch" (="Gray Bull") samples of *D. chacensis* (including *D. metsiacus*). The No Water sample of *Diacodexis* (excluding a single specimen referred to *D. robustus*) has a mean tooth size that falls well beneath that of Guthrie's sample and is smaller than many specimens in the Yale Collection. J. Damuth (unpublished data) has recently constructed stratigraphic plots of teeth of most *Diacodexis* in the Yale collection. These plots (Fig. 38) show a small and very gradual increase in mean size for M_1 and M_2 up section. *D. robustus*, represented by only the most meager material, is clearly distinguished on the basis of size alone. Because the No Water sample fits well with plots of *D. metsiacus* (as recognized by Damuth) from the lower levels of the Willwood Formation, the bulk

of this collection is assigned to that species. The length of P_4 (OR = 4.00-4.88, $\overline{X}$ = 4.27, N = 57) in No Water *D. Cf. *metsiacus* falls beneath those given by Sinclair (1914) for that species (OR = 4.20-5.30) and by Guthrie (1967a) for specimens from the Lysite Member of the Wind River Formation (OR = 4.40-5.45, $\overline{X}$ = 5.03, N = 8). Similarly, the size of M_1 in No Water *D. Cf. metsiacus* (OR = 3.61-4.23, $\overline{X}$ = 3.92, N = 42) is much smaller than in samples of that tooth from the Lysite Member of the Wind River Formation (OR = 4.10-4.50, $\overline{X}$ = 4.31, N = 14; Guthrie, 1967a). The No Water sample of P_4 is unusually variable in width (P_4W: OR = 1.93-2.72, $\overline{X}$ = 2.30, N = 57), a parameter that is often inversely correlated with P_4L.

UW 7537 (Fig. 59e) probably represents dP^{3-4} of *D. Cf. metsiacus*. dP^3 is fully as long as dP^4, but is considerably narrower transversely. The tooth has a strong lingually inflected border in the region of the protocone, but there is no distinct expression of that cusp. The labial border of the tooth possesses three cusps, a prominent paracone, a smaller metacone and a short but anteroposteriorly long parastyle. The parastyle is bulbous and is separated from the base of the paracone by a transversely oriented vespiform constriction. dP^3 lacks pre- and post-cingula and a basal cingulum, but has a short ectocingulum between the paracone and metacone. dP^4 resembles M^1, but is more trapezoidal and less triangular in occlusal outline. The tooth possesses good pre-, post-, and ectocingula and a basal cingulum, as in M^1, with the precingulum and postcingulum joining the postparaconule and postmetaconule cristae just labial to these cusps.
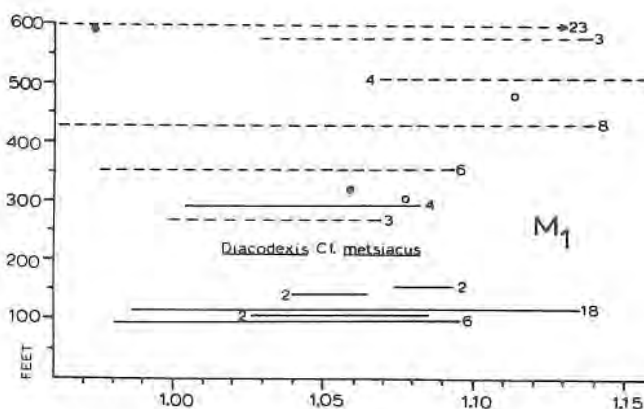

Figure 38. Stratigraphic plots of M_1 in *Diacodexis* Cf. *metsiacus* from the Willwood Formation. Solid lines are observed ranges of measurements of specimens in the No Water collection; dashed lines are observed ranges of specimens in the Yale collection (from John Damuth, unpublished studies); numbers are sample sizes; closed circles represent individual specimens in the No Water collection, open circles represent individual specimens in the Yale collection; abscissa is log $(L \times W)M_1$; ordinate is distance in feet above the base of the Willwood Formation.

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OCCURRENCE: Specimens of *D.*Cf. *metsiacus* were collected at 56 localities in the Sand Creek facies. These sites occur between the 7 and 590 foot levels, inclusive. The species is relatively common in Willwood faunules elsewhere in the Bighorn Basin and has been reported as well from the Four Mile, Powder River "Wasatch," Wind River Lysite and Lost Cabin, "Red Desert," "west of Elk Mountain" (Gazin, 1962), Bitter Creek, Laramie Basin (my unpublished data), "Sand Butte" (Gazin, 1965), and Table Rock faunas, and may occur in collections from the Golden Valley Formation.

Diacodexis robustus Sinclair, 1914

REFERRED SPECIMEN: UW 9222

DISCUSSION: A single specimen is referred to this species on the basis of its abnormally large tooth size. The only tooth (an M_2) measures 4.9 by 4.2 millimeters and is too large to confidently include in even Lysite or Lost Cabin Member samples of *D. metsiacus* (see Guthrie, 1967a). Sinclair (1914) gave an observed range of 6.0-6.3 millimeters (N=2) for the length of M_2 in *D. robustus*, figures much greater than that measured for UW 9222. In the stratigraphic plots of M_2 of Willwood *Diacodexis* in the Yale collection, Damuth (unpublished data) has separated samples of *D. robustus* teeth from those of *D. metsiacus* at the 500-700+ foot levels. UW 9222 and these Yale specimens are clearly separable from counterpart teeth of *D. metsiacus* at their respective stratigraphic levels, and the University of Wyoming specimen is clearly grouped with the *D. robustus* sample.

OCCURRENCE: UW 9222 was recovered at locality V-73022 (Slick Creek Quarry beds), at the 150 foot level of the Willwood Formation. This species has also been assigned by Gazin (1962) to large *Diacodexis* teeth from the Dad fauna of the eastern Washakie Basin.
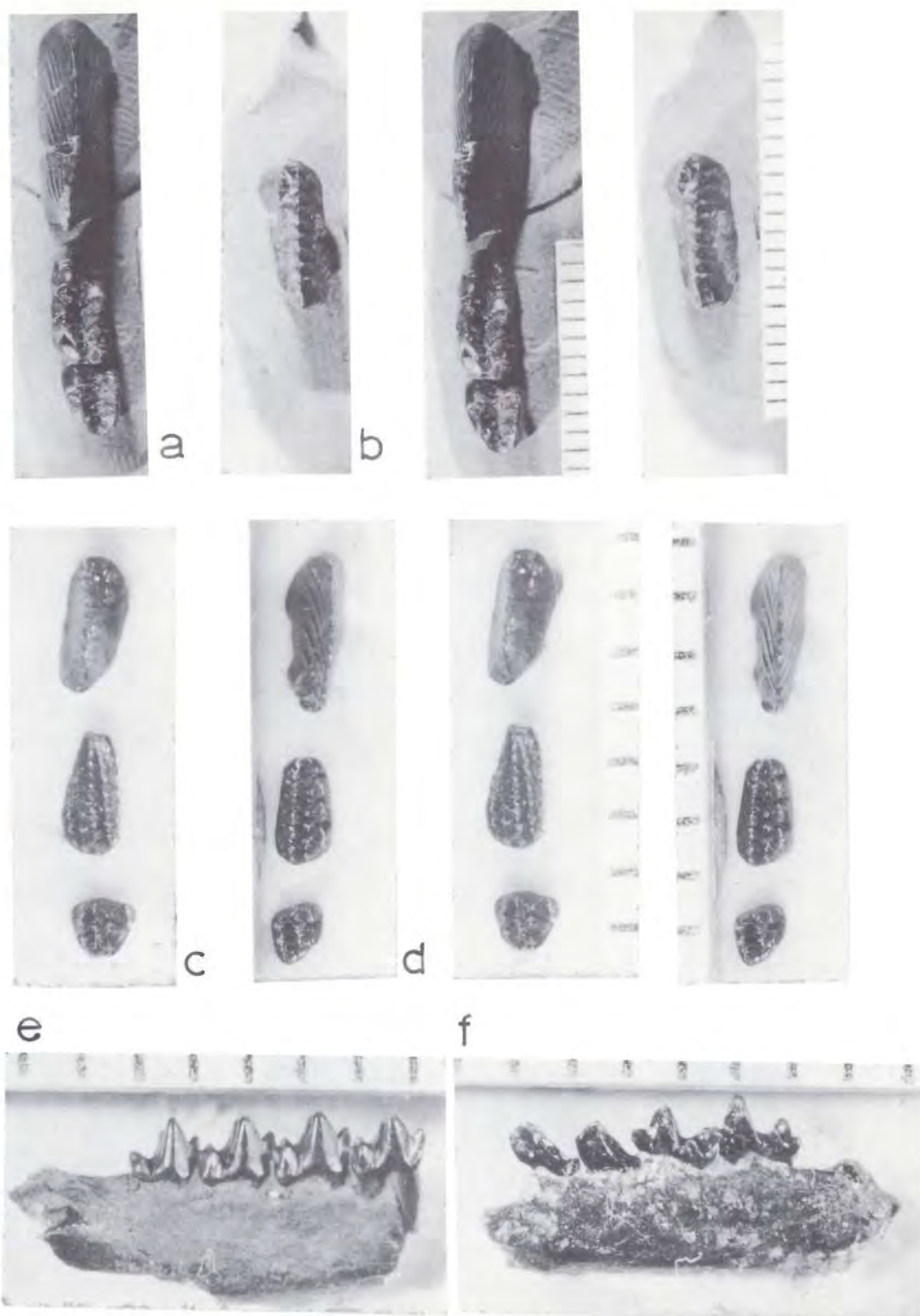
Figure 39. Multituberculata (a-d) and Marsupialia (e, f) from the Sand Creek facies. a. UW numbers 6577, 10428, and 10433, composite occlusal aspect of right P_4-M_2 of *Neoliotomus ultimus*; b. UW 10430, occlusal aspect of right P^4 of *Neoliotomus ultimus*; c. UW 6556, occlusal aspect of composite left P^4-M^2 of *Parectypodus* sp. "A"; d. UW 6562, occlusal aspect of composite left P_4-M_2 of *Parectypodus* sp. "A"; e. UW 9605, labial view of right M_{1-4} of *Peradectes chesteri*; f. UW 9564, lingual view of right P_2-M_2 of *Peratherium macgrewi*, sp. nov. (type). The scales are in millimeters; figures a-d are stereophotographs.

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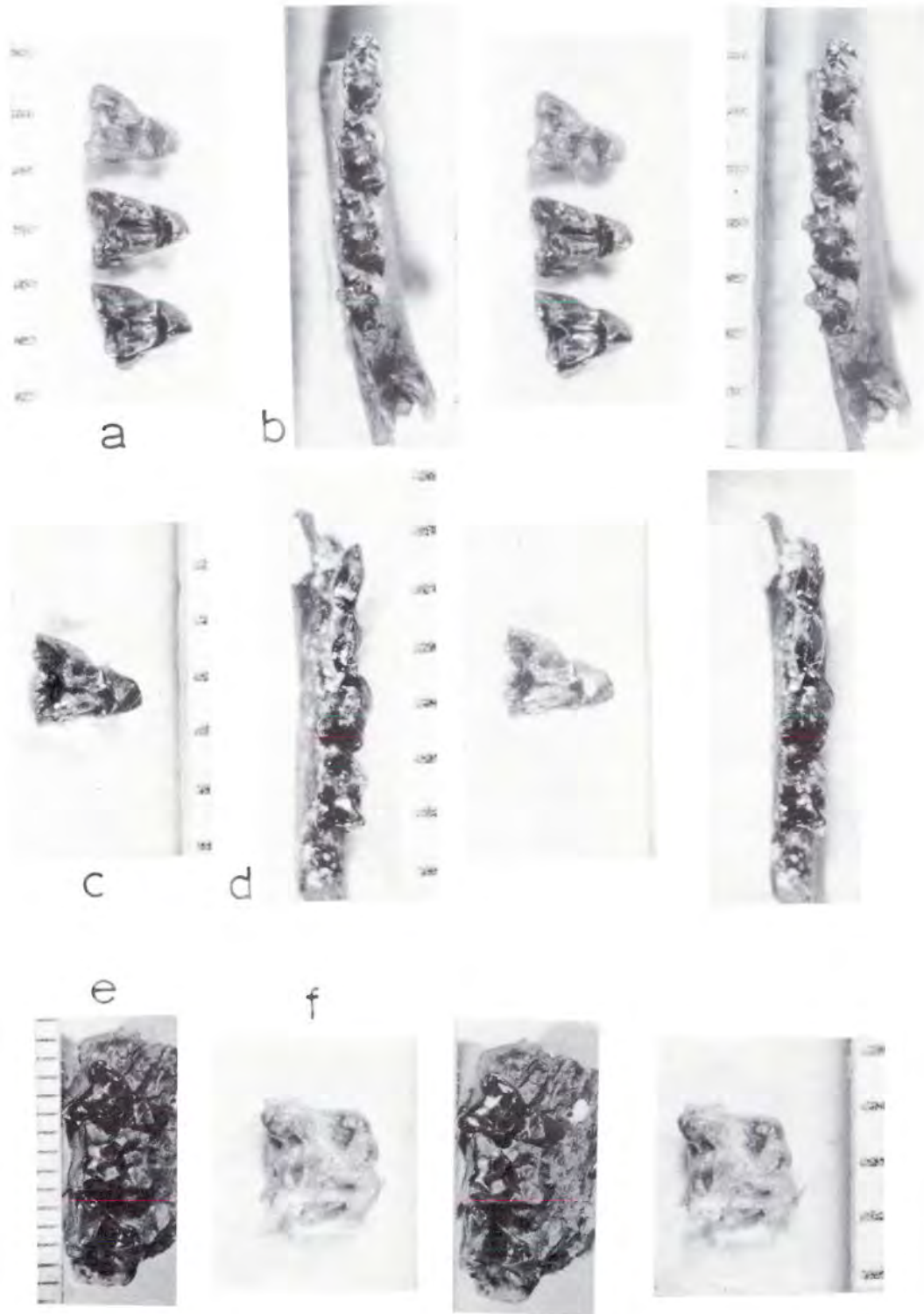
Figure 40. Marsupialia (a-d) and Proteutheria (e, f) from the Sand Creek facies. a. UW 9742, occlusal aspect of composite left M^{1-3} of *Peradectes chesteri*; b. UW 9605, occlusal aspect of right M_{1-4} of *Peradectes chesteri*; c. UW 10129, occlusal aspect of left M^2 of *Peratherium macgrewi*, sp. nov.; d. UW 9564, occlusal aspect of right P^2-M^2 of *Peratherium macgrewi*, sp. nov.; d. UW 9564, occlusal aspect of right P_2-M_2 of *Peratherium macgrewi*, sp. nov. (type); e. UW 9943, occlusal aspect of left P^4-M^2 of *Didelphodus absarokae*; f. UW 9634, occlusal aspect of right M^2 of *Apatemys* sp. The scales are in millimeters; all figures are stereophotographs.
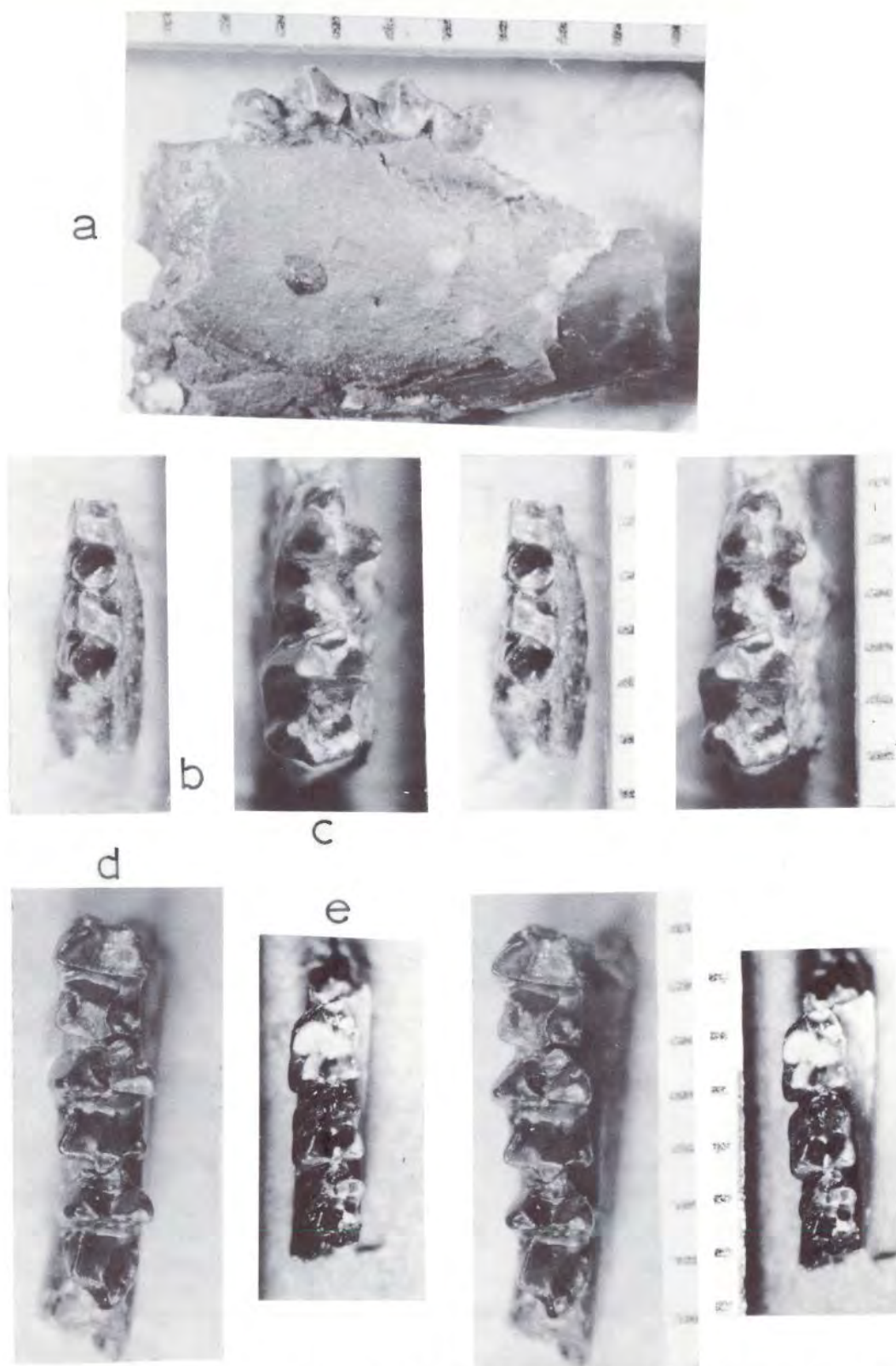
Figure 41. Proteutheria (a-d) and Insectivora (e) from the Sand Creek facies. a. UW 8999, labial view of right I, P_4-M_2 of *Apatemys* sp.; b. UW 9571, occlusal view of left M_{1-2} of *Apatemys* sp.; c. UW 10311, occlusal aspect of left P_4-M_1 of *Prodiacodon tauricinerei*; d. UW 9567, occlusal aspect of left M_{1-3} of *Prodiacodon tauricinerei*; e. UW 9568, occlusal aspect of left M_{1-3} of *Leipsanolestes* Cf. *seigfriedti*. The scales are in millimeters; figures b-e are stereophotographs.

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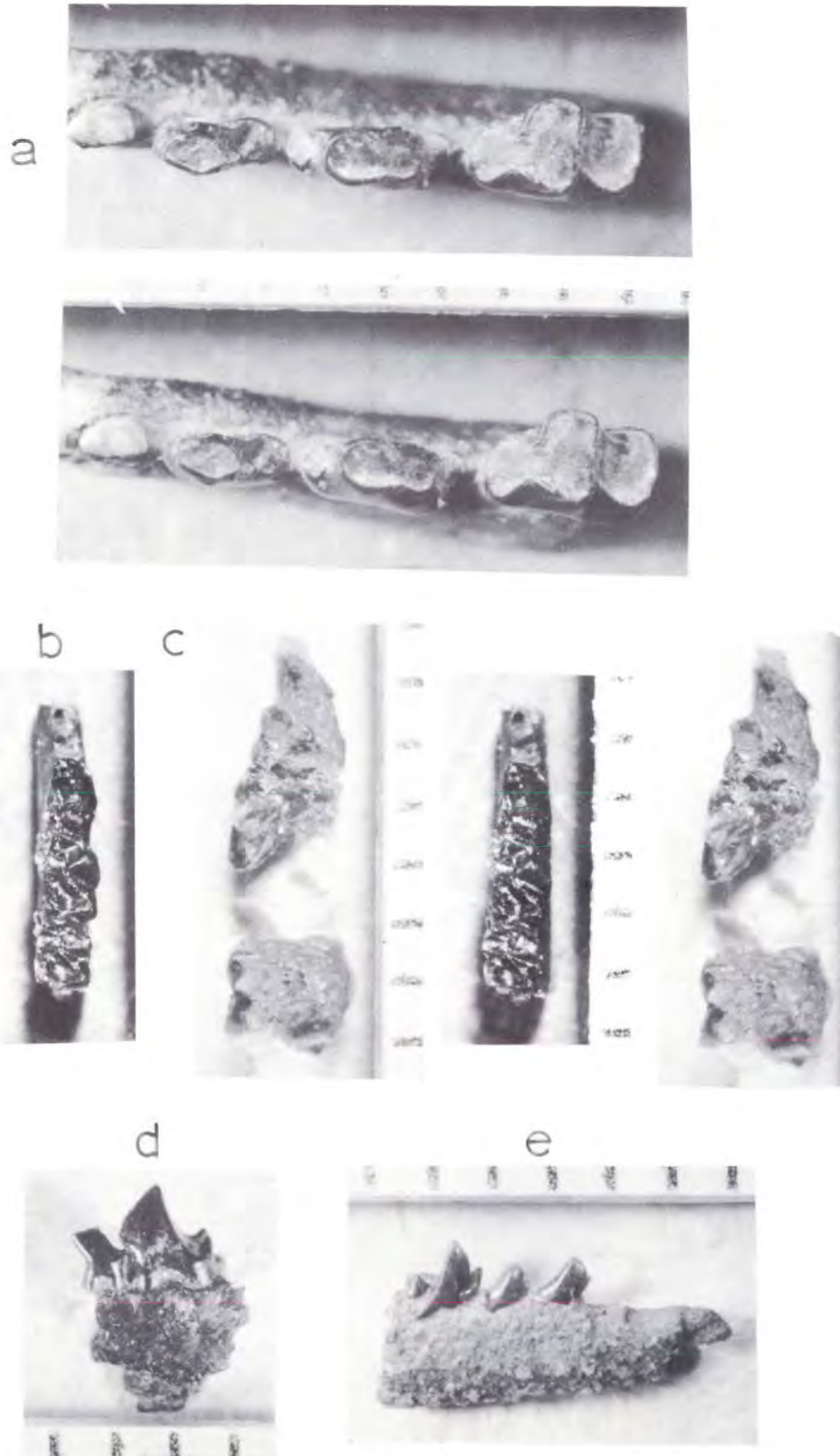
Figure 42. Proteutheria (a) and Insectivora (b-e) from the Sand Creek facies. a. UW 10159, occlusal aspect of left P_{1-4} of *Prodiacodon tauricinerei;* b. UW 9616, occlusal view of right P_4-M_2, type specimen of *Leipsanolestes simpsoni,* sp. nov.; c. UW 9638, occlusal apsect of right P^{3-4}, M^2 of Cf. *Scenopagus* sp., probably new; d. UW 8996, labial view of left P_{3-4} of *Macrocranion nitens;* e. UW 9682, labial view of right P_{2-4} of type specimen of *Plagioctenodon krausae,* gen. *et* sp. nov. The scales are in millimeters; figures a-c are stereophotographs.
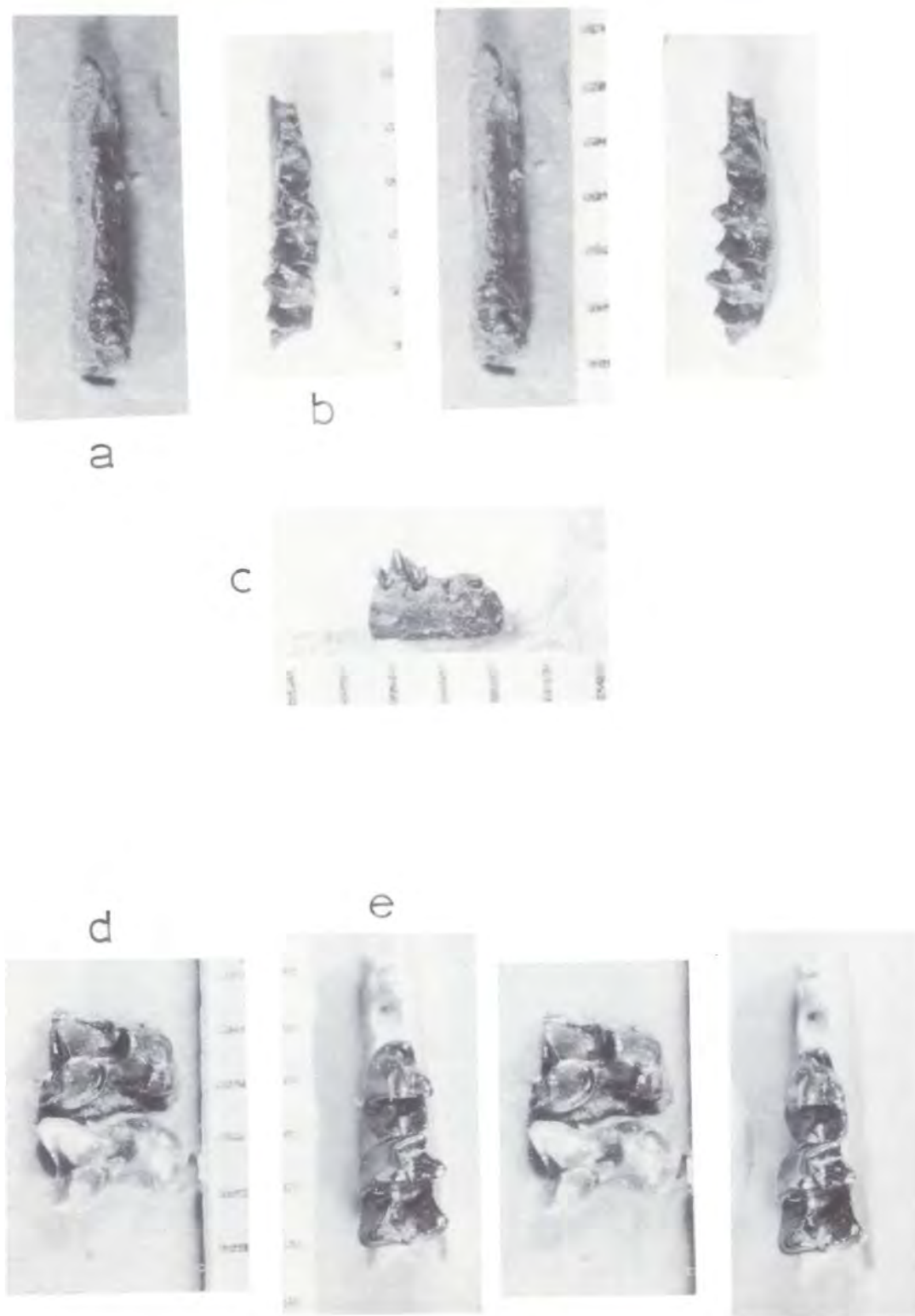
Figure 43. Insectivora from the Sand Creek facies. a. occlusal aspect of UW 9682, right P_{2-4} and type specimen of *Plagioctenodon krausae*, gen. *et* sp. nov.; b. UW 9624, occlusal aspect of right P_4-M_2 of *Plagioctenodon krausae*, gen. *et* sp. nov.; c. UW 9694, labial view of left P_{3-4}, holotype of *Plagioctenoides microlestes*, gen. *et* sp. nov.; d. UW 9730 and 10450, occlusal aspect of composite right M^{1-2} of adapisoricid indeterminate; e. UW 8998, occlusal aspect of left P_4-M_1 of adapisoricid, indeterminate. The scales are in millimeters; figures a, b, d, e are stereophotographs.

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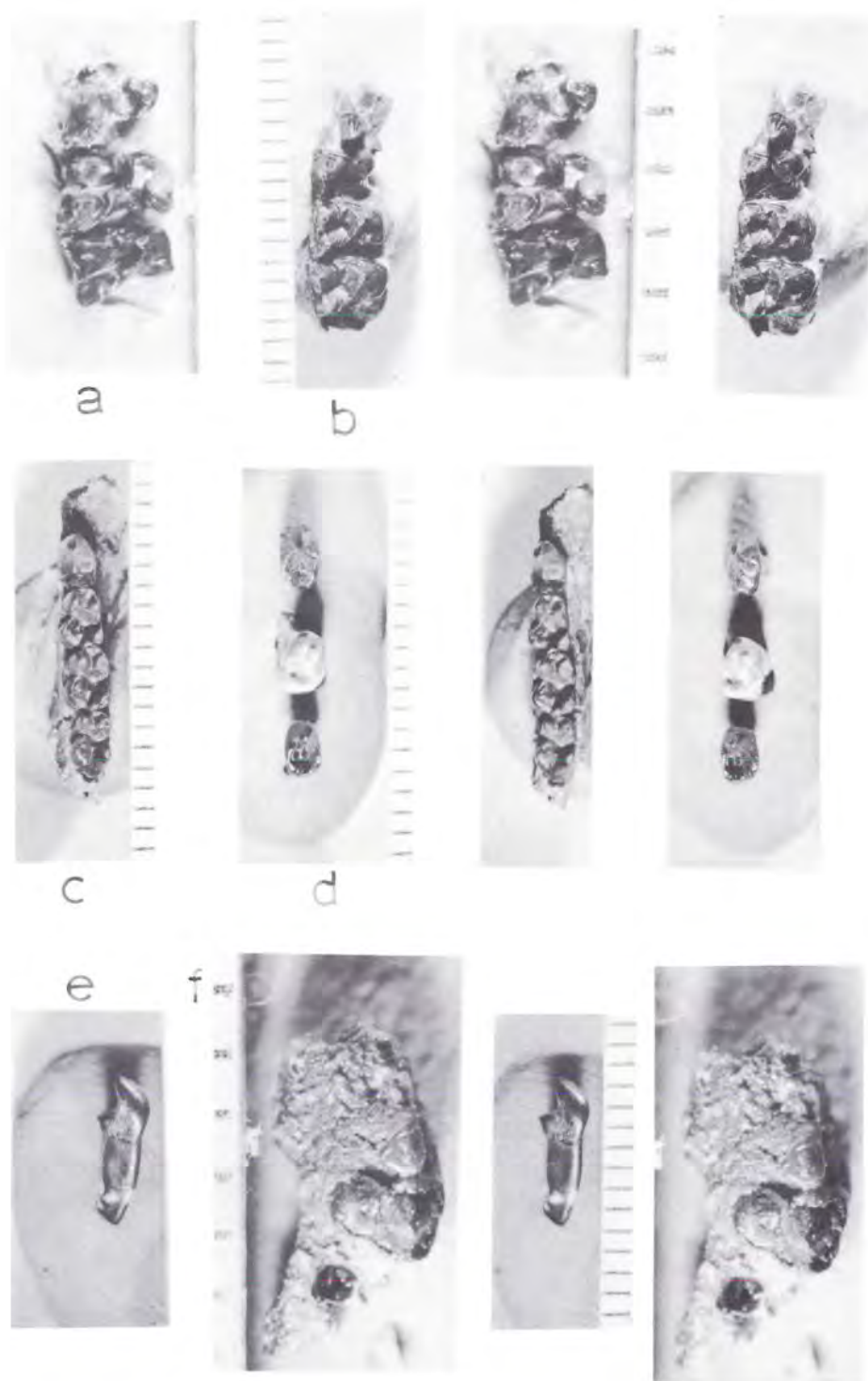
Figure 44. Insectivora (a) and Primates (b-f) from the Sand Creek facies. a. UW 10449 and 10456, occlusal aspect of composite right P^4-M^2 of *Pontifactor* Cf. *bestiola*; b. UW 10132, occlusal aspect of right P^3-M^2 of *Microsyops wilsoni*; c. UW 7194, occlusal aspect of left P_4-M_3 of *Microsyops wilsoni*; d. UW numbers 7112, 8838, and 8820, occlusal view of P_4 variation in *Microsyops wilsoni*; e. UW 6997, labial view of medial upper incisor of *Microsyops wilsoni*; f. UW 6897, occlusal aspect of left P^{3-4} of *Niptomomys doreenae*. The scales are in millimeters; all figures are stereophotographs.
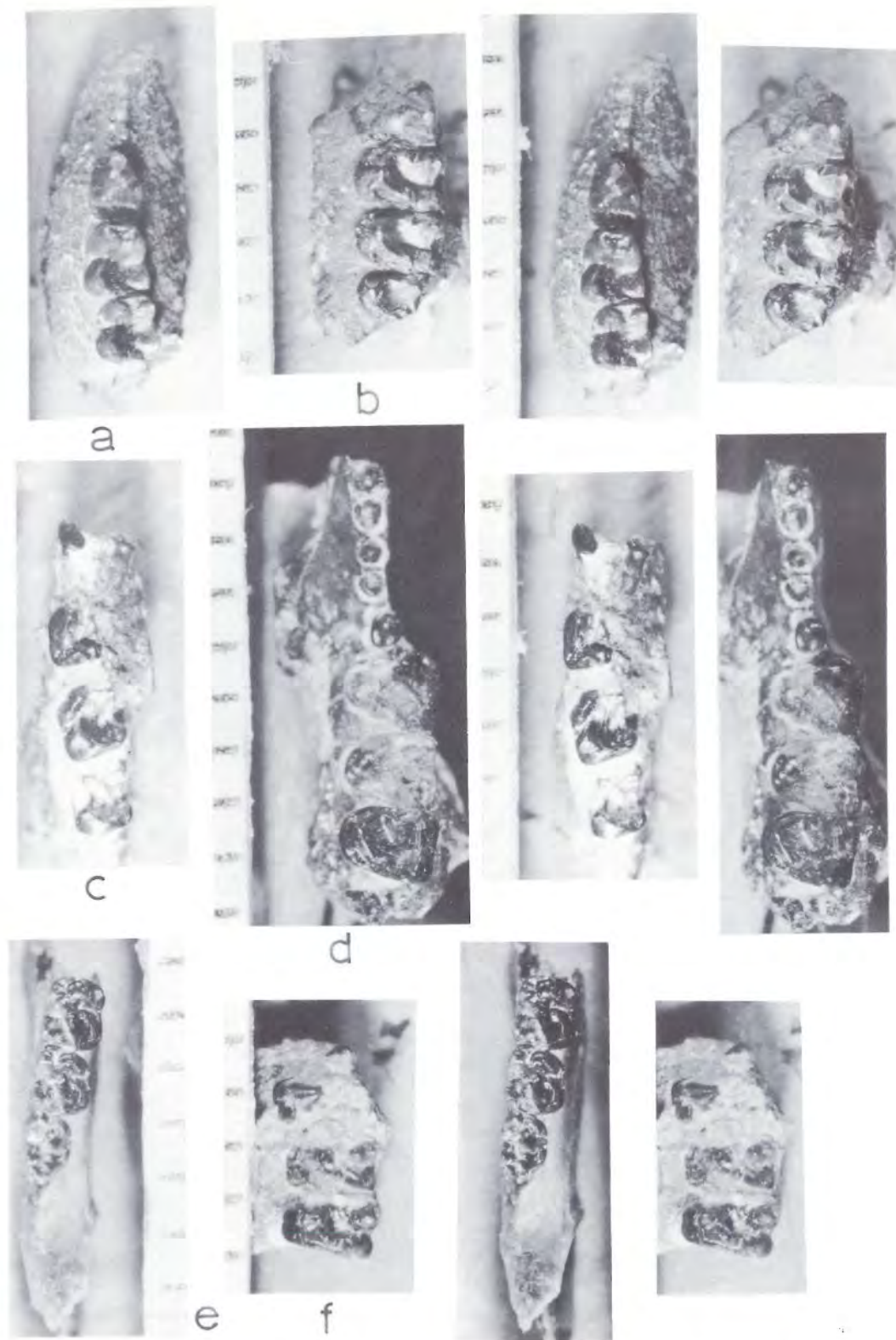
Figure 45. Primates from the Sand Creek facies. a. UW 7125, occlusal aspect of left P_3-M_2 of *Niptomomys doreenae*; b. UW 6898, occlusal aspect of left P^4-M^3 of *Niptomomys doreenae*; c. UW 8903, occlusal aspect of left P_2-M_2 of *Niptomomys doreenae*; d. PU 19550, occlusal aspect of left P^{3-4}, M^2 and alveoli for C/ and P^2 of *Niptomomys doreenae* (from the Willwood Fm. of the Clarks Fork Basin); e. UW 9410, occlusal aspect of right M_{1-3} of *Niptomomys doreenae*; f. UW 8956, occlusal aspect of left P^4-M^2 of *Tinimomys graybulliensis* (unprepared specimen). The scales are in millimeters; all figures are stereophotographs.
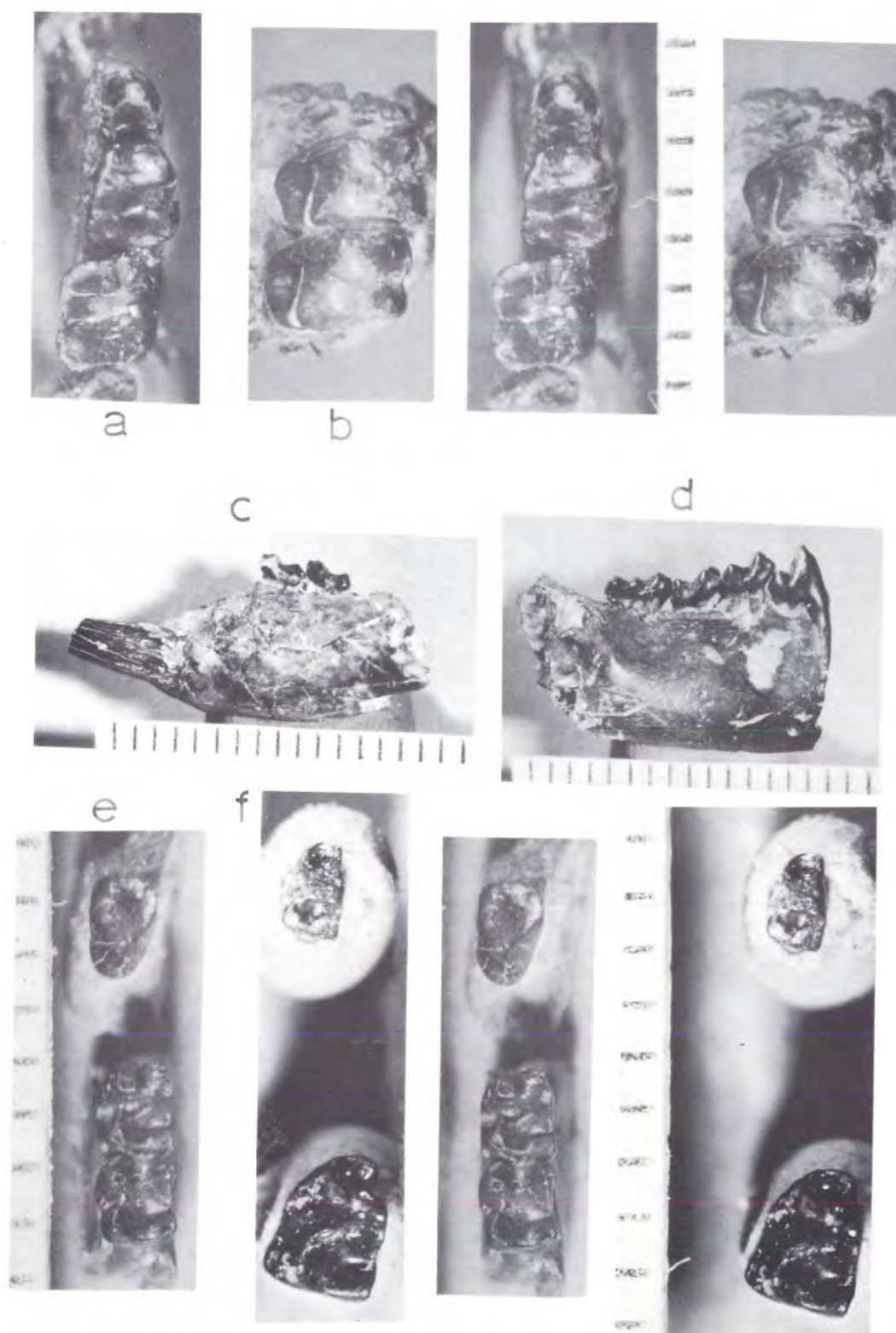
Figure 46. Primates from the Sand Creek facies. a. UW 7116, occlusal aspect of right P_4-M_2 of *Ignacius graybullianus*; b. UW 8954, occlusal aspect of left M^{1-2} of *Ignacius graybullianus*; c. UW 8907, labial view of left /I, M_{1-2} of *Ignacius graybullianus*; d. UW 10373, labial view of right P_4-M_3 of *Phenacolemur praecox*; e. uw 7322 and 7136, occlusal aspect of right P_4 and left M_{1-2} of *Phenacolemur simonsi*; f. UW 6795b, occlusal aspect of left dP_4 of *Phenacolemur simonsi*, and UW 10229, occlusal aspect of left dP_4 of *Phenacolemur praecox*. The scales are in millimeters; figures a, b, e, f are stereophotographs.
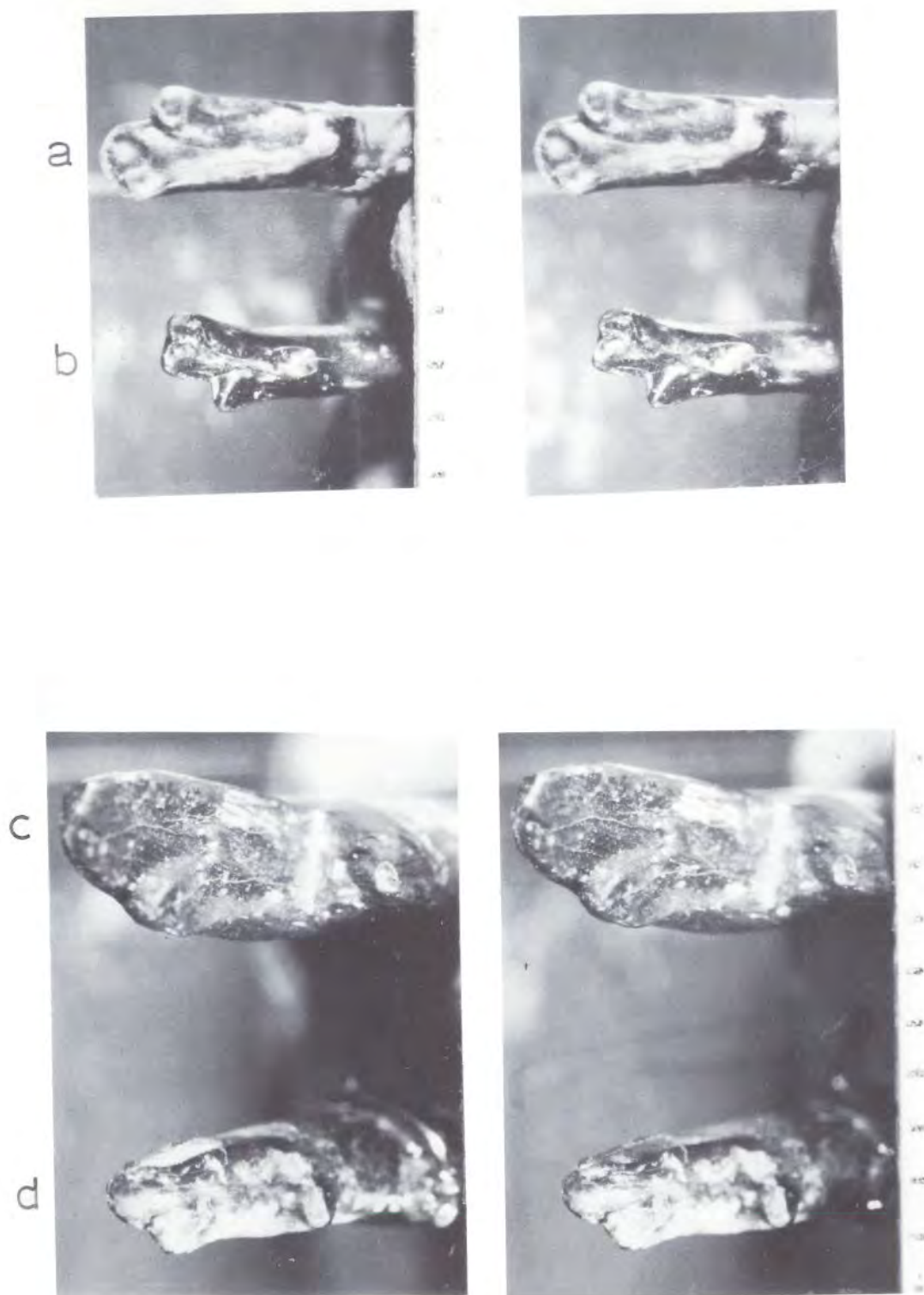
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Figure 47. Incisors of Primates from the Sand Creek facies (a and b) and from the Bison Basin (c and d). a. UW 8802, occlusal aspect of upper medial *left* incisor of *Phenacolemur praecox*; b. UW 10232, occlusal aspect of right upper medial incisor of *Phenacolemur simonsi*; c. UW 1086, occlusal aspect of right upper incisor of *Plesiadapis rex*; d. UW 2257, occlusal aspect of right upper incisor of *Plesiadapis* Cf. *anceps*. The scales are in millimeters; all figures are stereophotographs.
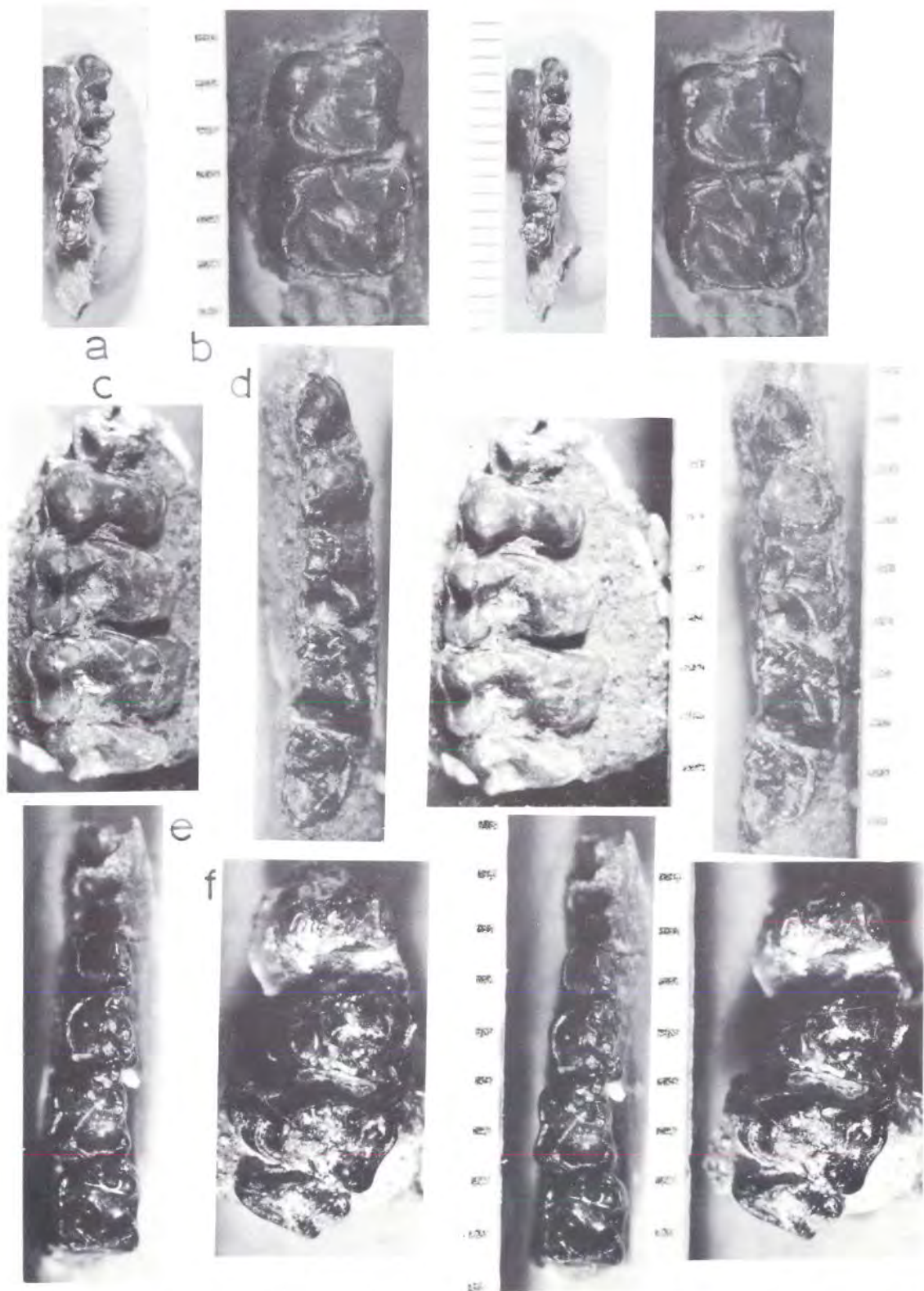
Figure 48. Primates from the Sand Creek facies. a. UW 10373, occlusal aspect of right P_4-M_3 of *Phenacolemur praecox*; b. UW 8953, occlusal aspect of left P^4-M^1 of *Phenacolemur praecox*; c. UW 6907, occlusal aspect of right P^3 (damaged), P^4-M^3 of *Tetonoides tenuiculus*; d. UW 7098, occlusal aspect of right P_3-M_3 of *Tetonoides tenuiculus*; e. UW 8959, occlusal aspect of left P_3-M_2 of *Tetonoides pearcei*; f. UW 8961, occlusal aspect of left P^4-M^3 of *Tetonoides tenuiculus*. The scales are in millimeters; all figures are stereophotographs.
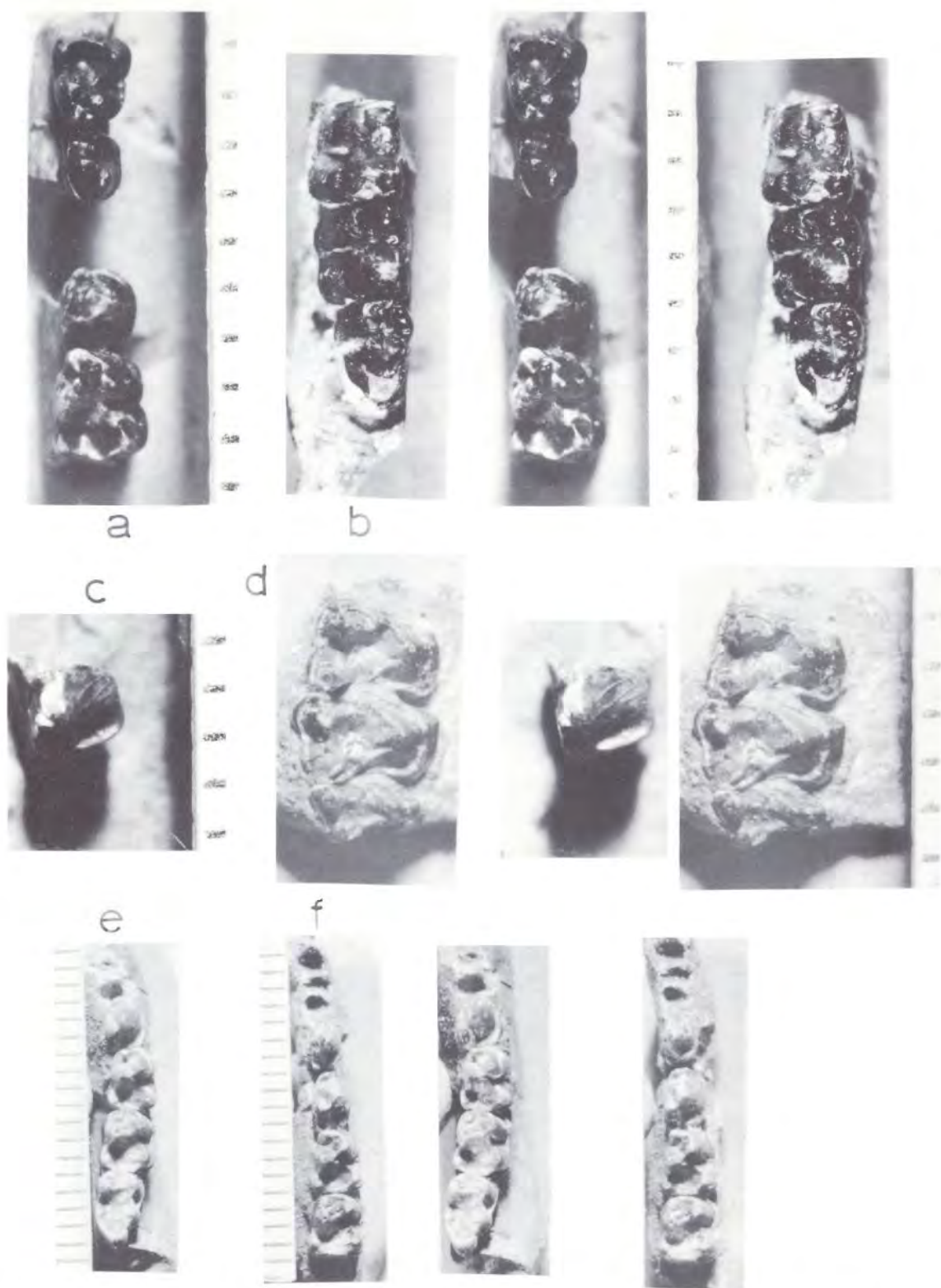
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Figure 49. Primates from the Sand Creek facies. a. UW 7165, occlusal aspect of left P_4-M_1 and UW 8960, occlusal aspect of right P_4-M_1 of *Tetonius homunculus*; b-UW 7910, occlusal aspect of left M_{1-3} of *Tetonius homunculus*; c. UW 8830, occlusal aspect of right P_4 of *Tetonius homunculus*; d. UW 7171, occlusal aspect of right M^{1-3} of *Tetonius homunculus*; e. UW 7063, occlusal aspect of right P_4-M_3 of *Pelycodus ralstoni*; f. UW 8842, occlusal aspect of right P_3-M_2 of *Pelycodus ralstoni*. The scales are in millimeters; all figures are stereophototgaphs.
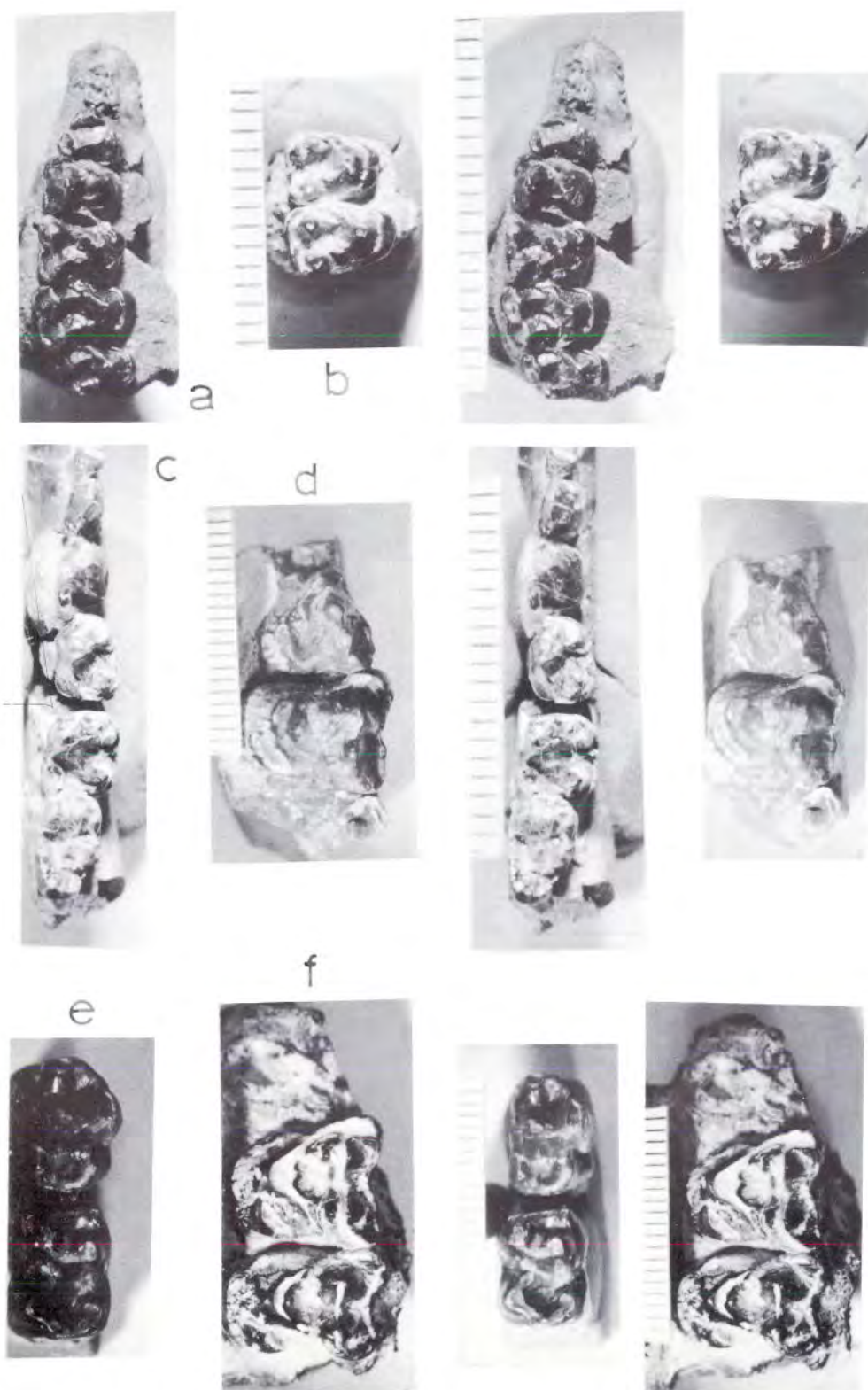
Figure 50. Primates (a-c) and Tillodontia (d-f) from the Sand Creek facies. a. UW 7066, occlusal aspect of right P^3-M^3 of *Pelycodus ralstoni*; b. UW 7068, occlusal aspect of right M^{1-2} of *Pelycodus ralstoni*; c. UW 8892, occlusal aspect of left P_3-M_3 of *Pelycodus trigonodus*; d. UW 9286, occlusal aspect of left P^{3-4} of *Esthonyx grangeri*; e. UW 9286, occlusal aspect of right P_4 and left M_1 of *Esthonyx grangeri*; f. UW 7436, occlusal aspect of left M^{1-2} of *Esthonyx grangeri*. The scales are in millimeters; all figures are stereophotographs.
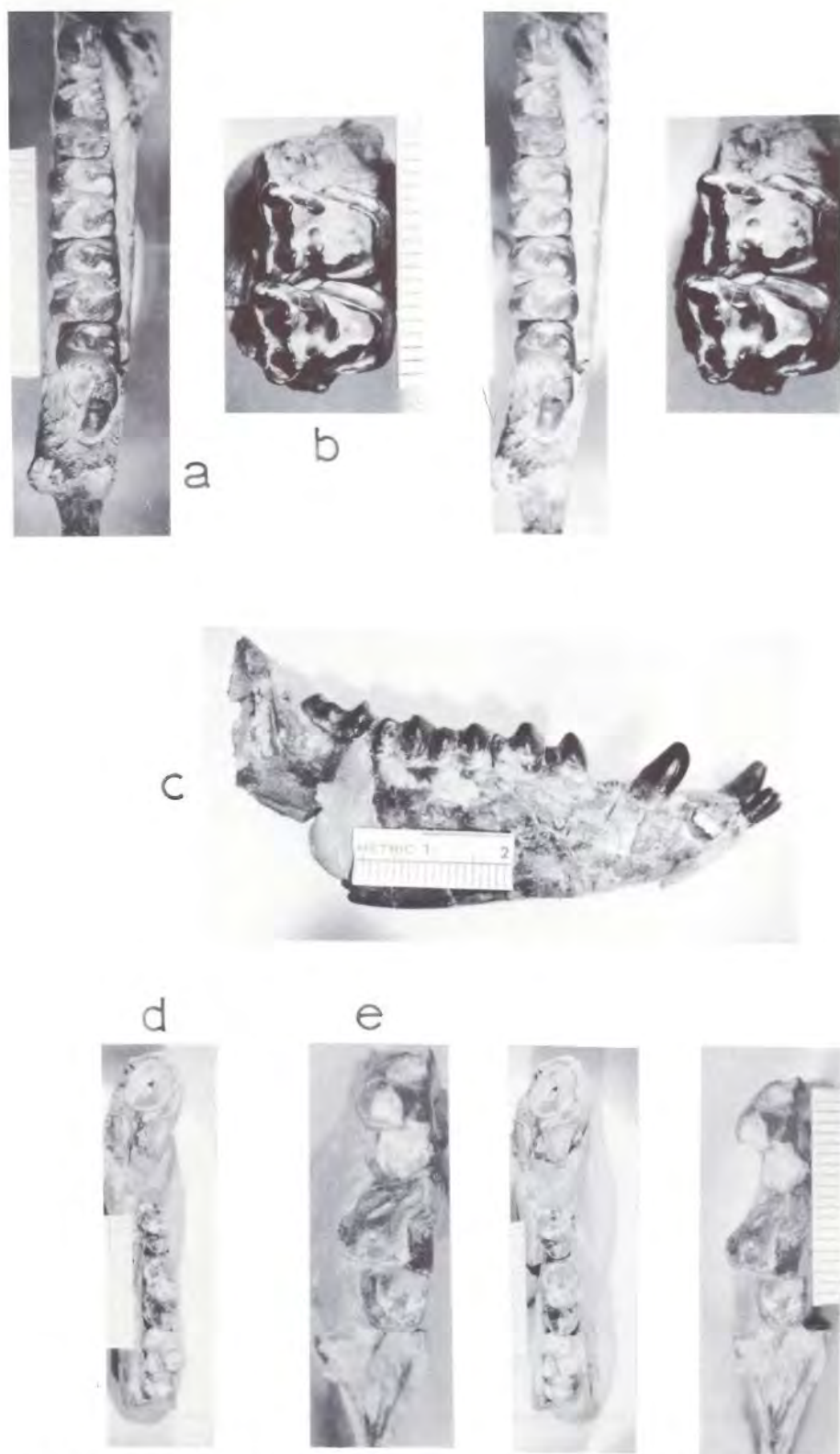
Figure 51. Tillodontia (a-c) and Creodonta (d, e) from the Sand Creek facies. a. UW 7448, occlusal aspect of left P_3-M_3 of *Esthonyx bisulcatus*; b. UW 7443, occlusal aspect of right M^{1-2} of *Esthonyx bisulcatus*; c. UW 7448, labial view of right I_1, C, P_3-M_3 of *Esthonyx bisulcatus*; d. UW 9759, occlusal aspect of right P_3-M_1 of *Oxyaena* sp., near *O. transiens*; e. UW 9790, occlusal aspect of left M_{1-2} of *Oxyaena* sp., near *O. transiens*. The scales are in millimeters; the scale in a is 2 cm long; figures a, b, d, e are stereophotographs.
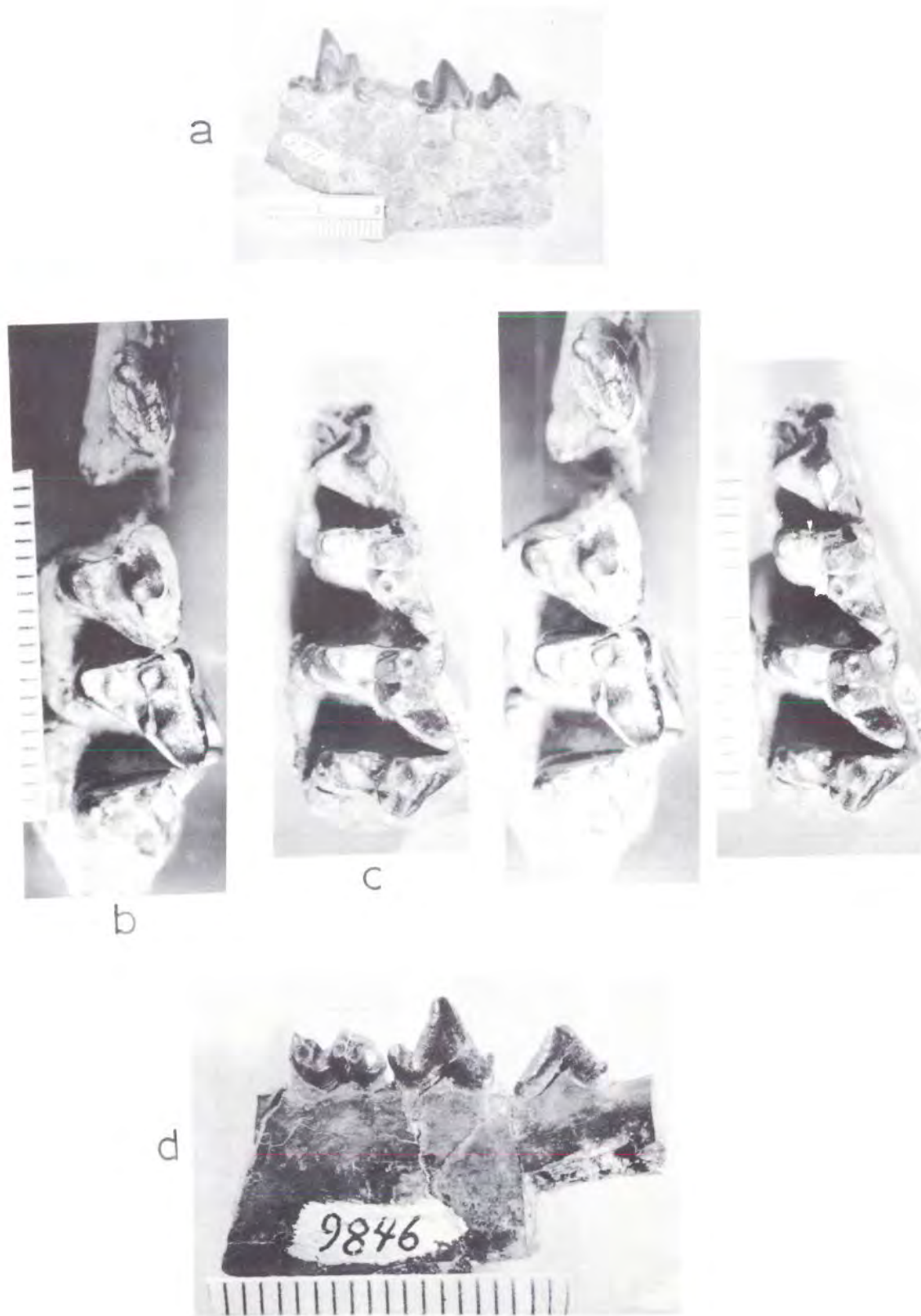
Figure 52. Creodonta from the Sand Creek facies. a. UW 9771, labial view of right P_{3-4}, M_2 of *Dipsalidictides amplus*; b. UW 9915, occlusal aspect of left P^2, P^4-M^1, M^2 (damaged) of *Arfia opisthotoma*; c. UW 9865, occlusal aspect of left P^4-M^3 of *Tritemnodon* sp.; d. UW 9846, labial view of right P_3-M_1 of *Tritemnodon* sp. The scales in b-d are in millimeters; the scale in a is 2 cm long; figures b and c are stereophotographs.
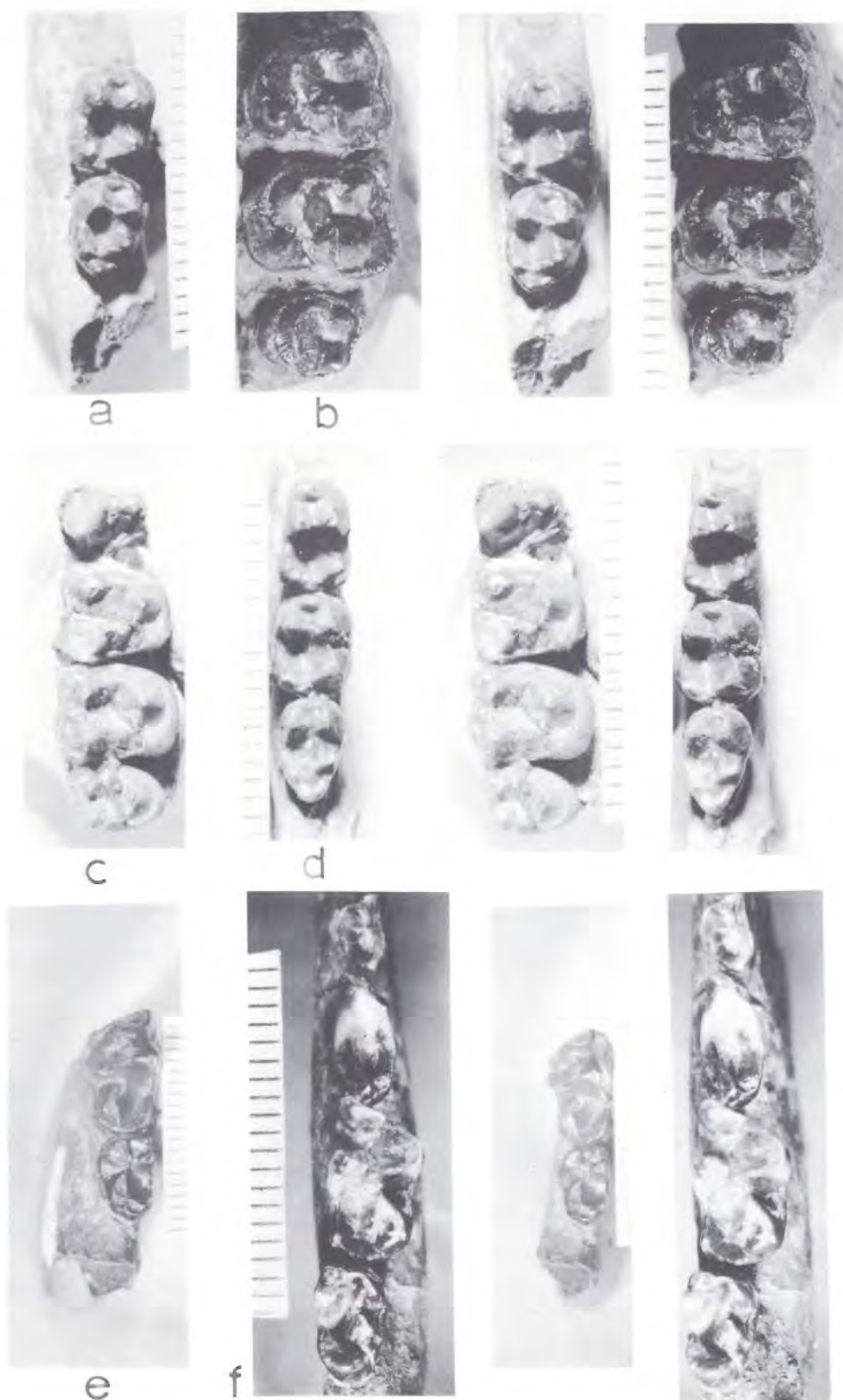
Figure 53. Arctocyonia (a-d) and Carnivora (e, f) from the Sand Creek facies. a. UW 7413, occlusal aspect of right M_{2-3} of *Thryptacodon* Cf. *antiquus*; b. UW 7412, occlusal aspect of left M^{1-3} of *Thryptacodon* Cf. *antiquus*; c. UW 7421, occlusal aspect of right P^4-M^3 of *Thryptacodon* Cf. *antiquus*; d. UW 7421, occlusal aspect of right M_{1-3} of *Thryptacodon* Cf. *antiquus*; e. UW 9772, occlusal aspect of left M_{1-2} of large variety of *Didymictis protenus*; f. UW 9786, occlusal aspect of right P_4-M_2 of small variety of *Didymictis protenus*. The scales are in millimenters; all figures are stereophotographs.
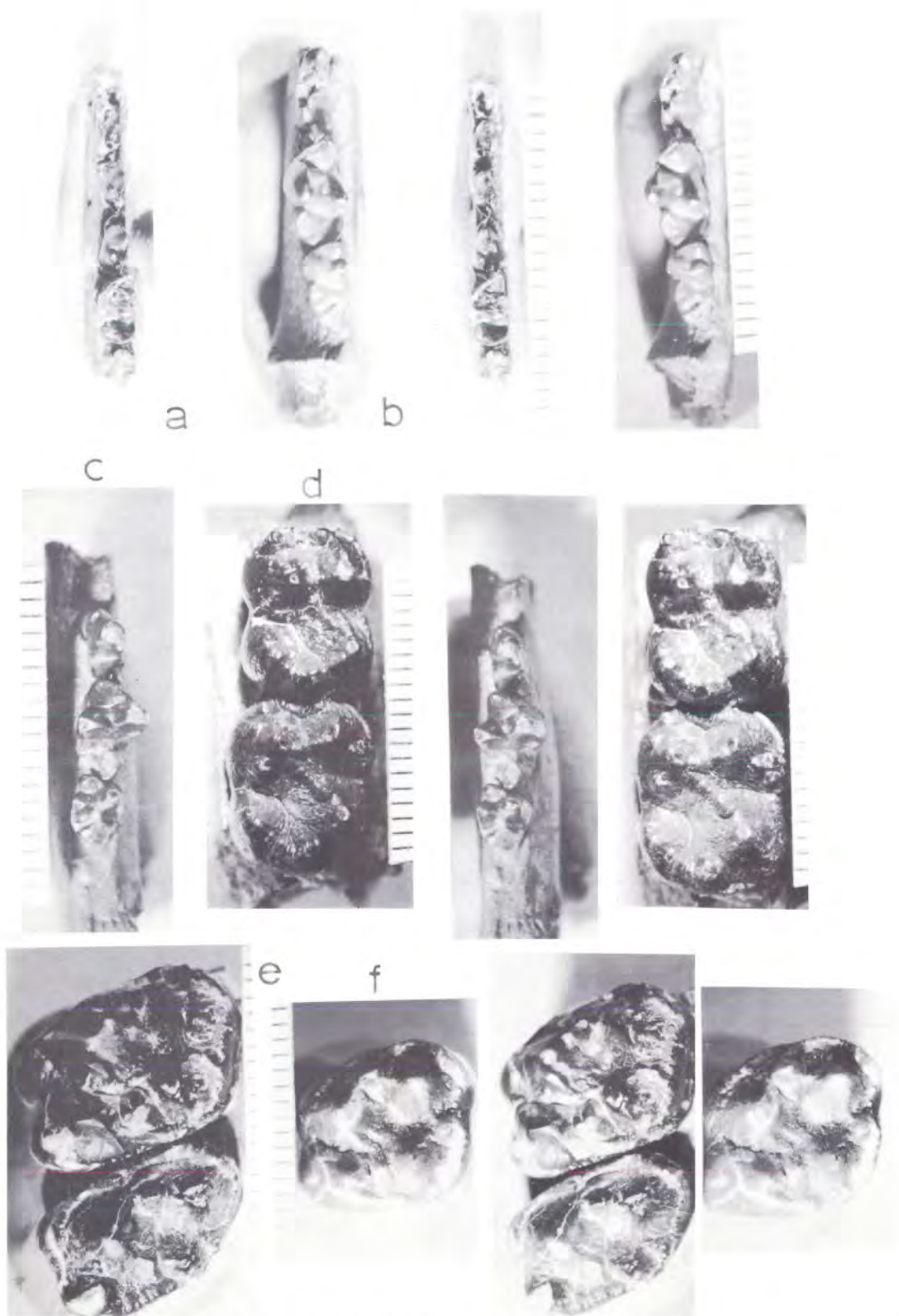
Figure 54. Carnivora (a-c) and Condylarthra (d-f) from the Sand Creek facies. a. UW 9832, occlusal aspect of left P_2-M_1 of *Viverravus* Cf. *acutus*; b. UW 9776, occlusal aspect of left P_4-M_2 of *Viverravus politus*; c. UW 9913, occlusal aspect of right P_4-M_2 of *Uintacyon massetericus*; d. UW 9273, occlusal aspect of right M_{1-2} of *Phenacodus primaevus*; e. UW 7460, occlusal aspect of left M^{2-3} of *Phenacodus primaevus*; f. UW 7475, occlusal aspect of left M^1 of *Phenacodus ?primaevus*. The scales are in millimeters; all figures are stereophotographs.

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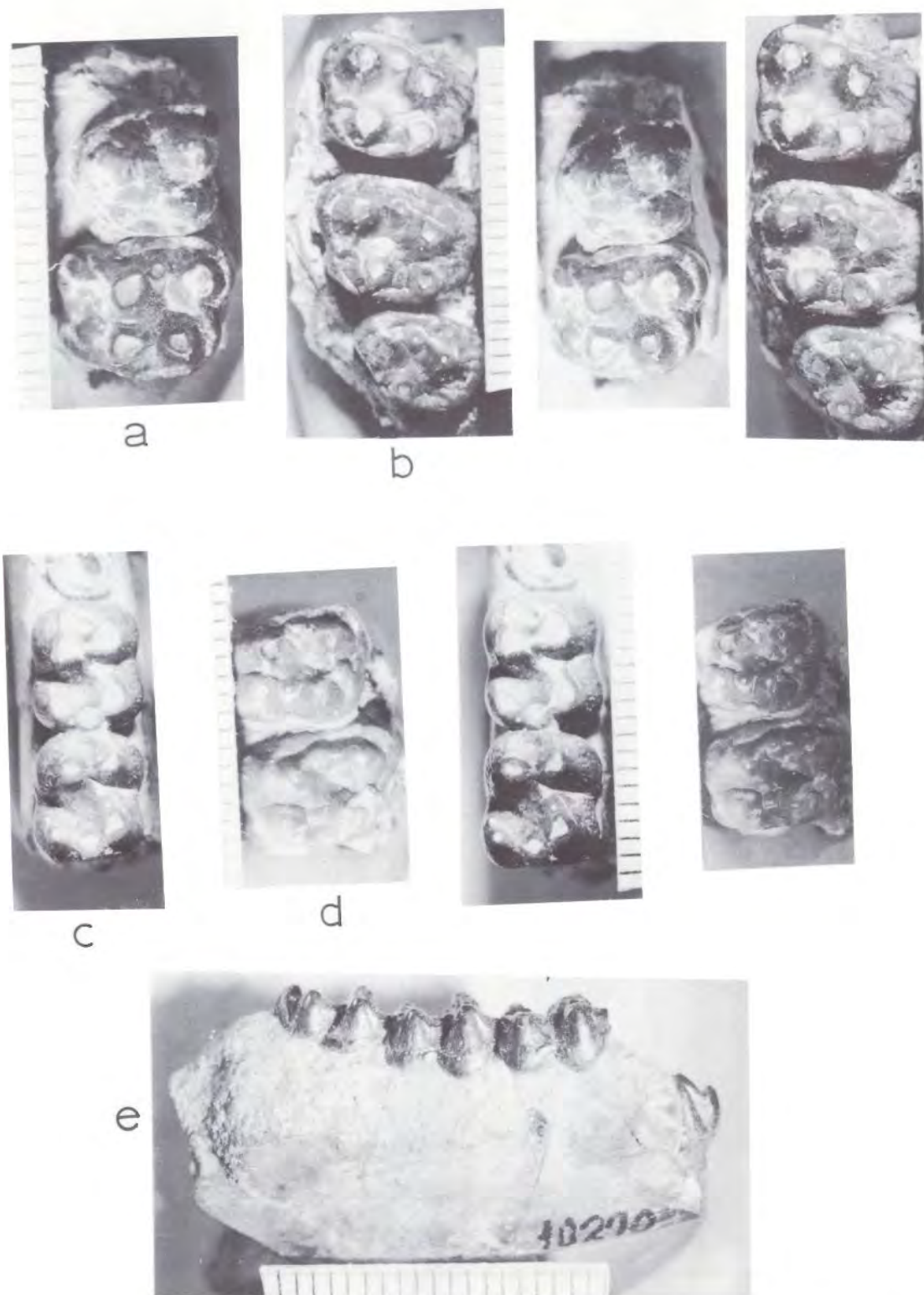
Figure 55. Condylarthra from the Sand Creek facies. a. UW 10396, occlusal aspect of left P^4-M^1 of *Phenacodus vortmani*; b. UW 9275, occlusal aspect of right M$^{1-3}$ of *Phenacodus vortmani*; c. UW 7468, occlusal aspect of right M$_{1-2}$ of *Phenacodus vortmani*; d. UW 7465, occlusal aspect of left M$^{1-2}$ of *Phenacodus brachypternus*; e. UW 10270, labial view of right P$_4$ (eruptive), M$_{1-3}$ of *Ectocion* Cf. *osbornianus*. The scales are in millimeters; figures a-d are stereophotographs.
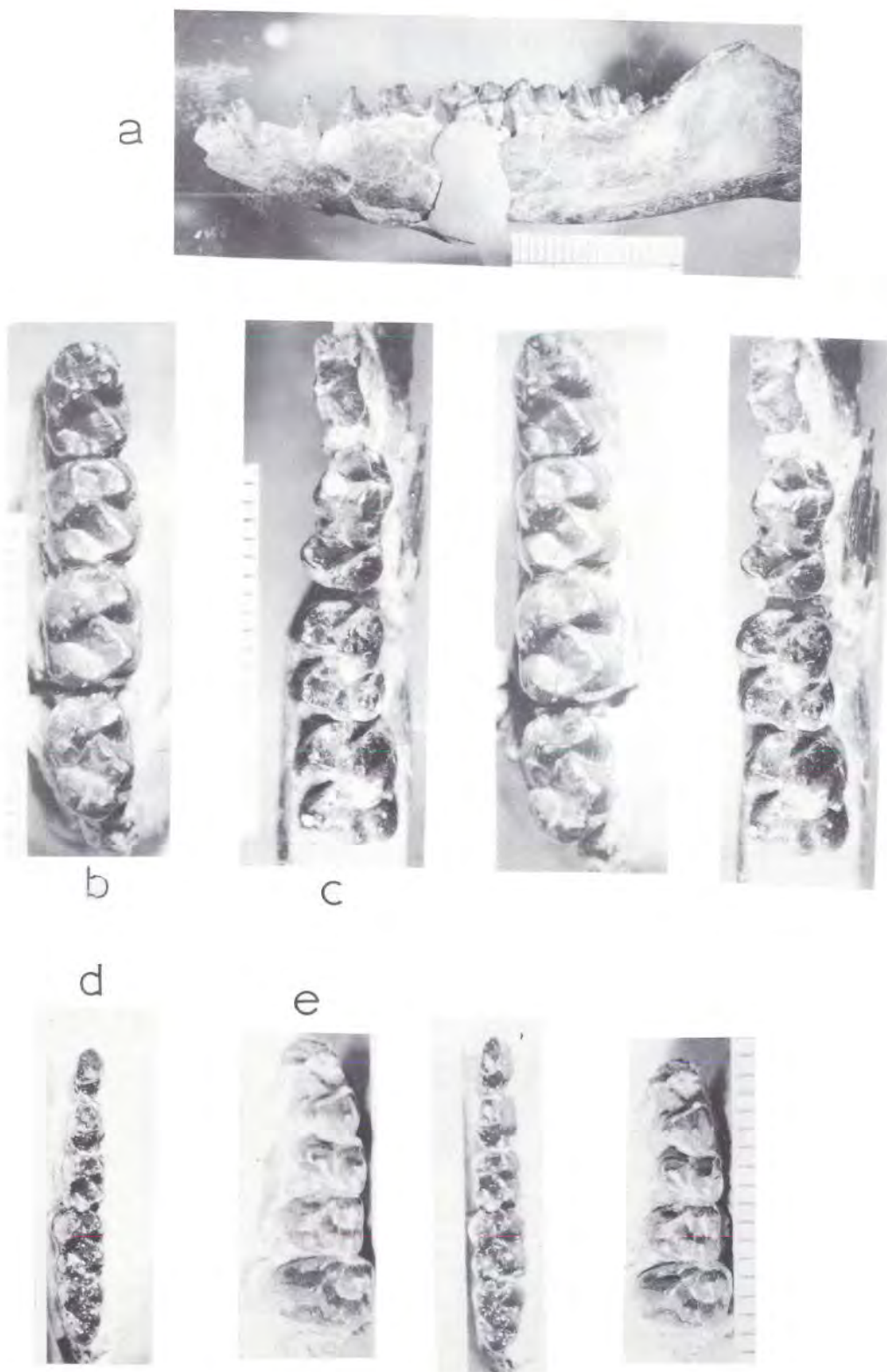
Figure 56. Condylarthra from the Sand Creek facies. a. UW 10267, labial view of left /C, P_{1-2}, dP_{3-4}, M_{1-3} (M_3 in crypt) of *Ectocion* Cf. *osbornianus*; b. UW 10269, occlusal aspect of right P_4-M_3 of *Ectocion* Cf. *osbornianus*; c. UW 10268, occlusal aspect of left dP_{3-4}, M_{1-2} and crypt for M_3 of *Ectocion* Cf. *osbornianus*; d. UW 9178, occlusal aspect of right P_3-M_3 of *Hyopsodus* sp.; e. UW 9113, occlusal aspect of left P^3-M^2 of *Hyopsodus*, sp. nov. The scales are in millimeters; figures b-e are stereophotographs.
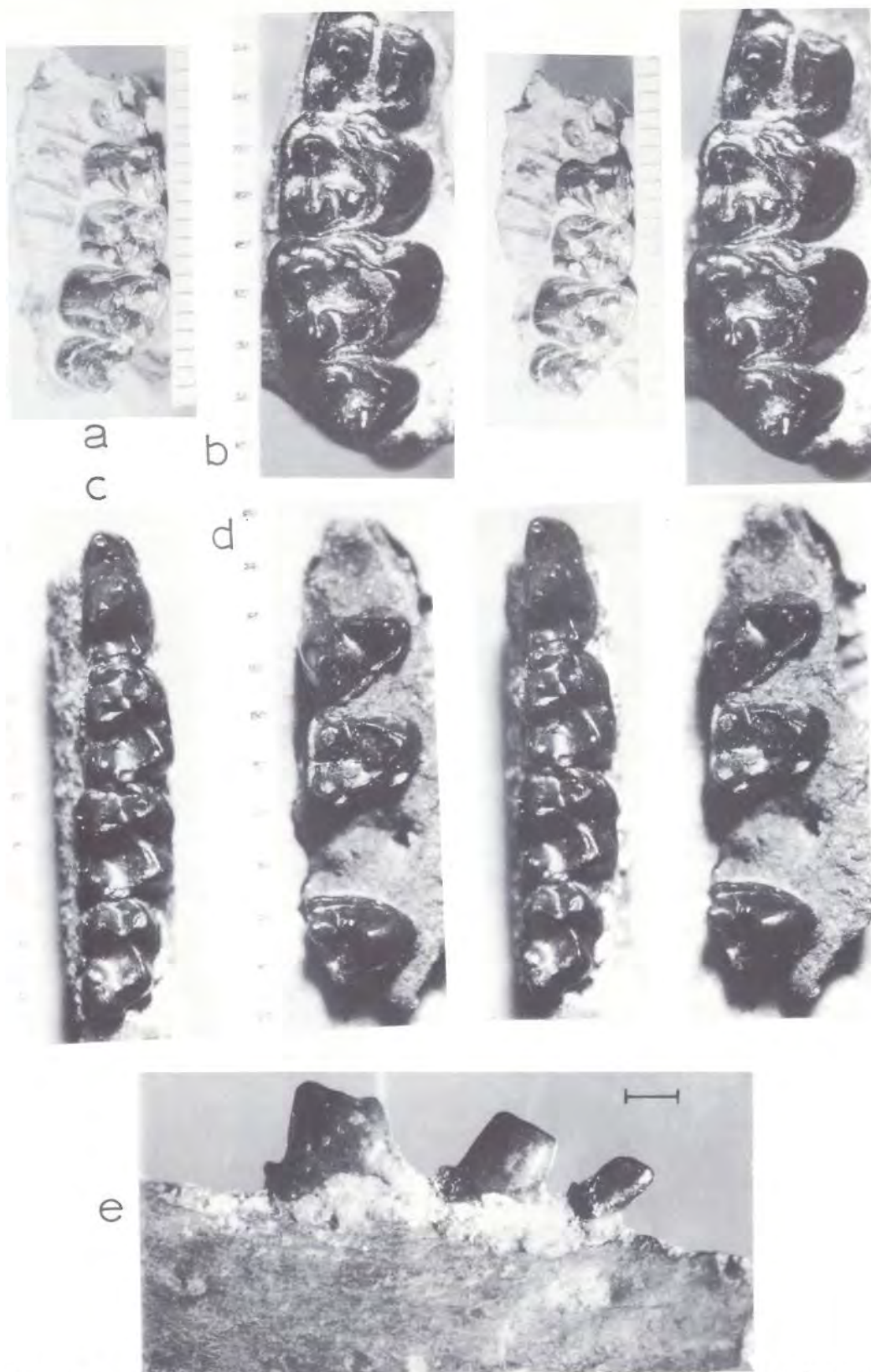
Figure 57. Condylarthra from the Sand Creek facies. a. UW 7677, occlusal aspect of left P^4-M^3 of *Hyopsodus* sp.; b. UW 8360, occlusal aspect of right P^4-M^3 of *Haplomylus speirianus*; c. UW 8361, occlusal aspect of right P_4-M_3 of *Haplomylus speirianus*; d. UW 7335, occlusal aspect of right P^4-M^1, M^3 of *Apheliscus* Cf. *insidiosus*; e. UW 8685, labial view of right P_{1-3} of *Haplomylus speirianus*. The scales are in millimeters; figures a-d are stereophotographs.
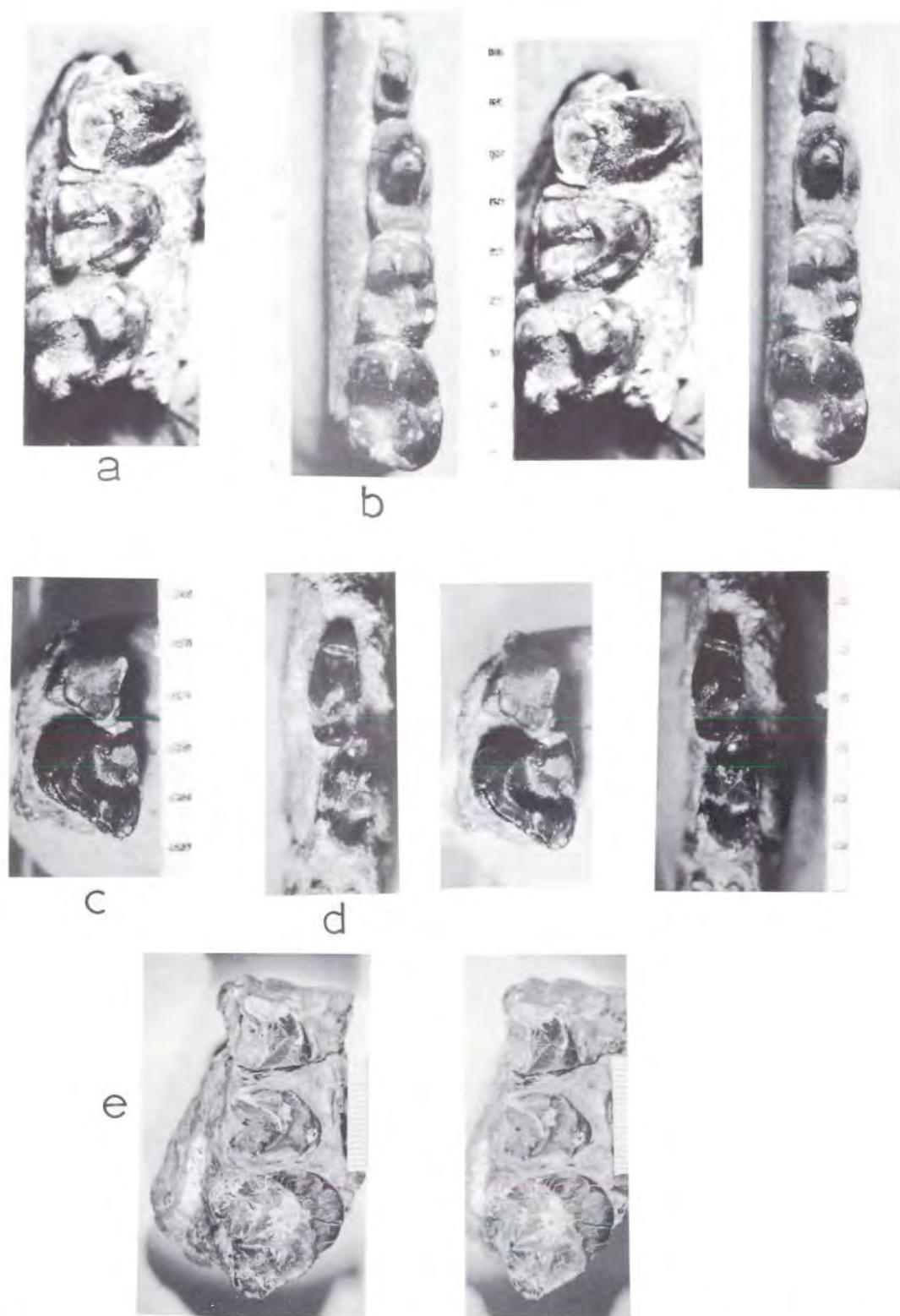
Figure 58. Condylarthra (a-d) and Pantodonta (e) from the Sand Creek facies. a. UW 7338, occlusal aspect of right P^4-M^2 of *Apheliscus* Cf. *insidiosus*; b. UW 8647, occlusal aspect of right P_3-M_2 of *Apheliscus* Cf. *insidiosus*; c. UW 7340, occlusal aspect of left dP^{3-4} of *Apheliscus* Cf. *insidiosus*; d. UW 7331, occlusal aspect of left dP_{3-4} of *Apheliscus* Cf. *insidiosus*; e. UW 9509, occlusal aspect of right dP^{2-4} of *Coryphodon* sp. The scales are in millimeters; all figures are stereophotographs.
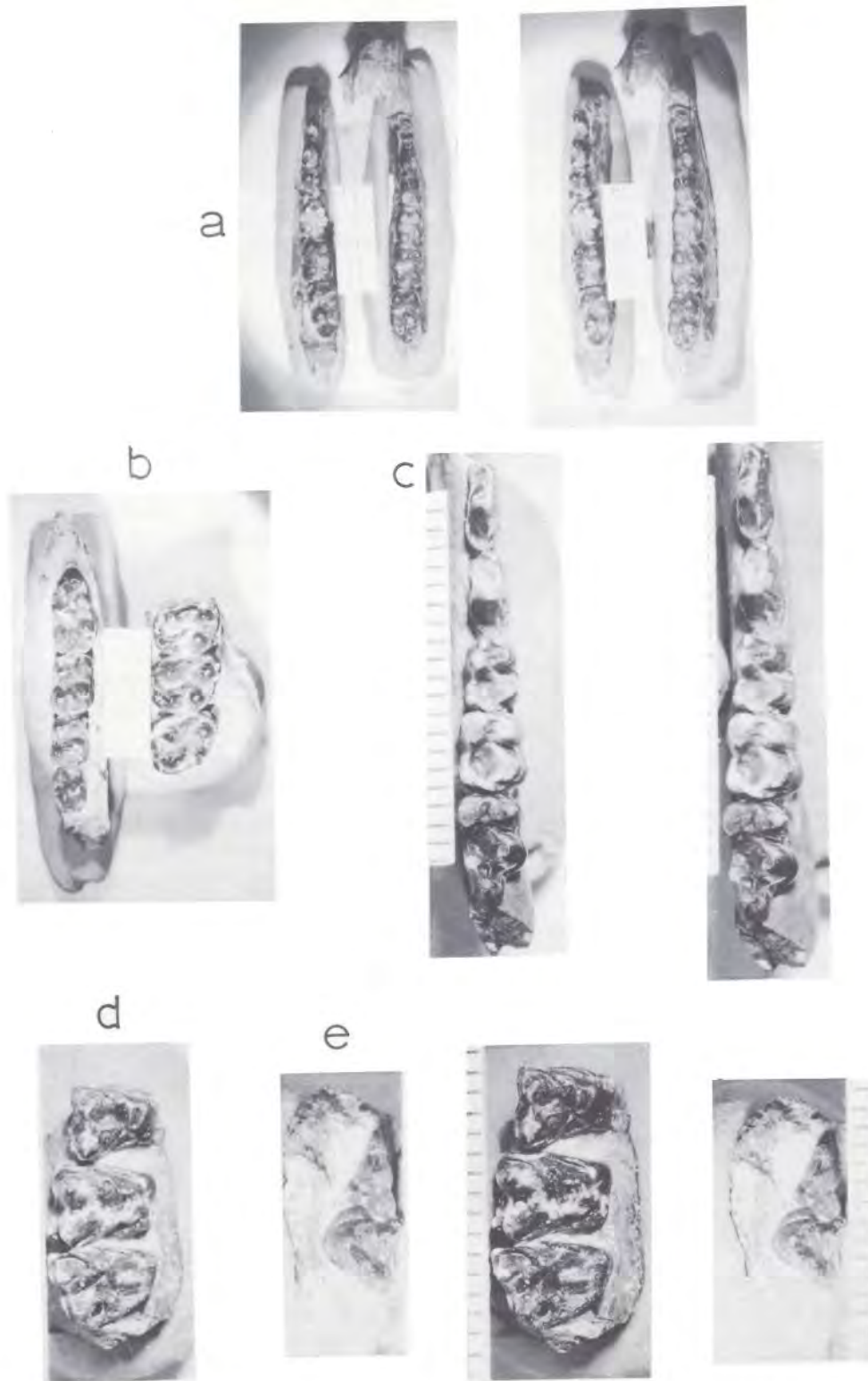
Figure 59. Perissodactyla (a, b) and Artiodactyla (c-e) from the Sand Creek facies. a. UW 7924, occlusal aspect of left P_2-M_3 and right P_3-M_3 of *Hyracotherium* Cf. *angustidens*; b. UW 8201, occlusal aspect of right P_4-M_3 and left M^{1-3} of *Hyracotherium* sp.; c. UW 7571, occlusal aspect of right P_3-M_3 of *Diacodexis* Cf. *metsiacus*; d. UW 9213, occlusal aspect of right M^{1-3} of *Diacodexis* Cf. *metsiacus*; e. UW 7537, occlusal aspect of left dP^{3-4} of *Diacodexis* Cf. *metsiacus*. The scales are in millimeters; the scales in a and b are 2 cm long; figures a, c, d, and e are stereophotographs.

FAUNAL COMPOSITION

COLLECTING BIAS

Because very large collections of fossil mammals were obtained from Class A gray mudstones and because these mudstones were exploited by quarry, wash, and surface prospecting techniques of collecting, an estimate of collecting bias can be made.

Both large and small skeletal elements were recovered by all three techniques. Samples of fossils recovered by each technique were catalogued separately in the field. Later, all of the specimens were separated into four size range categories on the basis of relative size of M_1. The following table shows percentages of total recovery, by recovery method, for each size range (Q = quarry; W = wash; S = surface prospecting):

		Techniques		
Mean size ranges of M_1		Q	W	S
Plagioctenoides	- Apheliscus size	2%	17%	81%
Haplomylus	- Pelycodus size	5%	15%	80%
Diacodexis	- Hyracotherium size	1%	9%	90%
Arfia	- Coryphodon size	1%	6%	93%

From these data, it is clear that 81 of 100 small mammal specimens were recovered by surface prospecting techniques, only 12 percent less than the percentage of large mammal specimens collected by this method; i.e., surface prospecting collection alone results in the collection of a slightly larger proportion of large than small mammal specimens, compared with their actual abundances.

FAUNAL ABSENCES

The Sand Creek facies apparently lacks some mammals expected in large collections from lower Willwood rocks. Some of these, e.g. Arctostylops, Probathyopsis, Ectoganus, and Palaeanodon*, are so rare in other lower Willwood faunules that their absence in the No Water fauna is hardly surprising. The forms listed below, however, are relatively common elements of other well-sampled lower Willwood faunules or their probable equivalents

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*Since this paper was written, a specimen of Palaeanodon Cf. ignavus was recovered at locality V-73125.

in other basins, yet have not been identified in the Sand Creek facies:

Homogalax
Plagiomene (abundant at a few central basin Willwood localities)
Dissacus
Miacis
Meniscotherium (two possible Willwood specimens; locally abundant in early Wasatchian faunas of southwestern Wyoming)

FAUNAL ABUNDANCES

Other taxa are characterized by abnormal relative abundances in the Sand Creek facies faunules: e.g.,

1. Haplomylus is more than three times as abundant as Hyposodus and comprises more than 25 percent of the total fauna.
2. Ectocion Cf. osbornianus is more than three times as abundant as all species of Phenacodus combined.
3. Pelycodus ralstoni is more abundant than all of the Rodentia.
4. Hyracotherium makes up only 10-12 percent of the fauna.
5. Apheliscus comprises 4 percent of the fauna.
6. Thryptacodon comprises more than 2 percent of the total fauna and is much better represented than in any other Willwood samples.

RANGE EXTENSIONS

The following taxa are recorded for the first time in Willwood rocks:

Parectypodus sp. "A"
Leipsanolestes Cf. siegfriedti
Chriacus sp.
Peradectes chesteri
Scenopagus sp.
Oödectes Cf. herpestoides

Peradectes, Parectypodus, Leipsanolestes, and Chriacus are known from other Wasatchian faunules outside the Bighorn Basin. Scenopagus and Oödectes are documented for the first time from rocks of Wasatchian age. (Scenopagus was recorded by Krishtalka, 1976a, while this manuscript was in press.)

COMPARISON WITH THE FOUR MILE FAUNA

Because there is no empirical evidence suggesting that certain elements of the mammal fauna of the Sand Creek facies were differentially fossilized or that they were concentrated by the vagaries of replacement, stream transport and sorting, or transport in feces, or that collecting bias was a significant factor, comparisons of the relative representation of mammalian taxa with other similar assemblages are of interest.

The Four Mile Fauna (McKenna, 1960) was chosen for comparison with the No Water fauna because both faunas are large and diverse, both faunas are believed to be of similar antiquity, both faunas were collected using a variety of techniques, and the Four Mile Fauna has been analyzed with respect to faunal composition, and is otherwise the best documented collection of early Wasatchian mammals.

The composition of the Four Mile fauna was assessed by the incorporation of the data of McKenna (1960, p. 13-25) with studies of the composition of additional samples housed at the American Museum of Natural History. Allowance for taxonomic revisions since 1960 has been made where possible.
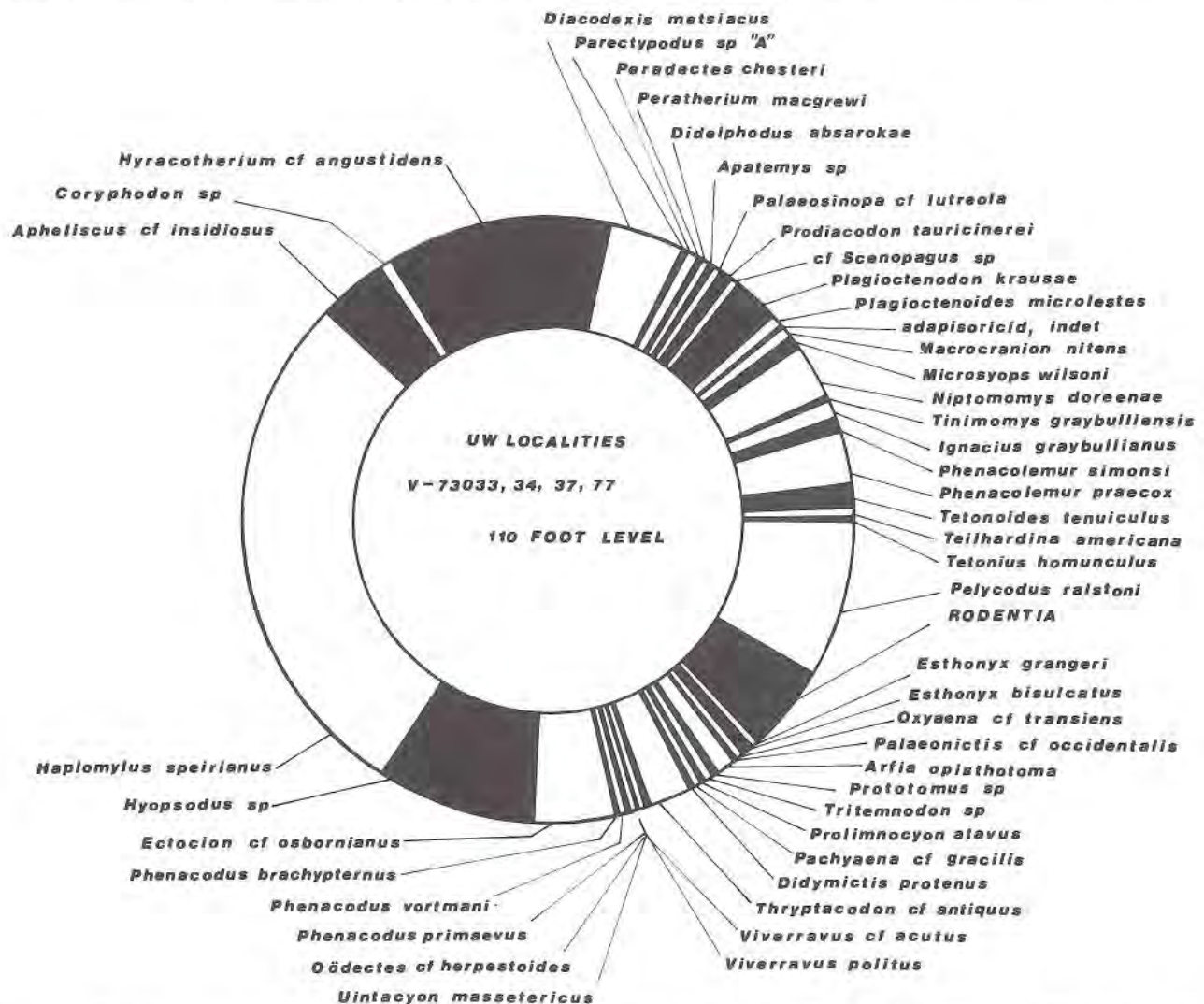
Figure 60. Relative representation of mammalian taxa at the 110 foot (33.5 m) level of the Willwood Formation (Sand Creek facies), in the Slick Creek Basin. This level is the richest known in the Sand Creek facies and has contributed about 23 percent of all the specimens described in this report; all are from a single Class A gray mudstone bed. The number of degrees in each sector was calculated from the mimimum number of individuals of each taxon necessary to account for all identifiable fossil specimens. About 800 fragmentary ramal and maxillary specimens and approximately 1,900 isolated teeth were studied in preparing this diagram.

Localities V-73033, 73034, 73037, and 73077 were developed in a single persistent Class A gray bed at the 110 foot (34 m) level of the Willwood Formation in the Slick Creek Basin. Approximately 800 mandibular and maxillary specimens and numerous teeth were recovered from this richly fossiliferous bed. Figure 60 depicts the relative species composition of the mammal fauna at this level. Similar results, but based on fewer specimens, were obtained for rich faunules at the 97, 150, and 319 foot (30, 46, and 97 meter) levels. The differences in abundance and diversity between the No Water and Four Mile faunas are depicted in Table 34.

From these comparisons, the following significant distinctions between the Four Mile and No Water faunas were noted: (1) The Multituberculata are equally diverse in both faunas, but are at least six times more abundant in the Four Mile fauna. (2) *Peratherium* and a new, large, and aberrant marsupial (Bown and Rose, 1979) are present in addition to *Peradectes* in the No Water collections, but the marsupials are about equally abundant in both faunas. (3) Insectivores and proteutherians are similarly diverse in both faunas, but are at least twice as abundant at Four Mile. (4) Primates are both more diverse and more abundant in the Sand Creek facies, but non-notharctines, although more diverse, are less abundant in the Sand Creek facies. (5) *Apheliscus* and *Haplomylus* are, together, at least two and one-half times as abundant in the Sand Creek facies. (6) Small phenacodonts are present in both faunas, but *Ectocion* is much more abundant in the Sand Creek facies. (7) The *Phenacodus primaevus* group is rare in both faunas and may be slightly more abundant at Four Mile. (8) *Homogalax* and *Hyracotherium* combined are slightly more than half as abundant at Four Mile than is *Hyracotherium* alone in the No Water collection. (9) *Hyopsodus* is nearly twice as abundant at Four Mile. (10) The Rodentia dominate the Four Mile fauna (23.2 percent) but comprise less than 7 percent of the No Water fauna. (11) The pantodonts are rare elements of both faunas, but may be slightly more abundant in the Sand Creek facies. (12) The tillodonts are more abundant in the Sand Creek facies and are represented there by two species, as opposed to one at Four Mile. Tillodonts are rare elements of both faunas. (13) The artiodactyls are more diverse at Four Mile with the presence of "*Wasatchia*", but are more abundantly represented by *Diacodexis* alone in the Sand Creek facies. (14) The arctocyonids and mesonychids are equally diverse in the two faunas, but the arctocyonid *Thryptacodon* is abnormally common in the Sand Creek facies. (15) Large hyaenodontids are equally diverse in both faunas, but may be slightly more abundant in the Sand Creek facies. Small hyaenodontids (*Tritemnodon*, *Prolimnocyon*) are apparently absent at Four Mile, but form a minor constituent of the carnivoran fauna in the Sand Creek facies. (16) Miacines are apparently more diverse in the Sand Creek facies, but are approximately twice as abundant at Four Mile. The viverravines *Didymictis* and *Viverravus* occur in both faunas, but are three times as abundant at Four Mile. (17) Oxyaenids are very rare elements in both faunas and are apparently somewhat more abundant in the Sand Creek facies. At least one individual of *Palaeonictis* and one individual of *Dipsalidictides*, forms not known to occur at Four Mile, are present in the No Water collection.

The apparent greater abundance of multituberculates, *Hyopsodus*, and rodents in the Four Mile fauna is matched by a correspondingly greater abundance of their possible predators, the miacines and viverravines. *Hyopsodus* and the miacines *Miacis* and *Vulpavus* are often associated in rocks of the Elk Creek facies. *Apheliscus* and *Haplomylus*, forms that are together better represented in the Sand Creek facies than in the Elk Creek facies or at Four Mile, may have been preyed upon by the small hyaenodontids *Tritemnodon* and *Prolimnocyon*, with help from the miacines and viverravines that also shared smaller populations of rodents and *Hyopsodus* for prey. The diversity of the oxyaenids may reflect the abundance of small phenacodontids (especially *Ectocion*) and *Hyracotherium* in the No Water fauna. However, oxyaenids were not particularly cursorial, and may have preferred the larger and slower members of the Phenacodontidae, leaving *Hyracotherium* to swifter predators such as *Pachyaena* and *Diatryma*. It is doubtful, however, that the food preferences of Early Tertiary carnivorans can be resolved meaningfully by analysis of faunal compositions alone, especially when it is possible that different elements of the fauna made up different proportions of their diets in disparate geographic areas. Some of the carnivorans undoubtedly ate carrion habitually, and others, *e.g.*, *Vulpavus*, probably had a mixed (omnivorous) diet.

Pelycodus was probably arboreal (Gregory, 1920), as were probably at least some of the anaptomorphines (Szalay, 1976). *Tetonius* and its close relatives *Tetonoides*, *Pseudotetonius*, and *Teilhardina* were probably at least in part insectivorous

Table 34. Faunal diversity and composition — Four Mile and No Water faunas

	Four Mile Fauna		No Water Fauna	
	Generic diversity	Percentage of total fauna	Generic diversity	Percentage of total fauna
multituberculates	3	6.3	3	0.9
marsupials	1	1.0	3	1.2
insectivorans-proteutherians	9	12.2	7	5.6
primates	8	13.0	10	17.7
primates, excluding *Pelycodus*	7	10.9	9	7.3
Apheliscus & *Haplomylus*	2	10.9	2	28.7
small phenacodonts (including *Ectocion*)	2	1.2	2	4.7
Phenacodus primaevus group	1	0.9	1	0.3
Homogalax	1	1.3	0	0
Hyracotherium	1	5.3	1	11.2
Hyopsodus	1	12.3	1	6.5
Rodentia	3?	23.2	3	6.7
Pantodonta	1	1.0	1	2.1
Tillodontia	1	0.7	1	1.8
Artiodactyla	2	3.6	1	5.5
arctocyonids	2	1.1	2	2.2
mesonychids	1	0.3	1	0.3
large hyaenodontids	2	1.0	2	1.4
small hyaenodontids	0	0	2	0.6
miacines	2?	1.5	3	0.8
viverravines	2	3.0	2	1.0
oxyaenids	1	0.3	3	0.6

(R.F. Kay, 1974, oral communication). It is interesting that these primates, with the paromomyids and microsyopids, are more abundant at Four Mile but more diverse in the Sand Creek facies. It is possible that the environment at Four Mile was exceptionally favorable to anaptomorphines and certain microsyopids while that of the Sand Creek facies was well suited to *Pelycodus* but more marginally favorable to a variety of other, smaller primates. *Pelycodus*, however, is a nearly eurytopic form, and is usually well represented in early Eocene faunules.

NON-MAMMALIAN TAXA

The herpetofauna of the Sand Creek facies is small, and the specimens fragmentary. The fauna probably contains at least six taxa of lizards (including the genus *Glyptosaurus*), one of snakes, and two of crocodilians. *Allognathosuchus* sp. is well represented by fragmentary jaws and teeth. Amphibians and fish are represented by rare jaws and vertebrae. Scales of *Lepisosteus* sp. are locally abundant.

J.H. Hutchison (1975, 1976, written communi-

cations) has kindly identified much of the fragmentary collection of turtle remains. His identifications follow:

Family Chelydridae
chelydrid, gen. *et* sp. indet.

Family Kinosternidae
kinosternid, gen. *et* sp. nov.

Family Emydidae
emydine, gen. *et* sp. indet.
emydine, gen. *et* sp. nov.
Echmatemys, sp. "A"

Family Trionychidae
Trionyx sp.

The Chelydridae are snapping turtles, and living members of the family are aquatic and frequent rivers, oxbow lakes, and sloughs. Carr (1952) noted that living snapping turtles prefer larger streams, but also frequent swamps and marshes not far from running water. The Kinosternidae are mud and musk turtles; living representatives occupy streams adjacent to swampy areas, the floodplains of rivers, and (Carr, 1952, p. 78) "lakes with fluvial histories or connections." The emydids are fresh-water and

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marsh turtles, and prefer marsh or muddy pond habitats. Most of the living trionychids prefer a fluviatile (riverine) habitat.

The large, cursorial, and predaceous *Diatryma* is the only identified bird in the No Water collection. Smaller, duck-size birds are probably represented by a few fragmentary postcranial bones.

J.H. Hanley (1975, 1976, written communications) has identified two fresh-water gastropod species from the Sand Creek facies as *Discus ?ralstonensis* and *Physa ?longiuscula*. Dr. Hanley's comments on the ecology of living relatives of these forms are: "*Physa* is an aquatic pulmonate gastropod whose living representatives inhabit all types of freshwater environments, from temporary ponds to rivers and large lakes. *Discus* is a terrestrial pulmonate gastropod whose living representatives prefer a moist habitat under dead wood and among rotting leaves in a humid forest."

Invertebrates are extremely rare in the No Water fauna; however, as noted above, there is abundant evidence of invertebrate activity in several of the sandstone and some of the mudstone beds. The evidence of the paucity of invertebrate fauna, the identified part of the herpetofauna, and the few fish remains does not refute the interpretation above, that these remains probably accumulated on sporadically aggrading floodbasins. The observation by Savage *et al.* (1972), that 50-100 percent of vertebrate fossil remains in certain Bitter Creek section faunules studied by them are non-mammalian, probably indicates a greater proportion of pond and palustrine environments on the Wasatch lithotope in that area. This interpretation is also borne out circumstantially by the predominance of drab over variegated mudstones in that section.

STRATIGRAPHIC CORRELATION

Precise stratigraphic correlation of the most fossiliferous part of the Sand Creek facies with equivalent rocks in the Elk Creek facies is made nearly impossible by the alluvial cover in the valley of the Bighorn River (Pl. 1). The correlation of Sand Creek facies localities V-73124-73127, situated west of the Bighorn River, was made using a log of Gulf Oil Corporation #1 Teeters, sec. 28, T.47N., R.93W. (Wyoming Geological Association, 1968), noting the position of the piping and the fossil localities, and measuring a section from the localities to the piping. The log from this well marks the base of the Willwood Formation at 790 feet (240 m). A similar thickness (642 feet - 195

m) was estimated from dips of Willwood rocks on and adjacent to West Worland Dome. Moreover, the well log notes the first occurrence of carbonate nodules at about the 410 foot (125 m) level. Such nodules are unknown through about 465 feet (142 m) of Willwood rocks east of the Bighorn River, and their sporadic occurrence this low west of the river reflects the intertonguing and overlapping relationship of the Elk Creek with the Sand Creek facies.

Sections across the drainages of Fifteenmile, Tenmile, and Fivemile creeks into the Elk Creek Basin have not been measured, but reconnaissance mapping indicates that the exposures are probably continuous enough for a series of composite sections to be made correlating the two areas. Such a section, however, would obliquely transect several gentle *en echelon* folds, and great care would be necessary in the tracing of beds.

The correlation of Willwood strata farther north into the Foster Gulch, Coon Creek, and McCulloch Peaks badlands is complicated by covered intervals, other broad gently dipping structures, and what is probably a considerable thickening of the Willwood Formation to the north and northwest (see below).

Class A gray mudstones and some elements of the Willwood fauna most typical of the Sand Creek facies (*e.g.* abundant *Haplomylus*, *Apheliscus*, and *Ectocion*; presence of *Phenacolemur simonsi* and *Tinimomys*; relative paucity of *Hyopsodus* and *Homogalax*) occur in a tract of badlands from Dobie Butte, west of Manderson, to the lower Elk and Antelope Creek drainages between the 0 and 400 foot (0 and 122 m) levels of the Willwood Formation (my unpublished sections). Faunal data is too imprecise to allow confident correlations.

Sinclair and Granger (1911, p. 114), Rohrer and Gazin (1965, p. 134), and Neasham (1967, p. 35) have noted that persistent purple beds are often of use in local correlation. Some of these beds are remarkably continuous; I have traced one such mudstone more than seven miles along the South Fork of Elk Creek Divide. However, the use of such units to correlate between widely separated beds is prohibited by gentle structural folds and alluvial cover.

Recent studies by Gingerich (*e.g.* 1974c, 1976a) have opened another avenue for interbasinal as well as intrabasinal correlation that warrants careful consideration. In the present study, measurements of the No Water samples of M_1 of *Pelycodus*, *Hyopsodus*, and *Haplomylus*

were plotted against their stratigraphic positions and compared with corresponding patterns from Gingerich's studies. Additional No Water taxa were given the same treatment as a basis for further comparative studies. The fair correlation of the *Hyopsodus* samples and the strong correlation of the *Pelycodus* samples (Figs. 48 and 41) suggest a close correlation between the Elk Creek and No Water samples in terms of gradual increase in size up section.

It is important, however, to recognize that the relative positions of the samples alone will not necessarily produce meaningful results. If two areas to be compared had differing depositional rates or depositional environments, the data obtained from measuring relative positions could be misleading. In the first instance, differing depositional rates will cause whatever trends that emerge to be attenuated in one section and telescoped in another. More seriously, differing intrabasinal depositional environments can, in the case of Willwood rocks, have affected the position of the base of the formation marked by the lowest persistent red beds.

Gingerich (1976a, p. 11-14) has presented additional data on stratigraphically documented size changes in Willwood populations of *Hyopsodus*. In that study, 152 additional localities were *interpolated* into the original figure "locality by locality, based *both* on the geographic relationship of the locality in question to those already in the section and on the average size of each species sample from the locality." He noted (1976a, p. 11, 14) that "localities near the major creeks in the region are significantly lower than adjacent localities farther away from the drainage. In other words, topography plays a greater role in the correlation than it was previously assigned." The correlation of fossil localities by geography and topography alone can only be accurately realized when the strata are horizontal. Willwood strata in the valleys of Antelope and Elk creeks are not, as Gingerich apparently assumes, always horizontal, but show dips from 0° to 23°. In his Figure 5, Gingerich (1976a) has interpolated data from localities separated, in some instances, by more than 25 miles. It is only necessary to err by 1° of dip from the true inclination of the rocks to acquire a stratigraphic error of at least 92 feet (28 m) in a section tranversing a single mile. Some of the localities Gingerich (1976a) has interpolated between the 450 and 650 foot (137-198 m) levels of the Willwood Formation are developed on strata controlled by the Elk Creek Anticline (Sinclair and Granger, 1911), a structure that manifests

dips of 5 to 23° on its western and northwestern flanks.

A discrepancy also exists between the Neasham-Vondra and Meyer-Radinsky sections of the Willwood Formation. The Meyer-Radinsky section (1965, unpublished; see Gingerich, 1976a, p. 6, 8) records approximately 1800 feet (548 m) of Willwood rocks from the contact with the Polecat Bench Formation on Antelope Creek to the contact with the overlying Tatman Formation on the Squaw Buttes Divide. Neasham (1970; Neasham and Vondra, 1972) measured 2,300 feet (700 m) of Willwood rocks, also beginning his section at the base of the formation on Antelope Creek. The top of this section, however, was closed by the contact with Tatman rocks on the east face of Tatman Mountain. In crossing Dutch Nick Flat and the eastern Buffalo Basin, 500 feet (152 m) of Willwood rocks are somehow lost between these sections. As noted by Hewett (1926), Neasham and Vondra (1972), Bown (1975), and Gingerich (1976a), the Willwood Formation unconformably overlies truncated Polecat Bench and older strata along the southwest margin of the Bighorn Basin. Both sections, however, were begun in the same rocks and were completed at the contact with the Tatman Formation, although on different topographic features. It is easy to maintain a relative stratigraphic level and to trace approximate Willwood stratigraphic equivalents from Wildcat Ridge and the Squaw Buttes Divide to Tatman Mountain.

Although the in-part gradualist model of evolution for certain Willwood mammals presented by Gingerich (1974c, 1976a) is basically substantiated by this study, further analyses of the faunal data for the Elk Creek-Buffalo Basin sections will have to await a more reliable stratigraphic basis.

FAUNAL CORRELATION

The vertebrate fossil collections of the Sand Creek facies are dominated by representatives of five orders: the Condylarthra, Primates (particularly notharctine Adapidae), Perissodactyla, Rodentia, and Artiodactyla. This association of mammals is generally acknowledged to typify the Wasatchian Provincial Age (*sensu* Wood *et al.*, 1941; West *et al.*, in press). Evernden *et al.* (1964) established that the North American Wasatchian land mammal age lasted from about 54 to 49 million years b.p. Further refinements were offered by Berggren and Van Couvering (1974; 55 to 49 million years) and McKenna *et al.* (1973; 53.5 to 49.0 million years). The Sparnacian and Cuisian

faunas of western Europe are in part correlative with this interval (54 to 47 m.y.; see, *e.g.*, Bonhomme, Odin, and Pomeral, 1968). The degree of similarity between Eurasian and North American early Eocene faunas has been adequately discussed in recent years by Savage (1971), McKenna (1975b), and Gingerich and Rose (1977).

Rocks of presumed latest Paleocene and early Eocene age in the Bighorn Basin have been divided, entirely on a faunal basis, into five units. By their original definitions, these units are:

"Clark Fork beds" — Granger, 1914, p. 204

"Sand Coulee beds" — Granger, 1914, p. 205

"Gray Bull beds" — Granger, 1914, p. 203

"Lysite Formation" — Sinclair and Granger, 1912, p. 61

"Lost Cabin Formation" — Sinclair and Granger, 1912, p. 61

The "Clark Fork," "Sand Coulee," and "Gray Bull" beds have their type occurrences in the Bighorn Basin, and the "Lysite" and "Lost Cabin formations" were borrowed by Sinclair and Granger (1912) from the Wind River Basin as replacements for Loomis's (1907b) "Big Horn Wind River." It is unnecessary to discuss in detail the chronologic evolution of this terminology and the problems entailed by the unfortunate suffixes "beds" and "formation" for units that are clearly recognizable only on the basis of their contained faunas. It is important to recognize, however, that this terminology, especially "Gray Bull," "Lysite," and "Lost Cabin," each in one of several variants, has been applied to rocks and faunas presumed to be of early Eocene age with little discrimination throughout much of the Rocky Mountain interior. Wood *et al.* (1941) contributed to this nomenclatural confusion by referring to the "Clark Fork" as both a member and a faunal zone of the Polecat Bench Formation (Clarkforkian was, additionally, proposed as a new provincial age). The "Sand Coulee" became a "local fauna," the "Gray Bull" became a *member* of the "Bighorn Wasatch," and the "Lysite" and "Lost Cabin" were accorded the designation "equivalents." This was perhaps symptomatic, since, from the outset, these concepts and terms were never defined on an equivalent basis.

The "Clark Fork" beds (and fauna; see Granger, 1914, p. 204) were characterized by the absence of perissodactyls, artiodactyls, rodents, and primates, by the widespread occurrences of *Phenacodus* and *Ectocion*, and by the presence of *Coryphodon* and *Bathyopsis*. The fauna of the "Clark Fork" beds has been reviewed by Wood (1967), who abandoned the term, and by Gingerich and Rose (1977), who convincingly demonstrate the utility of the Clarkforkian as a land mammal age and suggest that this fauna is most similar to the basal Sparnacian fauna from Meudon, France, and therefore is of early Eocene rather than late Paleocene age. These arguments are accepted here. As used by Gingerich and Rose, the Clarkforkian is a concurrent range zone.

The "Sand Coulee" beds (Granger, 1914, p. 205) were originally distinguished from the "Clark Fork" beds by the presence of *Hyracotherium* associated with artiodactyls, rodents, and primates, as well as the "last appearance of the primitive order Multituberculata." Multituberculates are now known in some abundance from rocks of late Eocene and even early Oligocene age, and *Hyracotherium*, "primates," and rodents are well known from faunas termed "Clarkforkian" (*sensu* Gingerich and Rose (1977) on other criteria. The first appearance of the artiodactyls is one of several first appearances that characterize the Wasatchian Provincial Age. From the superjacent "Gray Bull" beds, Granger (1914, p. 205) differentiated the "Sand Coulee" by the absence of *Systemodon* (=*Homogalax*), the presence of multituberculates, and "the generally more primitive character of such genera as are common to both horizons." It is difficult to quantify primitive characters in either field or laboratory in a manner which makes this usage a good criterion for faunal zonation. *Homogalax* was discovered in the typical "Sand Coulee" beds in 1928 by Jepsen (1930a), and the term "Sand Coulee" has been largely ignored by subsequent workers.

Granger (1914) applied the term "Gray Bull beds" to rocks characterized by the presence of the tapiroid *Systemodon* (=*Homogalax*). Because no other taxa were known at that time also to be diagnostic of Granger's *Homogalax*-bearing fauna, the "Gray Bull" beds (or faunal zone), in the original sense, comprised a taxon range zone. Later workers recognized that some forms (especially *Pelycodus ralstoni* and *Haplomylus speirianus*) are commonly associated with *Homogalax*-bearing rocks and apparently do not occur in younger faunas, and, informally, regarded a few of these taxa also to be "Gray Bull" index fossils. Naturally, this has led to the application of the term "Gray Bull" to *Haplomylus*- or *P. ralstoni*-bearing faunas that do not yield *Homogalax* (see, *e.g.*, McGrew and Roehler, 1960; Gazin, 1965; Prichinello, 1971). I wish to stress that the relative occurrences

and stratigraphic ranges of *Homogalax, Haplomylus,* and *P. ralstoni* with respect to subjacent and super-jacent rocks and faunas have never been delimited in the area of the type "Gray Bull" beds or else-where.

Gazin (1962) and Radinsky (1963) have docu-mented the occurrence of *Homogalax* (although probably not *H. protapirinus*) in beds in the eastern Washakie Basin that are judged to be post-"Gray Bull" on other criteria. Similarly, Guthrie (1971) reported *H. protapirinus* from type Lost Cabin Member faunules of the Wind River Forma-tion.

Radinsky (1963), apparently following Van Houten (1945), believed that *Homogalax* is recov-ered from about 2,000 feet (610 m) of Willwood rocks in the Bighorn Basin. This is certainly not the case for the Elk Creek section, as is outlined below, but may be true for the thicker lower Willwood section in the Clark's Fork Basin and the adjacent McCulloch Peaks area. Jepsen (1930a, p. 119) noted that *Homogalax* is exceedingly rare in the lowest "Gray Bull beds" (including the old "Sand Coulee beds"), but recent studies in the Clark's Fork Basin (Rose, 1976, personal communication) have documented the association of *Homogalax* with *Pelycodus* almost immediately after the first appearance of the latter genus. In the Clark's Fork Basin, *Homogalax*, then, would seem to be another form indicative of at least the beginning of Wa-satchian time.

Granger (1914) and Van Houten (1944) be-lieved "Wasatch" or Willwood rocks exposed east of the Big Horn River to be "Gray Bull" in age, but it is unknown whether or not either of these authors found remains of *Homogalax* there. The genus is unknown in the well-sampled No Water faunules, and these faunules can therefore be called "Gray Bull" in only the most liberal sense. In the Elk Creek facies, *Homogalax* is rare to abundant. Specimens of this tapiroid were collected by me in 1971 and 1973 and in 1972 by field parties from the Yale Peabody Museum in some abundance from the lower 200 feet (60 m) of the Willwood Formation exposed between the Seven Sisters and Gould Butte, southwest of Greybull. These collections demonstrate that *Homogalax* is at least locally common in the lowest Willwood rocks of the Elk Creek facies. In the Elk Creek section, *Homogalax* is a sporadic constituent of fossil mammal collections between about the 275 and 1100 foot (85-335 m) levels. The genus is very rare, but does occur, interestingly associated with *Heptodon*, at Yale localities 44 and 45 (1,600 foot

level). Stratigraphically above these localities, *Homogalax* is unknown.

No genera are known to be restricted to the so-called "Lysite equivalent" in the Bighorn Basin, and the "Lysite" fauna has typically been charac-terized by its taxonomic absences with respect to overlying and underlying faunas. Loomis (1907b) noted that about the upper 1000 feet (300 m) of the Big Horn "Wasatch" (=Willwood) is probably a rough equivalent, faunally, of the Wind River Formation. This correlation cannot be improved upon without more stratigraphic collecting in the Buffalo Basin. Loomis' interpretation is apparently borne out by the first known appearance of *Heptodon* at about the 1600 foot (485 m) level and by the occurrence of the upper contact of the formation at about 2300 feet (700 m) above the top of the Polecat Bench Formation. The Bighorn "Lysite" fauna is probably at least as diverse in faunal elements as the type collections from the Wind River Basin, but the Yale collections from this faunal interval in Willwood rocks remain to be studied.

Rohrer and Gazin (1965) believed that the Willwood "Gray Bull" and "Lysite" faunal zones overlap in "Bed A" (Rohrer, 1964a,b), a persis-tent purple mudstone — gray mudstone — sandstone complex developed in the Tatman Mountain and Sheep Mountain areas. These authors observed that "Bed A," exposed in an area of dominantly hori-zontal beds, was traceable for great distances at about the 4860-foot contour line, and believed that the bed occurs about 750 feet (230 m) beneath the top of the Willwood Formation. This would place the "Gray Bull" — "Lysite" faunal boundary approximately 350 feet (110 m) above that sug-gested by specimens in the large Yale collection. It is interesting, however, that both current con-cepts of this faunal boundary involve beds con-taining an overlap of diagnostic forms.

The so-called "Lost Cabin" interval in Will-wood rocks, as in Wind River rocks, is defined by the first appearance of the palaeothere *Lambdo-therium*. This genus occurs sporadically in collec-tions obtained from the higher Willwood levels on Sheep Mountain, near the top of Red Butte on the Elk Creek Divide, and in western Buffalo Basin adjacent to the Squaw Buttes divide and Tatman Mountain table. Most of these collections containing *Lambdotherium* are not tied with measured sections, but field relationships indicate that the genus probably does not occur beneath the 1,900 foot (580 m) level of the Willwood Formation. A relatively large collection of mammals was secured

from upper Willwood rocks in the Buffalo Basin in 1971 by the author and a Yale field party under the direction of E.L. Simons. The occurrence of *Lambdotherium* in this collection was restricted to localities west of Dead Indian Hill and Mac-Donald Cabin and to rocks exposed north and south of these landmarks at the bases of Tatman Mountain and the Squaw Buttes Divide, respectively. The "Lost Cabin" faunal interval is almost universally based on the possibly differential local range zones of *Lambdotherium*. Other faunal elements may characterize this interval in the Bighorn Basin and elsewhere, but this remains to be convincingly demonstrated by stratigraphically documented collections.

In sum, the "Gray Bull," "Lysite" and "Lost Cabin" faunas of the Willwood Formation are characterized, as is inevitable at present, by the occurrence of *Homogalax*, the absence of *Homogalax* and of *Lambdotherium*, and the occurrence of *Lambdotherium*, respectively. More detailed correlation of Willwood rocks and faunas with those of other basins is presently impossible. The bulk of collections from Willwood rocks, however, has been made in recent years, and excellent locality data exist for most sites. It will therefore be possible, in future years, to construct taxon and assemblage zones for most species. The No Water fauna is probably "Sand Coulee" or "Gray Bull" in the late sense (pending a general review of early Wasatchian faunas), and is at least as old as the Four Mile fauna of northwestern Colorado, but is younger than the Clarkforkian early Eocene faunas of the northern Bighorn Basin.

J.H. Hutchison (1975 and 1976, written communications) suggests that the No Water turtle fauna may correlate with the unsampled 200 feet (60 m) between the lowest Bitter Creek Wasatch and the highest Bitter Creek Fort Union samples. The correlation of the mammals will have to await description of the Bitter Creek collection of these animals.

In the absence of lateral continuity of strata, radiometric dates, or meaningful paleomagnetic data, the correlation of continental rocks is only possible through their contained faunas, and the precision of this correlation is restricted by the resolution of these fossils. Resolution can be affected by incompleteness of material, the inability to recognize endemic taxa, paleoenvironmental factors (see, *e.g.*, Black, 1967), and the related unpredictable persistence of taxa in some areas. The utility of biostratigraphic correlations depends largely on the choices of fossils employed in a cor-

relation. Obviously, the more strongly a population or species is tied to its environment, the more limited are the possiblities of applying correlations usefully.

Homogalax, the supposed index fossil of the "Gray Bull" interval, is absent in the well-sampled No Water fauna, but is locally abundant in rocks of the nearby, in part homotaxic, Elk Creek facies. It is extremely doubtful that any early Eocene physical barriers to intrabasinal dispersion were present, yet *Homogalax* is rare in the lower Willwood Formation in the Clark's Fork Basin, and is rare or absent from the Four Mile, Laramie Basin, and some greater Green River Basin faunules. Clearly, the dispersion of this animal in time and space relative to many other mammals is ecologically controlled, and the taxon is of little use in faunal correlation. The same is true for *Meniscotherium* (see Gazin, 1962), a medium-sized condylarth rare in Clarkforkian and "Gray Bull" faunules of the Bighorn Basin (there are perhaps two Willwood specimens), and absent in the well-sampled Four Mile and other reasonably well-documented faunas, yet locally abundant in the Bitter Creek section. Judging from their sporadic occurrences, *Ectocion* and *Plagiomene* can probably also be excluded as useful correlatives (*contra* Bown, 1974). The apparently eurytopic and abundant faunal representatives, such as *Hyracotherium*, *Hyopsodus*, *Haplomylus*, *Coryphodon*, and possibly some of the primates, offer the best avenues for exploration.

It is hoped that the strato-phylogenetic studies of some of these animals advanced by Gingerich can, when given a reliable stratigraphic base, be useful in the correlation of vertebrate faunas by phylozones or lineage segment zones (see, *e.g.*, Van Hinte, 1969). As discussed above, the variables involved in this potential process are also formidable.

In the systematic paleontology section, stratigraphic ranges of all No Water taxa in the Sand Creek facies are given. In a few instances, the known occurrences of these elements in the Elk Creek facies are also provided. Stirton (1936) and Jepsen (1940) believed that vertebrate fossils are generally too rare, and knowledge of their local and regional stratigraphic ranges too incomplete, to apply useful range zone terminologies to these animals. I believe that meaningful results along these lines can now be achieved by the evidence of faunal compositions and the application of sound stratigraphic procedures.

Well-exposed, fossiliferous Early Tertiary rocks in the Bighorn Basin can be meaningfully studied with respect to their ancient tectonic and environmental settings. The Bighorn Basin is an intermontane syncline surrounded by at least five major, differentially elevated positive structures: the Beartooth, Absaroka (and Washakie), Owl Creek, Bighorn, and Pryor ranges. Each of these features is belived to have been tectonically active during all or a portion of the Paleocene and Eocene epochs, and each has responded differently to regional compressive Laramide stresses. Because these uplifts are not of contemporaneous origin, yet each has presumably contributed sediment to the fluviatile Early Tertiary section, it should be possible, with increasing refinement, to document the progressive structural and sedimentary evolution of the Bighorn Basin region by utilizing a combination of stratigraphic, sedimentologic, petrographic, structural, and paleontologic evidence. This can be accomplished by broad, interdisciplinary studies or by detailed investigations with specific goals.

It has been one objective of this report to evaluate a collection of Willwood mammals in its sedimentologic and tectonic context; however, there was no opportunity to examine the evidence in all the detail it deserves, and several promising approaches had to be abandoned before meaningful results could be obtained. Some potentially profitable lines of future enquiry follow.

1- Stow (1938, 1952) has described the heavy mineral petrology of the Polecat Bench and Willwood Formations in the northern Bighorn Basin, Wyoming and Montana, and in related rocks. Such a study has never been undertaken in the southern Bighorn Basin, an area that was probably responsive to different tectonic and source controls. Stow noted that, in his area of study, the Polecat Bench — Willwood transition is marked by the appearance of hornblende and the persistent presence of red garnet and staurolite, and that the Wasatch (=Willwood) sediments are characterized by (1938, p. 85) the "extreme persistence and abundance of minerals derived from a crystalline rock." An evaluation of heavy mineral assemblages at different points in Polecat Bench and Willwood sections in the southern Bighorn Basin would provide information on the source areas of those rocks, and could be of use in determining the evolution of the Owl Creek and southern Bighorn Mountains as

potential sources of sediment. These mountains have only relatively small areas of crystalline rocks exposed today (Love, Weitz, and Hose, 1955; Tourtelot and Nace, 1946; Tourtelot, 1953), and it is possible that these Precambrian rocks had not been unroofed by erosion in late Paleocene and earliest Eocene times.

2- Several authors have described the conglomeratic sequences developed at the top of the Polecat Bench Formation and the bottom of the Willwood Formation in the Grass Creek, Gooseberry Creek, and. Blue Mesa areas of the southern Bighorn Basin. Hewett (1926), Pierce and Andrews (1941), Rohrer (1966), and Neasham (1970) have suggested that the Willwood body of conglomerates was derived from the reworking of conglomeratic Polecat Bench rocks. They based their evidence on the proximity to the hypothesized Polecat Bench source, composition of the cobbles, and comparisons of percussion fractures. My preliminary field work (following Love, personal communication, 1975) indicates that this evidence is contradictory because in some areas, Willwood conglomerates are more extensive than in adjacent Polecat Bench rocks and the mean size of the cobbles is larger. Love (1960), Love and Reed (1968), Young (1971), Lindsey (1972), and Rea and Barlow (1976) have favored a western source area for conglomerates in both the Polecat Bench and Willwood Formations in these areas. If major Paleocene drainage systems were directed out of the Bighorn Basin to the southeast (see above, p. 10), it is possible that these conglomerates are related to similar deposits in the southwestern Powder River Basin (as suggested by Love, 1960; 1975, personal communications). Paleocurrent data for Polecat Bench and Willwood fluviatile conglomerates and sandstones could be used to advantage in determining the timing of drainage reversals concomitant with uplift along the Owl Creek and Southern Bighorn ranges. Such drainage reversals in the southern Bighorn Basin could have initiated ponding and the onset of paludal coalforming conditions (see Masters, 1961). Moreover, a refinement of our knowledge of the sedimentary and tectonic settings of this area could be of use in paleoenvironmental and paleogeographic modeling (see, *e.g.*, Rea and Barlow, 1975, fig. 6).

3- Neasham (1970) and Neasham and Vondra (1972) measured a Willwood thickness of approximately 2,300 feet (700 m) in the Antelope Creek —

Elk Creek — Tatman Mountain section. The top beds of the Willwood Formation outcrop at an elevation of about 5,600 feet (1700 m) above sea level on Tatman Mountain (Rohrer, 1964b) and contain *Lambdotherium*, a so-called index fossil for the "Lost Cabin" faunal zone. Farther north, Willwood rocks are exposed at the top of McCulloch Peaks (elevation 6547 feet = 1996 meters). Fossils typical of the "Gray Bull" faunal zone occur only 200 feet (60 m) beneath the top of the McCulloch Peaks divide (my unpublished data; see also, Van Houten, 1945, p. 428). A few miles west-northwest of McCulloch Peaks, "Gray Bull" fossils occur at Hackberry Hollow (elevation 5200 feet = 1890 meters), and Willwood rocks persist to an elevation of 7,400 feet (2260 m) on the slopes of Heart Mountain (Pierce, 1966). It seems likely that the lower part of the Willwood Formation (including rocks of the "Gray Bull" mammals, especially *Homogalax*) does not occur above about the 1600 foot (485 m) level of the Willwood

Formation in the Elk Creek section. Thus, paleontological evidence is consistent with differential structural elevation *within* the Bighorn Basin in post-Willwood times.

4- Stratigraphically controlled samples of Willwood mammals are large enough to allow meaningful intrabasinal comparisons of faunal compositions, if the bases of the geographically disparate measured Willwood sections can be confidently correlated without the use of faunas. Fossil mammals from the richest and best stratigraphically documented sites could then be separated into their respective trophic guilds and analyzed from the viewpoints of community paleoecology and taphonomy. Unfortunately, stratigraphic control is inadequate to form the basis for such a study at the present time. It is hoped that continuing stratigraphic studies of Willwood rocks by D. Schankler (1976, personal communication), Gingerich, and myself can contribute to a more refined stratigraphic approach to these problems.

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ADDENDA

Since the completion of this paper, several additional references pertinent to the discussion of the origin of red beds and paleosols in the Willwood Formation have come to my attention. These and other papers not used in this study but of supplemental interest are cited here.

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Note added in press:

David W. Krause (University of Michigan) is currently studying samples of Clarkforkian and Wasatchian multituberculates, and informs me (written communication, 1979) that he disagrees with some of these identifications. According to Krause, of the specimens of P_4, UW numbers 6562, 6571-6574, and 10432 belong to *Ectypodus* Cf. *tardus*, whereas UW numbers 6566, 6570, 6575, 10437, and 10438 belong to *Parectypodus* sp. "A". For P^4, UW numbers 6552 and 10442 belong to *Ectypodus* Cf. *tardus*, and UW numbers 6553, 6555, 6556, 6576, and 10376 are *Parectypodus* sp. "A". Krause (in prep.) will deal with these identifications and those of the molars at greater length in a forthcoming paper.

PLATE I

CRETACEOUS AND
TERTIARY ROCKS
IN THE SAND CREEK-
NO WATER CREEK
AREA — WASHAKIE
COUNTY, WYOMING

Quaternary	Qa	Quaternary Alluvium
Eocene	Twl	Willwood Fm.
Paleocene	Tpb	Polecat Bench Fm.
Cretaceous Montana Group	Klm	Lance-Meeteetse Fms.
	Kmv	Mesaverde Fm.
	Kco	Cody Formation

1-6°
6-15°
>15°

Trace of Fault

Geology by
T. M. Bown, 1974-75

N

Compiled at a scale of
1:160,000; reduced to a
scale of 1:267,000.