SMITHSONIAN CONTRIBUTIONS TO PALEOBIOLOGY • NUMBER 18

Stratigraphy and Preliminary Biostratigraphy of the Flagstaff Rim Area, Natrona County, Wyoming

Robert J. Emry

SMITHSONIAN INSTITUTION PRESS
City of Washington
1973

ABSTRACT

Emry, Robert J. Stratigraphy and Preliminary Biostratigraphy of the Flagstaff Rim Area, Natrona County, Wyoming. *Smithsonian Contributions to Paleobiology,* number 18, 43 pages, 19 figures + frontispiece, 1973.—About 750 feet of sediments of the early Oligocene (Chadronian) White River Formation are exposed along Flagstaff Rim in south-central Natrona County, Wyoming. About 4,000 specimens of fossil vertebrates have been collected from these outcrops. The White River Formation unconformably overlies rocks ranging in age from Precambrian to medial or late Eocene. The lithology of the White River Formation is predominantly claystone and conglomerate in the lower part of the section, changing to predominantly tuffaceous siltstone and conglomeratic channel sandstones in the upper part. Four stratigraphic sections are described. A geologic map of about 40 square miles illustrates the areal limits of the White River Formation and its relationships to underlying and overlying formations. Several distinct and easily recognizable volcanic ash beds occur at intervals within the White River sequence. These serve as convenient markers for precise stratigraphic zonation of fossils and have also provided minerals for potassium-argon dating. Dates obtained range from 35.7 to 31.6 million years.

A boulder conglomerate unit, previously considered to be the basal unit of the White River Formation and/or part of the Wind River Formation is shown to be a distinct, and probably unnamed, unit, and should not be assigned to either of these formations. It unconformably overlies the Wind River Formation and is separated from the White River Formation by an erosional disconformity with several hundred feet of relief. This information allows new interpretations of the structure of the area and adds a previously unrecognized episode of deposition and erosion to the history of the area.

The most common fossil in the White River sequence is the artiodactyl genus *Leptomeryx,* which is represented by two morphologically distinct lineages. One lineage is provisionally divided into two and the other into three size groups that are believed to represent different species. The local stratigraphic ranges of the different groups do not overlap. In each lineage, the size increases higher in the section. None of the groups are definitely assigned to named species, pending studies to determine the validity and limits of the named species.

Preliminary analysis of other elements of the fauna shows that there is recognizable change through time within individual lineages and that the faunal composition as a whole changes through time, within the local sequence. When the entire fauna is analyzed in detail, it should be possible to establish local range zones of the fossil species and, by their use, to gain greater temporal resolution within Chadronian time than has previously been possible.

OFFICIAL PUBLICATION DATE is handstamped in a limited number of initial copies and is recorded in the Institution's annual report, *Smithsonian Year.* SI PRESS NUMBER 4790. SERIES COVER DESIGN: The trilobite *Phacops rana* Green.

Library of Congress Cataloging in Publication Data
Emry, Robert J., 1940–
Stratigraphy and preliminary biostratigraphy of the Flagstaff Rim area, Natrona County, Wyoming.
(Smithsonian contributions to paleobiology, no. 18)
1. Geology, Stratigraphic—Oligocene. 2. Vertebrates, Fossil. 3. Geology—Wyoming—Natrona Co. I. Title. II. Series: Smithsonian Institution. Smithsonian contributions to paleobiology, no. 18.
QE701.S56 no. 18 [QE693] 560'.8s [551.7'8] 72-13884

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Price 95 cents domestic postpaid or 70 cents GPO Bookstore

Contents

Doctors W. D. Matthew and R. S. Lull on an American Museum of Natural History expedition in 1899, at the head of Bates Hole, Wyoming, near the present study area. (By permission of the Department of Vertebrate Paleontology, American Museum of Natural History.)

Stratigraphy and Preliminary Biostratigraphy of the Flagstaff Rim Area, Natrona County, Wyoming

Robert J. Emry

Introduction

In south-central Natrona County, Wyoming, about 750 feet of strata of the early Oligocene (Chadronian) White River Formation are exposed along a prominent erosion scarp known locally as Flagstaff Rim. In the Frick Collection, American Museum of Natural History, are nearly 3000 specimens of fossil vertebrates collected from these outcrops. In addition, at least 1000 specimens were collected from the area for the National Museum of Natural History during the summer of 1971. Nearly all of the specimens were carefully related stratigraphically to a number of distinct volcanic ash beds that occur at intervals within the rock sequence. These volcanic ash beds serve not only as convenient markers for precise stratigraphic documentation of fossils, but have also yielded minerals for absolute age determinations, in terms of years before present, based on potassium-argon ratios.

The Flagstaff Rim area is of great potential importance to our understanding of the early Oligocene (Chadronian) of the entire Rocky Mountains area. The section here is thicker, and probably more nearly represents all of Chadronian time, than any other known single section. Much of the section is richly fossiliferous and all of the specimens from the area can easily be tied to a single reference section. The fauna is more diverse than any other known early Oligocene fauna in North America.

Chadronian vertebrates are quite widespread throughout the Western United States, but many of the sites from which they are derived are quite localized. In Canada, the Cypress Hills area of Saskatchewan is the most important locality. Montana has Pipestone Springs, McCartys Mountain, Canyon Ferry Reservoir area, and Sage Creek among its more important localities, but also has many smaller or less well-known localities. Wyoming has many isolated localities in addition to the larger areas of outcrop of Chadronian sediments in the eastern part of the state and along Beaver Rim in the central part of the state. In the northern end of the Bighorn Range, western part of the Black Hills, eastern side of the Medicine Bow Range, southeast end of the Wind River Range, and immediately south of Yellowstone Park are isolated localities that, because of their relatively high altitudes, have important structural connotations. Chadronian mammals have been found in Jackson Hole. The Pumpkin Buttes in the Powder River Basin are capped by Oligocene sediments of yet uncertain age. Farther south, there are isolated localities in the parks of central Colorado, and

Robert J. Emry, Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560

much farther south, the Vieja Group of the Basin and Range Province along the Rio Grande River in Texas contains important Chadronian faunas. But most of these localities have been difficult to place temporally, any closer than Chadronian, for several reasons, among these being scarcity of specimens at many localities, local occurrences of species unknown elsewhere, and the difficulty of establishing local stratigraphic sequences.

The Flagstaff Rim area of central Wyoming then becomes important in relating all of these localities. It has many assets that are lacking in other areas: relatively thick sequence, most of which is fossiliferous; extremely varied fauna; easily established local stratigraphic sequence with good marker beds for precise stratigraphic documentation of specimens; and, a central geographic location relative to most of the other localities. A study of the distribution of all the fossils within the Flagstaff Rim sequence should provide a section that could be subdivided on the basis of the fauna and which would allow more resolution in correlation of many of the other isolated localities.

The primary purpose of the present report is to make available the stratigraphic framework necessary for the faunal studies. This will not only facilitate the publication of my own work on various taxonomic groups but should also aid other workers who are studying other taxa from the area. The geologic map that was made during the course of my field work (Figure 19) covers about 40 square miles. This map illustrates the areal limits of the White River Formation and its relationships to both younger and older rock units, as well as a great deal of other information that would otherwise have required many pages of text.

My dissertation also included the results of studies of several mammalian taxa from the Flagstaff Rim area. These are briefly discussed in a following section of this report but publication of the details of these studies is deferred for reasons also outlined in the same following section. Detailed studies of the artiodactyl genus *Leptomeryx* and the rodent genus *Cylindrodon,* and preliminary studies of other genera, are sufficiently advanced to demonstrate that in members of these taxa, as well as in the fauna as a whole, there is recognizable change through time within this single stratigraphic sequence. When the stratigraphic ranges of all the species in the fauna are determined, it should be possible to recognize temporal units of much less magnitude within Chadronian time than has previously been possible.

ACKNOWLEDGMENTS.—Appreciation should first be expressed to the late Mr. Childs Frick, whose generous support made possible the geologic field studies as well as the collecting and preparation of the large number of fossil specimens from the Flagstaff Rim area.

I am also grateful to Mr. Morris F. Skinner and Mr. Ted Galusha, whose field parties collected the majority of the fossil specimens from the Flagstaff Rim area that are now in the Frick Collection, for including detailed stratigraphic and geographic information with each of the specimens. I would also like to take this opportunity to thank these two men for a great part of my informal and practical education in vertebrate paleontology—thanks not only for giving me much advice gained through long experience but also for putting me into positions where it was imperative that I use the information.

I thank the staff of the Department of Vertebrate Paleontology of the American Museum of Natural History for the use of the fossil collections and other facilities, including a place to work. This report is a part of my dissertation for my Doctor of Philosophy degree (Columbia University, 1970); Dr. Malcolm C. McKenna, as my major professor, provided direction for the research.

Assisting me in my field work during the summers of 1967, 1968, 1969, and 1971 were, respectively, Mr. Robert M. Hunt, my wife Susan, Mr. Julian Kadish, and Mr. Albert C. Myrick.

Figures 1, 14, and 16 were drafted by Mr. Raymond Gooris, Department of Vertebrate Paleontology, American Museum of Natural History. Figures 17 and 18, and the cross sections of Figure 19 were drafted by Mr. Larry B. Isham, Department of Paleobiology, National Museum of Natural History. Mr. Chester Tarka, Department of Vertebrate Paleontology, American Museum of Natural History, has helped and given advice with other aspects of the illustrations.

Critical reading of the final manuscript by Dr. J. D. Love, United States Geological Survey, Laramie, Wyoming, and by Dr. Richard H. Tedford, Department of Vertebrate Paleontology, American

Museum of Natural History, is gratefully acknowledged.

Part of the research for this report was carried out during my tenure as a Fellow of the Faculty of Pure Science of Columbia University, partially supported by a National Science Foundation Graduate Fellowship.

Location and Extent of Area

The Flagstaff Rim area of this report includes about 40 square miles near the geographic center of Wyoming in south-central Natrona County (Figure 1). It is near the southeast end of the Wind River structural basin on the southwest flank of the basin and at the extreme southeast end of the Rattlesnake Range. The city of Casper is about 25 miles to the northeast and the village of Alcova is about 5 miles to the southeast.

The area is approximately between latitudes 42°35′ and 42°40′30″ north and between longitudes 106°10′ and 106°48′ west and centers on the mutual corners of the following four United States Geological Survey 7½-minute quadrangle sheets: Benton Basin, Benton Basin N.E., Clarkson Hill, and Alcova, Wyoming.

Previous Investigations

The geology of the area of this report has been included in published reports and geologic maps of much larger areas and at much smaller scale with less detail, but no comprehensive report of the

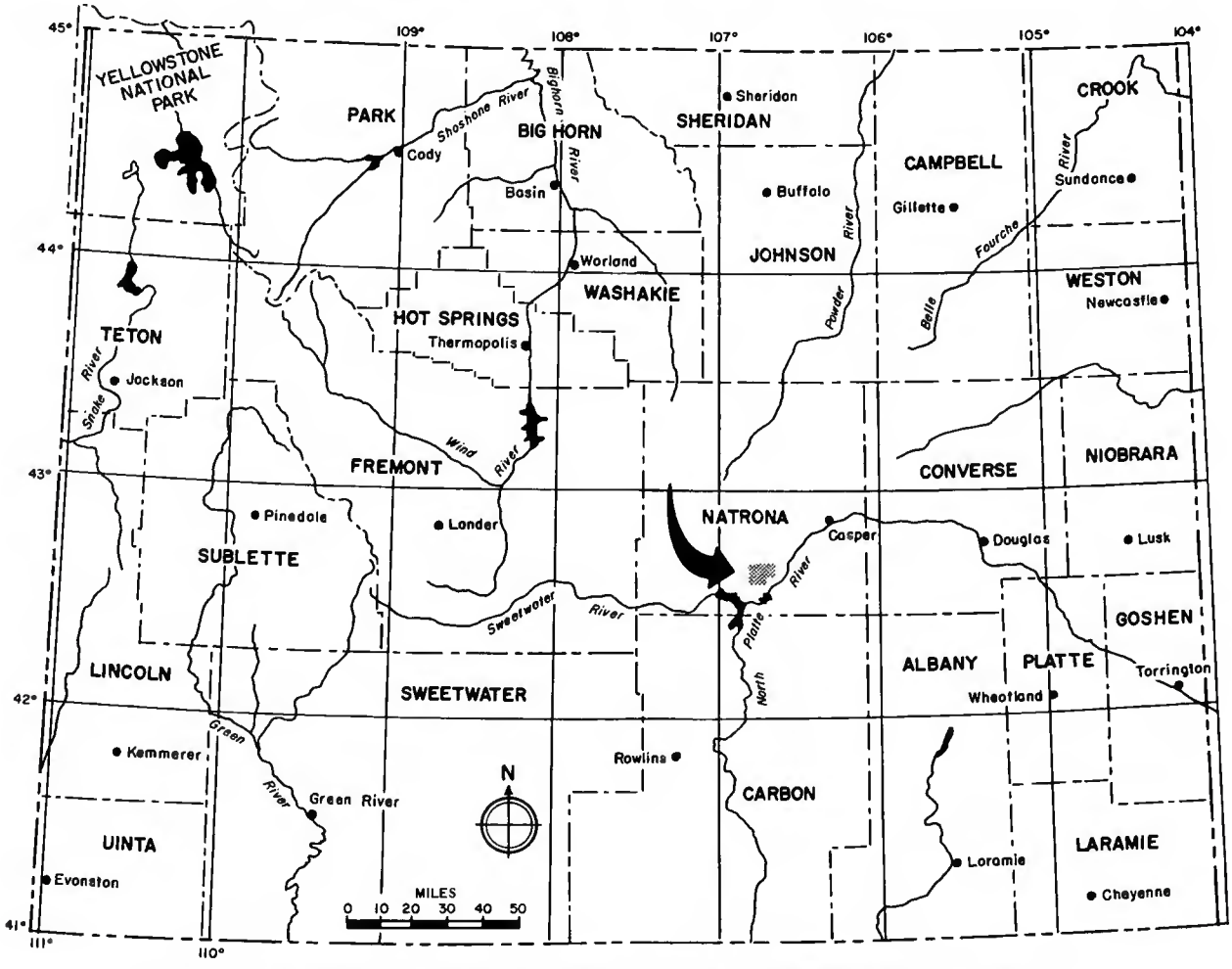

FIGURE 1.—Map of Wyoming with stipples indicating the approximate location and extent of the Flagstaff Rim area of this report (see geologic map, Figure 19).

Tertiary stratigraphy and biostratigraphy has been published.

The Oregon Trail traversed Willow Creek and Ryan Hill across the northwest corner of the mapped area, so it is certain that many thousands of people had passed through this area prior to the first geologic report by Dr. F. V. Hayden in 1869. He was the surgeon and naturalist attached to Captain W. F. Raynold's expedition of 1859 and 1860, and his reconnaissance study led to a report (1969) that briefly described the geography and included general statements about the tectonic history of the central Wyoming region. His geologic map, included in his report (1869), shows the Granite Mountains and the Rattlesnake Hills.

Knight (1895), in a summary of the coal deposits of Wyoming, described the upper Cretaceous and Paleocene coal-bearing rocks of the northeast flank of the Rattlesnake Hills anticline. The same author, in a later report (1900), was apparently the first to recognize the major fault system within the area, parts of which affect the area of the present report.

W. D. Matthew of The American Museum of Natural History made a reconnaissance of this area in 1899. After looking unsuccessfully for fossils in Oligocene outcrops in the Bates Creek drainage 15 miles to the southeast, Matthew's expedition then went northwest, crossed the North Platte River and continued westward up Poison Spider Creek, turned southward, crossed the Rattlesnake Hills and continued southeastward back to Alcova on the North Platte River. This route completely encircled the present area of study, a richly fossiliferous area, but Matthew's expedition was unsuccessful in finding fossil mammal remains. The account of this reconnaissance is unpublished but can be found in Matthew's field book of 1899, on file in the Department of Vertebrate Paleontology, American Museum of Natural History.

Hares (1916) briefly described the anticlines of central Wyoming and later (1946) published a reconnaissance geologic map of the southeast part of the Wind River Basin. A geologic map of Natrona County, Wyoming (Weitz et al., 1954), and the geologic map of Wyoming (Love et al., 1955) both include the area of the present study, but the small scale and consequent lack of detail make them both unsuitable as bases for this report.

A report and geologic map by Rich (1962) have been valuable in the present study. The map included in Rich's report and another map by Denson and Harshman (1969) both cover only part of the area of present concern, and both illustrate interpretations of the Tertiary stratigraphy and structural relationships that differ from mine in some details.

The interpretation of the stratigraphy and structural relationships of the Tertiary rocks of the area of this report are in part dependent upon numerous other reports of surrounding areas. Contributing in this capacity are the reports of Hayden (1871), Endlich (1879), Darton (1908), Granger (1910), Sinclair and Granger (1911), Woodruff and Winchester (1912), Bauer (1934), Van Houten (1964), Keefer (1965), Keefer and Van Lieu (1966), and Love (1970).

Unpublished reports that have had some influence on the present report are University of Wyoming graduate theses by Berry (1950), Bogrett (1951), Rachou (1951), and Roehler (1957).

So far as I can determine, no fossils of Eocene age have been reported from the area of present study. Fossils of early Oligocene (Chadronian) age were reported by Rich (1962). The merycoidodonts of the area have been described by Schultz and Falkenbach (1954, 1956, and 1968). A manid was described by Emry (1970). Shorter papers on new rodents include the description of a new beaver (Emry, 1972a), a new heteromyid (Emry, 1972b), and a new cricetid (Emry and Dawson, 1972).

Present Investigation

The present report is based on field work done at various times since 1957. The late Charles Falkenbach of the Frick Laboratory, American Museum of Natural History, collected mammalian fossils of Chadronian age from the area in 1941 and 1954, but these fossils have insufficient stratigraphic data to be used in this study.

In 1957 detailed stratigraphic collection of vertebrate fossils was begun in the area by a Frick Laboratory party under the leadership of Mr. Morris F. Skinner and Mr. Ted Galusha, who collected again in the area in 1958 and 1959. Skinner's field party spent a few days collecting in the area in 1963 and again in 1965. My particular interest in the area dates from 1958. During that field season,

and the subsequent seasons noted above, I was a field assistant for Morris Skinner.

For a cumulative time of about seven months during the summers of 1967, 1968, 1969, and 1971 I studied the stratigraphy, mapped, and collected additional fossils. The part of this report dealing with geology is based on field work done during these four summers. Paleontology is based on fossils collected since 1957.

The mapping (Figure 19) was done both on aerial stereophotographs and U.S. Geological Survey 7½-minute topographic maps. Stratigraphic sections were measured with a hand level, corrections for dip being made where necessary.

Geography

CLIMATE.—The Flagstaff Rim area, like most of central Wyoming, has a semi-arid middle-latitude steppe climate. It has an annual precipitation of from 10 to 20 inches, of which more than half normally falls during the months of April through July as heavy scattered thunderstorms, not infrequently accompanied by hail. With the exception of these scattered rains, the days of the summer months are usually hot, dry, and clear. Because of the dry climate, all of the streams of the mapped area are intermittent.

DRAINAGE AND TOPOGRAPHY.—The mapped area (Figure 19) is within the North Platte River drainage system, the river itself flowing northeastward only a few miles to the southeast of the area. The area above Flagstaff Rim is drained southwestward by small tributaries of Eagle Creek, an intermittent stream that flows southeastward to empty into the North Platte River at Alcova, Wyoming. The face of the Flagstaff Rim escarpment and the area below the rim are drained by Blue Gulch, Lone Tree Gulch, and Little Lone Tree Gulch, the first two flowing generally eastward to the North Platte River, and the last a tributary of the second. The north-central part of the area is drained by the heads of Willow Creek, which flows northeastward to the North Platte River.

Maximum relief of the mapped area is about 1300 feet. The altitude above mean sea level ranges from a minimum of 5480 feet at the east-central side of the mapped area to a maximum of 6781 feet at the northeast end of Flagstaff Rim.

The main positive features of the area are Flagstaff Rim, Flat Top, and Clarkson Hill. The first is a conspicuous topographic rim, the crest of which rises northeastward from about 6400 feet in the southwest part of the area to 6781 feet above sea level at its highest point. The plateau above the rim is a slightly dissected plain sloping gently southwestward. The escarpment below the rim is steep with the Oligocene rocks of the lower part dissected into well-developed badland topography. Flat Top is a large hill to the east of the rim. The flat top of this hill slopes gently southwestward from a maximum elevation of 6536 feet at the northeast end. Along the southeast and north sides of this hill are small areas of hummocky landslide topography below concave scars, some of which are now completely covered with vegetation, and others, of more recent origin, showing only bare rock (see Figure 2). Clarkson Hill, at the northeast corner of the mapped area, also has a rather flat top with a maximum altitude of about 6180 feet. The northwest side of this hill slopes gently into the surrounding terrain but the southeast side is steep with badland topography developed in Cretaceous, Paleocene, and Eocene rocks.

Stratigraphy

General Features

The rocks of primary consideration in this study are of early Oligocene (Chadronian) age. However, within the mapped area, rocks range in age from Permian to Quaternary, and within a short distance outside the mapped area rocks as old as Precambrian are exposed. Chadronian rocks unconformably overlie all of the rock units ranging in age from Precambrian to Eocene and are unconformably overlain by post-Chadronian rocks. The pre-Oligocene rocks, particularly the Precambrian, were sources of the locally derived clastic portion of the Chadronian rocks. Aside from this relationship and the physical relationships between the pre-Oligocene and Oligocene rocks, the older rocks are not directly relative to this study and will therefore be only briefly treated.

Precambrian

Gneiss, schist, granite, and black dike rocks of Precambrian age crop out a few miles to the south-

west of the mapped area. The area of outcrop of these rocks is now relatively small, being mainly hills and knobs of crystalline rocks of the former Granite Mountains protruding through the blanketing later Tertiary rocks. During Eocene and early Oligocene times, much larger areas of Precambrian rocks were exposed and these areas were apparently at much higher elevations relative to the depositional sites of Eocene and early Oligocene rocks. Large volumes of Precambrian rock were eroded from the Granite Mountains to provide clastics for the greater proportion of the early Eocene rocks of the southeast part of the Wind River Basin, which are predominantly coarse arkosic sandstones and conglomerates. By early Oligocene times the Granite Mountains had been worn down to much lower relief but were still contributing a significant amount of detritus to the locally derived clastic portion of the rocks of early Oligocene age.

Paleozoic Sedimentary Rocks

Paleozoic rocks of Cambrian, Mississippian, Pennsylvanian, and Permian age are exposed either in the mapped area or immediately to the south. These rocks dip generally northeastward on the southwest flank of the Wind River Basin. Because earliest Eocene deposits of the area contain Precambrian rocks, it is safe to conclude that the entire sequence of Paleozoic rocks had already been exposed by that time. The coarse early Eocene clastics also contain cobbles and, in some places, boulders of Paleozoic rocks, particularly of the more resistant rock types such as the Cambrian Flathead Sandstone and the Pennsylvanian Tensleep Sandstone. There are numerous published studies of the Paleozoic rocks of central Wyoming. For more detail the comprehensive review of the Paleozoic formations of the Wind River Basin by Keefer and Van Lieu (1966) is available and includes in its list of references many other works that may be consulted.

Mesozoic Sedimentary Rocks

Mesozoic rocks of the mapped area, like those of the Paleozoic, dip generally northeastward toward the axis of the Wind River Basin. Rocks of the Triassic, Jurassic, and Cretaceous systems are present. Within the mapped area, each of the formations of Mesozoic rocks is unconformably overlain by early Oligocene rocks. At the end of the Mesozoic the Wind River structural basin began to form with a slight downfolding. A small angular discordance between strata of the Cretaceous Lance Formation and Paleocene Fort Union Formation is a manifestation of this tectonic event. A much more spectacular tectonic event occurred at the end of the Paleocene or beginning of Eocene time; Paleocene and Mesozoic rocks were planed off and overlapped by early Eocene rocks, part of which were reworked from the Paleocene and Mesozoic rocks themselves. Cobbles of red Triassic sandstone and distinctive Cretaceous Cloverly Conglomerate are found in coarser units of the early Eocene rocks. Keefer (1965) discussed the later Cretaceous rocks of the Wind River Basin, and his reference list includes many other papers that discuss the Mesozoic rocks of the southeast end of the Wind River Basin.

Tertiary System

Paleocene Series

Paleocene rocks of the Fort Union Formation crop out in the mapped area only in a small area near the base of the east side of Clarkson Hill, near the axis of the Wind River structural basin. The Fort Union Formation is separated from the underlying Cretaceous Lance Formation by a slight angular unconformity of a few degrees and from the overlying Eocene rocks by a somewhat greater angular unconformity.

The Fort Union Formation consists of many thin and discontinuous beds of dark brown iron-stained sandstone, which are resistant relative to the thin to thick interbeds of gray to almost white siltstone and fine sandstone. Some of the coarser sandstone beds are arkosic and occasionally conglomeratic, containing fragments of reworked older strata. Fragments of siliceous Mowry Shale and chert pebbles like those of the characteristic Cloverly Conglomerate suggest that erosion of the margins of the basin had cut at least through the entire sequence of Cretaceous rocks by medial Paleocene time.

Eocene Series

The Eocene rocks of the area warrant more dis-

cussion than earlier rocks because in some places rocks of Eocene age can be separated only with difficulty from the early Oligocene rocks, which are of primary interest in this report.

Indian Meadows Formation

The oldest unit of Eocene age within the area is exposed on the east side of Clarkson Hill near the base of the escarpment. This unit unconformably overlies the Cretaceous Lance and Paleocene Fort Union formations and is separated from the overlying Wind River Formation by at least an erosional unconformity and perhaps by a slight angular discordance. The outcrop area is of limited areal extent, and there are apparently no other outcrops of this unit in the southeast end of the Wind River Basin. The unit is composed primarily of coarse angular grains of quartz and light-colored feldspar with the interstices filled with white to yellowish-gray clay. The upper part of the unit has discontinuous beds of pebbles and cobbles up to a foot in diameter in a coarse arkosic sandstone matrix. Throughout the sequence are layers, up to 5 feet thick, of dark carbonaceous siltstone and clay. The thickness of the unit is from 0 to 120 feet.

No fossils are known from this unit, so the age can be determined only by stratigraphic position. Rich (1962:487–488) referred to this unit as the "conglomeratic sandstone unit" of the Wind River Formation and mapped it with this formation. He concluded, however, that it was probably equivalent in age to the Indian Meadows Formation since it is unconformably overlain by beds of known early Eocene age and unconformably overlies the Fort Union Formation of Paleocene age. Rich (1962:487–488) interpreted this earliest Eocene unit as representing local deposition along a stream and described a measured section of it.

Keefer (1965:37) noted Rich's observations and on his map (pl. 1 of his report) showed the Indian Meadows Formation extending into the Clarkson Hill area. Love (1970:43) also concluded that the unit in question is the Indian Meadows Formation and reported that it thickens to more than 6000 feet in subsurface sections to the northwest. On his map (Love, 1970, pl. 1), he shows the Indian Meadows Formation in the Clarkson Hill area. I have followed these authors in mapping the unit as the Indian Meadows Formation. It should be recognized, however, that this unit may or may not have been originally continuous with the Indian Meadows Formation at its type area in the northwest part of the Wind River Basin. The assignment is made only because the unit is believed to be a correlative of the Indian Meadows Formation and, as no fossils have been found in the unit at Clarkson Hill, the correlation is based only on physical stratigraphic and structural relationships with enclosing rocks at the Clarkson Hill locality.

Wind River Formation

Rich (1962) divided the Wind River Formation of the southeast part of the Wind River Basin into two units—a lower fine-grained facies and an upper coarse-grained facies. The lower fine-grained facies does not extend into the extreme southeast end of the basin, and none is shown on Rich's map of the Clarkson Hill area (1962, pl. 7). The lower fine-grained facies, where present, has produced fossils that indicate approximate temporal equivalence to the Lost Cabin Member of the Wind River Formation in the Badwater area of the northeast part of the basin (Rich, 1962:493). The unit that Rich (1962) termed the upper coarse-grained facies overlies with erosional unconformity the fine-grained facies. The upper coarse-grained facies is therefore younger than any part of the Wind River Formation in the Badwater area where the Lost Cabin Member is the upper unit.

Rich (1962:496) concluded that the upper coarse-grained facies is of early Eocene age, however, because of its similarity to a unit in the Gas Hills area farther to the west which is overlain by middle to late Eocene pyroclastic rocks. Keefer (1965:53) believed that the most compelling evidence for an early Eocene age for the upper coarse-grained facies of Rich was the absence in this unit of volcanic debris, whereas upper Eocene and lower Oligocene rocks in nearby areas contain abundant volcanic debris.

Rich (1962:495) described a generalized section of the upper coarse-grained facies. I have mapped it (Figure 19) as Wind River Formation.

Unnamed Boulder Conglomerate

The latest unit of probable Eocene age within

the present map area is directly relevant to this study because on top of Clarkson Hill, this unit was mapped by Rich (1962, pl. 7) as White River Formation and considered by him to be early Oligocene in age. Denson and Harshman later (1969) mapped both the top of Clarkson Hill and the top of Flat Top, four miles to the southwest, as Wind River Formation. Love (1970, pl. 1) followed Rich in mapping the top of Clarkson Hill as White River Formation, but mapped what is apparently the same unit on top of Flat Top as Wind River Formation. Obviously, some clarification is needed. The unit in question unconformably overlies the upper coarse-grained facies of the Wind River Formation on Clarkson Hill and unconformably overlies Cretaceous strata on Flat Top. It can be demonstrated that the unit in question is separated from early Oligocene fossil-bearing strata by an erosional unconformity with several hundred feet of relief. The unit should not be assigned to either the Wind River or White River Formation.

As already noted, this boulder conglomerate unit covers the top of Clarkson Hill in the northeast part of the map area (Figure 19), the top of Flat Top 4 miles southwest, and laps onto Cretaceous and older strata even farther southwest. What are believed to be remnants of the same unit are present at various localities from 10 to 15 miles southeast of the present map area, preserved on the tops of rather flat-topped spurs extending out from the base of the Oligocene and Miocene escarpments between the head tributaries of Ledge Creek, Bear Creek, Bolten Creek, and the southwest tributaries of Stinking Creek. These are mapped as Wind River Formation and/or Wagon Bed Formation by Denson and Harshman (1969).

In the present map area the unnamed unit is up

FIGURE 2.—Boulder conglomerate of medial (?) or late (?) Eocene age unconformably overlying Cretaceous Frontier Formation at the south end of Flat Top. The stratification of the boulder conglomerate is more apparent in this perspective than when on the outcrop. The outcrop is a slump scar, with the slump debris spread out below and to the right of the scar. Telephoto view looking west-northwest from highway U.S. 220, about 2 miles northeast of Alcova, Wyoming.

to 250 feet thick and is characterized by thick beds of boulder conglomerate in a coarse arkosic sandstone matrix separated by thick to thin beds of coarse arkosic sandstone and occasional thinner beds of red or grayish green siltstone and claystone. On Clarkson Hill boulders 6 feet in diameter are common, while on Flat Top, nearer the Granite Mountain source area, boulders of 20 feet in diameter are not uncommon and rarely are 25 feet or more in the largest dimension. The boulders are predominantly of light-colored granitic rock, with lesser amounts of gneiss, schist, dark intrusive igneous rocks, and bright green Precambrian quartzite and Paleozoic and Mesozoic sandstones and quartzites.

The individual boulder beds vary in thickness laterally but are for the most part quite continuous over fairly large areas. The beds of finer material, on the other hand, are most often lenticular and can be traced for only short distances along the outcrops.

The following section is representative of the boulder conglomerate unit.

Section of Unnamed Boulder Conglomerate of ? medial or late Eocene age, north side of Flat Top, S ½ of Sect. 25, and N ½ of Sect. 36, T 31 N, R 83 W., Natrona Co., Wyoming. (Strata dip approximately 3° southwest; Unit 1 is oldest.)

Top of section at present land surface at approximately 6500 feet above sea level, about one-fourth mile west of VABM Kendricks bench mark

Unit		*Feet*
14.	Conglomerate, massive, poorly sorted, with boulders and cobbles of Precambrian and Paleozoic rock up to 25 feet in diameter, matrix of coarse angular grains of quartz and feldspar; partly covered by vegetation so beds of finer material may be present but not recognized	105

FIGURE 3.—Boulder conglomerate of (?) medial or (?) late Eocene age unconformably overlying Cretaceous Frontier Formation at the south end of Flat Top, in the south side of the NE ¼, Sect. 2, T 30 N, R 83 W, Natrona County, Wyoming. Same outcrop as shown in Figure 2. Man at left center gives approximate scale.

13. Sandstone, white to yellowish white, coarse grained, arkosic 12
12. Sandy claystone, brownish yellow with bands and lenses of pale green and red, poorly consolidated 5
11. Sandstone, yellowish white to white with resistant dark brown concretionary lenses, coarse grained, arkosic ... 8
10. Conglomerate, poorly sorted, with cobbles and boulders of Precambrian and Paleozoic rock up to 6 feet in diameter; covered by vegetation so the character of the matrix and whether or not units of finer material are present cannot be determined 48
9. Sandstone, pale brown to grayish green, coarse grained, poorly bedded, arkosic 12
8. Conglomerate, massive, poorly sorted, with cobbles and boulders of Precambrian and Paleozoic rock up to 2 feet in diameter; matrix of coarse-grained, pale yellowish brown, arkosic sandstone; granitic boulders weathered 4 to 6 inches deep 8
7. Sandstone, pale yellowish brown to white, relatively fine grained, bedded; interstices filled with pale green sandy clay 5
6. Conglomerate, massive, poorly sorted, with cobbles and boulders of Precambrian and Paleozoic rock up to 10 feet in diameter; matrix of coarse-grained pale greenish gray to yellowish brown arkosic sandstone; granitic boulders not so deeply weathered as in lower units 11
5. Conglomerate, massive, poorly sorted, with boulders up to 3 feet in diameter; matrix of coarse-grained yellowish brown arkosic sandstone; granite boulders weathered as in Unit 1 13
4. Sandstone, brown to grayish green, friable, medium texture, relatively well sorted 11
3. Conglomerate, massive, poorly sorted, with cobbles and boulders of Precambrian and Paleozoic rock up to 5 feet in diameter; matrix of coarse-grained brown arkosic sandstone; granitic boulders weathered as in Unit 1 18
2. Sandstone, gray to pale yellowish white, medium texture, relatively well sorted and bedded, arkosic 2
1. Conglomerate, massive, poorly sorted, with cobbles and boulders of Precambrian and Paleozoic rock up to 6 feet in diameter; matrix of coarse-grained yellowish brown arkosic sandstone; smaller granitic boulders weathered so that they can be easily disintegrated with geology pick; sandstone and quartzite boulders solid and relatively unweathered 11

Total thickness of unnamed boulder conglomerate 269

Angular unconformity at contact

Cody Shale Formation

FIGURE 4.—Lowest unit of boulder conglomerate of medial (?) or late (?) Eocene age at south end of Flat Top, in south side of NE ¼, Sect. 2, T 30 N, R 83 W, Natrona County, Wyoming. Same outcrop as Figures 1 and 2. Shows the deep weathering of the boulders of crystalline rock; note particularly the concentric weathering of the darker colored boulders of more basic composition.

Sections were also measured on the southeast side, south end, and west side of Flat Top. The section on the southeast side is quite similar to the section just described, but distributed throughout the section are several beds from 2 to 4 feet thick of fine siltstone and claystone that are pale green or purplish red with spots of limonite yellow. At the south end of Flat Top only the lower 140 feet of the section is present but the upper 30 feet of this is pale green to white coarse-grained arkosic sandstone with several bands of light green and two bands of red siltstone and claystone. The upper red band has bright green spots and the lower red band has spots of deep purple and limonite yellow. The section on the west side of Flat Top is generally similar to that of the north end described above.

On Clarkson Hill no sections were measured, but the sequence seems to be much like it is on Flat Top except the boulders are generally not so large. The unit here approaches 200 feet in thickness.

No fossils were found within the boulder conglomerate unit, so its exact age cannot be determined. On Clarkson Hill, just north of the North Granite Mountain fault zone, the boulder conglomerate unconformably overlies the upper coarse-grained facies of the Wind River Formation (Rich, 1962:497), so the maximum possible age is late early Eocene.

Rich (1962) considered the boulder conglomerate on Clarkson Hill to be the basal conglomerate of the White River Formation and early Oligocene

FIGURE 5.—Contact of Cretaceous Cody Shale (Kc) and Oligocene White River Formation (Twr) in Little Lone Tree Gulch drainage, in SW ¼, SW ¼, Sect. 18, T 31 N, R 82 W, Natrona County, Wyoming. The basal conglomeratic unit of the White River Formation varies from practically none to a few feet of cobbles of Precambrian crystalline rock and Paleozoic and Mesozoic sandstones in a coarse arkosic sandstone matrix. Directly overlying the conglomerate are silty bentonitic claystones more typical of the lower part of the White River Formation.

in age. This can be shown not to be the case. He stated (1962:497) that "the lower 12 to 50 feet of the White River Formation is a massive to poorly bedded conglomerate with granite boulders as much as 20 feet in diameter . . ." and described the composition and rock types of the conglomerate. In his section of the White River Formation (1962: 500) Rich described 12 feet of basal conglomerate. It is curious, then, that, after describing the basal conglomerate as 12 feet in thickness and writing that it varied from 12 to 50 feet, he should map more than 200 feet of boulder conglomerate on top of Clarkson Hill as White River Formation and apparently consider it all to be basal conglomerate.

Less than a half mile south of Clarkson Hill, in Sect. 18, T 31 N, R 82 W, the finer grained sandstones, siltstones, and bentonitic claystones containing early Oligocene mammals are in places lying directly on the upturned edges of Cretaceous strata, and in other areas there is only a thin layer of pebbles or cobbles at the interface (Figures 5 and 6). The contact can be traced over a considerable area just to the south of Clarkson Hill and the basal layer of cobbles and boulders rarely exceeds 10 feet in thickness. However, the thicker boulder conglomerate on Clarkson Hill is northeast of the North Granite Mountain fault zone and the area to the south, with but little Oligocene basal conglomerate, is southwest of the fault zone.

It is evident, then, that after deposition of the thick boulder conglomerate, the area southwest of the fault zone was moved upward relative to the northeast side and the boulder conglomerate was stripped from most of the southwest block before

FIGURE 6.—Lower conglomeratic unit of the White River Formation (Twr) overlying Cretaceous Cody Shale (Kc) in Little Lone Tree Gulch drainage, in SE ¼, SE ¼, Sect. 13, T 31 N, R, 83 W, Natrona County, Wyoming. The basal conglomeratic unit here is up to 15 feet of cobbles of Precambrian crystalline rock and Paleozoic and Mesozoic sandstones in a coarse arkosic sandstone matrix which is locally cemented and forms ledges. This view is typical of the lower conglomeratic unit of the White River Formation over much of the Little Lone Tree Gulch drainage. The conglomeratic unit is overlain by silty bentonitic claystones of the "lower banded zone."

deposition of the more typical finer grained early Oligocene rocks.

The thin basal conglomerate of the White River Formation southwest of the fault zone is probably primarily reworked from the earlier boulder conglomerate. It contains a higher percentage of cobbles and boulders of Paleozoic and Mesozoic sandstones and pale to bright green Precambrian quartzite, but this would be expected. If the boulder conglomerate were eroded, the deeply weathered granite boulders would tend to disintegrate or be reduced in size, whereas the more resistant sandstones and quartzites would remain.

That an erosion cycle separates the unnamed boulder conglomerate from the beginning of White River deposition can also be demonstrated by observations on the northwest side of Flat Top. In Sect. 35, T 31 N, R 83 W, the more typical finer grained tuffaceous siltstones and claystones of the White River Formation lap onto the eroded edges of the unnamed boulder conglomerate. In the same area the White River Formation overlies slump deposits containing jumbled masses of Cody Shale and the unnamed boulder conglomerate with both boulder units and finer red and green bands as described above. More recent analogs of these slump blocks can be seen on the north and southeast sides of Flat Top. Some of these slumps are now completely covered by vegetation but others are so recent that only bare outcrops of boulder conglomerate and underlying Cody Shale are exposed in the concave scars above the slump blocks (Figure 2).

On the northwest side of Flat Top, the basal

FIGURE 7.—White River Formation (Twr) lapping against and over Cretaceous Mesaverde Formation (Kmv) and boulder conglomerate (?Tbc) near Little Lone Tree Gulch, in the SE ¼, Sect. 13, T 31 N, R 83 W, Natrona County, Wyoming. The boulder conglomerate unconformably overlies the Mesaverde Formation and is probably the medial (?) or late (?) Eocene unnamed boulder conglomerate. Contacts located approximately at dashed lines. There are approximately 150 feet of relief on the base of the White River Formation at this locality. View is to northwest. Mesaverde Formation dips about 25 degrees northeastward; White River Formation is almost horizontal.

FIGURE 8.—Contact of White River Formation (Twr) and Cretaceous Cody Shale (Kc) in East Fork of Blue Gulch, west side of Flat Top. Contact approximately at dashed line. Basal unit of White River Formation is here a thin limestone that has within it occasional cobbles and pebbles of Precambrian crystalline rock and Paleozoic and Mesozoic sandstones. Slope in right foreground is Cody Shale; the cobbles on the surface are probably partly derived from the basal unit of the White River Formation and partly from the medial (?) or late (?) Eocene boulder conglomerate which overlies Cody Shale farther upslope to right of photograph.

FIGURE 9.—Relationships of the White River Formation (Twr) and underlying units in the South Fork of Lone Tree Gulch, near west side of Flat Top, in the NE ¼, SE ¼, Sect. 26, T 31 N, R 83 W, Natrona County, Wyoming. Basal unit of White River Formation is here a thin white limestone with occasional pebbles and cobbles, and is shown here lapping against Cody Shale (Kc). Within a few yards the limestone is overlying the medial (?) or late (?) Eocene boulder conglomerate (Tbc) which is overlying Cody Shale on the hill in the left part of the photograph. Contacts located approximately at dashed lines.

unit of the White River Formation is a white limestone up to 6 feet thick with seams of brown chalcedony and, near the bottom, a few boulders and cobbles. This relatively resistant limestone can be easily traced over the ancient slump deposits and up the west side of Flat Top to where it laps onto the unnamed boulder conglomerate in undisturbed outcrops.

The conclusions to be drawn from these observations are that after deposition of the unnamed boulder conglomerate, an erosion cycle produced several hundred feet of relief. The boulder conglomerate was stripped from part of the area southwest of the North Granite Mountain fault zone, but the northwest side of Flat Top remained an escarpment capped by the unnamed boulder conglomerate. Relief was abrupt enough so that slumping occurred, probably in much the same manner as it has in recent times on the north and southeast sides of Flat Top. The limestone immediately overlying the ancient slump deposits and lapping onto the eroded edges of the unnamed boulder conglomerate probably represents a relatively long interval of nondeposition before the beginning of deposition of the finer grained tuffaceous siltstones and claystones of the White River Formation.

The unnamed boulder conglomerate cannot yet be definitely correlated with any formation of the Beaver Rim area to the west. The Wagon Bed Formation near the northeast end of Beaver Divide, just west of the Rattlesnake Hills, about 40 miles west-northwest of the present map area does, however, have a unit, 25 to 50 feet thick, of giant boulders of Precambrian gneissic rock up to 20 feet in diameter (Love, 1970:54–55). This unit and the unnamed boulder conglomerate could both be manifestations of the same tectonic event that elevated the core of the Granite Mountains to provide a source area.

Within the present map area the finer units within the unnamed boulder conglomerate are neither tuffaceous nor bentonitic, at least not where examined. Along the north flank of the Shirley Mountains, about 25 miles southeast, however, a coarse boulder conglomerate underlying the White River Formation does have tuffaceous beds within it (J. D. Love, personal communication). This boulder conglomerate is very likely the same as that of the present map area, and that exposed along the heads of Ledge Creek, Bolten Creek, Bear Creek, and Stinking Creek, as noted before. The latter four localities are from 10 to 25 miles southeast of the present map area and from 10 to 15 miles north and northeast of the north flank of the Shirley Mountains. If these units are all the same, the presence of tuffaceous beds lends support to a medial or late Eocene age assignment, because early Eocene rocks of this part of Wyoming, where dated by fossils, are not characteristically tuffaceous.

The unnamed boulder conglomerate is apparently similar in lithology and stratigraphic relations to the Ice Point Conglomerate, described by Love (1970:59–62), about 50 miles west-southwest of the present map area. But the Ice Point Conglomerate is on the south flank of the Granite Mountains and apparently had the Wind River Range as its source area, whereas the unnamed boulder conglomerate is on the north flank of the Granite Mountains and had the Granite Mountains themselves as a source area. With the source areas being different mountain ranges, it is unlikely that both conglomerate units were even results of the same tectonic event. With these considerations in mind they could hardly be considered the same formation.

The age of the unnamed boulder conglomerate then cannot be accurately determined. It is younger than late early Eocene and older than early Oligocene. Its assignment to a previously named formation or recognition as a new formation must await further study. For purposes of this report, the most relevant conclusion regarding the unnamed boulder conglomerate is that it is not part of the White River Formation.

Oligocene Series

White River Formation

Definition.—The White River Formation of the present study area is generally composed of massive fine-grained tuffaceous siltstones. The lower part of the section has more variegated red and gray-green claystones and lenses of coarse arkosic sandstone and conglomerate than the upper part. The massive tuffaceous siltstones that make up the bulk of the deposits have interbedded thin lenses of claystone, occasional coarse channel sandstones,

FIGURE 10.—Panorama of Flagstaff Rim viewed from Flat Top, looking southwest (at left) to northwest (at right), showing outcrops of White River Formation. Letter symbols indicate positions of volcanic ash beds F and G. Contact of White River Formation and overlying Split Rock Formation is at abrupt change in vegetation in upper part of escarpment. Boulders and cobbles in foreground are part of underlying medial (?) or late (?) Eocene boulder conglomerate. Ferris Mountains can be seen in the distance at left.

FIGURE 11.—Outcrops of White River Formation in Lone Tree Gulch drainage. View is to southwest with North Fork of Lone Tree Gulch in foreground, Flagstaff Rim at right, and Flat Top in left distance. Letter symbols indicate volcanic ash beds discussed in text.

and distinct and easily recognizable beds of nearly pure volcanic ash or vitric tuff. The entire sequence is of Chadronian (early Oligocene) age.

It must be understood that the formation here under study is not lithologically identical to and only partly chronologically coincidental with the White River Group of the Great Plains. Meek and Hayden (1862) originally defined the White River Group in the Great Plains of Wyoming, Nebraska, and South Dakota. This was later subdivided into the early Oligocene Chadron Formation and medial and late Oligocene Brule Formation by Darton (1899:736). Later, Darton (1908:463) presented evidence that the Oligocene rocks of central Wyoming, which had previously been assigned to the Sweetwater Group (Hayden, 1871:29; Endlich, 1879:110–112), were originally continuous with the White River Group of the Plains area and suggested that the White River nomenclature be extended into the central Wyoming area.

A year after Darton's latter report, Granger (1910:238) found early Oligocene mammalian fossils along Beaver Rim, about 80 miles to the west of the present map area, and assigned the rocks producing the fossils to the White River Group. Granger noted that these Oligocene deposits were considered part of the Sweetwater Group by Hayden and Endlich but assigned them to the White River Group, because he felt that they were a westward extension of the "*Titanotherium* beds" of the Bates Hole area considered by Darton to be part of the White River Group (Granger, 1910: 241).

Since that time, the Oligocene rocks of central Wyoming have been variously termed the White River Group, White River Formation, Chadron, Chadron and Lower Brule, Brule, and Oreodon beds (Wood, 1948:39). Van Houten (1954, 1964), in stratigraphic studies of the Beaver Rim area, assigned the early Oligocene rocks there to the White River Formation and because of this work, Rich (1962) assigned the early Oligocene rocks of the present study area to the White River Formation also.

The early Oligocene rocks of the area of this report cannot now be traced continuously into those of the Beaver Divide area, 50 to 80 miles to the west. They may, however, be continuous in the subsurface south of the Rattlesnake Range and were almost certainly originally continuous north of the Rattlesnake Range and probably were continuous over much of the Wind River and Powder River Basins.

Oligocene rocks can be traced from South Dakota and northwestern Nebraska almost continuously to the area near Douglas, Wyoming. The generalization can be made that the rocks of Chadronian age become progressively coarser and more tuffaceous westward. West and southwest of Douglas, Wyoming, the Oligocene deposits extend far up some of the mountain valleys of the Laramie Range to the south, to within 25 miles of similar deposits on the southwest side of the Laramie Range. These latter are continuous with those of the Bates Hole area and the area of present study. The claystones and tuffaceous siltstones of the present study area were probably originally continuous with the generally finer sediments of the Great Plains area. Because the Chadron Formation cannot be recognized in the present study area, I have followed Van Houten (1954, 1964), Rich (1962), Love (1970), and others in using the term White River Formation for the Chadronian deposits here.

Distribution and Thickness.—The White River Formation within the mapped area (Figure 19) is, exposed mainly in the lower part of the Flagstaff Rim escarpment where it is dissected into badland topography in the heads of Blue Gulch, Lone Tree Gulch, and Little Lone Tree Gulch (Figure 10). The lower part of the section is exposed farther to the northeast along Little Lone Tree Gulch as far as the southwest side of Clarkson Hill, where it ends at the North Granite Mountain fault zone. Outside the present map area the formation can be traced in somewhat discontinuous outcrops for several miles to the northwest on the south side of the North Granite Mountain fault zone. A few miles south of the present map area the formation is exposed in Benton Basin. From 10 to 15 miles to the southeast similar rocks are exposed near the heads of Ledge Creek, Bolten Creek, Bear Creek, and Stinking Creek.

The maximum thickness of the White River Formation in the map area (Figure 19) is about 800 feet in Little Lone Tree Gulch. The original thickness cannot be determined, because the upper surface is an erosional disconformity. The formation

thins southwestward along Flagstaff Rim. The thinning is due partly to thinning of individual beds within it, but, at least in the lower part of the section, some of the beds apparently completely wedge out southwestward.

At the beginning of White River deposition the land surface was quite irregular, with at least 300 to 400 feet of relief. The area to the northwest of Flat Top was apparently a broad valley, with the west side of Flat Top forming the east side of the valley. The northwest side of the paleovalley cannot be determined but the valley must have been several miles wide. There is insufficient information to determine whether the land surface as a whole was predominantly upland with occasional valleys or predominantly lowland with occasional positive features. White River sedimentation began first in the bottoms of the valleys with deposition of claystone and stream channel sandstones with tongues of cobble and boulder conglomerate derived primarily from the ? medial or late Eocene unnamed boulder conglomerate that was being eroded from the tops of the adjacent positive areas. As deposition continued, the sediments became more tuffaceous and lapped farther up onto the sides of the valleys. Before the end of Chadronian time, the older positive features such as Flat Top had been completely covered and deposition of tuffaceous siltstones was on a broad flat plain.

General Features.—The White River Formation of the Flagstaff Rim area can be roughly divided into two parts with different lithologies: the lower part of interbedded silty claystone and conglomeratic sandstone and the upper part predominantly of tuffaceous siltstones. The lower part was deposited in the lower parts of valleys and is found only where the section is thickest. The upper tuffaceous siltstones are conformable on the lower part, the upward change in lithology being gradational and not necessarily at the same stratigraphic level in different areas.

The lower part of the section, the part deposited in the lower part of the preexisting valleys, is best exposed in Little Lone Tree Gulch but can also be studied in Lone Tree Gulch. It is characterized by units of bentonitic or montmorillinitic claystone of variegated pale green and pale to bright red color, separated by tongues of conglomeratic sandstone. The finer claystone units have within them occasional lenses of coarse arkosic channel sandstone that is frequently crossbedded. The conglomeratic sandstone tongues thicken and become coarser laterally so that near the edges of the preexisting valley in which they were deposited, they become a very coarse conglomerate with cobbles and boulders up to 10 or 12 feet in diameter. These large clasts were undoubtedly reworked from the unnamed boulder conglomerate of ? medial or late Eocene age which was exposed only a short distance to the south at a higher elevation. The cobbles and boulders are of similar rock types except that in the White River Formation there is a higher percentage of Paleozoic sandstones and bright green Precambrian quartzite. This is the expected result of reworking of the unnamed Eocene boulder conglomerate since the granitic boulders of the Eocene formation are deeply weathered and can be easily disintegrated, while the more resistant sandstone and quartzite boulders are almost completely unweathered.

The upper part of the White River Formation is predominantly massive tuffaceous siltstones of pale gray-green color. Within these siltstones are occasional thin lenses of pale green to brown claystone and lenses, up to several feet thick and 50 feet wide, of coarse channel sandstones. The bases of some of these sandstone lenses have a layer of cobbles, up to 6 inches in diameter, of granitic rock and Paleozoic and Mesozoic sandstones and brown to transparent chert and chalcedony pebbles, usually with a white coating. Within the tuffaceous siltstone sequence are many distinct beds, normally from 6 inches to several feet in thickness, of nearly pure vitric tuff or volcanic ash. Showers of volcanic debris were apparently frequent and prolonged with some of the debris falling directly onto the depositional surface as tuff and some falling into streams and ponds or onto bordering uplands and being reworked and incorporated into the tuffaceous siltstones.

Some of the beds of volcanic ash (vitric tuff) are of only very local extent, but others are continuous over fairly large areas and can be traced for several miles along the outcrops. These ash beds, particularly the more widespread ones, are very useful as marker beds for precisely describing the stratigraphic level of each of the fossils collected from the area. Radiometric dates from some of the

tuffs (Evernden et al., 1964) are also a useful adjunct to the fossils in correlating this formation with other rock units in other areas. Dates obtained by Evernden et al., are shown on Figure 16.

Rich (1962:498) in his description of the White River Formation observed that individual beds within the White River Formation are lenticular and could be traced only short distances along the strike. This is true of the stream channel sandstones and conglomerates and also of some of the thin claystone beds, but these together make up only a minor part of the formation. Most of the beds of volcanic ash or vitric tuff, however, can be traced for several miles along the outcrop and could hardly be considered lenticular. The geometry of the ash beds indicates that there was very little relief over most of the depositional surface. The massive nature of the tuffaceous siltstones makes it impossible even to determine a single bed, much less trace it along the strike; but the included ash beds support the inference that deposition of these tuffaceous siltstones was also over broad areas rather than in lenses. Individual concretionary or nodular layers within the siltstones are not continuous over large areas but these probably do not define individual beds but are rather a result of some diagenetic or other postdepositional process.

The basal unit of the White River Formation is not everywhere the same. In the lowest areas, in Little Lone Tree Gulch, where deposition began, the basal conglomerate is usually from 10 to 12 feet thick with cobbles and boulders up to 2 feet or more in diameter. In Lone Tree Gulch, along the northwest flank of Flat Top, the basal conglomerate occasionally has boulders up to 12 feet in diameter and these are in most cases the direct result of slumping of the unnamed boulder conglomerate. Along the west side of Flat Top the basal conglomerate is thinner, usually less than 4 feet in thickness, with cobbles and boulders up to 2 feet in diameter. As previously noted, in the South Fork of Lone Tree Gulch and the East Fork of Blue Gulch, the basal unit of the White River Formation is a white limestone up to 6 feet in thickness, with seams of brown chalcedony. Within the limestone are occasional boulders and cobbles. Southwest of this area, in the other parts of the Blue Gulch drainage, the basal conglomerate is even thinner and in some places the tuffaceous siltstones of the upper part of the White River Formation are directly overlying Mesozoic rocks, the only basal conglomerate being reworked pieces of the immediately underlying formation.

Because the basal conglomerate contains cobbles and boulders of granitic rock only in areas that are down slope from positive areas covered with the ? medial or late Eocene unnamed boulder conglomerate, it seems likely that these large clasts in the base of the White River Formation were derived from the preexisting boulder conglomerate. If the basal conglomerate of the White River Formation was derived directly from Precambrian outcrops, it should be thicker and coarser toward the Precambrian source. The reverse is true; in Blue Gulch, the basal conglomerate becomes finer and thinner southwestward.

The upper contact of the White River Formation is an erosional unconformity. Along Flagstaff Rim this contact is almost parallel to the White River strata, but in the northwest part of the map area (Figure 19), southeast of Ryan Hill, the overlying (?) early Miocene rocks fill a broad channel cut into the White River Formation. This was reported by Rich (1962:503) and supported by my own observations.

Within the White River Formation, the only physical evidences of breaks in deposition are the local channel cuts and fills. Channels up to 20 feet or more in depth were cut into the siltstones and subsequently refilled, usually with coarse, often crossbedded, sandstone at the base and green to brown claystone above. These cycles of cutting and filling were apparently short-lived, because lateral to the channels the tuffaceous siltstones are apparently continuous with no evidence that deposition was interrupted.

Stratigraphic Sections.—It is impossible to describe every detail of vertical and horizontal variation of the White River Formation of the present study area. Following are the descriptions of sections in four different areas which provide details of each particular area and illustrate changes from one area to the next.

North Fork of Lone Tree Gulch Section: Within the present study area (Figure 19), the North Fork of Lone Tree Gulch is the locality where the section of White River Formation approaches its maximum thickness and can be measured in con-

FIGURE 12.—White River Formation in North Fork of Lone Tree Gulch. View northwestward up North Fork of Lone Tree Gulch to northeast end of Flagstaff Rim. Letter symbols indicate volcanic ash beds discussed in text. In lower part of this view are variegated bentonitic claystones of the upper part of the "upper banded zone" which grade upward into tuffaceous siltstones. Contact of White River Formation and overlying Split Rock Formation is at abrupt break in vegetation in upper part of escarpment.

tinuous outcrop in the shortest horizontal distance. The section described below was measured along approximately the same route as a generalized section measured by Skinner (1957) and used for zonation of all the fossils subsequently collected from this area. Skinner's section did not include some of the basal beds so that marker beds used for zonation will not necessarily correspond in footage to those on the section described below. An abstracted version of Skinner's generalized zonation section is reproduced later in this report as Figure 16.

Section of White River Formation in the North Fork of Lone Tree Gulch, S½, Sect. 23, and E½, Sect. 22, T 31 N, R 83 W, Natrona County, Wyoming. (Section starts near the junction of the North and South Forks of Lone Tree Gulch and continues up the North Fork to the northeast end of Flagstaff Rim. Strata dip approximately 3° west-southwest. Unit 1 is oldest.)

?Early Miocene Split Rock Formation
Erosional unconformity
White River Formation

Unit		*Feet*
36.	Siltstone, tuffaceous, as in Unit 24	22
35.	Tuff, pale gray to white, vitric, with biotite and hard rust-colored spots. Ash J of generalized section used for zonation of fossils	5
34.	Tuffaceous siltstone, as in Unit 24	8
33.	Tuff, pale gray to white, vitric, with biotite crystals	2
32.	Tuffaceous siltstone, as in Unit 24	47
31.	Tuff, gray, vitric, with biotite and hard rust-colored spots. Ash I of generalized zonation section	1

30. Siltstone, tuffaceous, as in Unit 24 22
29. Tuff, bright bluish white, very glassy with biotite crystals and hard rust-colored spots. Ash H of generalized zonation section 2
28. Tuffaceous siltstone, as in Unit 24 55
27. Tuff, dark to black, with biotite crystals 1
26. Siltstone, tuffaceous, as in Unit 24 33
25. Tuff, pale bluish white, very glassy with many biotite crystals 2
24. Siltstone, pale greenish gray to white, very tuffaceous, with few concretionary bands that weather to reddish brown. Lower 12 to 15 feet of this unit weather to a vertical face 62
23. Siltstone, as in Unit 21 33
22. Tuff, silvery gray to white, distinct, vitric, with biotite crystals. Ash G of generalized zonation section 4
21. Siltstone, pale greenish gray, tuffaceous, few nodular layers that weather to reddish brown surface 57
20. Tuff, pale silvery gray to white, vitric, with biotite crystals. Ash F of generalized zonation section 1
19. Siltstone, as in Unit 17 72
18. Tuff, dark gray to black, vitric, with biotite and quartz grains. Ash D of generalized zonation section 2
17. Siltstone, greenish gray, massive, with thin nodular bands that weather to a reddish brown surface. Has occasional thin lenses of coarse channel sandstone 43
16. Claystone, darker grayish green, silty in some places. Weathers to rounded slopes with crumbly deeply weathered surface. This unit grades upward to the next unit 15
15. Siltstone, as in Unit 13. The top of this unit is more resistant than the overlying unit and usually forms a bench 12
14. Tuff, similar to Unit 12 1
13. Siltstone, pale greenish gray, tuffaceous, with harder concretionary bands that have a reddish brown weathered surface 11
12. Tuff, bright silvery gray to white, vitric, with many biotite grains 2
11. Siltstone, pale greenish gray to white, with reddish brown weathering concretionary bands, tuffaceous 44
10. Tuff, bright silvery gray to white, vitric, with biotite grains up to 1 mm or larger. Ash B of generalized zonation section 3
9. Siltstone, pale gray-green, tuffaceous, with harder concretionary bands that weather to a rich brown surface. Upper 5 feet of this unit is continuous concretionary zone that usually has vertical face. Upper part of unit has occasional lenses of coarse channel sandstone 11
8. Tuff, vitric, dark gray to black with hard rust-colored spots 1
7. Siltstone, pale greenish gray, tuffaceous, with harder nodular bands that weather to a rich brown surface. Upper part of unit has occasional lenses of coarse channel sandstone 15
6. Tuff, white, vitric, with small biotite grains: upper and lower contacts not sharp but mixed with overlying and underlying siltstones. Ash A of generalized zonation section 1
5. Siltstone, pale greenish gray, tuffaceous, with hard nodular bands several inches thick that weather to a rich brown color, but when broken are the same color as the surrounding sediment 42
4. Claystone, pale gray-green and pale to bright red banded and mottled in bottom part; changes upward to brown color and finally to pale gray-green siltstones near top 55
3. Conglomeratic sandstone and claystone. Sandstone pale yellow to brown, poorly sorted, arkosic, coarser upward with occasional cobbles and boulders up to 1 foot in diameter in upper part of unit; lower part of unit with lenses of green, brown, and red claystone 25
2. Claystone and sandstone; claystone variegated brown, green, and red, with more red bands near top of unit, massive; within claystone are lenses of coarse pale yellow to brown arkosic sandstone with occasional pebbles and cobbles. Unit grades upward 45
1. Conglomerate, massive, poorly sorted with cobbles and boulders of granitic rock, quartzite, and sandstone up to 6 feet in diameter in a matrix of coarse arkosic sandstone 18

Total thickness of White River Formation 775
Angular unconformity
Cretaceous Cody Shale Formation

Blue Gulch Section: Southwestward from the North Fork of Lone Tree Gulch the section of White River Formation becomes thinner. Most of the thinning occurs in the lower part of the section. The upper part of the section, equivalent to the upper 350 feet of the North Fork of Lone Tree Gulch Section, remains about the same thickness southwestward into the Blue Gulch drainage but becomes progressively more tuffaceous with fewer clay lenses.

Ash B (Unit 10 of the North Fork of Lone Tree Gulch Section) can be traced into the East Fork of Blue Gulch but cannot be traced farther southwestward into the other parts of the Blue Gulch drainage. Ash F (Unit 20 of the North Fork of Lone Tree Gulch Section) is the lowest ash bed that can be traced continuously from Lone Tree Gulch through most of the Blue Gulch drainage. Some of the channel deposits below ash F in the Blue Gulch area contain relatively pure but local deposits of white vitric tuff, but these cannot be definitely correlated with any of the tuff beds of the Lone Tree Gulch Section described above.

In the North and Trail Forks of Blue Gulch, the tuffaceous siltstones of the interval from about 20 feet below ash G to 100 feet above ash G have a pale pink color. This color is not like the red claystones of the lower part of the section in Lone

Tree Gulch and Little Lone Tree Gulch. The pink color may be due to clastics derived from the bright red upper Paleozoic and Triassic rocks only a short distance to the south.

Section of White River Formation in the Trail Fork of Blue Gulch, in the N ½, Sect. 34, and SW ¼, Sect. 27, T 31 N, R 83 W, Natrona County, Wyoming. Strata dip generally almost due west. Unit 1 is oldest.)

(?) Early Miocene Split Rock Formation
Erosional unconformity
White River Formation

Unit		*Feet*
21.	Siltstone, as in Unit 7	12
20.	Tuff, as in Unit 8	1
19.	Siltstone, as in Unit 7	4
18.	Tuff, as in Unit 8. This unit ash J (Unit 35 of North Fork of Lone Tree Gulch Section)	6
17.	Siltstone, as in Unit 7	107
16.	Tuff, as in Unit 8	1
15.	Siltstone, as in Unit 7	6
14.	Tuff, silvery bluish white, vitric, with crystals of biotite	1
13.	Siltstone, as in Unit 7	6
12.	Tuff, as in Unit 8	1
11.	Siltstone, as in Unit 7	51
10.	Tuff, as in Unit 8	1
9.	Siltstone, as in Unit 7	13
8.	Tuff, white, vitric, with biotite crystals	1
7.	Siltstone, pale gray-green to white except for lower 5 to 10 feet, which is pink, massive, tuffaceous, has occasional harder nodular bands	35
6.	Tuff, dark bluish gray, vitric, with many small biotite crystals	9
5.	Siltstone, pink, massive, tuffaceous; has occasional hard nodular layers that weather to a brown surface	33
4.	Tuff, bluish white, vitric, with biotite crystals up to 1 mm in diameter. This unit ash G (Unit 22 of North Fork of Lone Tree Gulch Section)	3
3.	Siltstone, pale gray green in lower part to pink in upper 20 feet, massive, tuffaceous; has occasional hard nodular layers that weather to a brown surface	48
2.	Tuff, white, vitric, with small biotite crystals; upper and lower contacts not sharp. This unit ash F (Unit 20 of North Fork of Lone Tree Gulch Section)	1
1.	Claystone, siltstone, and sandstone. Predominantly gray green to brown massive claystones becoming siltier and more tuffaceous toward top of unit. Throughout unit is a complex system of coarse channel sandstones, usually with smaller included lenses of pebbles and cobbles of granitic rock, sandstone, quartzite, chert, and chalcedony. Within some channels are local lenses of nearly pure white vitric tuff with biotite crystals	90
	Total thickness of White River Formation	423

Angular unconformity at contact
Cretaceous Cody Shale Formation

Little Lone Tree Gulch Sections: The lower claystone and sandstone part of the White River Formation is exposed for about 3 miles along the Little Lone Tree Gulch drainage from near the northeast end of Flagstaff Rim to the North Granite Mountain fault zone at the southwest side of Clarkson Hill. The upper part of the section is also exposed on the lower part of the Flagstaff Rim escarpment, but is immediately adjacent to and essentially identical to the corresponding part of the North Fork of Lone Tree Gulch Section and will not be described here.

The upper part of the section has been eroded away to below ash B (Unit 10 of the North Fork of Lone Tree Gulch Section) over most of the Little Lone Tree Gulch drainage. Ash B is present, however, on some of the higher ridges and can be traced almost to the North Granite Mountain fault zone at the southwest side of Clarkson Hill. Ash A and a dark gray tuff with rust-colored spots (Units 6 and 8 of the North Fork of Lone Tree Gulch Section) are also present in some localities and can be recognized within one-half mile of the North Granite Mountain fault zone.

A general description of the lower part of the White River Formation in Little Lone Tree Gulch can be given by expanding on the field terms used for the units for zonation of fossils collected from this part of the section. The field terms are (from oldest to youngest): lower yellow sandstones, lower banded zone, middle yellow sandstones, and upper banded zone.

The lower yellow sandstones are the basal unit, usually of boulders and cobbles of granitic rock, quartzite, and sandstones in a matrix of clayey arkosic sandstone of yellow to rust brown color. This unit is less than 10 feet thick over much of the Little Lone Tree Gulch drainage but thickens and becomes coarser southeastward.

The lower banded zone is predominantly of variegated red and greenish gray bentonitic claystones and siltstones with local thin lenses of coarse sandstones. This unit thickens northwestward and becomes coarser southeastward so that on the south side of the divide area separating Little Lone Tree Gulch and Lone Tree Gulch, it is composed of greenish gray arkosic sandstone and red sandy claystone with interbedded thin layers of cobbles and boulders.

The middle yellow sandstones are of yellow to rust-brown coarse arkosic sandstone with beds of cobbles and occasional lenses of finer siltstones and bentonitic claystones, especially near the top. Northwestward this unit becomes finer and is difficult to separate from the underlying lower banded zone and overlying upper banded zone. To the southeast the unit becomes coarser and thicker so that along the divide between Little Lone Tree Gulch and Lone Tree Gulch it contains many granite, quartzite, and sandstone boulders in a coarse arkosic sandstone matrix.

The upper banded zone is a unit of variegated red and pale greenish gray bentonitic claystones that become progressively more silty and tuffaceous upward into the tuffaceous siltstones typical of the upper part of the White River Formation.

The lower yellow sandstones and middle yellow sandstones are interpreted as tongues of coarse material reworked from the ? medial to late Eocene unnamed boulder conglomerate on top of Flat Top, immediately to the south and at a higher elevation. The lower banded zone is a tongue of finer sediments extending between the two tongues of coarser material, becoming thinner and coarser southeastward. The upper banded zone overlies the middle yellow sandstone and in some places interfingers with the upper part of the underlying coarser unit.

Two sections are described below to show the lateral variation within the lower part of the section.

Section I of Lower Part of White River Formation in Little Lone Tree Gulch, in the NW ¼, Sect. 24, and NE ¼, Sect. 23, T 31 N, R 83 W, Natrona County, Wyoming. (Beds are nearly horizontal. Unit 1 is oldest. Top of section at present erosion surface at about 6140 feet above sea level.)

Unit		*Feet*
5.	Tuff, silvery gray to white, vitric, with biotite crystals. This unit ash B (Unit 10 of North Fork of Lone Tree Gulch section)	3
4.	Claystone, siltstone, and sandstone. Lower 35 feet alternating bands of pale red and greenish gray massive silty claystone with local thin lenses of coarser sandstone. Above highest red band texture becomes progressively coarser and more tuffaceous and color changes progressively from pale red to brown and finally to pale greenish gray or white, which is more typical of the	

FIGURE 13.—White River Formation in Little Lone Tree Gulch. View generally northwestward with northeast end of Flagstaff Rim at left. Letter symbols indicate units discussed in text: LB = "lower banded zone," MY = "middle yellow sandstones," UB = "upper banded zone," B indicates approximate position of volcanic ash B.

tuffaceous rocks. Upper part of unit, then, is tuffaceous siltstone with occasional lenses of resistant channel sandstones up to 12 feet thick, with cobbles up to 10 inches in diameter near the base. Tuffaceous siltstone of upper part of unit, usually lateral to the channel sandstones, has hard concretionary bands several feet in thickness that weather to a rich brown surface but on a freshly broken surface still exhibit pale gray to white color, typical of the enclosing tuffaceous siltstones 92

3. Sandstone and conglomerate, pale yellow to rust-brown, arkosic, coarse. Some beds with cobbles and boulders up to 18 inches in diameter. Upper part has harder lenses of brown crossbedded coarse arkosic sandstone. Near top of unit are lenses of siltstone and variegated red and greenish yellow claystone 38
2. Claystone, variegated bright red and pale green to gray, massive, with occasional lenses of pale yellow to gray coarse arkosic sandstone 62
1. Conglomerate, very coarse at bottom, with boulders up to 3 feet in diameter of granitic rock, quartzite and sandstone in a matrix of coarse pale yellow to rust-brown arkosic sandstone. Unit becomes finer upward and has many chert pebbles in a finer sandstone matrix at the top 22

Total thickness of section 217

Angular unconformity at contact

Cretaceous Cody Shale Formation

Section II of Lower Part of White River Formation in Little Lone Tree Gulch, ½ mile southwest of Clarkson Hill, in the NW ¼, Sect. 18, T 31 N, R 83 W, Natrona County Wyoming. (Beds are nearly horizontal. Unit 1 is oldest. Top of section at present land surface at approximately 5960 feet above sea level.)

Unit		*Feet*
11.	Tuff, bright silvery gray to white, vitric, with biotite crystals. This unit ash B (Unit 10 of the North Fork of Lone Tree Gulch Section)	2
10.	Siltstone, as in Unit 8	20
9.	Tuff, dark gray to black, vitric, with hard rust-colored spots. Same tuff bed described as Unit 8 of North Fork of Lone Tree Gulch Section	3
8.	Siltstone, pale greenish gray, massive, tuffaceous. Has some resistant concretionary bands that weather to a brown color on the surface	7
7.	Tuff, white, vitric, with fine crystals of biotite. This unit ash A (Unit 6 of North Fork of Lone Tree Gulch Section.)	less than 1
6.	Claystone and siltstone, massive. Unit grades upward in color and texture from brown claystone at bottom to pale gray siltstone at top	35
5.	Sandstone, yellowish orange to white, coarse, arkosic, with harder lenses of coarse brown arkosic crossbedded sandstone	33

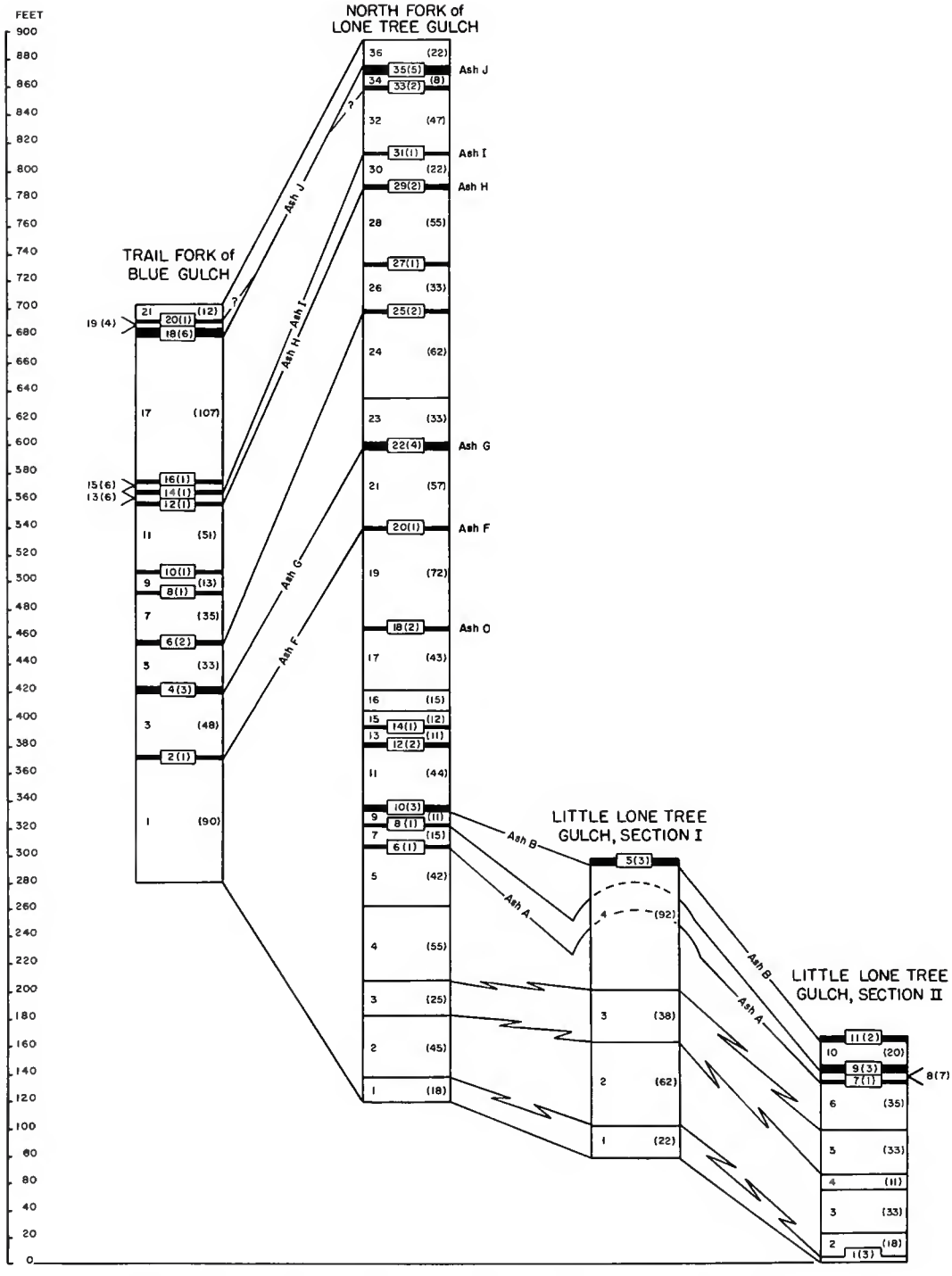

FIGURE 14.—Fence diagram showing correlation of volcanic ash beds and other important units of the four sections of the White River Formation described in text. Numbers at left in each column correspond to unit numbers of text description; numbers at right, in parentheses, are thicknesses in feet of the respective units. Bases of columns arranged in approximate relative elevations.

4. Claystone, variegated pale red and greenish gray; silty in places and has occasional thin lenses of coarse arkosic sandstone 11
3. Sandstone, pale yellowish brown to white, coarse, arkosic, with beds of pebbles and occasional resistant lenses of dark brown to gray crossbedded arkosic sandstone ... 33
2. Claystone, variegated pale red and pale greenish gray and brown, with some thin bands of lavender. Has local lenses of pale yellowish to gray sandstone 18
1. Conglomerate, very coarse, with cobbles and boulders of granitic rock, quartzites, and sandstones up to 3 feet in diameter in a matrix of sandy clay 3

Total thickness of section 166
Angular unconformity at contact
Cretaceous Lance Formation

Miocene Series

Although this study is not directly concerned with the post-Chadronian rocks of the area, the following comments are added in order to complete the description of the Tertiary deposits.

Split Rock Formation

Overlying the White River Formation along Flagstaff Rim are up to 250 feet of alternating greenish gray to brown claystones, light gray to pinkish gray sandy tuffaceous siltstones, and white lenticular conglomeratic sandstones. In the northwestern part of T 31 N, R 83 W, these rocks fill a broad valley cut into the White River Formation as noted by Rich (1962:503).

Love (1961) defined the Split Rock Formation and, on his map (1961, fig. 2) showing areas of outcrop of the formation, included the post-Chadronian rocks of the present study area. Love assigned an early Miocene age to the lower part of the Split Rock Formation on the basis of a vertebrate fossil, *Merycoides cursor,* which was found by Rich. No fossils have been found in the deposits of the upper part of Flagstaff Rim, but these rocks are apparently assignable to the lower porous sandstone sequence of the Split Rock Formation as defined by Love (1961).

Structure

Structure involving the White River Formation includes faulting and regional tilting.

The major fault system within the present study area is a northwest-southeast trending zone which is, according to Rich (1962) and Love (1970), continuous with the North Granite Mountain Fault zone, named and described by Carey (1954:33) in the Rattlesnake Hills anticline to the northwest. This fault zone is not well exposed within the present map area but only 1 mile to the northwest of the area it is clearly exposed, with the White River Formation on the south side and the upper coarse-grained facies of the Wind River Formation on the north side. Rich (1962:510) reported that the White River strata were displaced about 175 feet, the south side of the fault dropped relative to the north side.

Along the south side of Clarkson Hill the White River strata are also dropped downward on the south side of the fault zone. Rich reported the opposite to be true here, but this was no doubt due to his interpretation of the boulder conglomerate on Clarkson Hill as the basal conglomerate of the White River Formation rather than an unnamed unit of probable medial or late Eocene age as already shown in the present report. The small faults shown by Rich (1962:511, fig. 81), with displacement downward on the north side, are small faults of adjustment on the south side of the major fault zone. Southwest of the North Granite Mountain fault zone, in the Little Lone Tree Gulch drainage, are a number of small normal faults, with displacements of 10 to 30 feet. These are all nearly parallel to the North Granite Mountain fault zone and most have displacement downward on the north side, although a few have the opposite displacement. The most southwesterly of these small normal faults is about 3 miles southwest of the North Granite Mountain fault zone, near the northeast end of Flagstaff Rim.

The small normal faults are difficult or impossible to trace in the areas where only massive claystone is exposed, but on some of the higher ridges where ash B of the White River Formation crops out, the faults can easily be seen and the displacement measured. The total displacement of all these small faults observed is approximately 150 feet.

Rich reported (1962:510) that geophysical data indicate that displacement of Wind River and older strata along the North Granite Mountain fault zone may be as much as 5000 feet, with strata on the north side dropped relative to those on the south side. Because the unnamed boulder conglomerate of ? medial or late Eocene age is stripped

FIGURE 15.—Small scale normal faults in upper part of "lower banded zone" of White River Formation, south side of Little Lone Tree Gulch, about a mile and a half southwest of the North Granite Mountain fault zone. View is to southeast. Displacement is downward on southwest side (right) relative to northeast side (left). Total displacement of these three small faults is about 10 feet.

from the area south of the fault zone but is at least 200 feet thick on Clarkson Hill, north of the fault zone, movement after deposition of this unit was also downward on the north side relative to the south. This movement preceded deposition of the White River Formation.

Post-Oligocene movement along the North Granite Mountain fault zone probably occurred during ? Pliocene time (Love 1952:10; Rich, 1962: 512), and resulted in the White River and younger strata being down-dropped on the south side of the North Granite Mountain fault zone, opposite to the movement that preceded White River deposition.

During the ? Pliocene faulting, the central part of the Granite Mountains was dropped relative to the Wind River Basin to the north (Love, 1952). The southwestward tilting of the White River and younger strata is a result of these later tectonic events.

Preliminary Biostratigraphy

The Chadronian White River Formation of the Flagstaff Rim area, Natrona County, Wyoming, is, by vertebrate standards, quite richly fossiliferous. The Frick Collection, American Museum of Natural History, contains roughly 3000 individual specimens from this area. A collection made for the National Museum of Natural History in the summer of 1971, though not yet prepared and identified, contains at least 1000 additional specimens. The remains are primarily mammalian, but small reptiles are also well represented. Birds and amphibians are quite rare but present in the fauna. Approximately 80 genera and 100 species of verte-

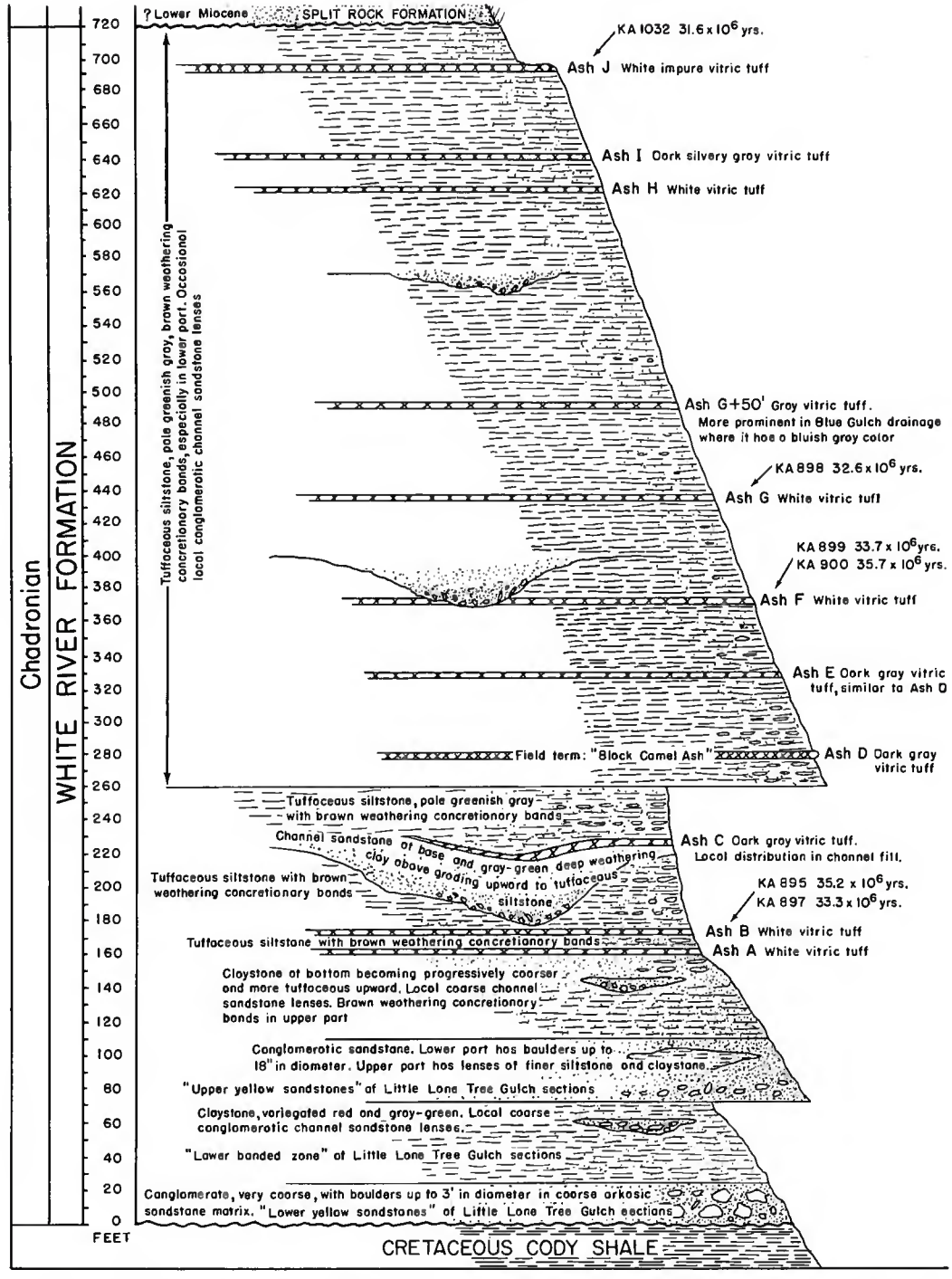

FIGURE 16.—Generalized section used for zonation of fossil specimens collected from the White River Formation of the Flagstaff Rim area. Part of section above ash B is only slightly modified from the original section measured by Skinner (1957, ms). Part of section below ash B is modified from Little Lone Tree Gulch Section I of this report. Potassium-argon dates of various ash beds are from Evernden et al. (1964). Where two dates are indicated for one ash, the second is on sanadine; all others are on biotite.

brates are represented. Nearly all of the specimens are precisely documented stratigraphically, usually in terms of feet above or below the nearest volcanic ash bed, and easily translated into footage on the generalized zonation section (Figure 16).

The badland area from which the specimens were collected extends for several miles along Flagstaff Rim. To provide more detailed geographic locations for specimens, the area was divided into a number of parts based on the washes that drain the area; for example, Little Lone Tree Gulch, North, Middle, and South Forks of Lone Tree Gulch (see Figure 17). These areas are all within visual reference of one another. The present-day erosion features or formal real estate descriptions had, of course, no effect on the Oligocene vertebrates, and, if the specimen has precise stratigraphic data, it makes little difference whether it comes from the North, Middle, or South Fork of Lone Tree Gulch. The section does, however, thin southwestward, and, for example, 20 feet above a particular ash bed in Blue Gulch may not be exactly the same stratigraphic level as 20 feet above the same ash bed in Lone Tree Gulch. Knowing the approximate geographic location is useful, then, in that it allows adjustment of the given stratigraphic position of a particular specimen when it is referred to the generalized zonation section.

When I began this study for my dissertation, I intended to analyze the entire collection, identifying each of the specimens and determining the observed local range zone of each of the species present. Changes in the composition of the fauna, or changes in individual lineages, through the section (through time) should permit the section to be subdivided biostratigraphically and provide a means for more precise correlations or greater temporal resolution within Chadronian time. Though this complete analysis proved to be too ambitious an undertaking for purposes of my dissertation, it has not been abandoned as a long-range project.

The taxonomic studies were limited for several reasons, all of which relate ultimately to the amount of time required to properly study all of the taxa represented. Before many of the taxa can be confidently assigned to species, it will be necessary to revise the genus and to establish which of the previously named species are valid and what the limits of these species are. For many of the genera this in itself will be a major research project.

There are also present in the fauna a number of new species and several new genera. To adequately diagnose and describe these requires a thorough knowledge of the previously described species of the genus or genera of the family. And, a new form, if known only from one locality, is useful in correlation only if its relationship (ancestor, descendant, collateral) can be demonstrated to another form from the unit one is attempting to correlate.

Many of the specimens of larger mammals from the present study area are not yet prepared and therefore not available for study. Among these are the titanotheres, a group which was apparently evolving rapidly during Chadronian time and would therefore be quite useful biostratigraphically.

Following is a systematic faunal listing of the vertebrate taxa from the White River Formation of the Flagstaff Rim area, in the Little Lone Tree Gulch, Lone Tree Gulch, and Blue Gulch drainages (see Figures 17 and 19). Identifications are only to the generic level in most cases, and because many specimens are not yet prepared and identified, the list may be incomplete. The genera that have been studied in some detail are discussed following the faunal list. Preliminary studies of other taxa are not yet complete. Because the known range zones of most of the genera are greater than the local observed range zones, determining the local range zones of genera would serve no useful purpose and is not done in most cases. In some instances, where genera appear to have restricted ranges, or forms have been identified to species, the local observed stratigraphic ranges are given. Where no range zones are given, it is not because the data is insufficient to do so, but rather because it would serve no useful purpose until it can be done at the specific level.

In the following list, the taxonomic arrangement above the rank of genus follows that of Romer (1966) for the amphibians and reptiles. For the mammals, I have followed Simpson (1945), except for groups that have been subsequently revised and rearranged. Identifiable bird bones were first discovered in the area in the summer of 1971, and these are not yet completely prepared, but preliminary identifications have been provided by Dr.

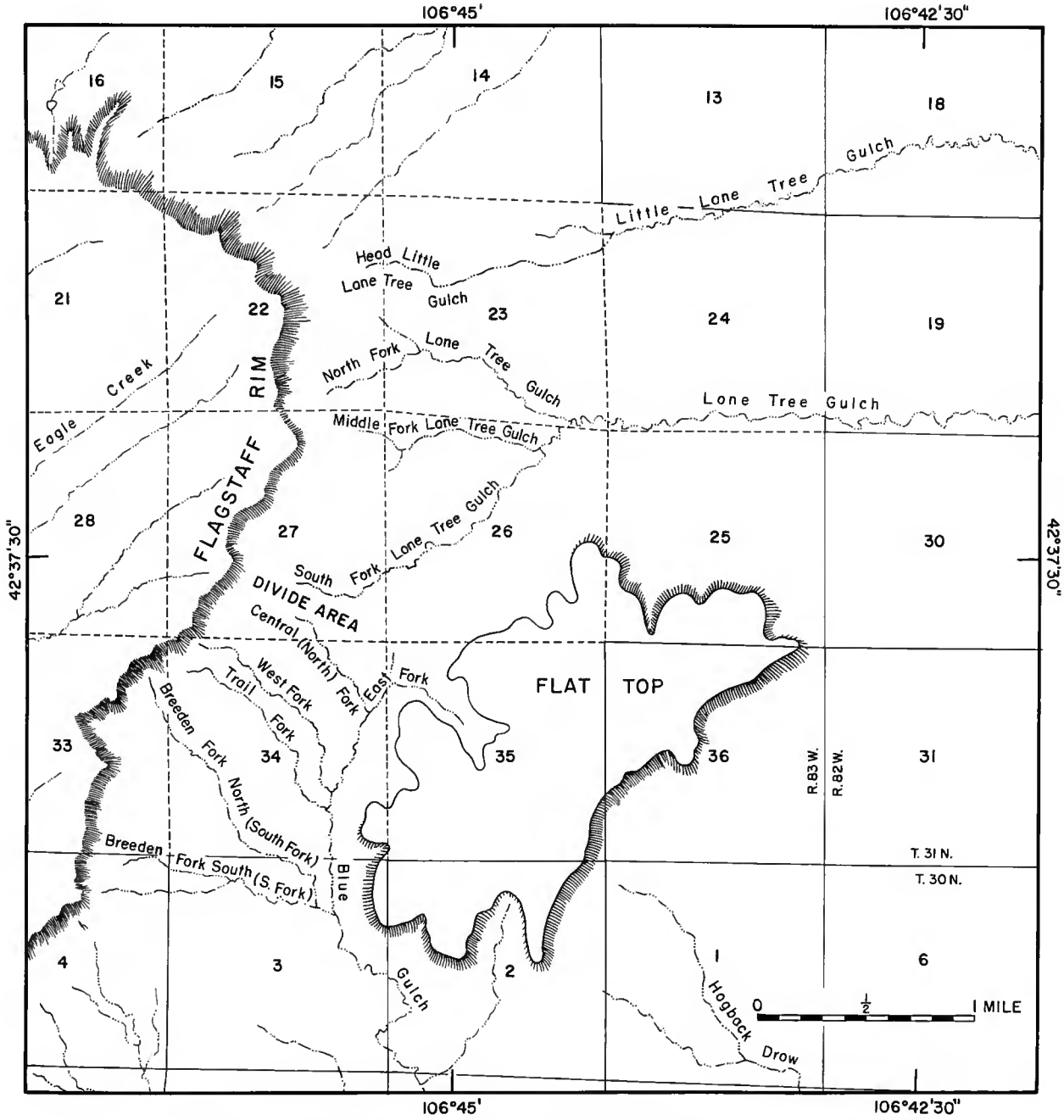

FIGURE 17.—Map of Flagstaff Rim area (part of area covered by Figure 19) showing collecting areas based on divisions of Little Lone Tree Gulch, Lone Tree Gulch, and Blue Gulch drainages. Each fossil specimen is referred to one of these localities.

Richard Zusi of the Division of Birds, National Museum of Natural History, Smithsonian Institution.

SYSTEMATIC FAUNAL LIST

Class Amphibia
Order Anura
Family Pelobatidae
Scaphiopus?

Class Reptilia
- Order Chelonia
  - Family Testudinidae
    - At least two genera present, not yet prepared and identified
- Order Squamata
  - Family Iguanidae
    - *Aciprion*
  - Family Amphisbaenidae
    - Two genera present, not yet identified
  - Family Anguidae
    - *Glyptosaurus*
  - Family Varanidae
    - *Saniwa*
    - *Thinosaurus?*
  - Family Boidae?
    - At least two relatively complete specimens of snakes, not yet prepared and identified

Class Aves
- Order Ciconiiformes
  - Family Ardeidae, one form, not assignable to any living genus
- Order Gruiformes
  - Family Aramidae, one form, not assignable to any living genus
- Order Strigiformes
  - Family Strigidae, two forms, both of which are probably not assignable to any living genera, and one of which shows some characters of Protostrigidae

Class Mammalia
- Order Marsupialia
  - Family Didelphidae
    - *Peratherium*
- Order Insectivora
  - Family Apternodontidae
    - *Apternodus,* cf. *A. brevirostris,* observed occurrences from 250 to 415 feet on zonation section
    - *Apternodus,* cf. *A. gregoryi,* observed occurrences from 295 to 415 feet on zonation section
    - *Apternodus? altitalonidus,* several specimens, all at 315 feet on the zonation section
  - Family Leptictidae
    - cf. *Leptictis acutidens,* observed occurrences from 250 to 415 feet on zonation section
    - (?) New genus and species
  - Family Erinaceidae
    - *Ankylodon,* observed occurrences from 250 to 415 feet on zonation section
    - *Geolabis*
  - Family Apatemyidae
    - *Sinclairella dakotensis,* two specimens, one at 131 and the other at 220 feet on the zonation section
- Order Chiroptera
  - Family?
    - At least one genus, not yet identified
- Order Pholidota
  - Family Epoicotheriidae
    - *Epoicotherium,* two specimens, one at 315 and the other at 410 feet on the zonation section
  - Family Manidae
    - *Patriomanis americanus,* two specimens, one at 260 and the other at 380 feet on the zonation section
- Order Rodentia
  - Family Ischyromyidae
    - *Ischyromys* (and, or includes, *Titanotheriomys*)
  - Family Paramyidae
    - *Prosciurus,* cf. *P. vetustus*
  - Family Cylindrodontidae
    - *Cylindrodon,* two species present, at least one of which is new
  - Family Sciuridae
    - *Protosciurus,* cf. *P. jeffersoni*
  - Family Castoridae
    - *Agnotocastor galushai* Emry, 1972, two specimens, one at 380 and the other at 405 feet on the zonation section
  - Family Eomyidae
    - *Paradjidaumo*
    - *Adjidaumo*
    - *Namatomys?*
  - Family Heteromyidae
    - *Meliakrouniomys skinneri* Emry, 1972, a single specimen at about 405 feet on the zonation section
    - *Heliscomys*
  - Family Cricetidae
    - *Nanomys simplicidens* Emry and Dawson, 1972, two specimens, one at 295–300 feet, and the other at 315 feet, on the zonation section
- Order Lagomorpha
  - Family Leporidae
    - *Palaeolagus*
    - *Megalagus*
    - *Desmatolagus?*
- Order Creodonta
  - Family Hyaenodontidae
    - *Hemipsalodon*
    - *Hyaenodon*
- Order Carnivora
  - Family Felidae
    - *Dinictis*
    - *Hoplophoneus?*
    - *Eusmilus?*
  - Family Daphoenidae
    - *Daphoenocyon*
  - Family Canidae
    - *Hesperocyon*
    - (?) New genus (cf. *Mesocyon*) and species
- Order Perissodactyla
  - Family Equidae
    - *Mesohippus*
  - Family Brontotheriidae
    - [Specimens not yet prepared, but probably several genera present. Local observed stratigraphic range is from about 10 to about 710 feet on the zonation section.]
  - Family Helaletidae
    - *Colodon*
  - Family Hyracodontidae
    - *Hyracodon,* cf. *H. priscidens*

Family Rhinocerotidae
Toxotherium, cf. *T. woodi,* a single specimen, at 44 feet below ash B or 131 feet above the base of the generalized zonation section
Trigonias
Subhyracodon
Caenopus?
Order Artiodactyla
Family Leptochoeridae
Stibarus
Family Entelodontidae
Brachyhyops, a single specimen at 40 feet above the base of the zonation section
Archaeotherium, cf. *A. coarctatum*
Family Anthracotheriidae
Bothriodon?
Family Agriochoeridae
Agriochoerus?
Family Merycoidontidae
Merycoidodon forsythae
Prodesmatochoerus natronensis
Bathygenys alpha
Megabathygenys goorisi
Parabathygenys paralpha
Family Oromerycidae
Eotylopus
Malaquiferus?
Family Camelidae
Poebrotherium
Family Protoceratidae
Pseudoprotoceras
"Leptotragulus," cf. *L. profectus*
(?) New genus and species
Family Hypertragulidae
Hypisodus
(?) New genus (cf. *Nanotragulus*) and species
Family Leptomerycidae
Leptomeryx, provisionally considered to represent five species, discussed in following section

Because it has so far been possible to study in detail only a limited number of taxa, the taxa analyzed were those that seemed to have the greatest potential for showing change through the section (through time). It seemed likely that changes through time could be most easily documented in genera that were well represented in terms of number of specimens and that occurred through much of the vertical extent of the rock sequence. The artiodactyl genus *Leptomeryx* and the rodent genus *Cylindrodon* met these requirements; they are the most common and second most common elements of the fauna, respectively, and both occur through much of the sequence. The fact that these two genera, and especially *Leptomeryx,* are widespread geographically also increases their potential in biostratigraphic application.

The analyses of *Leptomeryx* and *Cylindrodon* demonstrate that these two genera do change through the local sequence. *Cylindrodon* can be divided into two well-defined species, at least one of which is new, that have different (as yet mutually exclusive) local range zones. *Leptomeryx* can be divided into two morphologically distinct lineages, and the members of each lineage increases in size upward through the section. Publication of the details of these studies is deferred until the types, and hopefully, larger samples from the type areas, of the previously named species can be studied to determine the validity and limits of these species. The various recognized forms from the Flagstaff Rim area can then be more confidently assigned to species.

Regardless of the named species to which the forms of *Leptomeryx* can eventually be assigned, some useful information can be conveyed. Of the two morphologically distinct lineages of *Leptomeryx*, one is provisionally divided into three sequential species, the other into two sequential species. These are indicated in Figure 18 as species A, B, and C, and species D and E, respectively.

Species A is almost certainly *Leptomeryx yoderi* Schlaijker. Measurements of the type of *L. yoderi* fall very close to the mean values of similar measurements of a large sample from the Little Lone Tree Gulch area of the present report. Specimens included in species A occur from 20 to approximately 100 feet above the base of the zonation section.

Species C is almost certainly the same species as the large form of *Leptomeryx* from Pipestone Springs, Montana, which was referred by Matthew (1903) to *L. mammifer* Cope. The holotype of Cope's species is, however, a fragment of worn M_2 and part of M_3 from the Cypress Hills, Saskatchewan. So, although I am confident that species C and the Pipestone Springs form are the same species, I am less confident that both are *L. mammifer*. Specimens assigned to species C occur from about 235 to 425 feet on the zonation section.

The intermediate species in this lineage (species B of Figure 18) is morphologically similar to the other species of this lineage (A and B) but intermediate in size. It is apparently not referable to any previously named species, but is most like species C, which may be *L. mammifer*. Linear meas-

urements of the lower dental series overlap with those of species C, but the mean values of the measurements, based on large samples, show that species B is about 10 percent smaller than species C. Species B is more distinct from species A, with no overlap in observed ranges of linear measurements of the lower dental series. Specimens assigned to species B are primarily from a single concentration at 131 feet on the zonation section, but other specimens place the observed local stratigraphic range at about 110 to 210 feet on the zonation section.

Within the second morphologic group, species E is almost certainly the same species as the smaller form from Pipestone Springs, Montana, which was "provisionally" referred by Matthew (1903) to *Leptomeryx esulcatus* Cope. The holotype of *L. esulcatus* is a worn and broken upper molar from the Cypress Hills of Saskatchewan. So, although species E and the smaller Pipestone Springs form can confidently be considered the same, it is impossible at present to refer them confidently to any named species. Species E is more variable in morphology than the other local species and may include more than one species, but as here recognized, it occurs from about 220 feet to 530 feet on the zonation section.

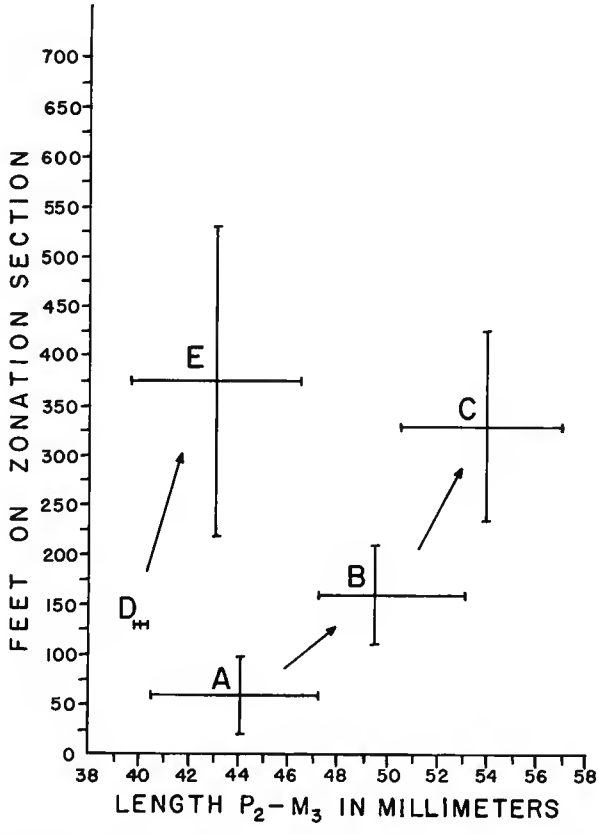

FIGURE 18.—Graph showing observed local stratigraphic ranges (vertical bars) of the five forms of *Leptomeryx* (A through E) discussed in text, and observed range of variation (horizontal bars) of one linear measurement (length P_2–M_3) of the respective forms. The vertical bars cross the horizontal bars at the mean value of measurements represented by the horizontal bars. For this single parameter (length P_2–M_3), N = 28 for form A, 24 for form B, 22 for form C, 4 for form D, and 12 for form E. Observed stratigraphic ranges were based on many more specimens, most of which were not complete enough to give the P_2–M_3 measurement.

Species D (Figure 18) is a small form known from only about a dozen specimens occurring at 131 feet on the zonation section, in the same rich concentration that provided most of the specimens of species B. Linear measurements of most of the specimens of species D fall within the lower end of the range of the same measurements of species E. The range of variation is much less, however, and because of this and minor morphologic differences it is provisionally kept distinct from species E.

Discussion

Fossils are the only practical means now available for making time correlations of sedimentary rock bodies, except for sequences with volcanic components that can be radiometrically dated. Fossils have been used in various ways in making correlations, among these methods being correlation by faunal zones (assemblage zones), correlation by hemera and epibole, correlation by index fossils, and correlation by range zones (and concurrent-range zones) of fossil taxa. A classic discussion of the various methods, and the concepts embodied in them, is that of Arkell (1933). Those familiar with Shaw's (1964) excellent analysis of these methods will also recognize its influence on the following discussion.

In order to evaluate the relative precision or resolution inherent in the different methods of correlation by fossils, it is necessary to understand the relationships between fossil species and rock bodies.

Any species is surely descended from an ancestral species and, unless it dies out without descendants, gives rise to yet another species, by evolutionary

processes — environmental influence on genetic changes. Many fossil species are separated from ancestral and descendant species by morphologic gaps that, owing to accidents of preservation or collection, have not yet been filled in. In some instances, continuous evolutionary sequences are known, and these are divided, for convenience, into segments considered to be species. The biochrons of species, and hence the range zones (biozones) of species, then are dependent upon the definitions of the species, which are based on morphological changes that arise through evolutionary processes. These processes are such that the range zone of one species has no direct relationship to that of another, unless there was some special biological dependence of one species upon the other, or perhaps a mutual dependence. But, even in these special cases, the range zones would be precisely coincident only if the two species with this special dependence became distinct from their respective ancestral species at the same time.

Because biochrons, and hence range zones (biozones) of species, are predictably noncoincidental, faunas should be expected to change through time by gradual appearance of new elements and gradual disappearance of others, with the range zones of the various species overlapping unsystematically. Observed local range zones (teilzones) of some species may, however, be coincidental due to any one or a combination of factors such as changes in the local environment or breaks in the sedimentary record due either to erosion or nondeposition of rocks representing some segment of time.

An assemblage of fossils from one time interval should be thought of as a sample of the fauna, the species of which are in a dynamic process of appearing and disappearing. A wholesale change in fauna at one horizon should indicate that some extrinsic factor has affected the record.

Species may disappear from the record in one of two ways: either by extinction, in the sense that they leave no descendant species, or by evolution, in the sense that they evolve into one or more new species. But, even in cases in which several species become extinct (in the former sense), apparently simultaneously, there is little chance of their range zones being precisely coincident, because to be so the first appearances would also have to be simultaneous.

It has been argued, and probably will be argued, that only by extinction in the true sense will a species have a definite termination, and that if a species disappears by evolving into one or more new species, the upper limit of its range will not be abrupt. If this argument were to be strictly applied, the lower limits of the range zones of all species would, by the same reasoning, not be abrupt. This argument is founded on confusion between evolutionary reality and taxonomy. Determination of species range zones, and correlations based on them, requires, of course, the use of taxonomic units. The taxonomic unit must be defined and its limits determined, perhaps arbitrarily in some cases. But, consistent with the definition, the taxon has a lower stratigraphic limit and, unless it still exists, an upper stratigraphic limit, below and above which it cannot be recognized.

It should be apparent that the overlap of range zones (concurrent-range zone) of two or more taxa is likely to be of lesser magnitude than the total range zone of any one of the individual species. This will not be true in cases where (1) the total range zone of one species is completely included within the total range zone of another or (2) in the very unlikely event that two zones are precisely coincident. In these two cases, the concurrent-range zone will be the same as that of the shortest ranging of the species or of both of the species. Concurrent-range zones, however, need not be limited to the joint occurrence of two species; they may involve a very large or very small percentage of the species present in the rock sequence. They must however be based on actual stratigraphically controlled occurrences of specimens. To be useful, concurrent-range zones must be explicitly defined by listing the taxa on whose mutual occurrence the unit is based. And, because none of the species is necessarily limited to the concurrent-range zone, the zone can be recognized only if all the species listed in the definition are present. The presence of any one or a portion of the species does not necessarily identify the concurrent-range zone. The point to be made here is that biostratigraphic units based on joint occurrences of taxa should have shorter temporal spans than those based on the ranges of individual taxa.

If correlations are made by index fossils or by hemerae, the maximum temporal resolution obtain-

able is the total temporal span of the particular species used. The presence in strata of an index fossil indicates only that the strata is somewhere within the total range zone of the index fossil species. Hemeral correlations reduce to the same thing. A hemera is defined as the time of maximum abundance of a species. But the maximum abundance of any particular species at one locality may not coincide temporally with its maximum abundance at any other locality. It can only be determined that all of the local abundance maxima are somewhere within the total range zone of the species.

Correlation of continental deposits by means of verterbrate fossils has traditionally been by means of faunal zones (assemblage zones), or by index fossils, or what amounts to correlation by these methods. Although the units of correlation may, in many cases, not be called assemblage zones and may not be named for one of the particularly prominent or diagnostic taxa, they otherwise correspond well to the definition of assemblage zone given in the *American Code of Stratigraphic Nomenclature* (1961, Article 21), namely, "a body of strata characterized by a certain assemblage of fossils without regard to their ranges." Most vertebrate faunal lists, and even many of the more detailed faunal studies, usually pertain to "the fauna" of a particular formation or member, but are deficient or utterly lacking in details of the stratigraphic distribution of specimens, or of species, *within* the rock unit. It seems to be a widespread assumption that the species found at some place in a formation (or other rock unit) will range throughout the vertical extent of that rock unit. Charts showing the stratigraphic distribution of taxa normally show the limits of the ranges of taxa coinciding with the boundaries of the formation or lithologic subdivision of the formation. As already noted, in some instances, local range zones may coincide with lithologic units, but this is certainly not always the case, and at any rate, is not because of any mechanism that actually controls the range zone of the species, but rather to extrinsic factors such as environmental shift and/or breaks in the rock sequence.

Assemblage zones, then, are in practice, recognized by the *presence* in a rock body of a particular assemblage, rather than on actual *stratigraphic positions* of specimens or species *within* the rock body. None of the taxa of an assemblage zone are necessarily restricted to the assemblage zone, nor are they all found in every part of the zone. In practice, however, assemblage zones are often identified by the presence of only a fraction of the constituent species of the assemblage. It is conceivable, and certainly often happens, that the temporal span of the assemblage zone is greater than the temporal span of any one of its constituent species.

The utility of assemblage zones is attested to by their widespread use in correlation, but their limitations, in terms of temporal resolution, are apparently not widely recognized. Assemblage zones are generalizations. They can be recognized only because it has been empirically shown that certain taxa existed together for a long enough period of time so that their mutual occurrence is common. Most assemblage zones used by verterbrate paleontologists were originally recognized because they were separated from underlying or overlying zones by breaks in the record that omitted the intergrading assemblages that would have linked them.

The tendency, at least among verterbrate paleontologists, has been to attempt to refine faunal zones beyond their real limits of accuracy. As stated by Shaw (1964:91), because faunas as immutable aggregates of species have no real existence, "faunal (or floral) zones are recognizable only to the degree to which the actual ranges of the constituent species are *not* established." Assemblage zones inherently have fuzzy edges; if the edges seem sharp it is only because the actual ranges of the species of the assemblage are not completely known.

Regarding the practical restrictions on refinement of faunal zones, Shaw (1964:92–93) discussed other problems that are either inherent in the method or accrue from attempted overrefinements. He writes:

> A psychological hazard exists in the attempt to refine zones beyond their real limits of accuracy. There is the tendency to make our information fit the preconception embodied in the zonal concept itself. If the paleontologist expects to find a series of successive faunas, he will find them. One way to produce successive faunas is by dealing only with species that are successive, as species in a single evolving lineage. Another way is to put emphasis only on those species that conform to the ideal of zonation and to disregard those forms which do not fit into the proposed scheme as "long-ranging" or "of little correlative value." In the second approach it is usually more satisfactory to use the rarest of fossils in the

fauna. By doing so we minimize the likelihood that we shall be faced with the awkward event of having two "successive" forms appear in the same bed.

Shaw concludes (1964:93) that faunal zones "can be refined only by omitting more and more of the species whose ranges do not conform to the definition. Ultimately these omissions reduce zonal correlation to something like hemeral correlation or to correlation based on such a small fraction of the total biota that the results are likely to be nonrepresentative."

The most recent attempt at dividing the Chadronian stage biostratigraphically is that of Clark et al. (1967). Here again, biostratigraphic subdivisions were not developed from precise knowledge of the stratal ranges of the included taxa. The species present in each of the three previously named lithologic members of the Chadron Formation of South Dakota were identified and the "ranges" of these species made to conform to the lithologic units. This resulted in what amounts to three assemblage zones, the limits of which were defined on lithologic rather than biologic criteria.

Clark (1954) divided the Chadron Formation of South Dakota into three members, the Ahearn, Crazy Johnson, and Peanut Peak, in ascending order. The three members have thicknesses of zero to 80 feet, 20 to 40 feet, 20 to 30 feet, respectively (Clark and Beerbower, *in* Clark, Beerbower, and Kietzke, 1967:21). The maximum thickness of the Chadron Formation as a whole, within the Big Badlands, is 130 feet. The authors admit that deposition was extremely slow or nonexistent during much of the time so that the rock sequence represents only a small fraction of Chadronian time. They further admit (p. 23) that the upper two members are separated by pond limestones and channel fill deposits only very locally and that outside these very local areas, the two upper members are unseparable.

Clark and Beerbower (*in* Clark, Beerbower, and Kietzke, 1967:21) state that "many species are known from only a few specimens." A survey of the systematic paleontology section of their report shows that a number of species are known only from single specimens, and that they often question the specific allocations of these. However, if a species is present in one of the members, even as a single specimen, the species is considered to range throughout the entire thickness of the member, even though the member in question may be separable from another only very locally on physical lithologic criteria. This is an uncritical view of the relationships between fossil species and rock bodies. It assumes that all of the species present at some place in the rock unit were present throughout the unit, and may indicate coexistence of species that in fact may not even have had overlapping range zones.

Correlations proposed by Clark and Beerbower (*in* Clark, Beerbower, and Kietzke, 1967) are no less uncertain than the biostratigraphic data on which they are based. The problems pointed out by Shaw (1964:91), and discussed above, that arise from overrefinement of assemblage zones become abundantly apparent. Correlation of the Pipestone Springs fauna of Montana, for example, with the Peanut Peak fauna, may or may not be accurate, but if so, not for the reasons given by Clark and Beerbower. Their correlation of these two units is based almost entirely on the fact that "five species, based on good material, are limited to these faunas and are unknown from pre-Peanut Peak members or from the [overlying] Brule Formation. These are *Apternodus mediaevus*; *A. altitalonidus*; *Metacodon magnus; Daphoenocyon dodgei;* and *Merycoidodon lewisi*" (Clark and Beerbower, *in* Clark, Beerbower, and Kietzke, 1967:56). The three insectivore species are represented in the Peanut Peak Member, however, by a single specimen each, and the authors admit (p. 56) that "these limited stratigraphic ranges may be accidents of sampling." They also refer only one specimen from the Peanut Peak Member to *D. dodgei*. And, in deference to their statement that these five species are not known from pre-Peanut Peak members, they refer (p. 31) a specimen from the upper part of the Crazy Johnson Member to *D. dodgei,* and also suggest (p. 55) that "*M. lewisi* or a related species" is present in the Ahearn Member. Confidence in their correlation is even further diminished by their statement (pp. 31–32) that "the *D. dodgei* specimens from South Dakota may represent a different species, with a more shallow jaw, but the samples are too small to justify such a division."

Four other species, *Hyaenodon horridus, Mesohippus latidens, Hyracodon priscidens,* and *Caenopus mitis,* are common to the Pipestone Springs

and Peanut Peak deposits (Clark and Beerbower, *in* Clark, Beerbower and Kietzke, 1967:56), but these species are also known from older and/or younger deposits. They were therefore not considered to be as definitive as the previously discussed five species. It seems obvious that they are less definitive only because their stratigraphic ranges are more completely known.

Mesohippus hypostylus is, according to Clark and Beerbower, known from the Pipestone Springs of Montana and from the lower two members of the Chadron Formation in South Dakota, but not from the Peanut Peak Member. This suggested to Clark and Beerbower (p. 56) a younger age for the Peanut Peak Member. But, because they believe that the medial Oligocene *M. bairdi* is a continuation of the *M. hypostylus* line, they concluded that *M. hypostylus* must have lived during Peanut Peak time and is therefore of no value for precise correlation. It would have been just as logical, of course, to assume that *M. bairdi,* or perhaps even an intermediate species, lived during Peanut Peak time; in other words, *M. bairdi* could be extended downward to connect with *M. hypostylus,* rather than *M. hypostylus* being extended upward to connect with *M. bairdi,* or, for that matter, the ranges of these two species may meet somewhere within Peanut Peak time, providing they are parts of one continuous lineage.

The relationships of the various species of the carnivore *Parictis* also suggested to Clark and Beerbower (p. 57) that the Pipestone Springs fauna is older than the Peanut Peak. But because *Parictis* is rare (which seemed not to matter with other species), and because no medial Chadron species are known, Clark and Beerbower concluded that *P. dakotensis* from the Peanut Peak Member, rather than being descended from the more primitive Pipestone Springs species, may merely have diverged more rapidly from a possible, but unknown, medial Chadron ancestor.

Several other genera (*Peratherium, Ictops, Menodus, Hoplophoneus, Dinictis,* and *Paleolagus,* and undoubtedly others not listed) are common to Pipestone Springs and the members of the Chadron Formation, but Clark and Beerbower (1967:57) considered the ranges of the genera to be too long for very precise correlation. They did not attempt specific allocations in some of the genera and in others considered the taxonomy too confused to allow specific determinations. The rodents were dismissed by Clark and Beerbower (p. 57) with the statement that they are conservative groups with high dental variability and therefore "of little value as guide fossils for restricted time zones."

Clark and Beerbower avoided another large and common group with the statement that "the taxonomy of the small artiodactyls is also too confused at present to allow their use in correlations." In their systematic paleontology section, Clark and Beerbower (p. 55) noted that "several species of small selenodont artiodactyls are common in the Chadron of South Dakota," but that "the taxonomy of the hypertraguloids is, however, so badly confused that we are reluctant to assign these specimens to recognized genera and species of hypertraguloids." They concluded (p. 55) that, for their study, "the most significant points are (1) the abundance of medium to large hypertraguloids in the Ahearn and Crazy Johnson Members; (2) absence of these types in the Peanut Peak Member; (3) presence of a few small hypertraguloids in the Peanut Peak and Crazy Johnson Members." Although not mentioned by Clark and Beerbower, The Pipestone Springs fauna of Montana has abundant medium and large *Leptomeryx* (hypertraguloids). The fact that the Peanut Peak Member has none of these forms, which are widespread geographically and usually very abundant where they do occur, may be more significant than the presence of the five rare species on which they base their correlation. At any rate, if the hypertraguloids from the two localities could be recognized as the same species, they would be equally useful for correlation purposes whether or not they have a formal taxonomic name applied to them.

Clark and Beerbower (p. 59) also note that several primitive species (which they do not list) in the Pipestone Springs fauna suggest an older age than that of the Peanut Peak Member, but they concluded that this was not due to an age difference but rather to "local survival of these species in a more favorable environment."

This correlation proposed by Clark and Beerbower is a good illustration of Shaw's (1964) discussion of the results of overrefinement of faunal zones. Most of these taxa were omitted as "long-ranging," "of little correlative value," or "too tax-

onomically confused to be used." Taxa that suggested different ages for the two deposits were rationalized out of consideration by suggesting different rates of evolution from unknown common ancestors, longer survival in favorable local environments, or that they lived during intervals in which they have not been found. The basis for correlation was reduced to five species, three of which are very rare forms whose restricted ranges may be accidents of sampling. Of the other two species, at least one is known from older deposits, and the specific allocation of the other is questioned.

It should be apparent that if greater temporal resolution in correlation is required, or desired, a method should be used that has the inherent potential of providing greater resolution, rather than attempting to refine faunal zones beyond their real limits. Correlations by concurrent-range zones of species, which are based on actual stratigraphically controlled occurrences, has an inherently greater potential for providing greater temporal resolution. That this method should afford the greatest resolution is so nearly axiomatic that it requires no additional support here by means of a series of citations of published opinions. It should be obvious, if one understands the relationships of fossil species to rock bodies, that this method allows the recognition of biostratigraphic units of less magnitude than do the other methods. But recognition of this fact has not been followed by its use in vertebrate paleontology.

Certain minimum requirements must be met for ranges of species correlations, namely: (1) the paleontological taxa must be clearly and unambiguously defined; (2) specimens must have accurate and precise stratigraphic documentation; and (3) the taxa must be present in more than one stratigraphic sequence. All specimens from one locality should be tied to a single reference section if possible. It is probably superfluous to note that the use of concurrent-range zones requires the presence and use of more than one species. At least conceptually, the greater the number of species used in the definition of a concurrent-range zone, the lesser should be the magnitude of this biostratigraphic unit. Ideally, all of the species in a rock sequence should be considered before the sequence is divided into biostratigraphic units based on concurrent ranges.

For purposes of correlation by species range zones, a paleontological species should have morphologic and/or biometric properties distinctive and consistent enough so that it can be defined sufficiently well to be recognized by other workers. This need not be inconsistent with a biological definition, although the purely biological definition cannot be strictly applied to paleontological species.

All species are to some extent indicators of favorable local environments. If species migrate with changing environment, they may transgress time planes, so that local species range zones will probably not represent the total range zones of species, but rather indicate the span of time at each locality when environmental conditions were favorable for them, or, perhaps, when local depositional factors were favorable for their preservation. Only where we have, in a local rock sequence, a continuous evolutionary sequence that can be arbitrarily divided into species, can we be reasonably confident that the local range zone approximates the total range zone of the species. In most cases, total range zones must be determined by summation of local range zones from different sequences. The range zone (= total range zone by definition), in order to be attainable, and therefore useful, must be based on the total stratigraphic range through which the species is actually preserved and can be found. The total stratigraphic range through which the taxon lived can probably only rarely, if ever, be determined with certainty in practice, and should not seriously occupy our time, except to the extent that we search for actual occurrences to approach it. We can gain no information from specimens that may extend the known stratigraphic range until they have been found.

In range zone correlations, the most confidence should be placed on species that are most common and whose ranges are most completely known. As the fossil record becomes more complete and evolutionary gaps are filled in, the range zones of species can be more accurately (if more arbitrarily) determined, and correlations based on them will gain resolution and confidence. This is in contrast to assemblage zones as now used by most vertebrate paleontologists. If, as is the practice, an assemblage zone is defined only on the presence of taxa within a rock unit, it can be refined, as previously pointed out, only by omission of more and more taxa that, as their ranges become more precisely known, no

longer conform to the definition of the assemblage zone. Correlation is finally reduced to reliance on a few taxa, usually the rarer forms, which may conform to the definition of the assemblage zone only because their ranges are very incompletely known. If by these omissions, the assemblage zone boundaries are sharpened and correlation seems more precise, it is certainly at the great expense of confidence in these correlations. Simply stated, correlations by species range zones and concurrent-range zones gain precision as evolutionary gaps are filled in, whereas with assemblage zones, problems of definition of the zone become progressively acute as the record becomes more complete.

The necessity of basing local range zones of species on actual occurrences in rock sequences cannot be overemphasized. This requires, of course, that collectors of specimens do more than record the formation, or other rock unit, that yields the specimens; they must record as accurately as possible the position of each specimen *within* the rock sequence. In cases where the local rock sequence is completely included within the range zone of a species, errors in correlation will not occur as a result of the local range zone of that species being considered the total rock sequence, even though it may not be based on actual occurrences. If, however, local species range zones of all species that begin and/or terminate within the local rock sequence are considered to coincide with the rock sequence, the effect is to add strata to the total range zones of these species that are not really within the total range zones. This is an inaccurate representation of the relationship between the species and the rock body. The use of these exaggerated range zones could result in miscorrelation, and, at the least, will diminish the temporal resolution of any correlations based on them. Obviously, precision in correlation cannot exceed the precision of the paleontological data on which they are based.

It must be admitted that many important vertebrate localities, particularly those of the later Tertiary of western North America, are very local in nature, both laterally and vertically. Many of these are, for example, rich concentrations of vertebrate remains in very local channel deposits that may occur within relatively thick but otherwise unfossiliferous sequences. In these instances, it will be impossible to determine local range zones for the species represented because they all occur at what is, for all practical purposes, a single horizon with no thickness. A useful concept in these instances, as developed by vertebrate paleontologists, is the "local fauna," which, though not a biostratigraphic unit, is often substituted for one as a unit of correlation (see Tedford, 1970:675–680).

The fact that local range zones cannot always be determined is no excuse for their not being used when we do have stratigraphic sequences that are more or less fossiliferous throughout their vertical extents, and where it is possible to determine local range zones. Important information and resolution are lost by assuming that each of the species present ranged throughout the rock unit. Important faunal changes that may have occurred within the sequence cannot be recognized. The only objectively recognizable single temporal events that we can know about a fossil species are the beginning and end of its range. Hence, the only paleontologic criteria that can be used to mark increments of time within a rock sequence are the beginnings and/or terminations of fossil species range zones within it.

An assemblage zone as a biostratigraphic unit is a body of strata characterized by a certain assemblage of fossils without regard to their ranges. The limits of assemblage zones are usually fixed, in practice, at lithologic boundaries and are therefore based on the temporal span of a rock unit. If we are to gain maximum temporal resolution (and, incidentally, to follow the Code of Stratigraphic Nomenclature), biostratigraphic units must be based on biologic criteria, the temporal spans of taxa or aggregates of taxa.

Unfortunately, many collections of Tertiary vertebrates lack one of the primary requisites for range zone correlations, namely detailed records of the stratigraphic levels at which specimens occurred. Many collectors apparently even yet consider adequate stratigraphic documentation to be the recording of the rock unit, usually formation, from which specimens are derived. Any specimens collected should, where possible, be accurately tied to a measured section of the local rock sequence. Only by having these data can we hope to be able to recognize biostratigraphic units of less magnitude than the total range zones of individual species.

The Chadronian White River Formation of the

Flagstaff Rim area of Natrona County, Wyoming, is relatively thick, compared to other Chadronian sequences, and probably represents much of Chadronian time. The approximately 4000 specimens of fossil vertebrates from the area have adequate stratigraphic documentation to allow determination of local range zones of the approximately 100 species, as time permits their study. This report has presented the stratigraphic framework necessary for determining the local range zones. When all of the specimens have been identified and the local range zones of all species determined, it will be possible to construct a reference section, and by comparisons and correlations of other sections, a composite reference section that will allow recognition of biostratigraphic units of much less magnitude within Chadronian time than has previously been possible.

Increased temporal resolution would permit more detailed and meaningful studies of faunal migrations and dispersal patterns. Phylogenetic histories of taxa could be determined in greater detail. Reduction or elimination of temporal uncertainties will increase confidence in paleoecological comparisons of different areas. Studies of rates of morphologic change can be better controlled, and if species range zones can be related to radiometric dates, this aspect is even further enhanced. Greater temporal resolution need not be an end in itself.

Literature Cited

American Commission on Stratigraphic Nomenclature
1961. Code of Stratigraphic Nomenclature. *Bulletin of the American Association of Petroleum Geologists,* 45 (5) :645–665.

Arkell, J. W.
1933. *The Jurassic System in Great Britain.* viii + 681 pages. Fair Lawn, New Jersey: Oxford University Press.

Bauer, C. M.
1934. Wind River Basin. *Bulletin of the Geological Society of America,* 45 (4) :665–696.

Berry, R. M.
1959. *Tertiary Stratigraphy of the Bates Hole-Alcova Region, Central Wyoming.* Unpublished graduate thesis, University of Wyoming.

Bogrett, J. W.
1951. *Geology of the Northwestern End of the Rattlesnake Hills, Natrona County, Wyoming.* Unpublished graduate thesis, University of Wyoming.

Carey, B. D., Jr.
1954. A Brief Sketch of the Geology of the Rattlesnake Hills, Natrona County, Wyoming. *Wyoming Geological Association Guidebook, Ninth Annual Field Conference, Casper Area,* 1954:32–34 and map.

Clark, John
1937. The Stratigraphy and Paleontology of the Chadron Formation in the Big Badlands of South Dakota. *Annals of the Carnegie Museum,* 25:261–350.
1954. Geographic Designation of the Members of the Chadron Formation in South Dakota. *Annals of the Carnegie Museum,* 33:197–198.

Clark, John, J. R. Beerbower, and K. K. Kietzke
1967. Oligocene Sedimentation, Stratigraphy, Paleoecology, and Paleoclimatology in the Big Badlands of South Dakota. *Fieldiana, Geology Memoirs,* 5:1–158.

Cope, E. D.
1885. The White River Beds of Swift Current River, Northwest Territory. *American Naturalist,* 19:163. [Also in *Geological and Natural History Survey of Canada,* new series (C) : 80 and appendix I.]
1889. The Vertebrata of the Swift Current River, Number 2. *American Naturalist,* 23:151–155.
1891. On Vertebrata from the Tertiary and Cretaceous Rocks of the Northwest Territory, Part 1: The Species From the Oligocene or Lower Miocene Beds of the Cypress Hills. *Geological Survey of Canada, Contributions to Canadian Paleontology,* 3:1–25, plates 1–14.

Darton, N. H.
1899. Geology and Water Resources of Nebraska West of the One Hundred and Third Meridian. *United States Geological Survey, 19th Annual Report,* part 4:719–785.
1908. Paleozoic and Mesozoic of Central Wyoming. *Bulletin of the Geological Society of America,* 19:403–474, plates 21–30.

Denson, N. M., and E. N. Harshman
1969. Map Showing Aerial Distribution of Tertiary Rocks, Bates Hole-Shirley Basin Area, South-Central Wyoming. *United States Geological Survey, Miscellaneous Geologic Investigations Map I–570.*

Emry, Robert J.
1970. A North American Oligocene Pangolin and Other Additions to the Pholidota. *Bulletin of the American Museum of Natural History,* 142 (6) :455–510, figures 1–32.
1970. *Stratigraphy and Paleontology of the Flagstaff Rim Area, Natrona County, Wyoming.* Ph.D. dissertation, Columbia University, 195 pages, plate 1.
1972a. A New Species of *Agnotocastor* (Rodentia: Castoridae) from the Early Oligocene of Wyoming. *American Museum Novitates,* 2485:1–7, figures 1–2.
1972b. A New Heteromyid Rodent from the Early Oligocene of Natrona County, Wyoming. *Proceedings of the Biological Society of Washington,* 85 (14) :179–190, figures 1–2.

Emry, Robert J., and Mary R. Dawson
1972. A Unique Cricetid (Rodentia: Mammalia) from the Early Oligocene of Natrona County, Wyoming. *American Museum Novitates*, 2508:1–14, figures 1–3.

Endlich, F. M.
1879. Report on the Geology of the Sweetwater District. *In* F. V. Hayden, *Eleventh Annual Report of the United States Geological and Geographical Survey of the Territories, Embracing Idaho and Wyoming, Being a Report of Exploration for the Year 1877*. Pages 3–158. United States Government Printing Office.

Evernden, J. F., D. E. Savage, G. H. Curtis, and G. T. James
1964. Potassium Argon Dates and the Cenozoic Mammalian Chronology of North America. *American Journal of Science*, 262 (2) :145–198.

Granger, Walter
1910. Tertiary Faunal Horizons in the Wind River Basin, Wyoming, with Descriptions of New Eocene Mammals. *Bulletin of the American Museum of Natural History*, 28:235–251.

Hares, C. J.
1916. Anticlines of Central Wyoming. *United States Geological Survey Bulletin*, 641 (I) :233–279, plate 1: figures 1–19.
1946. Geologic Map of the Southwestern Part of the Wind River Basin and Adjacent Areas in Central Wyoming. *United States Geological Survey, Oil and Gas Investigations Map 51*.

Hayden, F. V.
1861. Sketch of the Geology of the Country About the Headwaters of the Missouri and Yellowstone Rivers. *American Journal of Science*, Series 2, 31:229–245.
1869. *Geological Report of the Exploration of the Yellowstone and Missouri Rivers, 1859–60*. 174 pages. Washington, D.C.: United States Government Printing Office.
1871. *Preliminary Report of the United States Geological Survey of Wyoming and Portions of Contiguous Territories, Being a Second Annual Report of Progress for 1870*. 511 pages. Washington, D.C.: United States Government Printing Office.

Keefer, W. R.
1965. Stratigraphy and Geologic History of the Uppermost Cretaceous, Paleocene, and Lower Eocene Rocks in the Wind River Basin, Wyoming. *United States Geological Survey Professional Paper*, 495–A:A1–A77.

Keefer, W. R., and J. A. Van Lieu
1966. Paleozoic Formations in the Wind River Basin, Wyoming. *United States Geological Survey Professional Paper*, 495–B:B1–B60.

Knight, W. C.
1895. Coals and Coal Measures of Wyoming. *United States Geological Survey Annual Report*, 16 (4) :208–215.
1900. A Report on the Artesian Basins of Wyoming. *Wyoming University Agriculture Experiment Station Bulletin*, 45:107–251, plates 1–13.

Love, J. D.
1952. Preliminary Report on the Uranium-Bearing Pliocene (?) Rocks in the Split Rock Area, Central Wyoming. *United States Geological Survey*, TEI–282:1–13. [Issued by the United States Atomic Energy Commission Technical Information Service, Oak Ridge, Tennessee.]
1960. Cenozoic Sedimentation and Crustal Movement in Wyoming. *American Journal of Science*, 258–A: 204–214.
1961. Split Rock Formation (Miocene) and Moonstone Formation (Pliocene) in Central Wyoming. *United States Geological Survey Bulletin*, 1121–I:I1–I39.
1970. Cenozoic Geology of the Granite Mountains Area, Central Wyoming. *United States Geological Survey Professional Paper*, 495–C:C1–C154.

Love, J.D., J. L. Weitz, and R. K. Hose
1955. Geologic Map of Wyoming. *United States Geological Survey*.

Matthew, W. D.
1899. *Field Book for 1899*. Manuscript, on file in the Department of Vertebrate Paleontology, American Museum of Natural History, New York, N.Y.
1903. The Fauna of the *Titanotherium* Beds at Pipestone Springs, Montana. *Bulletin of the American Museum of Natural History*, 19 (6) :197–226.

Meek, F. B., and F. V. Hayden
1862. Descriptions of New Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary Fossils, Collected in Nebraska Territory, with Some Remarks on the Rocks from Which They Were Obtained. *Proceedings of the Academy of Natural Sciences of Philadelphia (1861)*, 13:415–447.

Rachou, J. F.
1951. *Tertiary Stratigraphy of the Rattlesnake Hills, Central Wyoming*. Unpublished graduate thesis, University of Wyoming.

Rich, E. I.
1962. Reconnaissance Geology of Hiland-Clarkson Hill Area, Natrona County, Wyoming. *United States Geological Survey Bulletin*, 1107–G:447–540.

Roehler, H.
1957. *Geology of the Bates Hole Region, Wyoming*. Unpublished graduate thesis, University of Wyoming.

Romer, Alfred S.
1966. *Vertebrate Paleontology*. viii + 468 pages. Chicago: University of Chicago Press.

Schlaijker, Erich M.
1935. Contributions to the Stratigraphy and Paleontology of the Goshen Hole Area, Wyoming, III: A New Basal Oligocene Formation. *Bulletin of the Museum of Comparative Zoology*, 76 (3) :69–93, figures 1–10, plates 1–8.

Schultz, C. B., and C. H. Falkenbach
1954. Desmatochoerinae, a New Subfamily of Oredonts. *Bulletin of the American Museum of Natural History*, 105 (2) :143–256, figures 1–25, charts 1–5.

1956. Miniochoerinae and Oreonetinae, Two New Subfamilies of Oredonts. *Bulletin of the American Museum of Natural History,* 109 (4) :373–482, figures 1–12.

1968. The Phylogeny of the Oredonts, Parts 1 and 2. *Bulletin of the American Museum of Natural History,* 139:1–498, figures 1–56.

Shaw, Alan B.

1964. *Time In Stratigraphy.* xi + 365 pages. New York: McGraw Hill Book Company.

Simpson, G. G.

1945. The Principles of Classification and a Classification of Mammals. *Bulletin of the American Museum of Natural History,* 85:i–xvi, 1–350.

Sinclair, W. J., and Walter Granger

1911. Eocene and Oligocene of the Wind River and Bighorn Basins. *Bulletin of the American Museum of Natural History,* 30 (7) :83–117.

Skinner, M. F.

1957. *Frick Laboratory, Bates Hole Field List Book (Field Catalog), No. 69.* Manuscript on file in Department of Vertebrate Paleontology, American Museum of Natural History, New York, N.Y.

Tedford, R. H.

1970. Principles and Practices of Mammalian Geochronology in North America. *Proceedings of the North American Paleontological Convention,* Part F:666–703.

Van Houten, F. B.

1954. Geology of the Long Creek-Beaver Divide Area, Fremont County, Wyoming. *United States Geological Survey Oil and Gas Investigations Map OM–140.*

1964. Tertiary Geology of the Beaver Rim Area, Fremont and Natrona Counties, Wyoming. *United States Geological Survey Bulletin,* 1164:1–99.

Weitz, J. L., J. D. Love, and S. A. Harbison

1954. Geologic Map of Natrona County, Wyoming. *Wyoming Geological Survey.*

Wood, H. E.

1948. Section at Beaver Divide. *In* P. O. McGrew, editor, *Society of Vertebrate Paleontology Guidebook, Third Annual Field Conference, Southeastern Wyoming (1948)* :37–41.

Wood, H. E., et al.

1941. Nomenclature and Correlation of the North American Continental Tertiary. *Bulletin of the Geological Society of America,* 52:1–48, plate 1.

Woodruff, E. G., and D. E. Winchester

1912. Coal Fields in the Wind River Region, Fremont and Natrona Counties, Wyoming. *United States Geological Survey Bulletin,* 471–G:516–564, figures 12–14, plates 49–57.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1973—516–220/13

Publication in *Smithsonian Contributions to Paleobiology*

Manuscripts for serial publications are accepted by the Smithsonian Institution Press, subject to substantive review, only through departments of the various Smithsonian museums. Non-Smithsonian authors should address inquiries to the appropriate department. If submission is invited, the following format requirements of the Press will govern the preparation of copy.

Copy must be typewritten, double-spaced, on one side of standard white bond paper, with 1½" top and left margin, submitted in ribbon copy with a carbon or duplicate, and accompanied by the original artwork. Duplicate copies of all material, including illustrations, should be retained by the author. There may be several paragraphs to a page, but each page should begin with a new paragraph. Number consecutively all pages, including title page, abstract, text, literature cited, legends, and tables. The minimum length is 30 pages, including typescript and illustrations.

The *title* should be complete and clear for easy indexing by abstracting services. Taxonomic titles will carry a final line indicating the higher categories to which the taxon is referable: "(Ammonoidea: Goniatitidae)." Include an *abstract* as an introductory part of the text. Identify the *author* on the first page of text with an unnumbered footnote that includes his professional mailing address. A *table of contents* is optional. An *index,* if required, may be supplied by the author when he returns page proof.

Two *headings* are used: (1) text heads (boldface in print) for major sections and chapters and (2) paragraph sideheads (caps and small caps in print) for subdivisions. Further headings may be worked out with the editor.

In *taxonomic keys,* number only the first item of each couplet; if there is only one couplet, omit the number. For easy reference, number also the taxa and their corresponding headings throughout the text; do not incorporate page references in the key.

In *synonymy,* use the short form (taxon, author, date:page) with a full reference at the end of the paper under "Literature Cited." Begin each taxon at the left margin with subsequent lines indented about three spaces. Within an entry, use a period-dash (.—) to separate each reference. Enclose with square brackets any annotation in, or at the end of, the entry. For *references within the text,* use the author-date system: "(Jones, 1910)" and "Jones (1910)." If the reference is expanded, abbreviate the data: "Jones (1910:122, pl. 20: fig. 1)."

Simple *tabulations* in the text (e.g., columns of data) may carry headings or not, but they should not contain rules. Formal *tables* must be submitted as pages separate from the text, and each table, no matter how large, should be pasted up as a single sheet of copy.

Use the *metric system* instead of, or in addition to, the English system.

Illustrations (line drawings, maps, photographs, shaded drawings) can be intermixed throughout the printed text. They will be termed *Figures* and should be numbered consecutively; however, if a group of figures is treated as a single figure, the components should be indicated by lowercase italic letters on the illustration, in the legend, and in text references: "Figure 9*b*." If illustrations (usually tone photographs) are printed separately from the text as full pages on a different stock of paper, they will be termed *Plates,* and individual components should be lettered (Plate 9*b*) but may be numbered (Plate 9: figure 2). Never combine the numbering system of text illustrations with that of plate illustrations. Submit all legends on pages separate from the text and not attached to the artwork. An instruction booklet for the preparation of illustrations is available from the Press on request.

In the *bibliography* (usually called "Literature Cited"), spell out book, journal, and article titles, using initial caps with all words except minor terms such as "and, of, the." For capitalization of titles in foreign languages, follow the national practice of each language. Underscore (for italics) book and journal titles. Use the colon-parentheses system for volume, number, and page citations: "10(2):5-9." Spell out such words as "figures," "plates," "pages."

For *free copies* of his own paper, a Smithsonian author should indicate his requirements on "Form 36" (submitted to the Press with the manuscript). A non-Smithsonian author will receive 50 free copies; order forms for quantities above this amount with instructions for payment will be supplied when page proof is forwarded.