UNIVERSITY OF KANSAS
PALEONTOLOGICAL CONTRIBUTIONS

VERTEBRATA

ARTICLE 4
Pages 1-120, Plates 1-2, Figures 1-26

A CONTRIBUTION TO THE TERTIARY GEOLOGY AND PALEONTOLOGY OF NORTHEASTERN COLORADO

By EDWIN C. GALBREATH

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University of Kansas Paleontological Contributions
Vertebrata, Article 4, Pages 1-120, Plates 1-2, Figures 1-26

A CONTRIBUTION TO THE TERTIARY GEOLOGY AND PALEONTOLOGY OF NORTHEASTERN COLORADO [1]

By EDWIN C. GALBREATH

CONTENTS

1. A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Kansas.

ILLUSTRATIONS

ABSTRACT

Mesozoic and Cenozoic deposits are exposed in Weld and Logan Counties, northeastern Colorado.

The Tertiary sequence of stratigraphic units and faunas is as follows:

1. Ogallala formation; Pliocene.
   a. ?Kimball member. Fauna unknown.
   Disconformity.
2. Pawnee Creek formation; early middle Miocene to earliest Pliocene, inclusive.
   a. Stratal unit of earliest Clarendonian age; Sand Canyon local fauna.
   Disconformity.
   b. Stratal unit of late Barstovian age; Vim-Peetz local fauna.
   Disconformity.
   c. Stratal unit of late Barstovian age; Kennesaw local fauna.
   Disconformity.
   d. Stratal unit of early Barstovian age; Eubanks local fauna.
   Disconformity.
   e. Stratal unit of early Hemingfordian age; Martin Canyon local fauna.
   Disconformity.
3. White River formation; late lower Oligocene to early upper Oligocene, inclusive.
   a. Vista member of Whitneyan age; Vista fauna.
   b. Cedar Creek member of Orellan age; Cedar Creek fauna.
   c. Horsetail Creek member of Chadronian age; Horsetail Creek fauna.

The Tertiary beds are an accumulation of silts, sands, and gravels resulting from alluviation in channels and on flood plains, colluviation on valley slopes, and eolian deposition. Local to regional disconformities and weathered soil profiles mark interruptions in deposition.

The three faunas of the White River formation, although united by having numerous genera in common, are distinguished from each other by the restriction of some genera to only one or two of the faunas and by restriction to a single age of certain species which belong to relatively long-lived genera. The genera and species common to two or more of these faunas suggest, however, a close relationship in time for all three faunas and imply that the faunal differences are partly facial. The lithology of the beds further supports this latter supposition. The absence of such Oligocene genera as *Metamynodon* and *Protoceras* and the rarity of anthracotheriids and agriochoerids suggest environmental differences between the Oligocene faunas of northeastern Colorado and other areas—especially those of Nebraska and South Dakota.

The Miocene faunas are distinguished from each other principally by differences in the stage of evolution of the various species. Comparison of the Miocene faunas with other faunas in the High Plains and the Great Basin shows much faunal similarity and little evidence of environmental differences.

The existence of the Sand Canyon fauna in the early Pliocene is somewhat hypothetical, but its presence is postulated to account for certain equid remains that appear to be advanced over specimens representative of the older faunas.

These studies demonstrate, in general, that the changes in composition seen in the successive Oligocene and Miocene faunas of northeastern Colorado are largely the result of repeated invasions and replacements by species which have evolved outside the area studied. Only a few species seem to have undergone much evolution while continuously in residence. For this reason it is thought that the time interval represented by each of the successive faunas is short and that there was no isolation of them from adjacent faunas known from other parts of the High Plains.

The systematic account of the species found in northeastern Colorado adds new information about the morphology and evolutionary changes of some of the species, especially of the Oligocene rodents.

Genera heretofore unreported from northeastern Colorado are *Nanodelphys, Apternodus, Arctoryctes?, Titanotheriomys, Proheteromys, Diplolophus, Parictis, Proamphicyon, Daphoenocyon?, Miohippus, Perchoerus, Heptacodon, Agriochoerus,* and *Eotylopus* from the Oligocene; and *Brachyerix, Oreolagus, Sciurus* (*s. l.*), *Peridiomys, Monosaulax, Plesiosminthus?, Leptocyon, Hypohippus,* and *Calippus* from the Miocene.

New genera and species are *Apternodus iliffensis*, n. sp. (Solenodontidae); *Ankylodon progressus*, n. sp. (Erinaceidae); *Domnina compressa*, n. sp. (Soricidae); *Pelycomys rugosus* and *P. placidus*, n. gen. and spp. (Ischyromidae); and *Drassonax harpagops*, n. gen. and sp. (Mustelidae?) all from the Oligocene; and *Plesiosminthus? clivosus*, n. sp. (Zapodidae) from the Miocene.

INTRODUCTION

In recent years, field observations and collections made in the Tertiary beds of northeastern Colorado have shown that the faunal lists of the several stages are incomplete; that many stratigraphic assignments of species are either incorrect or too broad or narrow in range; that the stratigraphy is inadequately known for the purpose of compiling detailed and accurate faunal lists; and that the relationships of the species to geologically older and younger forms, as well as to those of the same time range in other areas, are often unknown or uncertain and in need of critical restudy in the light of more recent information. It is the purpose of the following account to correct some of these deficiencies and to add to the fund of knowledge concerning the area. The method of research followed to attain these aims was (1) a study of the stratigraphic history of the area; (2) an identification of the fossils in the light of present knowledge; (3) a grouping of species into faunas with greater detail than heretofore attempted; and (4) a correlation of these observations with observations on other Cenozoic faunas and deposits in North America. It is hoped that this study will contribute to a knowledge of the history of individual groups of animals, especially their phylogenetic and distributional relationships, and to the correlation of the geological formations so necessary for the solution of such problems as the Cenozoic history of the Rocky Mountains and the Great Plains.

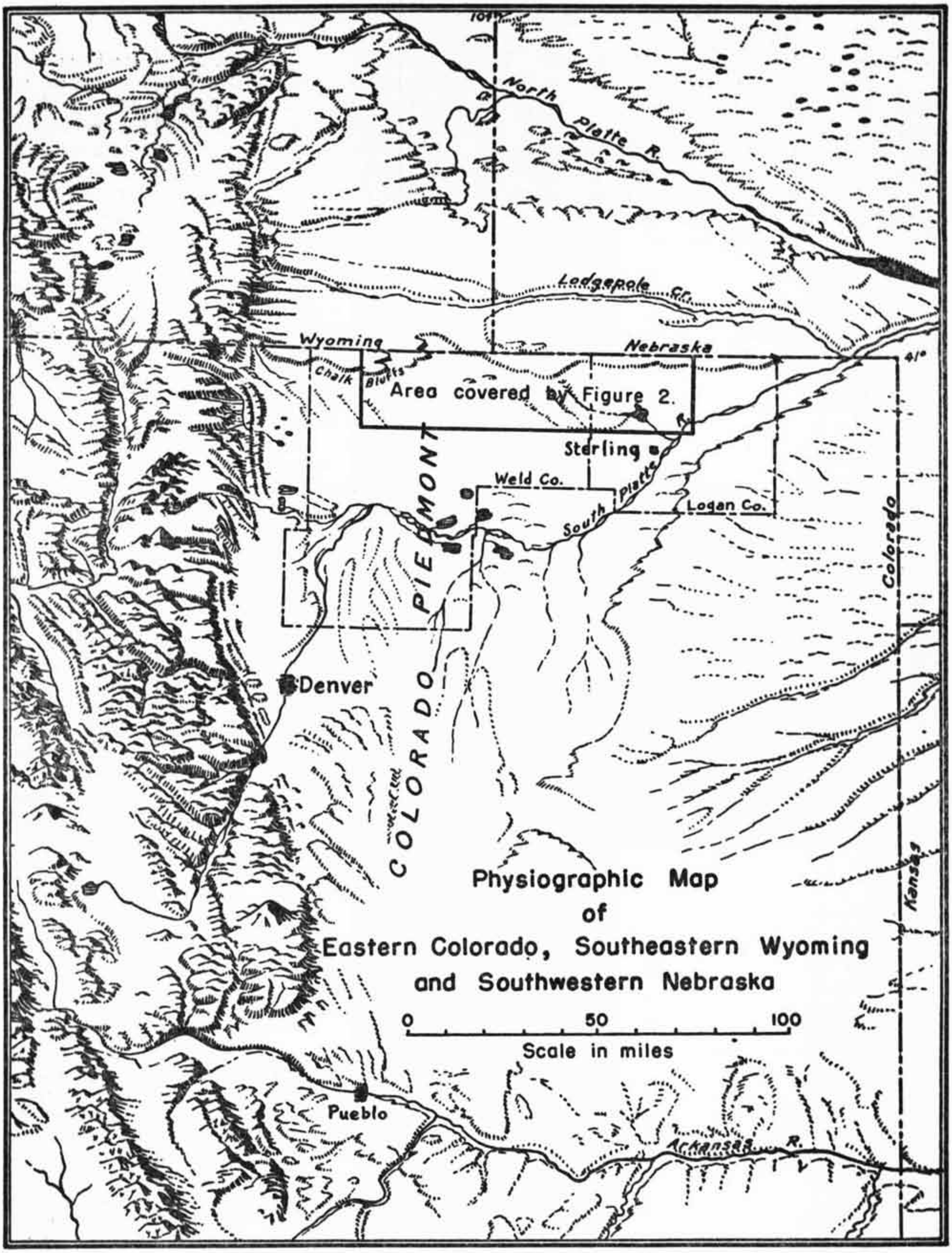
CLARK (1937) has presented a detailed analysis of the Chadron formation in the Dakota Badlands. H. E. WOOD (1949) has indicated the need for similar studies elsewhere. I regret that I cannot fully emulate CLARK and present a detailed sedimentational history of northeastern Colorado. For the most part, only specimens collected by me, or specimens from localities and levels known to me, were utilized in the present study.

Acknowledgment, with gratitude, is made first to Dr. ROBERT W. WILSON for his patient and kindly guidance throughout the course of this work. In addition, Dr. WILSON and Dr. G. EDWARD LEWIS permitted me to take over the study of the Cenozoic geology and paleontology of northeastern Colorado after they had devoted considerable attention to it. Drs. JOHN C. FRYE, EDWARD H. TAYLOR, A. BYRON LEONARD, and E. RAYMOND HALL, of the University of Kansas, advised and constructively criticized the work. The generous aid and cooperation of Mr. JACK CASEMENT and family and Mr. CLYDE WARD and family, of West Plains, Colorado, made the field work less rigorous and less difficult. Mr. A. B. ROPER granted permission to open Quarry A in Martin Canyon. The Plains Oil Company permitted me to make use of their well log for Haley-Smith Well No. 1 and to quote the part pertinent to this work. Mrs. RACHEL HUSBAND NICHOLS, of the American Museum of Natural History, furnished copies of American Museum records, checked specimens, and called my attention to many details which otherwise might have been overlooked. Mr. JOHN KOENIG prepared the maps, and Mrs. BERNITA MANSFIELD figured the specimens. There yet remain many citizens of northeastern Colorado, members of scientific staffs of many museums and universities, and others who, although unnamed, are remembered for their part in making this work a pleasure.

HISTORY OF GEOLOGICAL AND PALEONTOLOGICAL WORK IN NORTHEASTERN COLORADO

The first vertebrate paleontologist to investigate the Tertiary beds in northeastern Colorado was O. C. MARSH, who, in the summer of 1870, visited the beds in western Weld County (five miles south of the Wyoming state line on Little Crow Creek and "about thirty miles northeast . . . along the hills known as Chalk Bluffs") and noted the presence of "Titanotherium beds" and "above these . . . similar clay deposits . . . marked by abundant remains of *Oreodon Culbertsoni*, etc. . . . which characterize that horizon." His report (1870, p. 292) states that there were 150 feet of White River formation and 200 feet of post-Oligocene beds. BERTHOUD (1872, p. 48) reported the presence of fossils in the Crow Creek area during his search for ancient man in 1871. E. D. COPE visited the region in the summer and fall of 1873, and again in the fall of 1879, collecting fossils and studying the geology. He recognized the general similarity of the Tertiary beds to those of Nebraska and South Dakota (1874a). In 1882 an expedition from Princeton University collected in the region of the "Chalk Bluffs." Of these early expeditions only COPE's yielded anything that might have been considered a major publication upon the area and its fossils. In 1898, 1901, and 1902, field parties from the American Museum of Natural History led by MATTHEW, BROWN, and THOMSON explored Logan

FIGURE 1.—Physiographic map of eastern Colorado, southeastern Wyoming, and southwestern Nebraska showing the position of Weld and Logan Counties and the area covered by Figure 2. Based on the "Map of the Landforms of the United States" by ERWIN RAISZ; fourth revised edition; Ginn & Co., 1946; and reprinted by permission of Ginn & Co.



North Platte R.
Lodgepole Cr.
Wyoming
Nebraska
Chalk Bluffs
Area covered by Figure 2.
Sterling
Weld Co.
South Platte R.
Logan Co.
COLORADO PIEDMONT
Denver
Colorado
Kansas
Pueblo
Arkansas R.
Physiographic Map
of
Eastern Colorado, Southeastern Wyoming
and Southwestern Nebraska
0
50
100
Scale in miles

and Weld Counties (OSBORN, 1918, p. 19). The second and last major publication on the region (MATTHEW, 1901) resulted from these expeditions.

Since that time and until 1940 the collecting of fossils has been intermittent and, with the exception of work by the Denver Museum of Natural History, University of California, CHILDS FRICK, and University of Kansas, collecting has not been pursued on any large scale. In 1940 Dr. G. EDWARD LEWIS and Dr. ROBERT W. WILSON started in the area an intensive program of work which was interrupted by the war. In 1946 Dr. C. W. HIBBARD led a field party from the University of Kansas into the area at which time my interest in the area was stimulated. Subsequently, Drs. LEWIS and WILSON suggested that I continue and complete the investigation of the stratigraphy and mammalian paleontology.

GEOLOGY

GENERAL FEATURES

FENNEMAN (1931, p. 30) writes:

> Aside from the broad valleys of the Platte and Arkansas the Tertiary cover of the High Plains is almost unbroken along the eastern boundary of Colorado. On account of greater erosion farther west, this cover has mainly disappeared, its remnants being smaller, more scattered, and less flat. Where the mantle is entirely wasted away, the underlying rocks are themselves much eroded. The area which owes its topography to this dissection and denudation is the Colorado Piedmont. The outline of this section, as shown on the map, reveals at once its close relation to the two chief river systems which are the agents of the stripping. Along the axis of the Platte Valley, the denuded area extends far into northeastern Colorado and along the Arkansas it reaches to the Kansas boundary. On the divide between these two rivers the stripping is less perfect, and north of the South Platte the High Plains extend west to the mountains.
>
> The northern boundary of the Colorado Piedmont is almost coincident with that of the state. North of this line the streams of Wyoming and Nebraska flow east in consequent fashion down the original slope of the Tertiary mantle, having an elevation of a mile above sea level where they cross the Wyoming-Nebraska line. Along the same meridian, the South Platte, 50 miles to the south, is 1,000 ft. lower. Its small northern tributaries head against the south-facing break of the Tertiary upland.

This south-facing break in the Tertiary upland is the subject of the present study (see Figs. 1-3).

Tertiary deposits are best exposed in Ts. 11-12 N., Rs. 51-65 W. in Logan and Weld Counties, Colorado, and sporadically crop out to the north and south of this area, wherever left as outliers or not covered by soil or grass. Detailed mapping and study was confined to Ranges 53 and 54 in Logan County, an area which includes the type section of the "Martin Canyon Beds," and the type sections of the Horsetail Creek, Cedar Creek, and Vista members of the White River formation to be described in this paper.

Cretaceous beds underlie the Tertiary deposits in this region—the Laramie formation in western Weld County, and Fox Hills sandstone and Pierre shale in eastern Weld County and western Logan County. The White River formation is exposed to a limited extent in the South Platte valley floor (Chadronian and Orellan beds) and in the valley wall (Orellan and Whitneyan beds), where it lies disconformably upon Cretaceous beds (Fig. 4). Sections of the White River formation as much as 582 feet thick have been measured. Following deposition of the White River sediments, a long period of erosion and soil formation took place during all or most of early Miocene times. Middle and late Miocene deposits fill the valleys eroded into the Oligocene beds. A shorter interval of erosion preceded the deposition of the Ogallala formation. This formation caps the older Tertiary deposits and in a few places occupies channels cut in the older beds. A relatively resistant bed of Ogallala? limestone controls the topography of the High Plains in this region. The upland or plateau surface is commonly mantled with late Pleistocene loess in which the modern soil is formed, but at a few localities Pleistocene sands and gravels of Nebraskan age are present.

In the South Platte drainage system, which drains the area covered in this report, the valley floors are generally covered with Pleistocene and Recent deposits. Where the streams from the steep slopes of the valley wall emerge upon a valley floor, they abruptly change from degrading to aggrading, and large alluvial fans are built, many of which coalesce with their neighbors. Most of the small streams emerging from the steep slopes become braided and finally disappear on the aggraded plain of the valley floor. However, a few persist to unite with the South Platte tributaries. Because rainfall is scant, none of the streams of the region are permanent, except the South Platte River.

STRATIGRAPHY

COPE (1874, p. 9; 1874a, p. 429) presented a cursory description of the Tertiary deposits in northeastern Colorado and pointed out their similarity to the deposits in Wyoming, Dakota, and Nebraska. It remained for MATTHEW (1901, pp. 356-374) to describe the beds, discuss their probable origin, and make correlations with other sections.

Three Tertiary formations are recognized by me in northeastern Colorado (Fig. 5) — the White River, Pawnee Creek, and Ogallala formations. Evidence for an Arikareean formation is not conclusive.

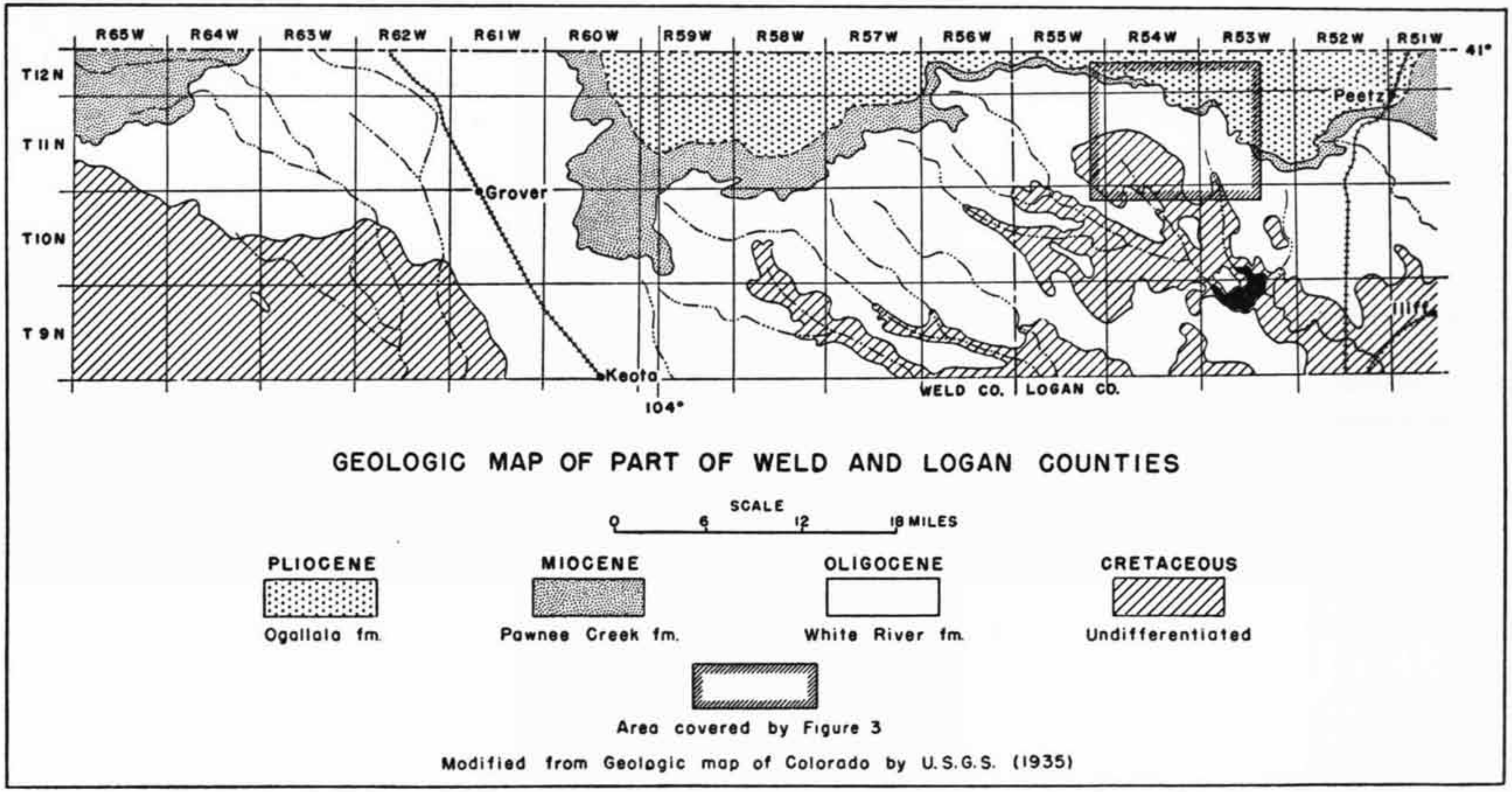


FIGURE 2.—Geologic map of part of Weld and Logan Counties showing areal distribution of the Ogallala, Pawnee Creek, White River, and Cretaceous beds, and area covered by Figure 3. Modified from geologic map of Colorado by United States Geological Survey (1935).

WHITE RIVER FORMATION

All of the Oligocene deposits are included in the White River formation and consist of three units—the Horsetail Creek, Cedar Creek, and Vista members. To group the Colorado Oligocene deposits in one formation in contrast to the practice in Nebraska and South Dakota appears justified on the following grounds. Disconformities between the Horsetail Creek and Cedar Creek members are not everywhere present. To recognize the Horsetail Creek beds as a formation means invoking a faunal definition to supplement the discontinuous lithologic break between the two members, but the faunal zones, especially the Chadronian, transcend the lithologic units. Therefore, to have a formation that was mappable would mean using a lithologic break when it was present and using faunal evidence elsewhere. But, since the fauna below the lithologic break at some points does not differ from the fauna above the break at other points, one would be at loss to map beds that grade vertically and laterally into each member. An arbitrary decision would be necessary to resolve these problems, which would mean a breakdown of the criteria that define each unit. The resulting confusion would not justify the practice.

Horsetail Creek member. — The oldest Tertiary deposits in the region are the Chadronian beds called the Horsetail Creek Beds by MATTHEW (1901, p. 356), Horsetail Creek by SIMPSON (1933, p. 99), and referred to as the Horsetail Creek facies of the Chadron formation by H. E. WOOD, *et al.* (1941, p. 22).

The Horsetail Creek member, of Chadronian and early? Orellan age, as herein described is based on exposures in Logan County, where gray, massive silts rest upon the Cretaceous surface (see measured section IX). The top of the member grades upward into tan to pink silt of the Cedar Creek member or is separated from that member by an erosional unconformity. Locally, there are beds of olive-colored silt and freshwater limestone with interfingering beds of whitish-gray silt at the top of the member.

Any concept of the pre-Chadronian surface in northeastern Colorado is to a great extent a product of speculation. The contacts are covered by grass, soil, or alluvium at almost all places. In western Weld County the Tertiary beds are known to rest on Laramie shales and sandstones. In eastern Weld County and as far east as R. 53 W., T. 11 N. in Logan County, I have seen outcrops of a soft, friable, mustard-yellow sandstone which is commonly considered to be Fox Hills sandstone. A deep well boring in sec. 26, T. 11 N., R. 54 W., Logan County, shows the Tertiary contact to be with Cretaceous beds reported as Pierre shale. Scanty as the evidence is, I think that the pre-Chadronian surface was developed on late Cretaceous rocks as a partially dissected topography with channels cut at least into the Pierre shale. Subsequent aggradation resulted in burial of the Cretaceous beds and continued, with minor interruptions, into late Oligocene time.

In the well boring mentioned above, a "gravel bed" was reported between the Pierre shale and the overlying silts. Its correlation with any exposed Chadronian beds is impossible at present. In South Dakota CLARK (1937, p. 277) found coarse sediments in the bottoms of lower Chadron channels resting on the Cretaceous floor. Comparison is made with the condition in South Dakota only to demonstrate that possibly the "gravel bed" in northeastern Colorado represents the first phase of Chadronian aggradation—one taking place in channels.

The lowest exposed Horsetail Creek beds are composed of grayish-white, massive silts and rest upon Fox Hills sandstone and Pierre shale. By the use of a Paulin altimeter 245 feet of Horsetail Creek beds were measured in T. 10 N., Rs. 53-54 W., Logan County. This measurement is based on a traverse of about eight miles across the valley floor and conceivably could be materially affected by dip, presence of channels, and error in measurement. Resting on the massive silts in Ts. 10-11 N., Rs. 51-54 W., Logan County, and interfingering with the massive silt at other localities, is a series of olive-green silts, gray-green freshwater limestones, and interbedded whitish-gray silts, which reaches a maximum thickness of 80 feet but may be thinner where part of the sequence is missing (Pl. 1, fig. *C*). The presence of freshwater limestones causes me to think that this sequence of beds was formed in a series of freshwater ponds.[2] At other localities the grayish-white, massive silt is in contact with pink, massive, fine-grained sandstone, and at still other localities the grayish-white silt grades upward into pink and buff silts. Faunal evidence is poor, but in all cases titanothere remains have been found near the top of the grayish-white, massive silts.

From the meager evidence present, it would appear that the Horsetail Creek member represented accumulating flood plain deposits terminating in an aggraded surface with sluggish streams and possibly marshes, ponds, or lakes upon it. At present the contact between the Horsetail Creek and Cedar Creek member beds is placed at the erosional break between the two members or, where deposition is continuous, at the base of the pink silts which coincides, apparently, with a change in fauna.

The location of the type section for the Horsetail Creek beds, as described by MATTHEW, is a matter for debate. CURTIS HESSE, who visited the region with H. T. MARTIN (a collector in the MATTHEW party in 1898), expressed the opinion, in a letter to Dr. R. W. WILSON, that the type section was not on the Horsetail Creek known today but did believe that the concepts of the beds were formed in the eastern Weld County-western Logan County area.

2. CLARK (1937, p. 283) reported similar series of deposits which he placed at the top of his Chadron section in South Dakota.

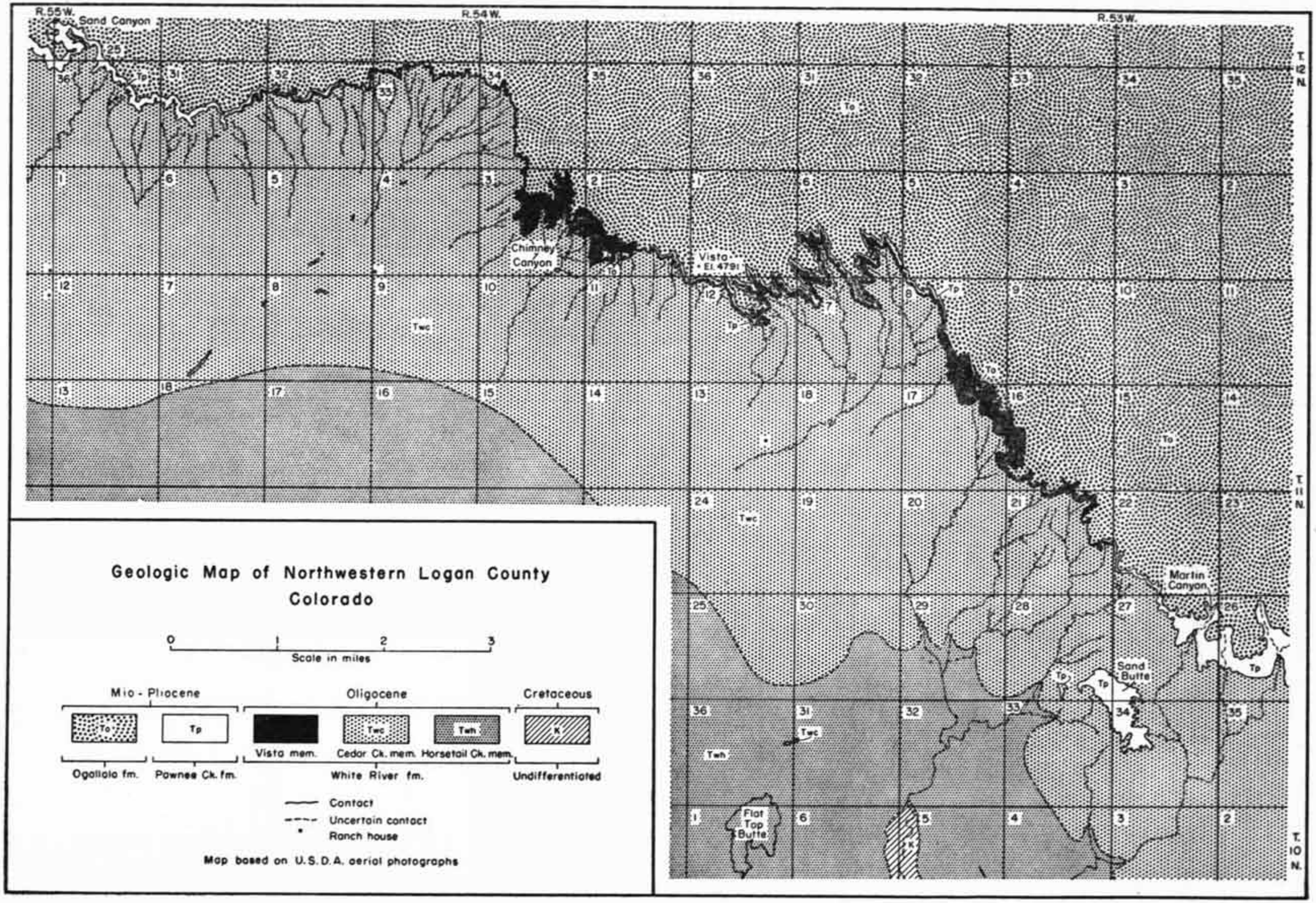


FIGURE 3.—Geologic map of northwestern Logan County showing areal distribution of formations and members of the Tertiary deposits described in this paper, prominent topographic features, and Vista triangulation station. Map based on United States Department of Agriculture aerial photographs, and modified to conform with corrected section lines.

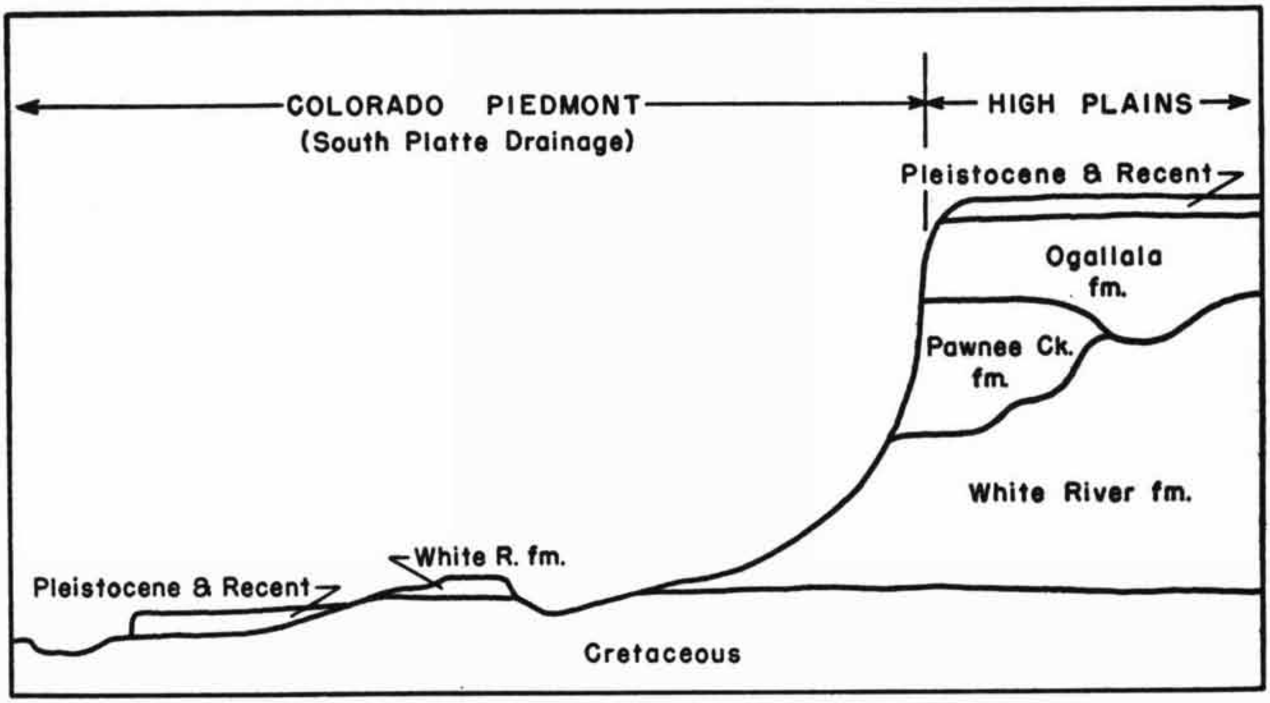


FIGURE 4.—Schematic cross section of beds in Logan County, Colorado, between the South Platte River and the northern boundary of the State.

OSBORN (1918, p. 19, fig. 10a) states that "The American Museum party of 1898 worked westward under Matthew to the head of Cedar (or Clear) Creek, . . ." This would limit MATTHEW's explorations, at the time when he was forming his concept of the Horsetail Creek beds, to places no farther west than Range 57, which would bring him to within a few miles of the present Horsetail Creek. In the southwest corner of T. 11 N., R. 56 W. there are good Chadronian exposures, and the Denver Museum of Natural History's Trigonias Quarry is less than a half-dozen miles southwest from this point on the Horsetail Creek drainage system. Chadronian beds are also exposed in T. 11 N., R. 57 W., Weld County, which MATTHEW possibly visited. Furthermore, the exposures of Horsetail Creek beds in T. 10 N., Rs. 51-54 W., Logan County are close to the Martin Canyon area. On the other hand, there is no evidence in MATTHEW's field notes that he visited any part of the northeastern Colorado area in 1898 other than Martin Canyon. For reasons that will be discussed later, it is possible that MATTHEW introduced the name Horsetail Creek beds after writing the manuscript of his 1901 paper because he saw beds at Horsetail Creek in 1901 that agreed with his original concept. In order to remove the existing uncertainty, I designate the Chadronian exposures in secs. 29, 31, 32, T. 11 N., R. 53 W., Logan County (see measured section XI) as the type locality of the Horsetail Creek member.

Cedar Creek member.—It is proposed here to use the term Cedar Creek member of the White River formation for the beds of Orellan age, composed of pink and tan sandstones and silts, that lie above the disconformity separating the Horsetail Creek member from this member or above the grayish-white silts where no disconformity is evident, and that lie below a "white marker" which is the lowest bed of the Vista member (Pl. 1, fig. *B*). These deposits are (seemingly) MATTHEW's (1901, p. 357) Cedar Creek beds, which the Wood Committee (WOOD, H. E., *et al.*, 1941, p. 16) called the Cedar Creek facies of the Brule formation. The Cedar Creek member is typically exposed in secs. 29 and 21, T. 11 N., R. 53 W., Logan County (see measured section XII). I think that the Cedar Creek member represents, in the upper part at least, the interval between the Orella and Whitney members which SCHULTZ & STOUT (1938) emphasized. If the complete history of the deposition of the White River formation were known, I think that the Cedar Creek and Orella members would maintain their identities.

With exceptions, the Cedar Creek may be divided naturally into three parts: a lower zone of pink to red, fine-grained sandstones or pink silts that interfinger with a massive, buff silt, containing channels filled with grayish, coarser sandstones or pinkish, arkosic sandstones in the upper part; an intermediate zone of thin-bedded silts and sandstones ranging from buff to red in color (but locally containing

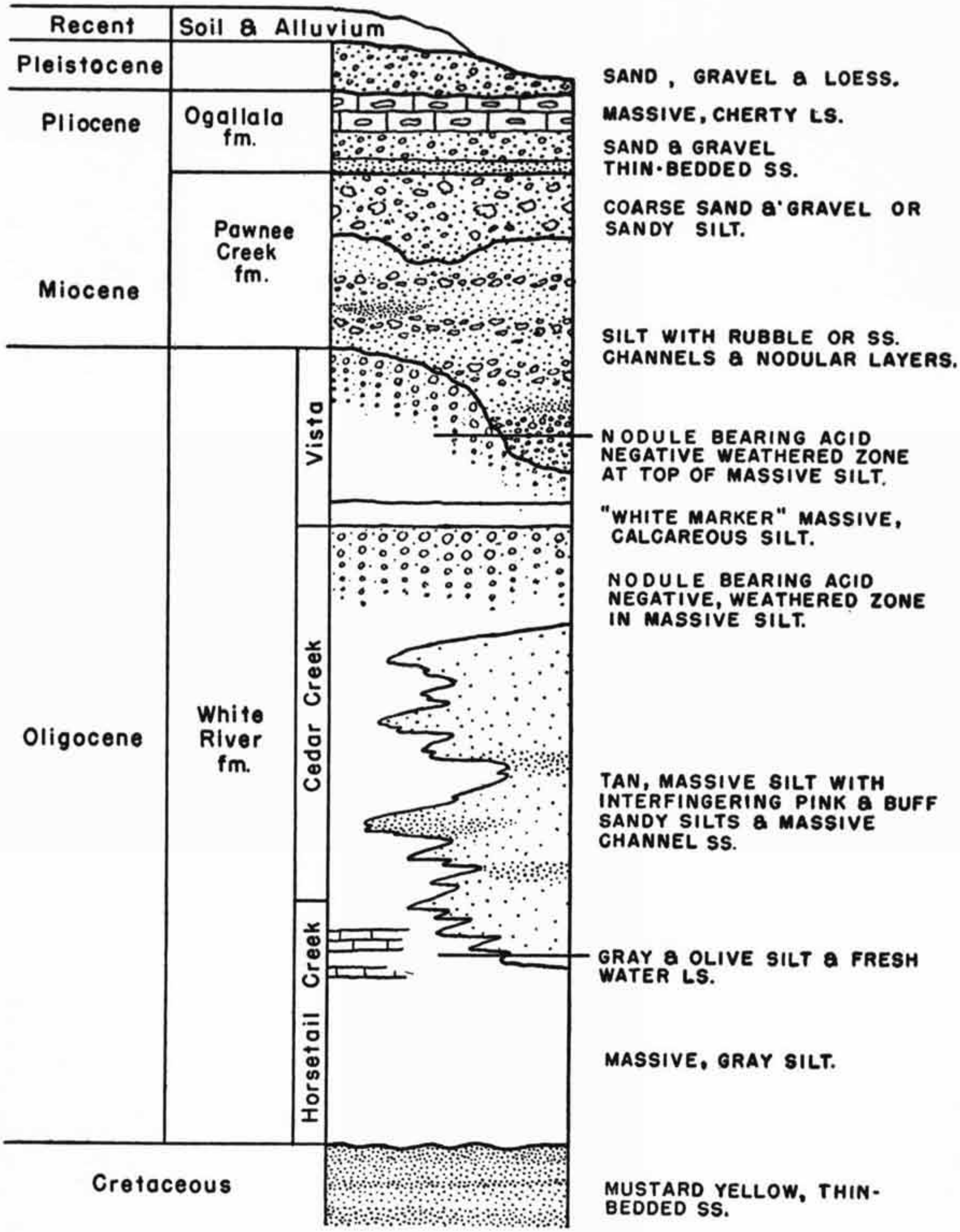


FIGURE 5.—Generalized columnar section in Logan County, Colorado.

beds of olive silts), which are a widespread continuation of the channel deposits seen in the lower zone; and an upper zone of massive, buff silt. Chunks of reworked volcanic ash are found in the lowest beds, and barite crystals are not uncommon in the upper half of the member. Thin clastic dikes of local extent are present, especially in the lower part of the Cedar Creek beds. No significant structural pattern has been traced for these dikes to date. The dikes are composed of sediments similar to those seen in the intermediate zone and cut into the lower massive silts. The "color-bands" mentioned by MATTHEW (1901, p. 357) are red or a shade of buff or tan. Most of the red zones are associated with the sandy silts or thin-bedded deposits. The possibility that these zones are old soil horizons or result from climatic conditions as suggested by MATTHEW should be seriously considered. The upper part of the massive Orellan silts are acid negative and bear nodules that are calcareous. These nodules reach a diameter of two to three inches near the top of the silt.

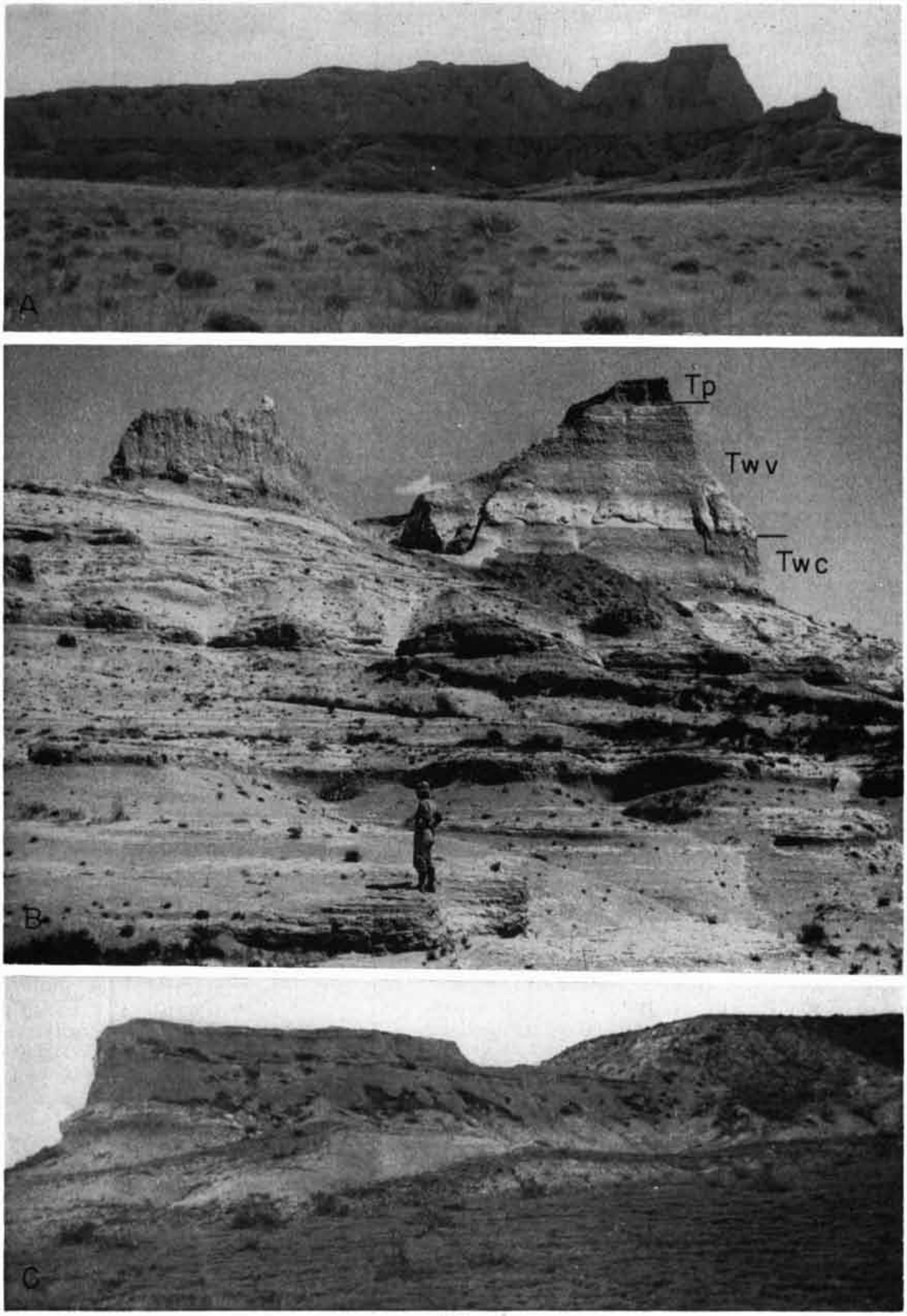
At present the top of the Cedar Creek member is considered to be immediately beneath the bottom of the white marker bed. Where MATTHEW placed the division between Whitneyan and Orellan beds is unknown since he stated that no stratigraphic demarcation could be made out, but it is possible that it was somewhere in the Orellan beds. The location of the Cedar Creek beds described by MATTHEW is not known definitely, but probably it was in Logan County. As in the case of the Horsetail Creek member, the typical section designated for the Cedar Creek member was selected because of its proximity to Martin Canyon, which would increase the probability of its being part of the exposures seen by MATTHEW when he described the beds, and because the most complete section is in this area.

Vista member.—The name Vista member is proposed as new for deposits of Whitneyan age found in Logan County, Colorado, and is derived from the Vista triangulation station located in the SW¼ sec. 1, T. 11 N., R. 54 W., which is almost at the center of the Vista member exposures. The beds are composed of massive, tan silt with a highly calcareous zone (the "white marker") at the bottom and have an erosional disconformity at the top. (See measured section XI for the beds at the type locality in N½ sec. 17, T. 11 N., R. 53 W., Logan County.)

The "white marker" is highly calcareous, to which fact it owes its distinctive color. Except for the highly calcareous condition and the absence of nodules, it is difficult or impossible to distinguish this stratum at close quarters, especially at the upper limit where the white color grades into buff. When viewed from a distance, however, this white band appears sharp and clear cut (Pl. 1, fig. *A*). A thickness as great as 25 feet has been measured, although the bed tends to be thinner. Above the white marker the silts are massive, hard, and not as fossiliferous as the Cedar Creek deposits. The calcareous nature of the beds decreases higher in the section and generally at a level 10 to 15 feet from the top of the smooth massive silt calcium carbonate is almost absent. At this level small, brown, highly calcareous nodules appear in the silt. These nodules increase in size upward and at places grade into the fluted cliffs described as the weathered zone of the old surface on the Oligocene deposits. Locally there are beds of noncalcareous siltstone two feet thick between these lower brown nodules and the fluted cliffs. The presence of nodules at the top of the Vista member causes an unusual weathering feature whereby the vertical surface presents a distinctive type of face that appears to have long vertical streamers or a corrugated or fluted surface. A superficial examination would lead one to believe that these vertical streamers were solid vertical concretionary masses, but by digging into the streamers the nodular structure is revealed. These beds are resistant and the silt in the interstices of the nodules is harder and more compact than in the lower beds. As elsewhere in the White River formation of northeastern Colorado, the nodules are highly calcareous and the silt is noncalcareous or nearly so. No fossils have ever been found in these nodular silts to my knowledge, with the possible exception of a Daimonelix tube, which certainly supports the possibility that the surface was a weathering surface during Miocene times. However, this weathered zone appears so distinct from the typical Oligocene beds, especially the buff silts, that some observers have considered them as a separate entity not associated with the Oligocene beds. For the most part, the zone has been called Arikareean. Nevertheless, a careful examination will show that these nodular "beds" cut across deposits of Whitneyan and Orellan age and are continuous with whatever deposits they rest upon. Post-Oligocene erosion in this region at places has

EXPLANATION OF PLATE 1

FIGURE	PAGE
A—North side of Chimney Rock, Chimney Canyon, sec. 3, T. 11 N., R. 54 W., Logan County, showing "white marker" bed at bottom of Vista member of the White River formation. Photograph by C. W. HIBBARD	16
B—South side of Chimney Canyon, showing small remnant of Pawnee Creek formation (Tp), and Vista (Twv) and Cedar Creek (Twc) members of the White River formation. Photograph by C. W. HIBBARD	14
C—South end of Flat Top Butte, sec. 1, T. 11 N., R. 54 W., Logan County, showing massive silt and freshwater limestone of the Horsetail Creek member of the White River formation. Photograph by ALLEN BIGGERSTAFF of Sterling, Colorado	12


A
Tp
Twv
Twc
B
C

removed all the Vista member and part of the Cedar Creek member prior to the weathering process, and later Miocene channeling at a few localities has cut away the old weathered surface and all evidence of the nodules.

The Vista member represents a part of a cycle of sedimentation which includes the Cedar Creek member. It remains today as local remnants and its areal extent probably is not large (50 to 75 square miles). The only exposures known to me are those in Logan County. Today, as they did during Miocene times, these beds represent a topographic high.

The Vista can be distinguished faunally and lithologically, but it should be emphasized that the lithologic separation from the Cedar Creek is largely arbitrary. Were the fauna not known, the lithologic differences would have no stratigraphic significance. Matthew realized this and stated (1901, p. 357) "The upper part of the formation is separated on account of the difference in fauna, but no stratigraphic demarcation can be made out, the beds becoming gradually finer and softer as we ascend, but retaining all their characters to the top." When reading this sentence of Matthew's, one should keep in mind the fact that Matthew's original concept of the White River formation in northeastern Colorado included the Horsetail Creek, Cedar Creek, and Martin Canyon beds as units. Therefore, he meant that not only was a lithologic break absent between the Cedar Creek beds and the Martin Canyon beds, but that deposition was continuous in the Martin Canyon beds. Matthew did, however, separate the Martin Canyon beds into lower and upper parts, of which the lower part is Whitneyan, and the upper part, thought by Matthew to be early Miocene in age, is Hemingfordian (Fig. 8).

Arikareean? Deposits

Material referred to *Nothocyon* and *Mesocyon* reported by Thorpe (1922) from northeastern Colorado is subject to too many conditional assumptions to have any value in correlation or identity of beds. Granting that the specimens came from northeastern Colorado, it is possible that they came from a burrow, fissure, or very small deposit in the Arikareean soil surface. If they came from northwestern Weld County, it is possible that an extension of the "Harrison beds" of Wyoming into the area would explain their presence here.

Pawnee Creek Formation

Matthew did not designate a type section for the Pawnee Creek beds. His published description (Matthew, 1901, p. 358) of the beds would fit the section at Martin Canyon, Sand Canyon (SW¼ sec. 25, T. 12 N., R. 55 W., Logan County), and Pawnee Buttes. Of these localities, we know that Matthew, in 1898, saw the section at Martin Canyon and may have seen the section at Sand Canyon. Matthew's field notes for 1898 have a description of the Pawnee Creek beds at Martin Canyon. The manuscript for his 1901 publication, which was completed prior to his visit to the Pawnee Buttes area in 1901, has a postscript, written following the 1901 field season, stating that the exposures in this area confirmed the stratigraphic conclusions set forth in the memoir. The fauna that accompanied the description appears to be a composite of specimens collected in the Martin Canyon, Sand Canyon, and Pawnee Buttes area. Probably more important is the fact that Matthew used the name "Pawnee Creek" very few times, mostly using the terms "Loup Fork" and "Protolabis beds" both in the text and the figure captions. This fact gives me the impression that the term "Pawnee Creek" was introduced into the paper after it was originally prepared. Support for this view is seen in the terms "Horsetail Creek beds" and "Cedar Creek beds," both of which were used as headings and not in the text, which leads me to think that these names were also introduced later. Whatever the significance of these introduced names may be, I think that it indicates that Matthew had the Miocene deposits in the Pawnee Buttes area in mind when he named the beds.[3] Subsequent publications and faunal lists leave no doubt that Matthew considered the beds and faunas at Pawnee Buttes, Sand Canyon, and Martin Canyon to be the Pawnee Creek beds and the Pawnee Creek fauna (Matthew, 1924). Curtis Hesse, in a letter (September 27, 1940) to Dr. Robert W. Wilson, quotes Mr. H. T. Martin as saying that Matthew's type locality for the Pawnee Creek beds was in the area around the "old Eubanks Ranch house" which was in or near the NE¼ sec. 1, T. 10 N., R. 59 W., Weld County.

It is evident that the Pawnee Buttes area became the basis for the "Pawnee Creek" concept, and, although I cannot present an adequate description of the faunas (or fauna) and their stratigraphic levels, the type locality of the Pawnee Creek formation is designated as NE¼ sec. 1, T. 10 N., R. 59 W., Weld County, Colorado (see measured section I).

Pawnee Creek formation is used in this paper as a mapping unit for the known Miocene beds in Logan and Weld Counties. As used here, the term includes Matthew's Pawnee Creek beds and the Pawnee Creek fauna, and the upper part of his Martin Canyon beds with its fauna. This is an expedient to avoid further confusion in the use of the term Martin Canyon and to avoid the introduction of a new term prior to solving the stratigraphic and correlation problems in the area. It is difficult to determine whether or not Matthew's Pawnee Creek beds included "upper Martin Canyon beds" in other localities, but possibly they did at all points except in the Martin Canyon area. Questions pertaining to the faunas and the complexities of depo-

3. This may seem contrary to the reasons for putting the Horsetail Creek and Cedar Creek type sections in Range 53, but it must be remembered that Matthew was selecting names in all three cases and, in addition, shifted his concept of the typical Miocene beds to the Pawnee Buttes area.

sition make it inadvisable to separate the Pawnee Creek formation into members at present.

The Pawnee Creek formation is represented in northeastern Colorado by a series of valley fills which eventually covered most of the uplands of the old Oligocene surface. The oldest deposits (MATTHEW's upper Martin Canyon beds at Martin Canyon and ?Pawnee Creek beds at other localities) are seen in the bottoms of canyons cut into the Oligocene surface and consist of massive silt or fine consolidated sand in thin layers. Superficially these deposits resemble White River deposits in many ways, but on the whole they are noncalcareous and less indurated. Capping the silts is a widespread, coarse rubble bed composed mainly of fragments of gray nodules, probably locally derived from the weathered Oligocene surface. Overlying the channel rubble are beds of massive, sandy silts containing layers of nodular concretions, gravel lenses, and thin channel sandstone. Locally the rubble may be absent, and it is possible that similar sequences of channel fills are not contemporaneous. This is a problem that needs much more attention, but at present the sequence of beds (see measured sections) is such that the same depositional cycle for all the channel rubble is accepted until positive evidence to the contrary is discovered.[4] In some places the rubble is overlain by an olive-gray silt followed by the massive silts, and in still other localities the rubble seems to be replaced by the olive-gray silt in the depositional sequence.

This description of the beds is equally applicable to most exposures in Logan County and eastern Weld County. The exposures in the Pawnee Buttes area have not been studied in sufficient detail to allow a comparable statement to be made concerning them. At least part of the sequence of beds that occur above the channel rubble in Logan County seems to be duplicated in the Pawnee Buttes area. Farther west, in Range 65, a sequence of beds is seen that appears generally similar to that in Logan County, but no fauna has been collected from it by me. It may be that the *Nothocyon* and *Mesocyon* material was collected from this general area if, indeed, the specimens came from northeastern Colorado. Were such the case, then some of these post-Oligocene beds might be part of the Arikaree formation.

Although the statement that the description of the beds is equally applicable to most of the exposures in Logan County is true, exceptions exist in that the Pawnee Creek formation exposed east of the type section of the Vista member (Fig. 3) shows a thicker section of beds containing a Martin Canyon fauna, and those lying to the west of this area have thicker sections containing a Pawnee Creek fauna.

The upper part of the Pawnee Creek formation, more than the lower part, shows intermittent periods of cut and fill. The lithologic similarity of each phase of channel cutting and filling often makes correlation of the beds from one exposure to the next difficult and very uncertain over large areas. Intermittent deposition of Pawnee Creek sediments continued throughout Barstovian time and perhaps into Clarendonian time. At least the youngest deposits were laid down probably during the transition from Miocene to Pliocene time, or in earliest Pliocene time.

The "Martin Canyon" problem.—At the site of the American Museum's Merycochoerus Quarry in the bottom of Martin Canyon (MATTHEW, 1901, p. 398, fig. 17) there are silts that superficially match the Cedar Creek silts in near-by exposures, but that yield Miocene fossils. MATTHEW (1901, p. 372) considered deposition to be continuous from Oligocene into early Miocene time and named the Oligocene layers and the "horizon C" Miocene deposits at Martin Canyon (Fig. 8) the Martin Canyon beds (which were subsequently often referred to as lower and upper Martin Canyon beds, respectively). Later OSBORN (1909, p. 75) and MATTHEW (1909, p. 112) included all of the lower Miocene in this section. The arrangement has not been challenged, although H. E. WOOD, *et al.* (1941, p. 25) wrote of it as "a poorly defined formation? or group? or referable to the standard formations to the northeast?"; and SCHULTZ & FALKENBACH, after visiting the area, wrote (1947, p. 203) "although some of the sediments in the Martin Canyon area have a typical White River appearance, a part of the section appears to be equivalent to the Marsland of Nebraska because of the similarity in mammalian forms and in certain lithologic characters." It is evident that extensive Miocene channeling has taken place in the area and that all of the Vista member and part of the Cedar Creek member have been removed by erosion before the sediments carrying the Miocene fauna were deposited. The nearest exposures of the Vista member are more than one mile distant from Martin Canyon. Continuous deposition of sediments is an impossibility. (See tables of measured sections and figures showing these sections graphically.) The quarry beds, which are composed of fine sands in thin, laminated beds or of fine, massive, noncalcareous silt with small, carbonaceous root marks, resemble Oligocene silts but on close inspection are found to be clearly separate from them lithologically.

Considerable confusion has existed concerning the section in Martin Canyon (physiographically it is a gully). Actually a few feet of Orellan silts are exposed in the bottom of the gully into which are channeled MATTHEW's Martin Canyon beds consisting of one exposure, 25 by 75 feet (MATTHEW, 1901, lower part of fig. 17) where the American Museum quarry was located, and possibly including two or three other smaller exposures within a

4. A note in the description of measured section No. X bears on this question, and it will also be considered again in the discussion of the faunas and the correlation of the beds.

few yards of the site (whether or not Matthew was aware of similar exposures to the west is unknown). The remaining 115 feet of section is what Matthew considered to be Pawnee Creek beds or later deposits. Martin Canyon is a term that should be abandoned as a name for a lithologic unit. The section did not exist as described: the lower part is assigned to the White River formation, and lithologically the upper part cannot be distinguished from similar beds that grade into the Pawnee Creek formation. The fauna is Hemingfordian and not Arikareean in age.

Ogallala Formation

The Ogallala formation was named by Darton (1899, p. 734) from a locality in southwestern Nebraska. In 1905 (p. 178) he commented on its presence in northeastern Colorado. Matthew (1901, p. 359) observed the beds at the top of the section in the valley wall at Martin Canyon and at Pawnee Buttes and commented on their resemblance to the Ogallala deposits, but he included them and their fauna in the Pawnee Creek beds. Lugn (1939, p. 1262) defined and described, as the uppermost units of the Ogallala group, the Kimball and Sidney formations from deposits in Kimball County, Nebraska and commented upon their extension into northeastern Colorado. However, none of the beds specifically identified by Lugn are included in the measured sections.

At the top of the Pawnee Creek formation, at the edge of the valley wall, there are deposits of undetermined age that may be a part of the Kimball member and are referred to in this paper as Ogallala formation. The lowest bed of the Ogallala formation, where it is exposed in the valley wall in northern Logan County, is a thin-bedded sandstone one to two feet thick, but locally exceeding this thickness—two examples being 5 and 12 feet. With few exceptions, the bed is always present unless removed by erosion. Above this lies a massive, coarse-grained, tan sandstone which is consolidated and hard when not weathered. It normally ranges in thickness from 5 to 15 feet but in some places is absent. Capping the massive sandstone is a cherty and silty limestone, ranging from 1 to 24 feet in thickness. These thicknesses, and those given in the measured sections, are deceptive inasmuch as only the rock exposed on the plateau surface at the valley edge was measured. Above the exposed part of the limestone, between the valley edge and the Nebraska state line, loess and soil mantle the Ogallala deposits, which include the Kimball exposures listed by Lugn (1939).

There is no mammalian faunal evidence to suggest that beds of late lower Pliocene or middle Pliocene age are represented here in the Ogallala formation. It may be inferred that Schultz & Falkenbach (1947, p. 202) think that much of the Pawnee Creek formation is referable to the Valentine member of the Ogallala formation and is of Pliocene age. The Pawnee Creek formation is a mapping unit as I have used it, and it is entirely possible that part of it is equivalent to the Valentine; but until some means is found to differentiate the parts, there can be no value in mapping some of the Pawnee Creek as Valentine. Until Schultz and Falkenbach amplify their statements on the Ogallala beds at Pawnee Creek, it is necessary to assume that they place *Merychippus paniensis* and its associated fauna in either the Marsland equivalent beds or in the Pliocene Valentine. Further reference to the age of the beds will be treated in the section on faunal correlations.

Pleistocene Deposits

Although this paper is not concerned with the Pleistocene deposits in northeastern Colorado, the following comments are added in order to complete the description of the Cenozoic beds. Sand and gravel terraces of Nebraskan age are found near and at the top of the South Platte valley wall in several places, notably W½ sec. 22, T. 11 N., R. 52 W., sec. 36, T. 11 N., R. 53 W., and SE¼ sec. 21, T. 11 N., R. 55 W., Logan County.

Grand Island gravels with a Pearlette ash lentil are exposed in W½ sec. 11, T. 10 N., R. 51 W., Logan County. This locality is six miles north of the South Platte, and midway between the Platte and the valley wall to the north.

Younger deposits are found between the Grand Island exposures and the river.

Late Pleistocene loess mantles the uplands or High Plains to the north of the valley.

GEOLOGIC SECTIONS

The following stratigraphic sections, from Weld and Logan Counties, are arranged from west to east. Measured sections II-XVI are given graphically in Figure 6. Figure 7 shows the locality of these sections. All thicknesses were measured by hand level, unless otherwise indicated, and were taken to the nearest foot except for certain significant smaller measurements. None of the sections were measured upward higher than the appearance of grass and soil at the top of the bluffs.

I. *Section at "Eubanks Ranch House," Pawnee Buttes, NE¼ sec. 1, T. 10 N., R. 59 W., Weld County.*

	Thickness in feet
?Pawnee Creek formation:	
8. Gravel, lime cemented; and channel sandstone	11
Pawnee Creek formation:	
7. Sandstone, brown, fine; grades into localized layers of gray- or olive-colored silt which becomes sandy and indurated in places	49
6. Silt, brown to tan; divided into equal upper and lower parts by a 2-3 foot layer of hard, sandy or silty, gray limestone. Silt grades into localized patches of sand, gravel, or indurated sandstone	32

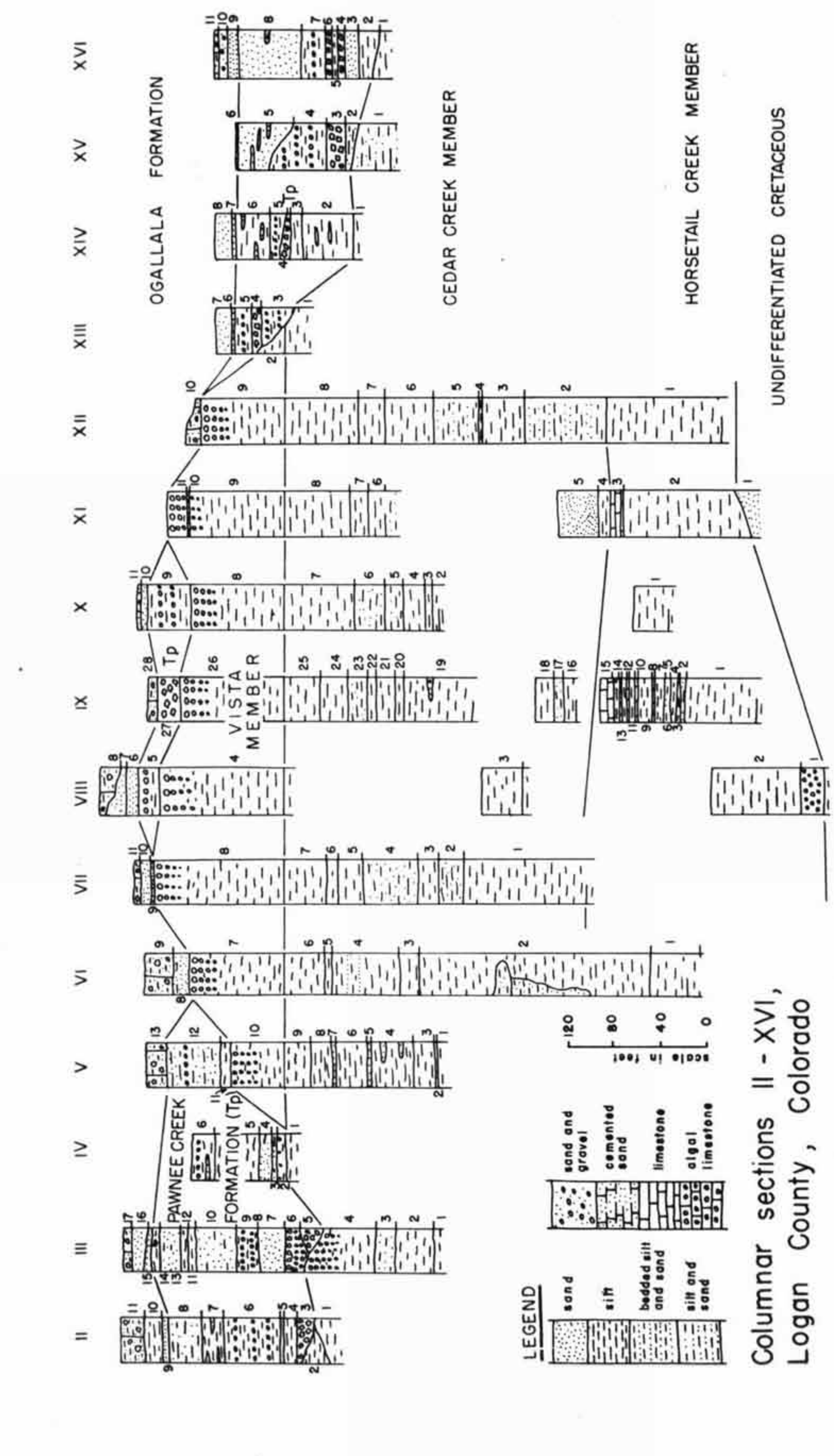


FIGURE 6.—Columnar sections Nos. II-XVI in Logan County, Colorado.

5. Silt, gray, limy, indurated; locally split into bands with soft, limy, gray silt between	16
4. Sand, brown to tan, locally soft or indurated; grades into silty limestone at top	28
3. "Pawnee Buttes" volcanic ash, weathered. Contains numerous fossil bones and teeth, especially of *Merychippus paniensis*	0–2
2. Sand, brown to tan, locally soft or indurated; grades into limy silt at top	17
White River formation:	
Cedar Creek member:	
1. Silt, tan, sandy, massive	Not measured

At least two volcanic ash falls are found in the Pawnee Buttes area. Miss Ada Swineford, of the State Geological Survey of Kansas, supplied the data for the following descriptions of the two ash falls and suggested that distinctive names be attached to each—inasmuch as there is no definite evidence at present to demonstrate their similarity to any other ash fall.

Pawnee Buttes ash.—Sample collected from NE¼ sec. 1, T. 10 N., R. 59 W., Weld County. The refractive index is variable, but most of the shards are less than 1.504, whereas the Sheep Creek ash (from the type locality) has a refractive index of 1.505-1.507. The shards are not so elongate as the shards of the Sheep Creek ash, and the color is somewhat more orange. Miss Swineford does not think that the impurities, mostly orange-stained quartz, can account for the difference in color. However, the Pawnee Buttes sample is slightly more weathered than the Sheep Creek sample, and that might change the color, reduce the index, and even make the shards more fragile so that the proportion of long ones is reduced.

Keota ash.—Sample collected from E½ sec. 34, T. 10 N., R. 59 W., Weld County. Swineford reported the index of refraction of this ash as 1.499-1.500. It has curved and fibrous shards similar to those of the Pearlette ash, but its color is slightly pinker than typical Pearlette ash. It contains flakes of biotite. The stratigraphic position, age, and areal extent of this ash have not been determined.

II. *Section in Canyon in SW¼ sec. 26, T. 12 N., R. 55 W., Logan County.*

	Thickness in feet
Ogallala formation:	
11. Limestone, gray, thick, resistant; contains sand and silt	22
10. Silt, brown, sandy	16
9. Sandstone, tan, thin-bedded	5
Pawnee Creek formation:	
8. Silt, reddish-brown, soft, sandy; with restricted 2- to 6-inch thick channel sandstone occurring intermittently	27
7. Silt, tan-brown, indurated; grades into beds above and below where not separated by local channel sandstone	20
6. Sand and silt, tan, soft, fine; with calcareous nodules (often in layers), and gravel and sandstone lenses. Most productive fossil zone	49
5. Silt, grayish-olive	3
4. Silt, limy, often indurated	11
3. Cobble, grading into bed above	3–15
2. Silt, soft, fine	0–20
White River formation:	
Cedar Creek member:	
1. Silt, tan, massive	Not measured

III. *Section at "Sand Canyon," SW¼ sec. 25, and NW¼ sec. 33, T. 12 N., R. 55 W., Logan County.*

	Thickness in feet
Ogallala formation:	
17. Limestone, gray, massive to thin-bedded; contains some silt	5
16. Sand, tan, massive, coarse, with gravel lenses; both are consolidated and hard when not weathered	15
15. Sandstone, thin-bedded	2–5
Pawnee Creek formation:	
14. Silt, with hard, limy, irregularly shaped, gray nodules which thicken to a solid bed at the top	8
13. Sandstone or sandy silt, tan, massive, indurated; weathers with a honeycomb appearance	19
12. Silt, capped by a layer of limy nodules 6 inches thick	5.5
11. Silt, capped by a layer of limy nodules 6 inches thick	5.5
10. Sand or sandy silt, tan, massive, soft; with small, white, pipy concretions averaging ⅜-inch in diameter	38
9. Silt, with two layers of nodules 2 and 7 feet from base	16
8. Sand, gray, indurated; grades laterally into patches of consolidated gravels or limy silt. Surface weathers to a "knobby" or "warty" appearance. Bench forming	0.2–0.5
7. Sand, tan, massive, indurated; weathers to form a smooth cliff face	24
6. Silt, capped by solid layer of nodules; contains two layers of nodules 5 to 6 feet apart that form benches	18
5. Channel fill of cobble derived from weathered Oligocene nodules	0–15
White River formation:	
Cedar Creek member:	
4. Silt, tan, massive. Part of the upper surface shows weathering and formation of nodules, and at other points this old surface is eroded away. Wherever the nodular silts (No. 6) rest on the Oligocene beds not having nodules, there is a hard, resistant, 2-inch thick, limy layer	50–65
3. Silt, tan, stratified, hard, sandy	19
2. Silt, tan to pinkish, stratified, bench-forming	34
1. Silt, tan	Not measured

IV. *Section at east side of sec. 36, T. 12 N., R. 55 W., Logan County.*

	Thickness in feet
Pawnee Creek formation:	
6. Silt, brown, sandy; with large nodules and gravelly sandstone lenses	16
5. Silt, light brown, limy, indurated; weathers with a honeycomb appearance	38
4. Sand, brown, silty	11
3. Silt, indurated, sandy	4
2. Silt, gray-olive; with nodules grading into above bed	9
White River formation:	
Cedar Creek member:	
1. Silt, massive	Not measured

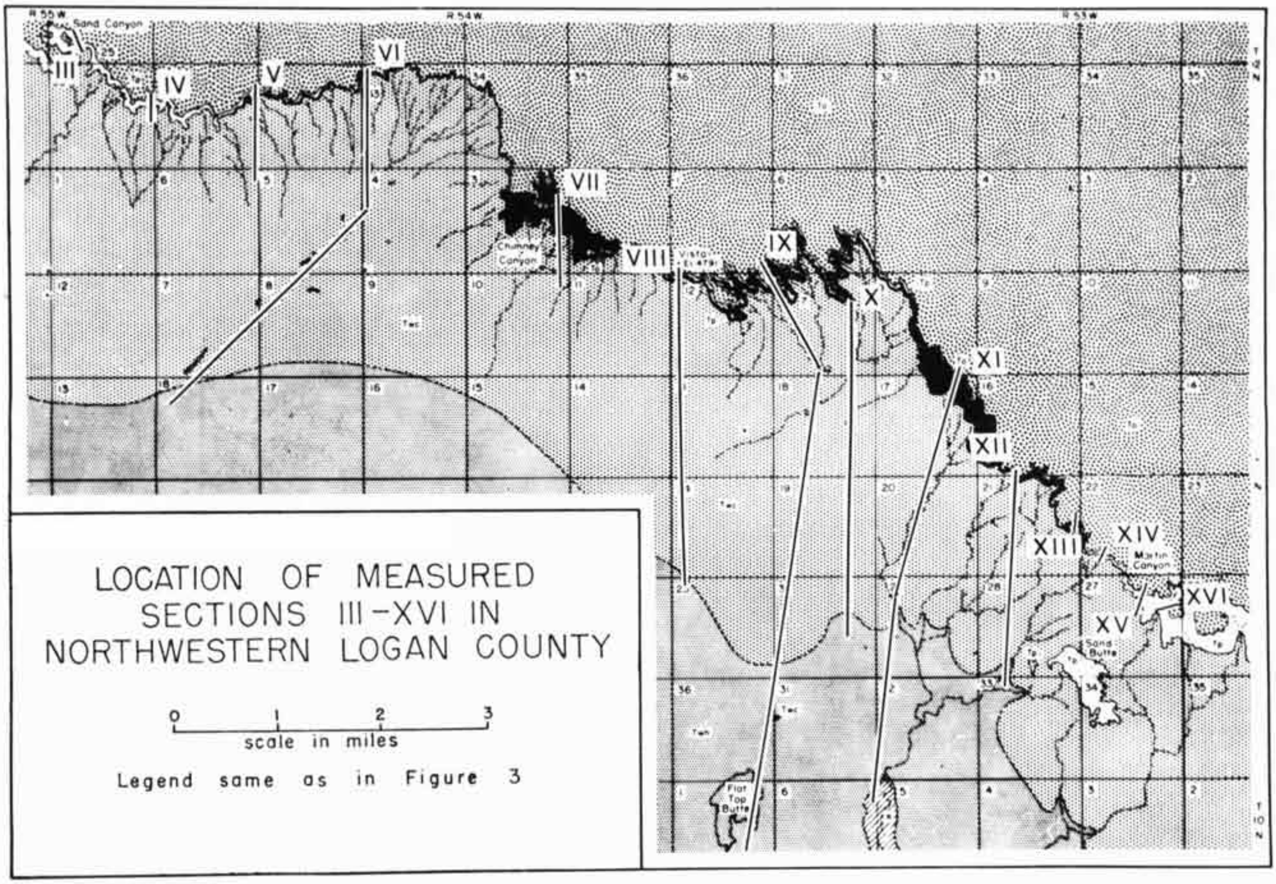


FIGURE 7.—Map showing location of measured sections Nos. III-XVI in Logan County, Colorado.

V. *Section in E½ sec. 31, T. 12 N., R. 54 W., and NE¼ sec. 6, T. 11 N., R. 54 W., Logan County.*

	Thickness in feet
Ogallala formation:	
13. Limestone, gray, thick, resistant; contains sand and silt	19
Pawnee Creek formation:	
12. Sand, brown, silty, with nodules	46
11. Silt, indurated, limy; with zones of gravel and sand that grade laterally into the gray silt, channel sandstone, and cobble capped by thin 2- to 6-inch channel sandstone	8
White River formation:	
Vista member:	
10. Silt, tan, massive; weathered at top and with highly calcareous zone at the bottom	46
Cedar Creek member:	
9. Silt, tan, massive	26
8. Silt, pinkish, laminated	20
7. Sandstone, dark red, resistant	1
6. Silt, pinkish, laminated	29
5. Sandstone, dark red, resistant	1
4. Silt, pink, laminated; with channel sandstone at top and channel of gray silt at bottom	39
3. Silt, pinkish-buff	21
2. Caliche-like zone	0.5–0.8
1. Silt, pink	Not measured

VI. *Section in W½ sec. 33, T. 12 N.; W½ sec. 4, N½ sec. 8, E½ sec. 7, and sec. 18, T. 11 N., R. 54 W., Logan County.*

	Thickness in feet
Ogallala formation:	
9. Limestone, gray, thick, resistant; contains sand and silt	24
8. Sand, limy, indurated; grading upward into soft silty sand	16
White River formation:	
Vista member:	
7. Silt, tan, massive; with weathered top zone and a highly calcareous zone at the bottom that appears white at a distance	79
Cedar Creek member:	
6. Silt, tan	38
5. Silt, pink	6
4. Silt, tan, massive; with 6-inch red zones 13 and 25 feet from top of the bed	58
3. Silt, red	19
Cedar Creek and Horsetail Creek members:	
2. Silt, whitish gray; grading upward into tan silt at about 60 feet from the top of the bed	200
1. Silt, whitish-gray; noncalcareous in upper part and containing a zone of nodules extending to within a few feet of the top	35
Not measured below this point.	

The bottom 35 feet of unit No. 2 and all of unit No. 1 were measured with an altimeter and cannot be considered as more than reasonable estimates of the true thicknesses of the beds.

Lateral to the point from which unit No. 2 was measured, there is a large prominent channel fill of red sandstone and silt whose top is 60 feet below the top of the silt—thus, in general, coinciding with the level at which the silt changes color from white to tan. The channel fill reaches thicknesses of 90 feet and more. Above the channel the beds continue as unit No. 3. The whitish-gray silt below the channel is probably part of the Horsetail Creek member, but the evidence to support this view needs more detailed study. To the west in Weld County this same channel cuts into definite Chadronian beds. Whitish silt lies below the channel.

VII. *Section at "Chimney Canyon" in E½ sec. 3, T. 11 N., R. 54 W., Logan County.*

	Thickness in feet
Ogallala formation:	
11. Limestone, gray, resistant; contains sand and silt	4
10. Sand, tan, massive	10
9. Sandstone, thin-bedded	2
White River formation:	
Vista member:	
8. Silt, buff, massive; with concretions in upper 30 feet and a highly calcareous zone at the bottom (referred to in this paper as the "white marker bed")	113
Cedar Creek member:	
7. Silt, buff, massive	37
6. Silt, reddish, sandy	11
5. Silt, tan	22
4. Silt, reddish, sandy	48
3. Silt, tan, massive	16
2. Silt, pinkish, sandy	22
1. Silt, gray, massive; grading into tan silt at the top and into pink, sandy silts and channel sandstones laterally	107
Not measured below this point.	

VIII. *Section in W½ secs. 12, 13, 24, and 26, T. 11 N., R. 54 W., Logan County.*

	Thickness in feet
Ogallala formation:	
8. Limestone, gray, resistant; contains sand and silt. (Top of this bed at this point has triangulation station Vista with elevation at 4,791 feet.)	6–14
7. Sand, tan, massive	14
6. Sandstone, thin-bedded	12
Pawnee Creek formation:	
5. Silt with layers of concretionary nodules	18
White River formation:	
Vista member:	
4. Silt, buff, massive; with concretionary nodules in upper part that weather to give the appearance of vertical fluting or stringers	110
Cedar Creek member:	
Grass covered valley wall and floor interval of approximately	170
3. Silt, tan; interbedded with areas of reddish, sandy silts	35
Section continued from well log of Haley-Smith Well No. 1 in NW¼ NE¼ sec. 26, T. 11 N., R. 54 W., Logan County. Elevation 4,254 feet. Valley floor interval approximately	170
Horsetail Creek member:	
2. "White clay"	75
1. "Gravel"; resting on Pierre shale	20

IX. *Section in NE¼ sec. 12, T. 11 N., R. 54 W.; W½ sec. 7, T. 11 N., R. 53 W.; E½ sec. 36, T. 11 N., R. 54 W., and N½ sec. 1, T. 10 N., R. 54 W., Logan County.*

	Thickness in feet
Ogallala formation:	
28. Limestone and thin-bedded sandstone	6
Pawnee Creek formation:	
27. Cobble channel fill; derived from weathered Oligocene surface	20
White River formation:	
Vista member:	
26. Silt, buff, massive; with concretionary nodules in upper 25 feet and highly calcareous zone at the bottom that appears white at a distance	90
Cedar Creek member:	
25. Silt, brown	32
24. Silt, tan; with barite crystals	24
23. Silt, reddish, resistant, sandy	17
22. Silt, dark tan, massive	11
21. Silt, pinkish-tan	16
20. Silt, pink	5
19. Silt, tan, massive; grading into laminated, sandy silt at top and containing tan and gray channel sandstone 27 feet from top	62
Section continued 3⅓ miles south at top of peak in sec. 36, T. 11 N., R. 54 W. Valley floor interval	57
18. Silt, brown, massive	15
17. Silt, reddish, resistant, sandy	9
16. Silt, tan, massive	11+
Section continued on "Flat Top," a butte in sec. 1, T. 10 N., R. 54 W. Valley floor interval	21
Horsetail Creek member:	
15. Limestone, hard, resistant	5
14. Silt, gray	7
13. Limestone, white, chalky, soft; weathers into large slabs	2
12. Silt, gray	7
11. Same as No. 13	2.5
10. Silt, gray	7
9. Same as No. 13	2.5
8. Silt, pink; grading upward and laterally into gray silt	14
7. Limestone, olive-gray, fine textured	1
6. Silt, pink; grading upward into gray silt,	8
5. Silt, pink; interbedded with sandy silts,	8
4. Silt, reddish-brown	3–4
3. Silt, olive-colored, resistant	3–4
2. Silt, pinkish-tan, sometimes sandy	3–4
1. Silt, gray-white, massive	60+
Section not measured below this point.	

X. *Section in E½ sec. 7, T. 11 N., R. 53 W., Logan County.*

	Thickness in feet
Ogallala formation:	
11. Limestone, gray, resistant; contains sand and silt	1.5
10. Sand, tan, massive	5
Pawnee Creek formation:	
9. Silt; with layers of concretionary nodules resting on cobble channel 5-15 feet thick or next lower bed	38
White River formation:	
Vista member:	
8. Silt, tan, massive; capped by a 2-foot layer of mudstone and containing brown concretionary nodules in upper 10 feet.	

Lower part highly calcareous giving a white appearance to the beds at a distance	81
Cedar Creek member:	
7. Silt, tan, massive; with narrow, red zone at bottom	62
6. Silt, pinkish and tan, sandy; with sandstone stringers	27
5. Silt, tan, sandy	16
4. Silt, tan	21
3. Silt, tan; with reddish zone at bottom	5
2. Silt, pinkish	5
Exposure continued, but beds not measured below this point. Section continued in E½ sec. 30, T. 11 N., R. 53 W. Position as shown in Figure 6 is approximate.	
Horsetail Creek member:	
1. Silt, gray	30
Not measured below this point.	

On either side of unit No. 9 of this measured section there are local areas in which there are no Pawnee Creek deposits. Also, there are local areas where the cobble channels are repeated and are in association with the massive limestone (unit No. 11). At one point the limestone overlies a local silt deposit containing seeds of *Biorbia fossilia*. However, I have not been able to get a traceable sequence of silt, cobble, and limestone, or cobble, silt, and limestone, as the case may be, that contains either plant or animal fossils. Until this is done, part of the rubble beds mapped as Pawnee Creek formation from the E½ sec. 2, T. 11 N., R. 54 W., to the W½ sec. 8, T. 11 N., R. 53 W., should be considered possibly as part of the Ogallala formation.

XI. *Section in N½ sec. 17, T. 11 N., R. 53 W., Logan County.*

	Thickness in feet
Ogallala formation:	Not measured
White River formation:	
Vista member:	
11. Silt; with gray nodular concretions that weather to form vertical columns to give a fluted appearance	14
10. Mudstone	3
9. Silt, tan, massive; with brown, concretionary nodules in upper 8 feet and a highly calcareous zone in the bottom 11 feet that appears white from a distance	80
Cedar Creek member:	
8. Silt, tan	59
7. Silt, reddish-tan; with barite crystals	15
6. Silt, tan, sandy	16
Exposure continued but bed not measured below this point. Section continued in W½ sec. 29, W½ sec. 32, T. 11 N., and E½ sec. 6, T. 10 N., R. 53 W. Correlated horizontally with measured sections on either side.	
5. Sandstone, red, massive, resistant; with prominent cross-bedding and internal channeling	35
4. Silt, red	10
Horsetail Creek member:	
3. Limestone; four one-foot thick, gray-green, fine-textured beds separated by three olive-gray silt beds	10
2. Silt, whitish-gray, massive	100
Cretaceous deposits:	
1. Sandstone, khaki-colored, soft, thin-bedded	Not measured

XII. *Section in W½ sec. 21, W½ sec. 28, and W½ sec. 33, T. 11 N., R. 53 W., Logan County.*

	Thickness in feet
Ogallala formation:	
10. Limestone, gray, resistant; contains sand and silt	5–10
White River formation:	
Vista member:	
9. Silt, tan, massive; with upper 20 feet weathered and nodular; white marker at base	70
Cedar Creek member:	
8. Silt, tan	65
7. Silt, pink	24
6. Silt, tan	43
5. Sand and silt, pink and tan	41
4. Silt, olive-gray	2
3. Silt, tan	38
2. Sandstone and silt, red and pink	71
Horsetail Creek member:	
1. Silt, white to gray, massive	100
Exposures continued but beds not measured below this point.	

XIII. *Section in NE¼ of SE¼ sec. 21, T. 11 N., R. 53 W., Logan County.*

	Thickness in feet
Ogallala formation:	
7. Sand, coarse	15
6. Sandstone, thin-bedded	2
Pawnee Creek formation:	
5. Silt, gray; with layers of concretionary nodules	15
4. Nodular rubble; in channel cut into next lower bed and Oligocene beds	8
3. Silt, tan; with layers of tan concretionary nodules; channeled into Oligocene beds	0–30
White River formation:	
Vista member:	
2. Remnants of "white marker" zone	0–20
Cedar Creek member:	
1. Silt, buff	Not measured

It should be noted that here none of the Oligocene beds have a weathered upper zone, a fact shown by the absence of nodular concretions.

XIV. *Section in SW¼ of sec. 22, T. 11 N., R. 53 W., Logan County.*

	Thickness in feet
Ogallala formation:	
8. Sand, coarse	15
7. Sandstone, thin-bedded	2
Pawnee Creek formation:	
6. Silt, limy, indurated; or sand with channel gravel; at places is caliche-like or bears nodules	30
5. Silt; with layers of nodules	9–15
4. Cobble derived from weathered Oligocene nodules	1–6
3. Silt, limy; alternately indurated or soft layers	13
2. Silt, tan, massive, soft; with lenses of sand and gravel	44
White River formation:	
Cedar Creek member:	
1. Silt	Not measured

XV. *Section in west side of Martin Canyon, NW¼ of NE¼ sec. 27, T. 11 N., R. 53 W., Logan County.*

	Thickness in feet
Ogallala formation:	
6. Sandstone, thin-bedded	1
Pawnee Creek formation:	
5. Sand, soft or indurated, limy; with channel fills of gravel or sandstone. Contact with underlying beds marked by thin, warty sandstone, gravelly sandstone, or channel fills of hard, thin-bedded, limy silts	28–55
4. Silt, noncalcareous; at this point more or less equally divided into four parts by three layers of nodular concretions	49
3. Cobble, derived from weathered Oligocene nodules	15
2. Silt and sand	6–11
White River formation:	
Cedar Creek member:	
1. Silt, tan, fine or sandy	35
Base of exposures covered by post-Tertiary deposits.	

Quarry A of the University of Kansas is located in unit No. 4 between the first and second layers of nodular concretions and is the source of the greater part of the Martin Canyon local fauna.

XVI. *Section in east side of Martin Canyon, NE¼ of NE¼ sec. 27, T. 11 N., R. 53 W., Logan County.*

	Thickness in feet
Ogallala formation:	
11. Limestone, gray, massive, cherty	2
10. Sand and gravel, coarse	8
9. Sandstone, thin-bedded	5
Pawnee Creek formation:	
8. Sandstone, fine, brown; with consolidated channel gravels	55
7. Silt, with concretionary nodule layers	21
6. Rubble, nodular	5
5. Mudstone	4
4. Rubble, nodular	5
3. Sand, tan, fine, consolidated; in thin layers	14
2. Silt, hard, massive	10–20
White River formation:	
Cedar Creek member:	
1. Silt, pink	5
Base of beds covered by wash of valley floor.	

This section is measured practically through the middle of the deposits shown in the photograph by Matthew (1901, p. 398, fig. 17). The American Museum Merycochoerus Quarry is in unit No. 2. In unit No. 10 a type of opalized rock occurs that is characteristically present below the algal limestone in Wallace and Norton Counties, Kansas, in beds judged to be of "Kimball" age.

XVII. *Section in W½ sec 16, T. 10 N., R. 51 W., Logan County.*

	Thickness in feet
White River formation:	
Horsetail Creek member:	
3. Silt, tan; grades into unit No. 2 below, but possibly channel sandstones separate units 2 and 3 locally	16
2. Silt, white	49
1. Silt, gray, with sandstone lenses and zones of pinkish-gray silt	50
Exposures continue downward but are obscured by valley fill at this point.	

Beds No. 1 and No. 2 carry titanothere bones, but nothing diagnostic was found in bed No. 3. Possibly No. 3 is the equivalent of the earliest Cedar Creek beds farther west.

ORIGIN OF THE BEDS

Matthew's demonstration (1901, p. 359) that the White River deposits were not lacrustrine in origin is now classic. In contrast to the theory prevailing at that time, he placed emphasis upon aeolian mechanics in accounting for the deposition of the unlaminated silts. This interpretation was based upon comparison of the White River deposits with "loess" of the High Plains and other regions. Neither he nor anyone else at that time knew that part of the High Plains deposits—called loess because of lithologic appearance—was actually redeposited loess and other accumulations of fine materials. That the White River deposits are partly the result of aeolian action is not questioned, and that some of the wind-borne deposits remained undisturbed is not questioned, but I think that a greater part of the originally wind-borne deposits was reworked by sheet flood, colluvial action on slopes, and fluvial action of aggrading streams in the valleys, and that this same action also applies to fine material derived from local sources that was never wind-borne at any time. That the Whitneyan deposits may be aeolian in a strict sense is a possibility that deserves inspection. It should also be kept in mind that these statements are applicable only to northeastern Colorado.

The post-Oligocene Tertiary beds are, for the most part, channel fills and flood plain deposits.

THE FAUNAS

The following Tertiary faunas are discussed in this paper. For their position in the Tertiary rock column see Figure 8.

Faunas of the White River formation
- Horsetail Creek fauna
- Cedar Creek fauna
- Vista fauna

Faunas of the Pawnee Creek formation
- Martin Canyon local fauna
- Eubanks local fauna
- Kennesaw local fauna
- Vim-Peetz local fauna
- Sand Canyon local fauna

Information is too scanty, or too unreliable, to permit one to discuss, as a faunal unit, the specimens reported by Thorpe (1922) that possibly came from Arikareean beds.

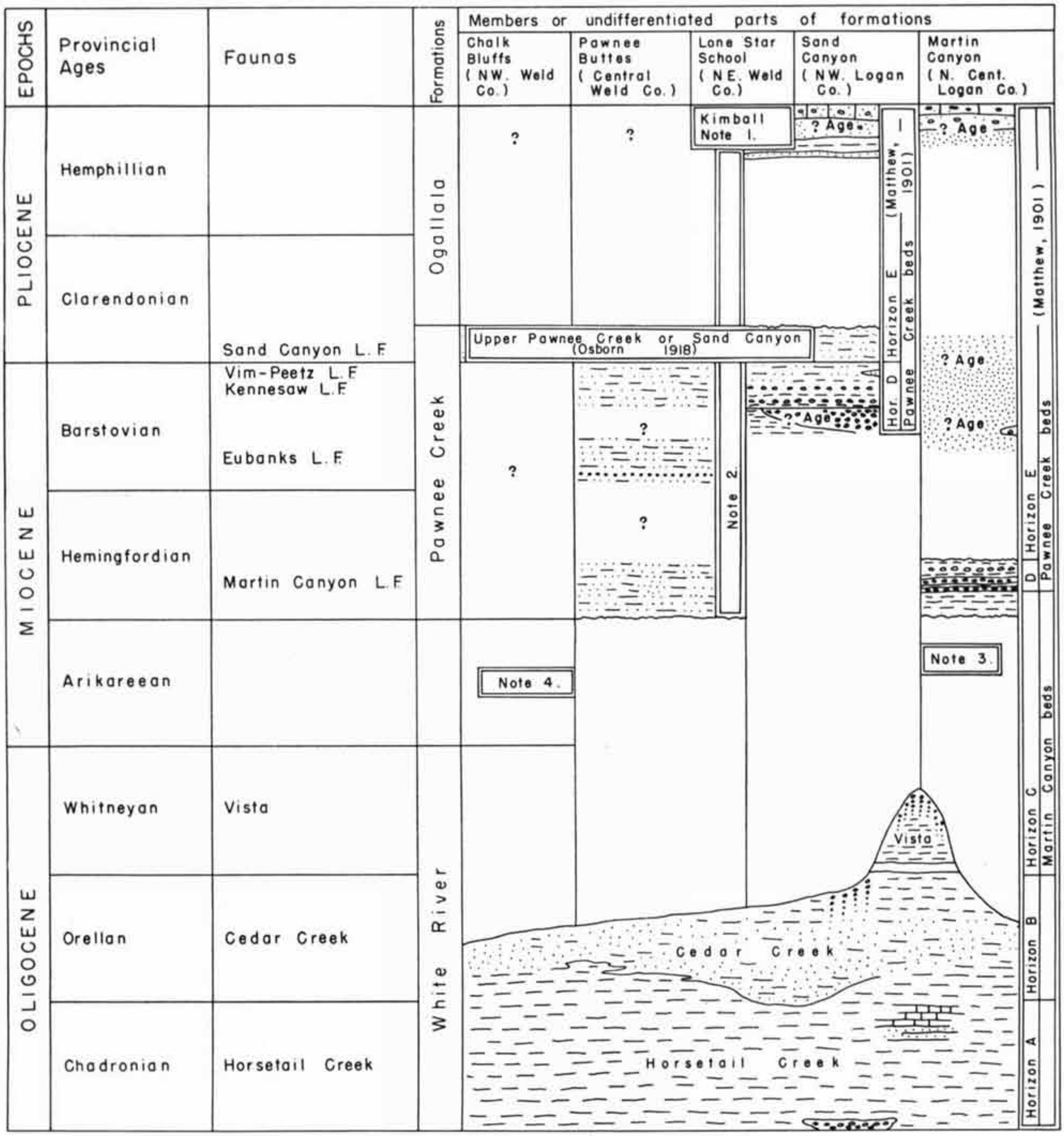


FIGURE 8.—Chart showing the Tertiary faunas and deposits and their relationship to the Tertiary time scale. The boxes (except note 4) contain the opinions and terminology used by other workers.

Note 1. LUGN (1939) listed only one specific occurrence of the Kimball member in northeastern Colorado, but stated that the deposits were widespread.

Note 2. MATTHEW referred all the beds in this area to the Pawnee Creek, without differentiating them as horizon D or E. OSBORN (1918) referred all the beds below upper Pawnee Creek to lower Pawnee Creek, or Pawnee Creek A, of middle upper Miocene age. SCHULTZ & FALKENBACH (1947) referred all the beds to the Ogallala, except the lower part of the section, which was considered a remnant of Marsland or "Martin Canyon" beds.

Note 3. MATTHEW thought there was continuous deposition from Oligocene through lower Miocene time at this point.

Note 4. Evidence for an Arikareean formation is not conclusive.

FAUNAS OF THE WHITE RIVER FORMATION

Never since the early explorations by MARSH has there been any doubt that faunal zones, roughly comparable to those in the Oligocene beds of Nebraska and South Dakota, existed in northeastern Colorado. The divisions were simple: Titanothere beds or zone, Oreodon beds or zone, and Leptauchenia beds or zone [the last being introduced, as the lower part of horizon C or upper White River, for this area by MATTHEW (1899, p. 51)].

The change in the mammalian population from one level to the next in the White River formation is effected by change in facies, by gradual or rapid extinction, by introduction of migratory species, and by evolution of resident species. The sediments, representing a more or less continuous period of deposition, show two important facies. One facies, massive silt, interfingers with the second facies, which may be thin-bedded silt, channel fill of sand and gravel, or lenses of freshwater limestone and olive-gray silt (marsh and pond deposits). The changes in facies are local and reflect the proximity of different environments, which has led to a mixing of the faunas found in each facies. The faunal units, although united by having numerous genera in common, are distinguished from each other by the restriction of some genera to only one or two of the faunas, and by restriction to a single age of certain species which belong to relatively long-lived genera. The genera and species common to two or more of these faunas suggest, however, a short time interval for each successive faunal stage and a close relationship of all the faunas. This situation is even more strikingly exhibited by the upper Miocene faunas in the region.

The comparison of the Oligocene faunas in northeastern Colorado with adjacent faunas in other parts of the High Plains shows that there was no isolation of the northeastern Colorado faunas. The absence of such genera as *Metamynodon* and *Protoceras*, and the rarity of anthracotheriids and agriochoerids suggest important environmental differences between the Oligocene faunas of northeastern Colorado and other regions — especially those of South Dakota and Nebraska.

HORSETAIL CREEK FAUNA

The mammalian fauna of the Horsetail Creek member is composed of the following species:

Peratherium fugax
Apternodus iliffensis, n. sp.
Palaeolagus intermedius
Pelycomys rugosus, n. gen. and sp.
Ischyromys troxelli
Titanotheriomys cf. *T. veterior*
Titanotheriomys? sp.
Adjidaumo sp. (Small form)
Paradjidaumo trilophus
Pseudocynodictis nr. *P. paterculus*
Parictis nr. *P. dakotensis*
Dinictis sp.
Mesohippus proteulophus
Mesohippus sp.
Megacerops acer
Hyracodon sp.
Trigonias osborni
Caenopus premitis
Caenopus mitis [5]
Stibarus obtusilobus
Stibarus lemurinus
Archaeotherium ramosus [5]
Archaeotherium potens [5]
Archaeotherium mortoni
Archaeotherium crassum
Perchoerus nr. *P. minor*
Anthracotheriid sp.
Merycoidodon culbertsonii
Merycoidodon gracilis
Eotylopus sp.
Poëbrotherium sp.
Leptomeryx esulcatus
Leptomeryx evansi
Hypisodus sp. (Form A)

GREGORY & COOK (1928, p. 3) considered the beds at the Denver Museum's Trigonias Quarry to be in the "Lower Chadron formation." HORACE E. WOOD (1931, p. 415) considered the titanothere zone to be an equivalent of the early Chadron beds in South Dakota. Since these opinions were stated, CLARK (1937) has listed the faunas of the lower, middle, and upper Chadron beds of South Dakota. There is not too much in common between the faunas of South Dakota and northeastern Colorado, but if the rarity of Chadronian fossils, the poor preservation, and the probable facies and locality differences are considered, this does not cause surprise. The presence of *Trigonias osborni* and *Archaeotherium crassum*, which CLARK thought might be restricted to the middle Chadron member, is evidence of an equivalent middle Chadronian age for the Horsetail Creek member. On the other hand, the similarity of the species to the upper Chadron fauna should not be overlooked. Neither should the fact be overlooked that the Horsetail Creek fauna represents an advance over the Pipestone Creek fauna, especially in the presence of Orellan species. In fact, at some localities, the only non-Orellan aspect of the fauna is the absence of *Eumys* and *Hypertragulus* and the rare occurrence of titanotheres. In my opinion, the Horsetail Creek fauna is not older than middle Chadronian and more probably represents a late Chadronian phase.

CEDAR CREEK FAUNA

Tentatively, the Cedar Creek fauna has been divided into lower, middle, and upper parts. Perhaps the division should not be made, inasmuch as only a few of the species are restricted to any one level. The divisions will be used, however, for their possible future value. Some of the species, for which there are no data as to level at present, may serve to accentuate the difference between the three units when better collections are made. It should be pointed out that these divisions are limited to the

5. Occurrence probably here rather than in the Cedar Creek member, but not yet demonstrated.

area in northwestern Logan County that was studied in detail (Fig. 9). The mammalian fauna is distributed in the three parts as follows:

	Lower	Middle	Upper[6]
Nanodelphys minutus	1[7]		
Metacodon magnus	1		
Ankylodon annectens	X		
Palaeolagus haydeni	X		
Titanotheriomys? sp.[8]	X		
Adjidaumo minutus	X		
Heliscomys vetus	X		
Proheteromys? sp.	1		
Agnotocastor coloradensis	X		
Eumys obliquidens	X		
Hyaenodon crucians	X		
Hyaenodon mustelinus	1		
Perchoerus nr. *P. nanus*[9]	1		
Poëbrotherium labiatum	X		
Peratherium huntii	X	X	
Peratherium fugax[8]	X	X	
Ictops sp.	X	X	
Metacodon mellingeri	X	X	
Ankylodon progressus, n. sp.	1	1	
Domnina gradata	X	X	
Domnina compressa, n. sp.	1	1	
Prosciurus relictus	X	X	
Ischyromys typus	X	X	
Paradjidaumo trilophus[8]	X	X	
Eumys nr. *E. exiguus*	X	X	
Pseudocynodictis gregarius	X	X	
Mesohippus eulophus	X	X	
Hyracodon sp.[8, 9]	X	X	
Subhyracodon occidentalis	X	X	
Stibarus lemurinus[8]	X	X	
Leptochoerus spectabilis[9]	X	X	
Archaeotherium mortoni[8]	X	X	
Merycoidodon spp.[8]	X	X	
Poëbrotherium wilsoni	X	X	
Hypertragulus calcaratus	X	X	
Hypisodus minimus	X	X	
Leptomeryx esulcatus[8]	X	X	
Leptomeryx evansi[9]	X	X	?
Palaeolagus intermedius[8, 9]	X	X	X
Megalagus turgidus	X	X	X
Eumys elegans (*s. l.*)	X	X	X
Cedromus wardi and *Cedromus* sp.	X	1	1
Proscalops sp. (Small form)		1	
Arctoryctes?		X	
Pelycomys placidus, n. gen. and sp.		X	
Heliscomys tenuiceps		1	
Diplolophus sp.		2	
Daphoenus cf. *D. vetus*		1	
Palaeogale lagophaga		2	
Drassonax harpagops, n. gen. and sp.		1	
Dinictis sp.		1	
Heptacodon sp.		1	
Leptomeryx sp. (Small form)		X	
Palaeolagus burkei[9]		X	X
Hyaenodon horridus		1	1
Pseudocynodictis lippincottianus		X	1
Protomeryx campester[9]			(?)1
Hypisodus sp. (Form B)			X

This list shows that the lower and middle zones carry closely comparable faunas. The interfingering of stratified silts and sands with unlaminated silts in the lower zone, and their gradual encroachment upon unlaminated silts which results in the widespread sandy silts and channels of the middle zone present a definite facies problem. However, most of the known species are common to the two types of deposits in both the lower and middle zones, which would suggest that the differences between the vertical zones are of greater importance than the possible facies differences. In the lower zone the distribution of the species (with the exception of *Subhyracodon*, *Perchoerus*, and *Agnotocastor*, which were found in a "pond" type of deposit) between the unlaminated clays and the interfingering sandy silts shows that the environmental differences were not great enough to reflect a distinct stream border fauna. The species, especially *Palaeolagus haydeni*, restricted to the lower zone probably are reliable indicators of that zone. Carnivores and perissodactyls are rare. The abundant remains of rodents, artiodactyls, and lizards indicate the presence of ecological niches similar to those on the High Plains today. Of course, some of this abundance reflects the fact that there are more unlaminated silts than laminated sandy silts in the lower zone.

With the encroachment of sandy silts and channel deposits over the whole area there seems to have been a definite change in the environment. The presence of *Subhyracodon occidentalis* and *Heptacodon* suggests that the streams involved in this change must have been larger and less transitory than before. Carnivores show a greater diversity of kinds and were more abundant than the figures in the faunal list would indicate (the list being, with few exceptions, a record of my personal collecting). Many of the species listed from the middle zone alone may actually be restricted to it. That this may be so is suggested by the fact that the few well-developed channel and silty phases in the lower level would provide an equally favorable environment. On the other hand, the extreme rarity of individuals of some of the species found only in the middle zone suggests that they may be present but undiscovered in the lower zone.

The occurrence of *Palaeolagus haydeni* and *Palaeolagus burkei* deserves special mention. Regardless of lithology of beds, *Palaeolagus haydeni* has a widespread distribution in the lower beds of the Cedar Creek member and then rather abruptly disappears at the top of the lower zone. Almost as abruptly *Palaeolagus burkei* appears and continues to be present throughout the remainder of the Oligocene section—regardless of lithology of beds or environment. So far I have found these two species to be excellent index fossils, but my observations were made only on exposures in Logan County (Ranges 53 and 54 West) where each exposure was divided into five-foot vertical intervals and the specimens were collected as a unit from each interval. While it is obvious that *Palaeolagus burkei* replaced *Palaeolagus haydeni* in the fauna at these exposures, so many factors affect observations of

6. The vertical range of these three zones is shown in Figure 9.

7. Numeral indicates number of specimens of species rare in northeastern Colorado.

8. Present in Horsetail Creek member.

9. Present in Vista member.

this kind that much more detailed work over a larger area, and a better understanding of the relationship of the unlaminated silts to the interfingering sandy silts and channel fills, would be required to make any generalization about the abruptness of this change in the *Palaeolagus* population in particular, and about its correlation with changes in the Cedar Creek fauna in general.

The beds of the upper part of the Cedar Creek member consist of fine massive silt, frequently cliff-forming, so that specimens are rare as float. Consequently, not enough of the fauna from the upper zone is known to show whether or not a faunal change took place that would be in keeping with the lithologic change. At present the only criterion of the upper zone is the fact that it is composed of massive silt.

This attempt to divide the Cedar Creek member and its fauna into three parts will have value for purposes of regional correlation if the fauna in each of these parts is the result of something more than local environmental or facies change. The lithologic and faunal separation of the lower and middle parts of the Cedar Creek is based on the change from a predominantly massive silt facies to a predominantly thin-bedded, sandy silt facies and on the change in the *Palaeolagus* population, that coincides, generally, with the level at which the sandy silt facies becomes widespread.[10] The separation of the middle and upper parts of the Cedar Creek member is based on the change from the sandy silt facies to the massive silt facies. I have already pointed out that specimens from the massive silt facies are rare and that it cannot be determined whether or not a distinctive faunal change took place. It is of interest to recall that Schultz & Stout (1938) pointed out that there was a hiatus in deposition between the Orella and Whitney members in northwestern Nebraska; and that Barbour & Stout (1939, pp. 30-31) stated: ". . . the recent collections of the University of Nebraska State Museum disclose that . . . [*Ischyromys pliacus* and *Diplolophus*] . . . are both probably good index fossils for the uppermost faunal level of the middle Oligocene in northwestern Nebraska." In this area of Logan County under discussion there is continuous deposition of beds from Orellan time into Whitneyan time; and the occurrence of *Ischyromys* specimens similar to *Ischyromys pliacus*, as

10. Whether or not change in the *Palaeolagus* population, similar to that in the Cedar Creek in northeastern Colorado, takes place in other middle Oligocene beds is not known.

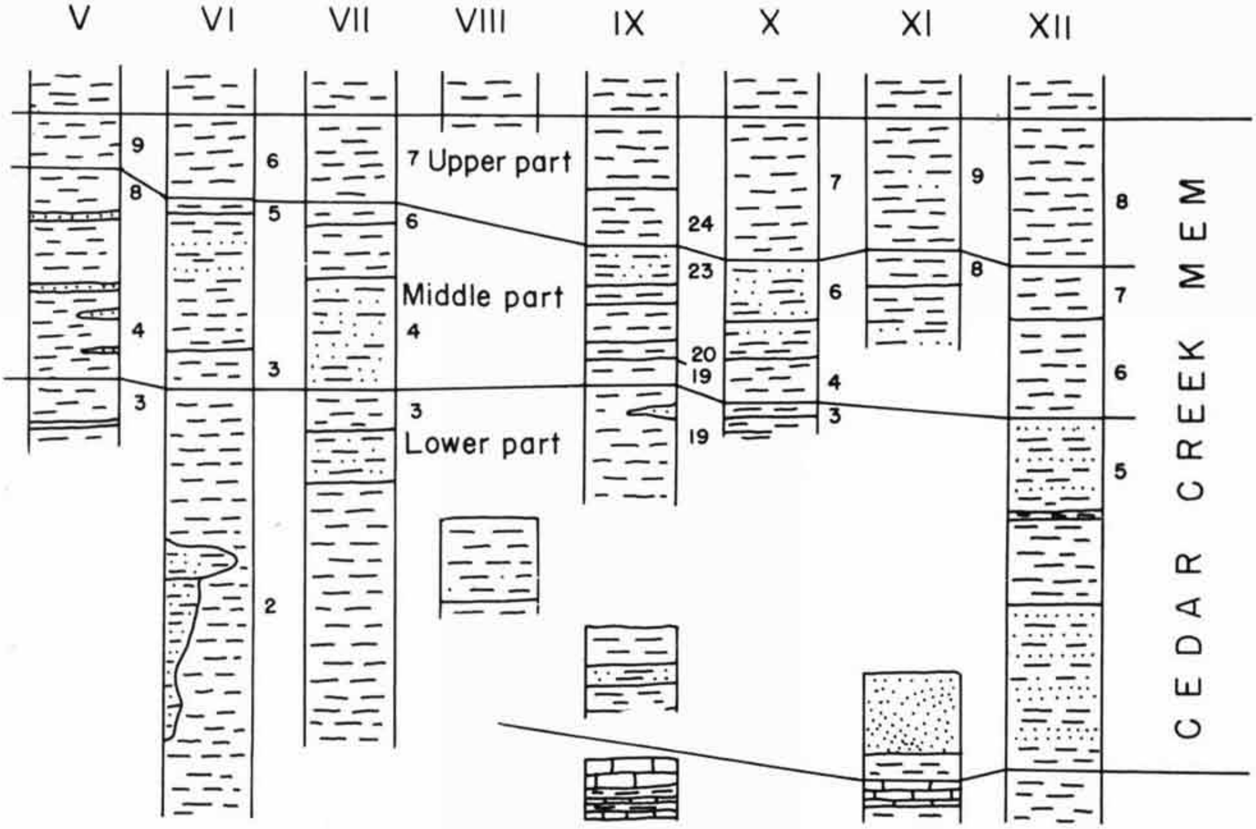


Figure 9.—Modified diagram of the columnar sections of Figure 6 showing the approximate vertical ranges of the lower, middle, and upper divisions of the Cedar Creek member.

well as the rare occurrence of *Diplolophus,* is at the top of the sandy silt phase. It may be that the period of deposition of the massive silt of the upper part of the Cedar Creek member corresponds to the erosional interval between the Orella and Whitney members in Nebraska.

VISTA FAUNA

The Vista fauna is scanty, and the fossils are individually rare. The fauna is significant, however, in that *Perchoerus* is the only genus present that is supposed to have been restricted to the vicinity of stream or river valleys. The absence of anthracotheres, entelodonts, *Subhyracodon,* and *Protoceras* further emphasizes the similarity of the Vista fauna to the "clay fauna" of MATTHEW (1901, p. 370), which he thought to be analogous with the fauna of the modern plains. This view is supported by the lithology of the Vista member.

Peratherium nr. *P. fugax*
Proscalops miocaenus
Palaeolagus intermedius
Palaeolagus burkei
Eumys brachyodus
Pseudocynodictis temnodon
Miohippus sp.
Hyracodon sp.
Leptochoerus spectabilis
Perchoerus nr. *P. nanus*
Eporeodon major
Leptauchenia decora
Protomeryx campester
Leptomeryx evansi
Hypisodus sp. (Form B)

FAUNAS OF THE PAWNEE CREEK FORMATION

The Pawnee Creek formation, a complex of flood plain accumulations and channel fills, covers a range of time from middle Miocene to late Miocene or possibly earliest Pliocene. The very nature of these deposits and their span of time make determination of the faunal zones and their correlation with other faunas a problem whose solution depends on a knowledge of many definitely identified and (stratigraphically) correctly placed fossils. Unfortunately, the Pawnee Creek formation is rich in species and poor in specimens with adequate morphologic and stratigraphic data. With exception of the Martin Canyon fauna, too few fossils have been found in the formation by me, and the published information and museum records are too inadequate or contradictory to satisfactorily establish the vertical and areal distribution of all the species. The complete answer can come only when, if ever, we have additional information concerning the earlier finds, when we have a surer means of identifying referred material, and when we have a better knowledge of the range of variation in the species — a knowledge gained by utilizing specimens from known localities and levels correlated with geological history. These additional data will then permit a re-evaluation of the species and a closer correlation of the faunas of northeastern Colorado with other faunas. The studies of mammalian groups, and their correlations, that have been made for other High Plains Miocene deposits do not appear adequate as yet to solve the problems found in northeastern Colorado. The University of Kansas Museum of Natural History is engaged currently in carrying out this phase of Tertiary research in northeastern Colorado.

COLBERT (in OSBORN, 1942, p. 1491) summarized the early work and opinions concerning the Pawnee Creek fauna made by MATTHEW and OSBORN thus:

> Dr. Matthew, in his first description of the Pawnee Creek beds of northeastern Colorado, recognized two fossiliferous layers or zones within the formation, but at that time he pointed out the fact that the separation between these zones, either stratigraphically or faunistically, was very inconstant, so he was inclined to regard the zoning of the Pawnee Creek beds as of little importance. Later, in 1909, in 1918, and in 1924, he regarded the Pawnee Creek formation as a unit containing a single fauna.
>
> Professor Osborn, however, held to the view that the Pawnee Creek formation consists of two levels, which he designated as "A" and "B," for the lower and upper divisions respectively. This view was expressed in 1918, in the monograph on the Tertiary Equidae of North America, . . .

In what was the first detailed study of the Miocene fossils of northeastern Colorado as a faunal unit, MATTHEW (1901) tried to divide the Pawnee Creek beds into what he called "horizon D" and "horizon E." An evaluation of MATTHEW's field notes, of museum records of specimens, and of my own observations on the Pawnee Creek formation shows that beds Nos. 4-6 of measured section II in this paper, 6-12 in section III, 2-6 in section IV, 11-12 in section V, 4 in section XV, and 7 in section XVI probably correspond to MATTHEW's description of "horizon D" (1901, p. 358, last paragraph). All the beds above this level, including the Ogallala formation, seem to correspond to "horizon E" (1901, p. 359, first paragraph). "Protolabis beds," a term used by MATTHEW, seems to refer to all or part of "horizon D." That MATTHEW considered the stratigraphic sequence west of Sand Canyon to be equivalent to the sequence at Martin Canyon seems substantiated by the faunal lists for "horizon D" and "horizon E" which show that the collections from these two localities were listed together. I am rather confident that MATTHEW got the idea of two faunal zones from fossils collected at Sand Canyon and Martin Canyon, and the idea that the zones could be separated stratigraphically from observation of the deposits at Martin Canyon. To realize fully why MATTHEW abandoned the concept of faunal zones, one must understand that "horizon D" at Martin Canyon is Hemingfordian in age and that "horizon E" is younger—including beds of latest Barstovian and ?late Hemphillian age (Fig. 8). On the other hand, although there may be Hemingfordian exposures in the Sand Canyon area, the beds, which I think MATTHEW correlated with "horizon D" of Martin Canyon, are middle to late Barstovian in age. "Horizon E" at Sand Canyon was even younger—the part in the Pawnee Creek formation being latest Barstovian, with possibly a Miocene-Pliocene transitional stage or earliest Pliocene. This confusion was compounded by the fact that the Pawnee Creek beds at Pawnee Buttes, which MATTHEW thought had a homogeneous fauna, contain species found in each of the local faunas described in this paper. The initial error in correlating the Hemingfordian fauna at Martin Canyon with the late Barstovian fauna at Sand Canyon and the close relationship between the faunal zones in the Barstovian deposits inevitably led to a union of the fossils as one fauna.

Oddly enough, the beds that prompted MATTHEW to give up zoning the Pawnee Creek formation contained the faunas that suggested two zones to OSBORN. To OSBORN, the "typical" Pawnee Creek fauna was represented by the *Merychippus paniensis* zone (Eubanks local fauna of this paper and at least some of the species in the Kennesaw local fauna). The "Upper Pawnee Creek" or Sand Canyon fauna was represented by fossils considered to be Pliocene in age and included at least part of the fauna of MATTHEW's "horizon E" at Sand Canyon. MATTHEW continued, as stated by COLBERT, to regard the all inclusive Pawnee Creek fauna as homogeneous. In his comparison of the Pawnee Creek fauna with the lower Snake Creek fauna [11] (1924, p. 72), he specifically referred to the fossils that are now regarded as older or younger than the fauna of the *Merychippus paniensis* zone at Snake Creek but concluded that "The differences between the two faunas are probably only facies, due to some environmental difference, geographic range, or selective action of different conditions of sedimentation." Although it has not always appeared so in print, most workers, other than MATTHEW, thought that all of the Hemingfordian fossils, especially *Merycochoerus proprius magnus*, from northeastern Colorado came from the "upper Martin Canyon beds," and not the Pawnee Creek beds. COLBERT (1943, p. 303) was of the opinion that the specimens of *Merychyus elegans* from Martin Canyon had been assigned the wrong age and concluded that they were obtained from the Martin Canyon beds of lower Miocene age, thus removing them from the Pawnee Creek fauna. Less specific doubt concerning the homogeneity of the Pawnee Creek fauna is expressed by COOK (1926, p. 29), FRICK (1937, p. 7), and H. E. WOOD, *et al.* (1941).

Considering that the Pawnee Creek formation is made up of a series of flood plain deposits and channel fills, covering a span of time from middle through late Miocene or early Pliocene, it is not difficult to postulate a series of faunas, or faunules, in the successive flood plain and channel accumulations. COOK (1926, p. 29) and FRICK (1937, p. 7) have expressed more or less the same view of the post-Oligocene deposits and faunas in this area. How these faunas are to be grouped is a problem dependent upon the geological history of the area, the range in time of the species, and the results of facies differences. The following tentative faunal zonation of the Pawnee Creek formation is presented as a working hypothesis.

Sand Canyon local fauna		Pawnee Creek fauna of MATTHEW
Vim-Peetz local fauna [12]	Pawnee Creek fauna of authors	
Kennesaw local fauna [13]		
Eubanks local fauna [14]		
Martin Canyon local fauna		

Based on the known fossils this represents five faunal divisions that may exist in the Pawnee Creek formation. It is theoretically possible that a typical Sheep Creek faunal stage is present. Neither the Kimball member of the Ogallala of ?late Hemphillian age nor the ?Arikareean deposits in northern Weld County have yielded a fauna that can be assigned to a definite age.

Evolutionary changes preclude these faunas from being different facies of the same age. On the other hand, the overlap of the vertical ranges of the species, or the close relationship of species at different levels, does not allow much time difference between the faunas.

MARTIN CANYON LOCAL FAUNA

The beds at Martin Canyon were divided by MATTHEW into three parts—"horizons C, D, and E." The Miocene part of "horizon C" (the upper part of MATTHEW's Martin Canyon beds) contains the well-known American Museum Merycochoerus Quarry. The faunule of this quarry, including a camelid found at this level by me and the fossils from "horizon D" are considered to be the Martin Canyon local fauna. The following species are known to occur in this local fauna, which was collected in the University of Kansas Quarry A and from beds containing the quarry.

Brachyerix sp.
Soricid sp.
Talpid sp.
Oreolagus nr. *O. nebrascensis*
Mesogaulus paniensis
Sciurus sp.
Sciurid sp.
Proheteromys sp.
Monosaulax nr. *M. curtus*
Plesiosminthus? clivosus n. sp.
Tomarctus sp.
Phlaocyon leucosteus
Parahippus pawniensis
?*Merychippus* sp.
?*Macrotherium matthewi* [15]

11. Throughout this paper the term "lower Snake Creek" refers to the fauna that MATTHEW associated with *Merychippus paniensis*. See MATTHEW (1924) and ELIAS (1942).

12. Named for Vim Postoffice and the village of Peetz, Logan County.
I am indebted to Mr. J. N. MINICK and Dr. P. O. MCGREW of the University of Wyoming for information on the lithologic pecularities of the post-Oligocene beds in northeastern Colorado which made it possible for me readily to distinguish the beds containing the Vim-Peetz local fauna.

13. Named for Kennesaw Valley, an area in northwestern Logan County bordering prominent exposures that carry the fauna.

14. Named for Eubanks Ranch at Pawnee Buttes.

15. For reasons discussed in the systematic account of each species, this species must be assigned tentatively to this fauna until better and more reliable discoveries are made.

Aphelops profectus
Tayassuid sp.
Merycochoerus proprius magnus
Merychyus elegans
Camelid sp.
Blastomeryx cf. *B. elegans*
Blastomeryx cf. *B. medius*

MATTHEW, as has been previously stated, considered the upper part of "horizon C" (upper part of the "Martin Canyon" beds) to be of lower Miocene age and "horizon D" as part of the Pawnee Creek beds, with its fauna showing only a facies difference from that of the lower Snake Creek fauna. Subsequently, specimens from "horizon D" that appeared too old to be included in the Pawnee Creek fauna have been ignored or considered to be from the "Martin Canyon" beds. SCHULTZ & FALKENBACH (1947, pp. 202-203) have presented the most recent opinion on the age of the "upper Martin Canyon beds" stating:

> The type section of the "Martin Canyon" of Matthew . . . was also visited by Falkenbach and later by Schultz. The exact location from which the skeletons . . . of *Merycochoerus proprius magnus* (Loomis) were collected was also determined. Although some of the sediments in the Martin Canyon area have a typical White River appearance, a part of the section appears to be equivalent to the Marsland of Nebraska because of the similarity in mammalian forms and certain lithologic characteristics.

It has been mentioned before that the beds in Martin Canyon containing the skeletons of *M. p. magnus* are the beds that have an appearance typical of the White River, and above these beds are nodular silts or "horizon D" (which MATTHEW called Pawnee Creek) that also contain remains of *M. p. magnus*. Although SCHULTZ and FALKENBACH do not specifically refer the beds above the American Museum quarry to the Marsland, as long as these authors restrict *Merycochoerus* to the Marsland formation, presumably they consider any fauna containing this genus to be older than the Sheep Creek fauna. Exclusive of *Merycochoerus* and *Merychyus*, the age of the Martin Canyon local fauna can only be arrived at by a consideration of a small part of the known fauna. *Phlaocyon leucosteus*, which MCGREW (1941, p. 34) considered more primitive than *Phlaocyon marslandensis* of the Marsland of Nebraska, would support a Marsland (or earlier) age determination. Suggestive evidence, but certainly not conclusive, is seen in the similarity of the *Plesiosminthus* specimen to the lower Miocene species in Europe. The general similarity of the teeth of *Proheteromys* to those of *Proheteromys floridanus* of the Hawthorn of Florida indicates an early middle Miocene age. That *Aphelops profectus* may be more primitive than *A. megalodus* is possible, and if *A. megalodus* is present in the Sheep Creek fauna, then this possibility might be indicative of an earlier age for the Martin Canyon beds. *Oreolagus* nr. *O. nebrascensis* cannot be safely used to indicate a correlation with the Marsland beds, since the species, or something as near *O. nebrascensis* as the Martin Canyon specimens, has been found in lower Snake Creek equivalent beds in southeast Fremont County, Wyoming. The talpid tooth from Martin Canyon is also similar to a talpid tooth obtained by me from the same beds in Fremont County. *Mesogaulus paniensis* has been reported from the lower Snake Creek fauna, but COOK & COOK (1933, p. 49) question its occurrence in the *Merychippus paniensis* zone of that fauna. The near identity of the *Monosaulax* teeth from Martin Canyon to those from the Eubanks local fauna is suggestive of an age closer to the lower Snake Creek fauna than is indicated by the species of "Marsland age," although the exact relationship of these specimens to *Monosaulax curtus* must be determined by more material. When enough specimens of *Parahippus pawniensis* and *Parahippus coloradensis* with accurate stratigraphic records are known, it may be possible to determine the relationship of these two species, if they are distinct, and the bearing of this relationship on the correlation of the beds in the Pawnee Creek formation. Until a revision of *Blastomeryx* is made, complete with localities, measured sections, and associated faunas, the genus offers nothing that is useful for correlation. The present identification of our cervid material suggests lower Snake Creek and Sheep Creek affinities for the Martin Canyon local fauna. The remaining specimens of the fauna cannot be utilized in any satisfactory manner. The fauna, as a whole, suggests the close relationship of the Marsland, Sheep Creek, and lower Snake Creek faunas—perhaps a closer relationship than is recognized at present.

The Martin Canyon local fauna and the beds that contain the fauna cannot be easily recognized at localities too distant from Martin Canyon. This is primarily owing to the lack of specimens. Enough material was found at Lewis Canyon, which is not far distant from Martin Canyon, to establish the age of the immediately overlying post-Oligocene beds. Also, the beds show a distinct lithologic similarity to the beds at Martin Canyon. In the Sand Canyon area, which is west of Martin Canyon, not a single fossil of Hemingfordian age has been found; and while some similarity is found between the two areas in the sequence of silts and cobble at the base of the Pawnee Creek formation, the evidence is not conclusive for pronouncing Hemingfordian beds to be either present or absent. At Pawnee Buttes the lithologic dissimilarity is greater, but fossils are present that suggest an age near that of the Martin Canyon local fauna for some of the beds in the area. On this subject SCHULTZ & FALKENBACH (1947, pp. 202-203) state:

> The writers noted the presence of 5 to 10 feet of massive brown sand at the base of the Ogallala (Pliocene) deposits in some instances. These basal deposits may be Miocene in age and may represent a remnant of Marsland (or "Martin Canyon," in part). No identifiable fossils were collected

from this basal horizon but the lithology was very suggestive of the Marsland formation in Nebraska, even to the type of sand crystals which were present.

The presence of *Mesogaulus paniensis* and *Merychyus elegans* in this area suggests a Martin Canyon equivalent. American Museum records suggest the possibility that *Merychyus elegans* came from the lower level mentioned by SCHULTZ & FALKENBACH, and these authors imply that such was the case.

PAWNEE CREEK FAUNA OF AUTHORS

The establishment of the Martin Canyon and Sand Canyon local faunas has revised, to some extent, MATTHEW's concept of the Pawnee Creek fauna. By 1941 (H. E. WOOD, *et al.*) the general concept of the Pawnee Creek fauna included, for the most part, only fossils of Barstovian age. While WOOD, *et al.* placed the Pawnee Creek beds in the early Barstovian stage, their comments on the relationship of the Pawnee Creek beds and the Ogallala formation (p. 28) suggest that they were aware of certain elements in the fauna that did not fit into this time category. Nevertheless, there is no evidence that at anytime these authors, or SIMPSON (1933), or STIRTON (1936), ever included the whole late Barstovian fauna in the Sand Canyon fauna. Therefore, it is my opinion that the Eubanks, Kennesaw, and Vim-Peetz local faunas make up, essentially, the Pawnee Creek fauna of these authors. This fauna is composed of the following reported forms:

Brachyerix sp.
Cf. *Condylura*
Hypolagus sp.
Ceratogaulus rhinocerus
Mylagaulus laevis
Proheteromys sp.
Peridiomys sp.
Monosaulax curtus
Amblycastor? sp.
Tomarctus brevirostris
Leptocyon vafer
Euoplocyon sp.
Amphicyon sinapius
Amphicyon reinheimeri
Cynarctus saxatilis
(?)*Ursavus pawniensis*
Plionictis ogygia
Plionictis parviloba
Leptarctus primus
Pseudaelurus intrepidus
Pseudaelurus marshi
Serridentinus proavus
Serridentinus productus
Rhynchotherium rectidens
Mammut merriami
Parahippus coloradensis [16]
Hypohippus osborni
Merychippus paniensis
Merychippus sejunctus
Merychippus sphenodus
Merychippus republicanus
Merychippus labrosus
Merychippus proparvulus
Merychippus eoplacidus
Merychippus eohipparion
Merychippus proplacidus
Merychippus campestris
Merychippus sp. (Advanced protohippine)
Calippus sp.
?*Macrotherium matthewi* [17]
Tapiravus? sp.
Aphelops megalodus
Teleoceras medicornutus
Ustatochoerus medius
Ustatochoerus? schrammi
Protolabis fissidens
Protolabis heterodontus
Protolabis angustidens
Protolabis longiceps
Alticamelus leptocolon
Alticamelus giraffinus
Blastomeryx gemmifer
Barbouromeryx pawniensis
Dromomeryx pawniensis
Cranioceras pawniensis
Merycodus furcatus
Meryceros warreni
Meryceros minor
Ramoceros osborni

If the Pawnee Creek fauna is a homogeneous unit, there cannot be much question about its age or its correlation with the *Merychippus paniensis* fauna at Snake Creek, or roughly, with the Sucker Creek, Skull Spring, Beatty Buttes, Virgin Valley, and Mascall faunas from more western areas. Seventeen of the species show a specific correlation with the lower Snake Creek fauna, and 11 have a close relationship with all the faunas listed above. This is a remarkably close agreement, considering that no doubt some of the species listed above are not correctly identified and others possibly do not even belong in the fauna.

Seemingly against any division is the fact that the Columbia Plateau and Great Basin faunas cited above contain about equal numbers of species closely related to each of the divisions suggested for the Pawnee Creek fauna. A similar comparison could be made with the fauna of the *Merychippus paniensis* zone at Snake Creek, but it is probable that this collection is too unreliable for such purposes. The possibility that the Columbia Plateau and Great Basin faunas may represent intermediate stages, with small differences in the species, is avoiding the fact that subdivision is not practical if it takes a specialist working with a mass of data to detect these small differences. Nevertheless, evolution, migration, and interruptions in the deposition of the sediments are real phenomena, and eventually enough associated fossils may be found to give a picture of the changing faunal populations during the late Miocene.

EUBANKS, KENNESAW, AND VIM-PEETZ LOCAL FAUNAS

The division of the Pawnee Creek fauna into three local faunas — the Eubanks, Kennesaw, and Vim-Peetz local faunas—is suggested by differences in the composition of the three faunas.

16. Type probably from Martin Canyon local fauna. *Parahippus* from Eubanks local fauna not yet demonstrated to be *Parahippus coloradensis.*

17. See Martin Canyon local fauna.

The Eubanks local fauna is characterized by the presence of *Parahippus* and *Merychippus paniensis*. At present the fauna must be based on specimens collected from the Pawnee Buttes ash layer and the beds immediately above and below it at the type locality of the Pawnee Creek formation. Several species have been added to the faunal list as probable associates of *M. paniensis* and *Parahippus*, but only future collecting, with careful attention to stratigraphic relationships, will reveal further characteristics of the composition and vertical range of the fauna. The known and supposed members of the Eubanks local fauna are:

Occurrence certain [18]
- *Monosaulax curtus*
- *Parahippus* sp. (Possibly *P. coloradensis*)
- *Merychippus paniensis*
- *Merychippus sejunctus*
- *Aphelops* sp.
- *Ustatochoerus* sp.
- *Protolabis* sp. (Probably *P. heterodontus* and/or *P. angustidens*)

Occurrence probable
- *Amblycastor?* sp.
- *Tomarctus brevirostris*
- *Amphicyon sinapius*
- Proboscidea
- *Aphelops megalodus*
- *Ustatochoerus? schrammi*
- *Cranioceras pawniensis*

The Kennesaw local fauna is characterized by the presence of a more advanced species of *Merychippus, Merychippus sphenodus*, and the observed absence of *Parahippus*, which distinguishes this fauna from the Eubanks local fauna. Differences between the Kennesaw local fauna and the Vim-Peetz local fauna will be emphasized in the discussion of the latter fauna. Probably several species, other than horses, would characterize the Kennesaw fauna equally well. The fauna is based on collections made near Sand Canyon from beds Nos. 4-6 of measured section II or their equivalents to the east and west. The known and supposed members of the Kennesaw local fauna are:

Occurrence certain	
Brachyerix sp.	*Leptarctus primus*
Cf. *Condylura*	Proboscidea
Mylagaulus laevis	*Merychippus sphenodus*
Proheteromys sp.	*Calippus* sp.
Peridiomys sp.	Rhinocerotids
Leptocyon vafer	*Ustatochoerus medius*
Plionictis ogygia	*Protolabis longiceps*
Occurrence probable	
Ceratogaulus rhinocerus	*Alticamelus leptocolon*
Euoplocyon sp.	*Dromomeryx pawniensis*
Amphicyon reinheimeri	*Meryceros warreni*
Cynarctus saxatilis	*Meryceros minor*
Hypohippus osborni	

18. In this list, and those given for the Kennesaw and Vim-Peetz local faunas, the occurrences listed as certain mean that I am personally satisfied that the species occur at that level. Those species listed as probably occurring at one or the other levels are based upon less reliable information.

The Vim-Peetz local fauna is characterized by the presence of advanced protohippine and merychippine horses whose stage of evolution has reached the point where the occlusal patterns of the cheek teeth are closely similar to those of Clarendonian horses, but still retain the short, curved crowns of typical *Merychippus*. Another difference between this fauna and the Kennesaw fauna is the presence of cement on the deciduous teeth of the horses of the Vim-Peetz local fauna. The fauna is based on collections made in the area west of Sand Canyon from deposits (lower part of MATTHEW's "horizon E") which immediately overlie the beds containing the Kennesaw local fauna, and from the part of MATTHEW's "horizon E" at Martin Canyon that underlies the Ogallala formation. This fauna probably has more species in common with the Kennesaw local fauna than is recognized at present, but its relationship may be equally close to the Sand Canyon local fauna. The fauna which MATTHEW (1901, p. 359) listed for "horizon E" is a combination of species from the Martin Canyon, Kennesaw, and Vim-Peetz local faunas. Several species suggest that this is the level that OSBORN had in mind when he made the Sand Canyon fauna (OSBORN, 1918, p. 19). The name Sand Canyon, however, has become so firmly associated with *Neohipparion coloradense* and a typical Clarendonian fauna that it seems best not to use the name Sand Canyon for this level. The known and supposed members of the Vim-Peetz local fauna are:

Occurrence certain
- Cf. *Condylura*
- *Hypolagus* sp.
- *Mylagaulus* sp.
- *Tomarctus* sp.
- *Plionictis ogygia*
- Proboscidea
- *Merychippus republicanus*
- *Merychippus* sp. (Advanced protohippine)
- *Aphelops* sp.
- *Teleoceras* sp.
- *Ustatochoerus medius*
- *Alticamelus giraffinus*
- *Ramoceros osborni*

Occurrence probable
- *Pseudaelurus intrepidus*
- *Merychippus proplacidus*
- *Merychippus campestris*
- *Teleoceras medicornutus*

Unaccounted for in these three faunas are several species that have been assigned to the Pawnee Creek fauna. These present individual problems, the solution of which depends on the discovery of more material with accurate stratigraphic data.

SAND CANYON LOCAL FAUNA

Subsequent to MATTHEW's work, OSBORN (1918, p. 19) thought that the faunal evidence indicated, in addition to the "typical Pawnee Creek beds," an "Upper Pawnee Creek" horizon ("Pawnee Creek B" or "Protohippus-Hipparion zone") at Sand Canyon, Logan County, and at a place 10 miles west[19] of Grover, Weld County. He generally considered this hypothetical faunal stage to be of Pliocene age, although he vacillated on this point, sometimes referring to the age as late Miocene or Mio-Pliocene transition. H. E. WOOD, *et al.* (1941) used the name "Sand Canyon local fauna" for this stage and indicated that the age was questionable. The fauna consists of:

Neohipparion coloradense
Merychippus proplacidus
Pliohippus sp.
Serridentinus spp.
Rhinocerotid spp.

Of the species listed above, only *Neohipparion coloradense*, reported as coming from Sand Canyon, needs serious consideration. The rhinocerotid and serridentine specimens have been referred to known species, but much better material is needed to determine whether their real relationship lies with Barstovian or Clarendonian species. *Pliohippus* sp. may be referable to *Merychippus campestris* or *Merychippus perditus*. *Merychippus proplacidus*, reported in association with *Neohipparion coloradense*, has been referred questionably to the Pawnee Creek fauna (as defined in this paper) by STIRTON (1940, p. 182).

The stratigraphic position of *Neohipparion coloradense* is critical for the Sand Canyon problem. This species has been regarded as Clarendonian in age and comparable (or nearly so) with *Neohipparion* populations in unquestioned Clarendonian faunas (HESSE, 1936, p. 62; MCGREW, 1938, p. 317). However, no collecting party from the University of Kansas has ever found fossils referable to *N. coloradense*, or for that matter a fauna comparable with the fauna at the Burge locality or the one at the Laverne locality. CURTIS HESSE (personal communication to R. W. WILSON) not only failed to find a Clarendonian fauna at Sand Canyon, but finally came to doubt the correctness of the locality given for the type of *N. coloradense*.

It remains to be demonstrated whether or not a large series of specimens of *Neohipparion coloradense* from northeastern Colorado would be strictly equivalent to a large series from one or the other of the Clarendonian deposits cited by HESSE and MCGREW. Even if the population of *N. coloradense* in northeastern Colorado is more primitive than either the Burge or Laverne populations, there still would seem to be too great a difference ever to allow the association of the topotype population of *N. coloradense* with the closest related horse found in the area—that referred to *Merychippus republicanus*.

The Sand Canyon local fauna probably did not exist as OSBORN pictured it, and it is clear that there is no definite Sand Canyon fauna (*i. e.*, *Neohipparion coloradense* with an associated Clarendonian fauna) known which may be associated with any particular beds of the Pawnee Creek formation.

19. Catalogue records of the American Museum of Natural History suggest that OSBORN meant northeast of Grover. This possibility is supported by the fact that there are no post-Oligocene beds 10 miles west of Grover. On the other hand, OSBORN's map (1918, p. 19, fig. 10a) suggests that he could have had in mind exposures 20 to 30 miles northwest and west of Grover.

SUMMARY OF CORRELATION OF THE POST-OLIGOCENE BEDS AND FAUNAS

Figure 10 shows, diagrammatically, the history of attempted correlations of the Tertiary beds and faunas known in northeastern Colorado.

So far as I know, MATTHEW never commented upon the Sand Canyon fauna postulated by OSBORN and, presumably, more or less held to the views expressed in 1901. Nor did MATTHEW ever consider the Pawnee Creek beds and fauna to extend upward to correlate with the Niobrara River local fauna where I have placed the Vim-Peetz local fauna.

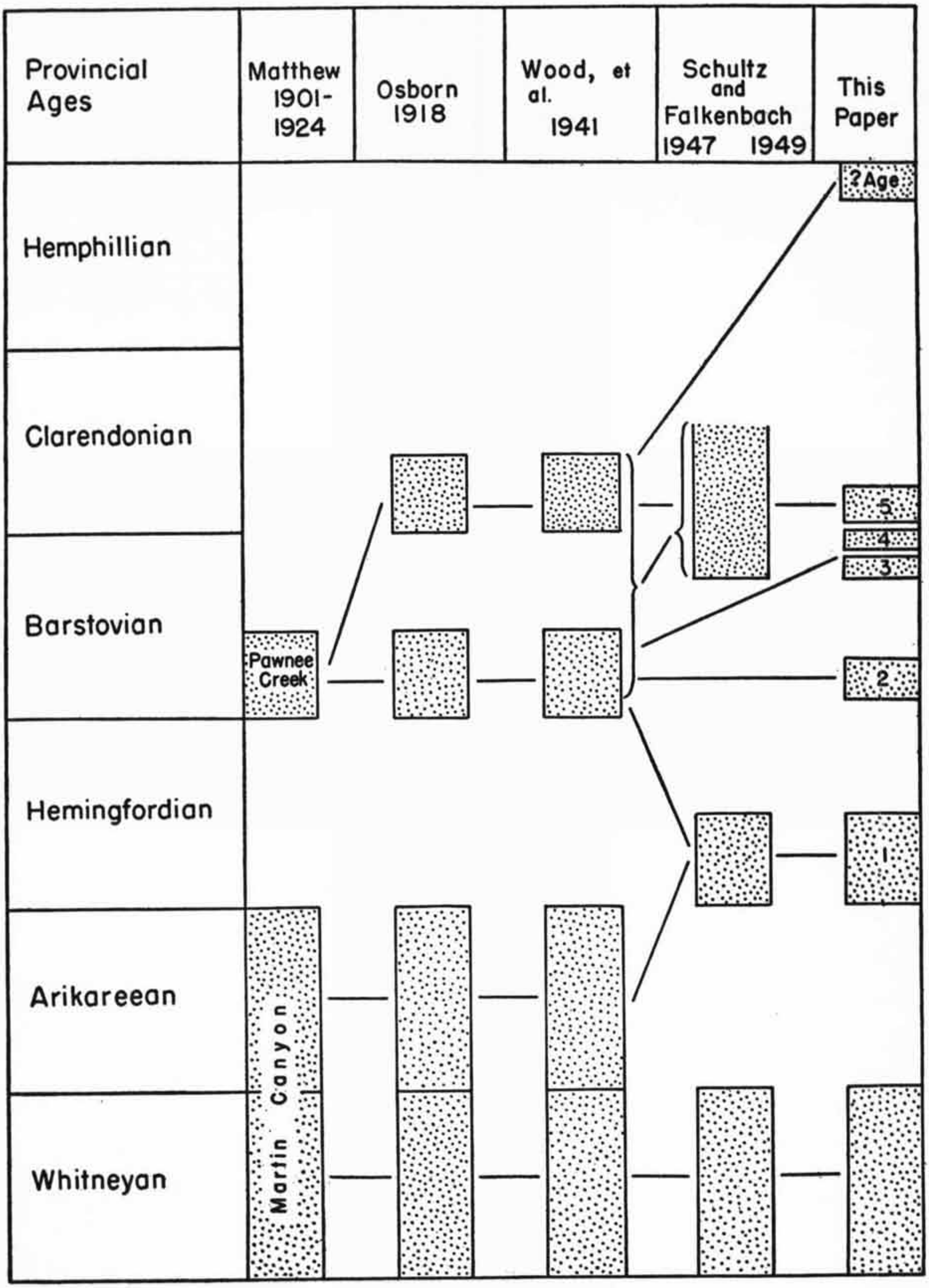
After MATTHEW and OSBORN there was no definite change of opinion concerning the beds, but WOOD, *et al.* (1941) did express the view of vertebrate paleontologists that certain problems of stratigraphy and correlation needed reinvestigation.

A radical departure from earlier opinion was expressed by SCHULTZ & FALKENBACH (1947). It should be kept in mind that while SCHULTZ & FALKENBACH called the post-Hemingfordian beds (including, seemingly, those bearing *Merychippus paniensis*) Pliocene in age, these authors consider the Pliocene (and Ogallala formation) to extend downward to include upper Barstovian beds.

My opinion of the stratigraphic and faunal sequence does not differ greatly from earlier views. The correlation of the Martin Canyon local fauna with the Marsland and Hawthorn (or younger than the Hawthorn and older than the Sheep Creek) seems valid. The Eubanks local fauna occupies the same place in the time scale, early Barstovian, as was held by the Pawnee Creek fauna of authors. The Kennesaw local fauna is considered to be older than, but near to, the Niobrara River local fauna in age. The Vim-Peetz local fauna is probably equivalent to the Niobrara River local fauna in age, and the hypothetical Sand Canyon local fauna must be considered as early Clarendonian on the basis of *Neohipparion coloradense*.

In Figures 8 and 10 I have shown beds of questionable late Hemphillian age. In both figures the beds referred to are those at the top of the valley wall, and not the Kimball exposure cited by LUGN (see part on Ogallala formation in this paper).

FIGURE 10.—Comparative views of correlation of the post-Oligocene beds in northeastern Colorado with the provincial ages. Level of occurrence of: (*1*) Martin Canyon local fauna; (*2*) Eubanks local fauna; (*3*) Kennesaw local fauna; (*4*) Vim-Peetz local fauna; and (*5*) Sand Canyon local fauna.


Provincial Ages
Matthew 1901-1924
Osborn 1918
Wood, et al. 1941
Schultz and Falkenbach 1947 1949
This Paper
?Age
Hemphillian
Clarendonian
Barstovian
Hemingfordian
Arikareean
Whitneyan
Pawnee Creek
Martin Canyon
5
4
3
2
1

SYSTEMATIC PALEONTOLOGY

The account of the species and specimens is presented in three parts — the Oligocene faunas, the Miocene faunas, and the Pliocene fauna.

For each species the type is cited if from northeastern Colorado, and the geological ages and localities of the type specimens are those of the describer unless otherwise stated.

For the referred specimens collected by me, the geological ages given are as determined and indicated in the section on geology and stratigraphy in this paper. Other referred specimens carry the locality and level cited by the author reporting the specimen unless there is positive evidence for modifying the data. All localities are in Colorado unless otherwise indicated.

Catalogue numbers without institution names apply to the Vertebrate Paleontological Collection of the Museum of Natural History, University of Kansas, Lawrence, unless otherwise stated. American Museum of Natural History specimens are referred to by the initials AMNH or F:AM.

Although I have studied primarily the mammals, the known occurrences of other groups are included. The taxonomic arrangement above the rank of species is that of CAMP, WELLES, & GREEN (1949) for the Amphibia and Reptilia; WETMORE (1940) for the Aves; and SIMPSON (1945) for the Mammalia. In most cases the authorities for the use of taxonomic names above the rank of genus are HAY (1930) and SIMPSON (1945).

THE OLIGOCENE FAUNA

CLASS **AMPHIBIA**

Fragmentary bones of frogs, and possibly also those of salamanders, have been found with the remains of small lizards and mammals in the concentrated microfaunas of the Cedar Creek member in western Logan County.

CLASS **REPTILIA**

ORDER **TESTUDINES** BATSCH, 1788

FAMILY **TESTUDINIDAE** GRAY, 1825

Testudo ligonia COPE

Testudo ligonius COPE, 1873a, p. 6.

Type.—AMNH No. 1148.

Testudo amphithorax COPE

Testudo amphithorax COPE, 1873a, p. 6.

Type.—AMNH No. 1145.

Testudo quadrata COPE

Testudo quadratus COPE, 1884a, p. 764.

Type.—AMNH No. 1149.

Testudo cultrata COPE

Testudo cultratus COPE, 1873a, p. 6.

Type.—Cannot be found.

Gopherus laticunea (COPE)

Testudo laticuneus COPE, 1873a, p. 6.
Gopherus laticunea, WILLIAMS, 1950, p. 25.

Type.—AMNH No. 1160.

HAY at first (1908) stated that these types were obtained from the Oreodon beds at the head of Horsetail Creek, northeastern Colorado, but later (HAY, 1930) he gave the stratigraphic position as Chadron Oligocene. As has already been pointed out, the position of this stream is in doubt, but if the present Horsetail Creek was the one referred to by COPE, it is probable that the age of the beds is Chadronian. There are several sizes of turtles referable to *Testudo* (*s. l.*) present in the Chadronian beds, where they are fairly common, and a few may be found in the Orellan beds.

WILLIAMS (1950, p. 29) considers the types of *Testudo quadrata* and *T. cultrata* too indeterminate to be "defined, synonymized, or allocated."

FAMILY **EMYDIDAE** GRAY, 1825

Stylemys nebrascensis LEIDY

Stylemys nebrascensis LEIDY, 1851, p. 173.

Referred specimen. — Cedar Creek member (middle): No. 8239; carapace and plastron; S½ sec. 21, T. 11 N., R. 53 W., Logan County.

This species of turtle is the common form found in the Orellan beds. Poorly preserved specimens indicate that perhaps this genus existed into Whitneyan time.

ORDER **SAURIA** MACARTNEY, 1802

In the following list I have cited GILMORE (1928) as the authority for the horizon and level for all the species described by COPE. However, there is no evidence that COPE collected from any localities in Logan County during his 1873 field season. All of COPE's specimens probably came from Weld County.

FAMILY **IGUANIDAE** GRAY, 1827

Exostinus serratus COPE

Exostinus serratus COPE, 1873c, p. 16.

Type.—AMNH No. 1608; Oreodon beds, White River formation, Cedar Creek, Logan County, Colorado (*fide* GILMORE, 1928).

Aciprion formosum COPE

Aciprion formosum COPE, 1873c, p. 17.

Type.—AMNH No. 1609; Oreodon beds, White River formation, Cedar Creek, Logan County, Colorado (*fide* GILMORE, 1928).

Aciprion majus GILMORE

Aciprion majus GILMORE, 1928, p. 20.

Type.—Princeton Univ. Mus. No. 10015; Oreodon beds?, White River formation, Chalk Bluffs, Logan County, Colorado.

FAMILY AMPHISBAENIDAE GRAY, 1825

Rhineura coloradoensis (COPE)

Platyrhachis coloradoensis COPE, 1873c, p. 19.
Rhineura coloradoensis, GILMORE, 1928, p. 42.

Type.—AMNH No. 1607; Horsetail Creek beds, White River formation, Horsetail Creek, Logan County, Colorado (*fide* GILMORE, 1928).

Rhineura hibbardi TAYLOR

Rhineura hibbardi TAYLOR, 1951, p. 539.

Type.—Univ. Michigan Mus. Paleont. No. 25431; Cedar Creek member, White River formation, center W½ sec. 7, T. 11 N., R. 53 W., Logan County, Colorado.

Rhineura amblyceps TAYLOR

Rhineura amblyceps TAYLOR, 1951, p. 543.

Type.—Vert. Paleont. Coll., Univ. Kansas Mus. Nat. Hist. No. 7649; Cedar Creek member, White River formation, W½ sec. 7, T. 11 N., R. 53 W., Logan County, Colorado.

Rhineura wilsoni TAYLOR

Rhineura wilsoni TAYLOR, 1951, p. 548.

Type.—Vert. Paleont. Coll., Univ. Kansas Mus. Nat. Hist. No. 7651; Cedar Creek member, White River formation, W½ sec. 7, T. 11 N., R. 53 W., Logan County, Colorado.

Rhineura hatcherii BAUR

Rhineura hatcherii BAUR, 1893, p. 998.

TAYLOR (1951, p. 551) has referred specimens from the Cedar Creek member in Logan County to this species.

FAMILY HYPORHINIDAE BAUR, 1893

Hyporhina galbreathi TAYLOR

Hyporhina galbreathi TAYLOR, 1951, p. 532.

Type.—Vert. Paleont. Coll., Univ. Kansas Mus. Nat. Hist. No. 8221; Cedar Creek member, White River formation, SW¼ sec. 12, T. 11 N., R. 54 W., Logan County, Colorado.

FAMILY HELODERMIDAE GRAY, 1837

Heloderma matthewi GILMORE

Heloderma matthewi GILMORE, 1928, p. 89.

Type.—AMNH No. 990A; Oreodon zone, White River formation, Lewis Creek, Logan County, Colorado.

FAMILY ANGUIDAE BONAPARTE, 1831

Peltosaurus granulosus COPE

Peltosaurus granulosus COPE, 1873a, p. 5.

Type.—AMNH No. 1610; Cedar Creek beds, Oreodon zone, Cedar Creek, Logan County, Colorado (*fide* GILMORE, 1928).

Xestops pawneensis GILMORE

Xestops pawneensis GILMORE, 1928, p. 150.

Type.—Vert. Paleont. Coll., Univ. Kansas Mus. Nat. Hist. No. 1281; White River formation, sec. 28, T. 11 N., R. 53 W., Logan County, Colorado.

Glyptosaurus sp.

GILMORE (1928, p. 120) reported fragments referable to this genus from northeastern Colorado.

SAURIA, *incertae sedis*

Cremastosaurus carinicollis COPE

Cremastosaurus carinicollis COPE, 1873c, p. 18.

Type.—AMNH No. 1604; Oreodon zone, Logan County, Colorado (*fide* GILMORE, 1928).

Cremastosaurus rhambastes (COPE)

Platyrhachis rhambastes COPE, 1884a, p. 779.
Cremastosaurus rhambastes, GILMORE, 1928, p. 152.

Type.—AMNH No. 1606; Horsetail Creek beds (Titanotherium zone), White River formation, Oligocene, Horsetail Creek, Logan County, Colorado (*fide* GILMORE, 1928).

Cremastosaurus unipedalis (COPE)

Diacium unipedalis COPE, 1873c, p. 18.
Cremastosaurus unipedalis, COPE, 1874a, p. 516.

Type.—AMNH No. 1605; Horsetail Creek beds, Horsetail Creek, Logan County, Colorado (*fide* GILMORE, 1928).

Diacium quinquepedale COPE

Diacium quinquepedalis COPE, 1873c, p. 17.

Type.—AMNH No. 1602; White River formation, Logan County, Colorado (*fide* GILMORE, 1928).

ORDER SERPENTES LINNAEUS, 1758

FAMILY BOIDAE BONAPARTE, 1831

Calamagras murivorus COPE

Calamagras murivorus COPE, 1873c, p. 15.

Type.—AMNH No. 1603; Oreodon beds, Cedar Creek, northeastern Colorado (*fide* GILMORE, 1938).

Calamagras angulatus COPE

Calamagras angulatus COPE, 1873c, p. 16.

Type.—AMNH No. 1654; Oreodon beds, ?Cedar Creek, Colorado (*fide* GILMORE, 1938).

Calamagras talpivorus (COPE)

Aphelophis talpivorus COPE, 1873c, p. 16.
Calamagras talpivorus, GILMORE, 1938, p. 12.

Type.—AMNH No. 1598; Cedar Creek, northeastern Colorado (*fide* GILMORE, 1938).

FAMILY CROTALIDAE GRAY, 1825

Neurodromicus dorsalis COPE

Neurodromicus dorsalis COPE, 1873c, p. 15.

Type.—AMNH No. 1599; Oreodon beds, Cedar Creek, Pawnee Buttes, northeast Colorado (*fide* GILMORE, 1938).

Dr. E. H. TAYLOR, who is studying the amphibian and reptilian material collected by me, states that he has recognized a few snake vertebrae among the specimens collected from the Cedar Creek member in Logan County.

CLASS AVES

ORDER PELECANIFORMES SHARPE, 1891

FAMILY PHALACROCORACIDAE BONAPARTE, 1838

Phalacrocorax mediterraneus SHUFELDT

Phalacrocorax mediterraneus SHUFELDT, 1915, p. 58.

Type.—Yale Univ., Peabody Mus. Nat. Hist. No. 943; middle Oligocene (White River): Gerry's Ranch, northern Colorado.

From examination of old maps and from discussions held with "old timers" in Weld County, I think that Gerry's Ranch may have been in T. 11 N., R. 64 W., Weld County. In this area and in Ts. 11 and 12 N., Rs. 64, 65, and 66 W. are Oligocene exposures locally known, today and in the past, as Chalk Bluffs. Some of the exposures are Chadronian in age, whereas the remainder of the Oligocene beds are Orellan in age. No Whitneyan beds are recognized.

ORDER FALCONIFORMES SEEBOHM, 1890

FAMILY ACCIPITRIDAE SWAINSON, 1837

Buteo fluviaticus MILLER & SIBLEY

Buteo fluviaticus MILLER & SIBLEY, 1942, p. 39.

Type.—Univ. California Mus. Paleont. No. 36266; Univ. California Mus. Paleont. locality V-3743, Chalk Bluffs, Oreodon beds, Roy Elum Ranch on Owl Creek, T. 11 N., R. 66 W., six miles east of Carr, Weld County, Colorado.

FAMILY CATHARTIDAE HUXLEY, 1867

Phasmagyps patritus WETMORE

Phasmagyps patritus WETMORE, 1927, p. 3.

Type.—Denver Mus. Nat. Hist. No. 804 (fossil catalogue).

Palaeogyps prodromus WETMORE

Palaeogyps prodromus WETMORE, 1927, p. 5.

Type.—Denver Mus. Nat. Hist. No. 803 (fossil catalogue).

ORDER GRUIFORMES COUES, 1884

FAMILY RALLIDAE VIGORS, 1825

Palaeocrex fax WETMORE

Palaeocrex fax WETMORE, 1927, p. 9.

Type.—Denver Mus. Nat. Hist. No. 1078 (fossil catalogue).

FAMILY BATHORNITHIDAE WETMORE, 1933

Bathornis veredus WETMORE

Bathornis veredus WETMORE, 1927, p. 11.

Type.—Denver Mus. Nat. Hist. No. 805 (fossil catalogue).

The types of the last four species were collected from the Trigonias Quarries in the lower part of the Horsetail Creek member in sec. 26 and sec. 27, T. 10 N., R. 57 W., Weld County.

ORDER GALLIFORMES GARROD, 1874

FAMILY PHASIANIDAE VIGORS, 1825

Phasianid sp.

Referred specimen.—Cedar Creek member (lower): No. 9393; distal end of left tarsometatarsus; SW¼ sec. 12, T. 11 N., R. 54 W., Logan County.

TORDOFF (1951) thinks that this fragment represents an unknown species which (in the distal end of the tarsometatarsus, at least) fairly closely resembles *Colinus* and *Lophortyx*. It is the earliest record of the American Quail, subfamily Odontophorinae.

CLASS MAMMALIA

ORDER MARSUPIALIA ILLIGER, 1811

FAMILY DIDELPHIDAE GRAY, 1821

Peratherium fugax (COPE)

Herpetotherium fugax COPE, 1873b, p. 1.
Peratherium fugax, COPE, 1884a, p. 794.

Type.—AMNH No. 5254; Brule, Cedar Creek, Colorado (*fide* SCOTT, 1941).

Referred specimens.—Horsetail Creek member: No. 9792; fragment of jaw with right M_4; E½ sec. 30, T. 11 N., R. 53 W., Logan County.

Cedar Creek member: No. 8290; right ramus with M_1-M_3; SE¼ sec. 17, T. 11 N., R. 65 W., Weld County. Nos. 8162, 8291, 8307, 8309-8311, and 8313-8314; rami with one or more teeth; secs. 2, 3, 12, T. 11. N., R. 54 W., and secs. 7, 28, T. 11 N., R. 53 W., Logan County. Nos. 8308 and 8312; maxillaries with right M^1-M^4, and M^2-M^3, respectively; E½ sec. 7, T. 11 N., R. 53 W., Logan County.

As a whole these specimens agree with the description and measurements of the type. There are variations in the dimensions. For example, 12 jaws with M_3-M_4 have a range in length in these two teeth of 3.45 mm. to 3.9 mm. and a mean of 3.72 mm. The same specimens have a mandibular depth at M_3 ranging from 2.7 mm. to 3.6 mm. with a mean of 3.14 mm. In seven specimens there are positive correlations between size of teeth and size of rami, but in the remaining five specimens there is a negative correlation. As yet there is insufficient information to correlate variation with position in the stratigraphic section. The vertical position of one-third of the specimens is known to within five feet, and the remainder, with one exception, are at least known to be in the Cedar Creek member.