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OLIGOCENE SEDIMENTATION, STRATIGRAPHY, PALEOECOLOGY AND PALEOCLIMATOLOGY

IN THE BIG BADLANDS OF SOUTH DAKOTA

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Chapter I

INTRODUCTION

Successive faunas preserved in the classic Oligocene sequence of western South Dakota offer clear evidence that the Oligocene Period was a time of climatic change in western North America. The strata themselves have long been recognized as "typical floodplain deposits." This study attempts to analyse critically these two generalities by applying modern techniques and theory to both the fossils and the sediments. The data resulting from this analysis are used to reconstruct the Oligocene paleogeography of western South Dakota in detail. An attempt is then made to reconstruct the successive paleoclimates of the area. Finally, the interaction of the physical environments upon the faunas is considered.

Study of the fossils has been complicated by the fact that the philosophy of collection, as well as the documentation, of the classic collections makes them unsuitable for analytical use. It has been necessary to make collections specifically for this study, and modern collections in the area are subject to certain unpredictable variables which need not have operated at the time the older collections were made. The limited statistical treatment justified has, nevertheless, revealed sufficient information to merit its presentation here.

Study of the sediments has naturally devolved about several basic problems:

1. Did the position of South Dakota relative to the Earth's rotational poles differ materially from its present position, or did it change significantly during Oligocene time?

2. Which characteristics of the sediments are attributable respectively to their ancestry, to their paleographic position, to the paleoclimate during deposition, and to epigenetic changes?

3. What geomorphic controls determined that Oligocene streams would deposit thick floodplain sediments within 30 miles of their headwaters?

4. What is the length of time represented by the total sedimentary pile; what was the thickness of individual increments; and what time is represented by the increments as opposed to the intervening episodes of non-deposition?

5. What is the geomorphic pattern established by a group of streams whose primary regimen is deposition rather than erosion?

6. Do fossil faunules reflect the local paleogeography evidenced by the sediments?

The first question can be answered in advance with a probable negative. Even the most positive advocates of various hypotheses of continental drift seem to feel that post-Oligocene movement of North America relative to the poles of rotation has been slight. Abundant paleobotanical and marine-paleontologic evidence tends to confirm this. The study has, therefore, been conducted with the primary assumption that South Dakota occupied essentially the same position relative to the North Pole, and to the continents of North America and Eurasia, which it occupies today.

Chapters V, VI, and VII, which form the core of this report, were originally written as separate papers, intended for separate publication. The research was done at somewhat different times, under quite different auspices. Each chapter retains its own acknowledgments in order to make clear the extent of assistance received. The senior author wishes to acknowledge here the unstinted assistance of Dr. B. G. Woodland, who checked most of the author's identifications of mineral species of sand grains for various chapters. He also wishes to express his appreciation of Dr. T. Perenyi's patient and skillful art work on the charts, maps, and diagrams.

This study raises approximately as many new problems, both local and fundamental, as it solves. I have attempted to indicate these in all cases where the problem seems either to cast some doubt upon my favored hypothesis, or to be fundamental enough to merit general interest.

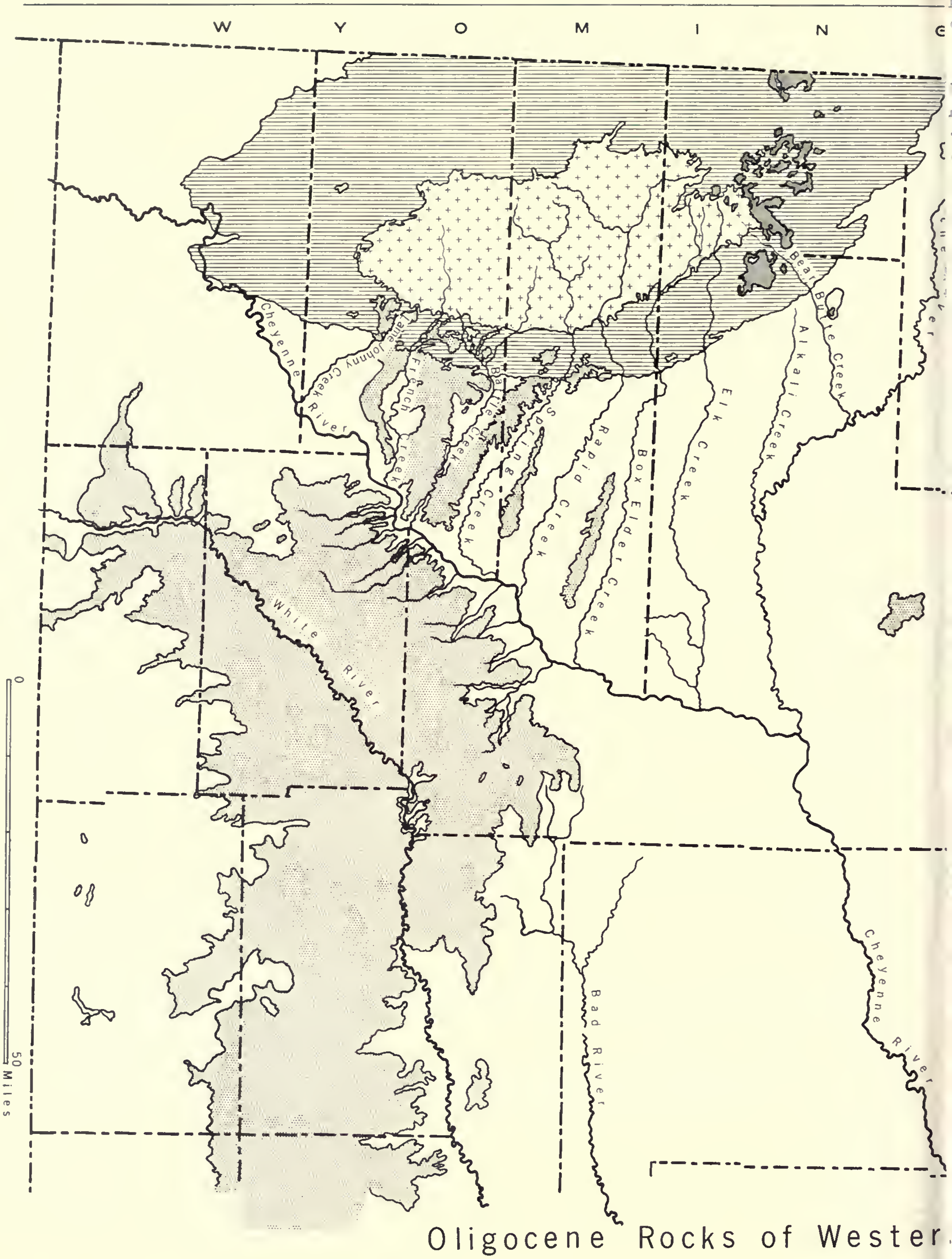
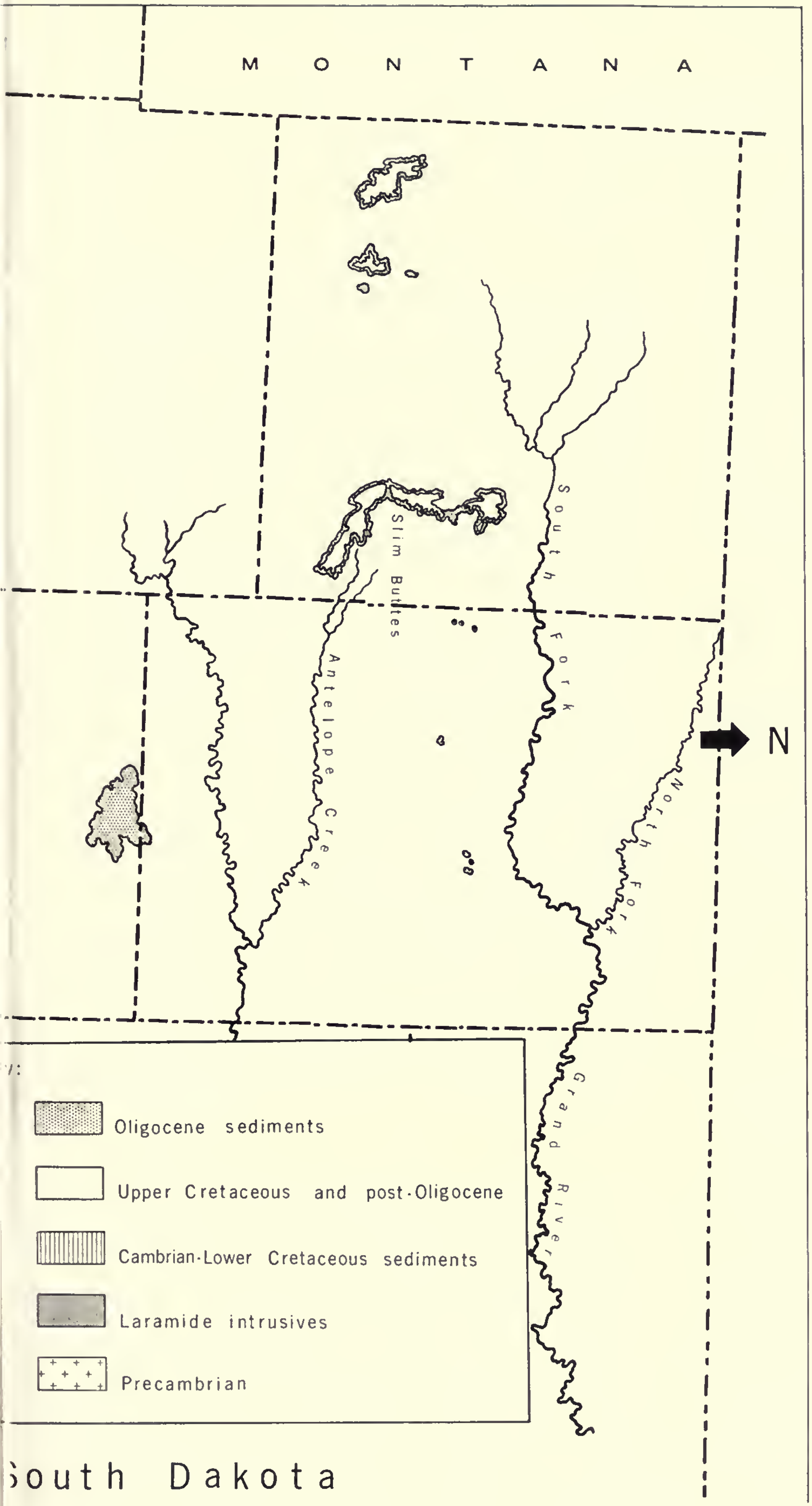


FIG. 1. Oligocene rocks of western South Dakota. The overlap of Oligocene sediments upon the Paleozoics is clearly indicated. Note also that clastics derived from the Laramide intrusive of the northern Black Hills are available to Box Elder and Elk Creeks at present.


MONTANA
Slim Buttes
South Fork
Antelope Creek
North Fork
Grand River
N
Oligocene sediments
Upper Cretaceous and post-Oligocene
Cambrian-Lower Cretaceous sediments
Laramide intrusives
Precambrian
South Dakota

Chapter II

GENERAL GEOGRAPHY

The area under consideration is roughly 60 miles long, E-W, by 15–30 miles wide. It lies in western South Dakota, east and southeast of the Black Hills (Fig. 1). It includes parts of Pennington, Shannon (including old Washington and Washabaugh), and Jackson Counties. Rapid City to the northwest, Kadoka to the east, and Wall to the north constitute the principal towns. South Dakota route 40, and U.S. 16, 16A, and 18 provide access. A fair network of county roads and an excellent series of trails make almost every spot easily accessible by light truck. About half of the area under study lies within the Badlands National Monument; much of the remainder is scheduled to be included in the future.

Physically, this district comprises the classic fossil-collecting areas of the Big Badlands, plus the finest exposures of Oligocene sediments in South Dakota. It consists of short-grass prairie uplands and table-top buttes, separated by badlands topography from short-grass prairie lowland flats and brushy floodplains. Local relief is usually 40–300 ft., with an extreme of 485 ft. at the south rim of Sheep Mountain, and of 600 ft. southeast of the Pinnacles (Sec. 17, T. 2 S., R. 16 E.). Elevations vary from about 2450 ft., along Cheyenne River and southeast of Interior, to 3282 feet. at the southwest edge of Sheep Mountain (Sec. 32, 43 N., R. 44 W.). Cheyenne River drains the Badlands northwestward, White River southward, and Bad River northeastward.

The present climate is continental-temperate semiarid. The average annual rainfall of 17 in. has fluctuated between 5 and 29 in.; the average annual temperature is 47° F., with recorded summer highs of 115° and winter lows of −35°. Local, diurnal, and annual fluctuations make the averages almost meaningless for any particular year and district.

The vegetational cover at any one spot is necessarily adjusted to the climatic extremes for that spot, which means that it is usually sparse, small, and consisting of a limited number of species. The bulk of plant material is so small, and oxidation so active, that vegetational decay rarely, if ever, contributes significantly to chemical weathering processes.

The native fauna is of no geologic significance. Grazing, mostly by cattle, usually keeps the grass cover down to the minimum necessary to maintain itself, and undoubtedly does somewhat aid erosion. The ungrazed areas within the National Monument have developed a heavier grass cover, but I have seen no evidence that erosion has been significantly influenced thereby.

Human activity has altered the geologic situation in two ways. First, construction of small dams across draws and gullies has progressed to the point where run-off and the regimen of intermittent streams have been significantly altered. Second, local rockhounds and commercial collectors have so actively worked over most of the classic collecting areas that proper collection of faunas for statistical purposes is possible only in the most difficultly accessible spots. This is a serious impediment to detailed paleoecologic work: since there is no correlation between paleogeography and ease of access, several interesting paleoecologic environments have been ruined for study, while certain others remain untouched.

Chapter III

GENERAL GEOLOGY

A. *Stratigraphic column.*

The stratigraphic column within the area studied is shown on the chart, Figure 2. Dips in the Pierre shale are usually indeterminable at any one outcrop, due to the fact that unloading expansion, followed by weathering, alters bedding structures to a depth of about 30 ft. Alteration of disseminated pyrite to gypsum has usually progressed to completion down to about the same depth, which further disrupts bedding.

The 6–70 ft. of Pierre shale directly underlying the Cretaceous-Tertiary unconformity is in most places colored yellow, brown, purple, green, or red. This color change accompanies a slight increase in Fe_2O_3 and MnO_2, and decrease in Ca and Mg, which suggests that the colored zone is a pre-Chadron soil. Distribution of the colored zone, thickest where the overlying Chadron is thinnest, and thinnest underlying the old valley which the Ahearn member of the Chadron fills, further suggests soil, best developed in the gently-rolling hills of the old upland. X-ray diffraction analyses of the colored clays have not been run in sufficient quantity to reveal generalities, but four analyses known to me show a consistent increase in kaolin over the unaltered Pierre. Southwest of the town of Pine Ridge, again in T. 36 N., R. 46–48 W., and in several places between Fairburn and Buffalo Gap, the same colored zone is developed on the Niobrara formation.

The usual color succession of the thicker sections is:

Yellow to pale blue
Brown
Purple
Gray
Unweathered gray or black.

Three to five feet of red form the very top, in the area of Sage Ridge but not elsewhere (see Fig. 3). Limy nodules up to 6 in. in diameter, with rough surfaces or actual zones of blending into the surrounding sediments, often lie at the contact between the red zone and the overlying greenish Chadron. Since equally thick sections of colored Pierre in the eastern and southern portions of its area of outcrop do not display this uppermost red zone, it is possible that the red zone represents topsoil weathering of a Pierre stratum originally somewhat more calcareous than those exposed elsewhere. The Sage Ridge (Clark 1937, p. 289) apparently existed as a structural uplift subject to pre-Chadron erosion, which might well have exposed a stratum covered elsewhere.

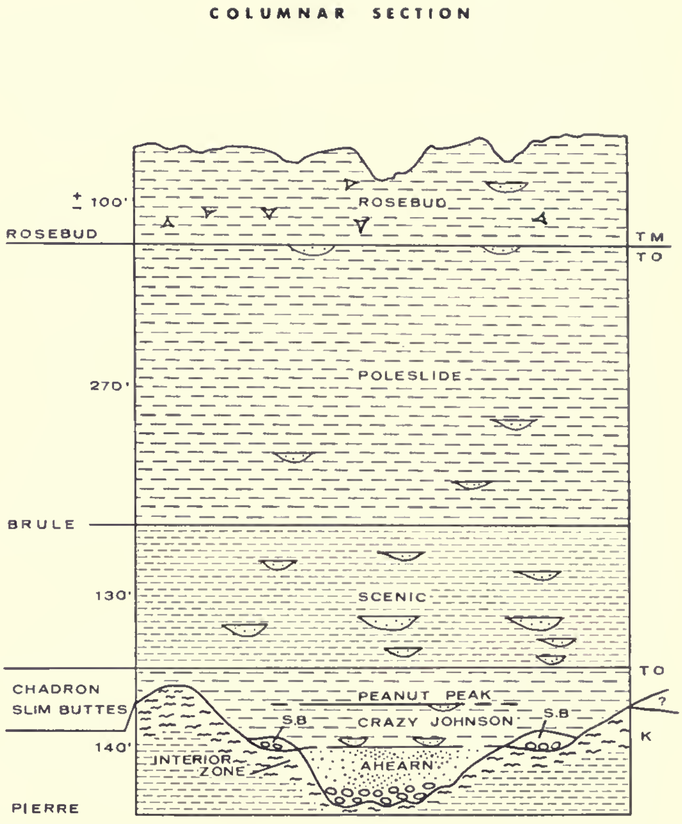


FIG. 2. Columnar section for the Big Badlands.

The entire colored zone was named the "Interior Formation" by Ward in 1921, and recognized as a soil zone rather than a formation by Wanless in 1923. The latter interpretation is now generally accepted; all of the pertinent data observed since Wanless' original interpretation support it.

Slim Buttes Formation: This formation was first recognized, and a standard section established, in the Slim Buttes of Harding County, northwestern South Dakota (Malhotra and Tegland, 1959). The name is applied here to sediments of similar gross lithology and appearance, roughly similar mineralogy, and similar stratigraphic situation. The fauna of the Slim Buttes formation in its standard locality has not yet been adequately studied, and the outcrops here referred to it have yielded no identifiable fossils except wood, so correlation based upon fossils is impossible.

The formation consists characteristically of white to very pale greenish and olive-white sandstones, generally quite well-sorted, bimodal, comprising a clay and a

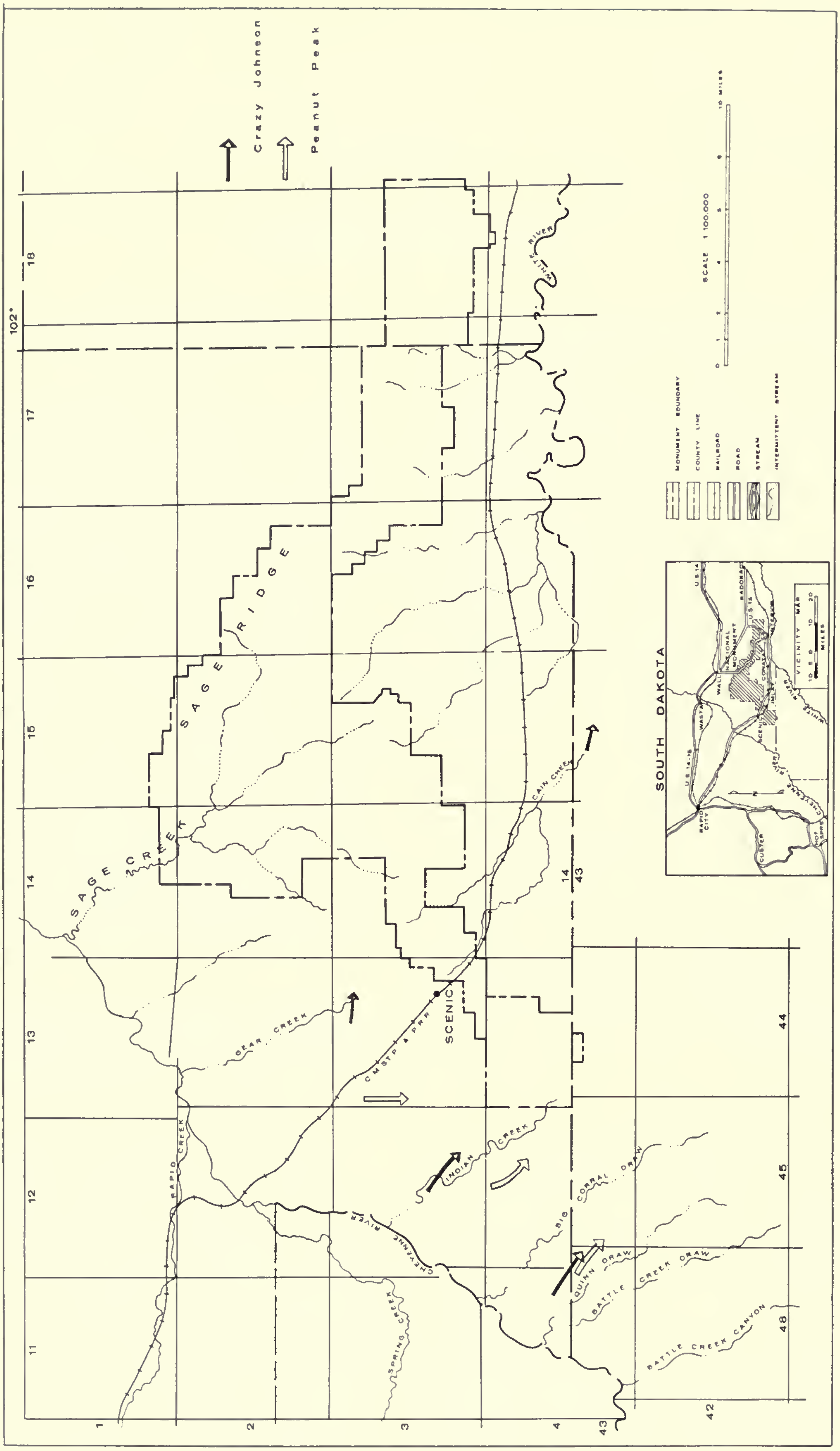


FIG. 3. Upper Chadron channel directions.

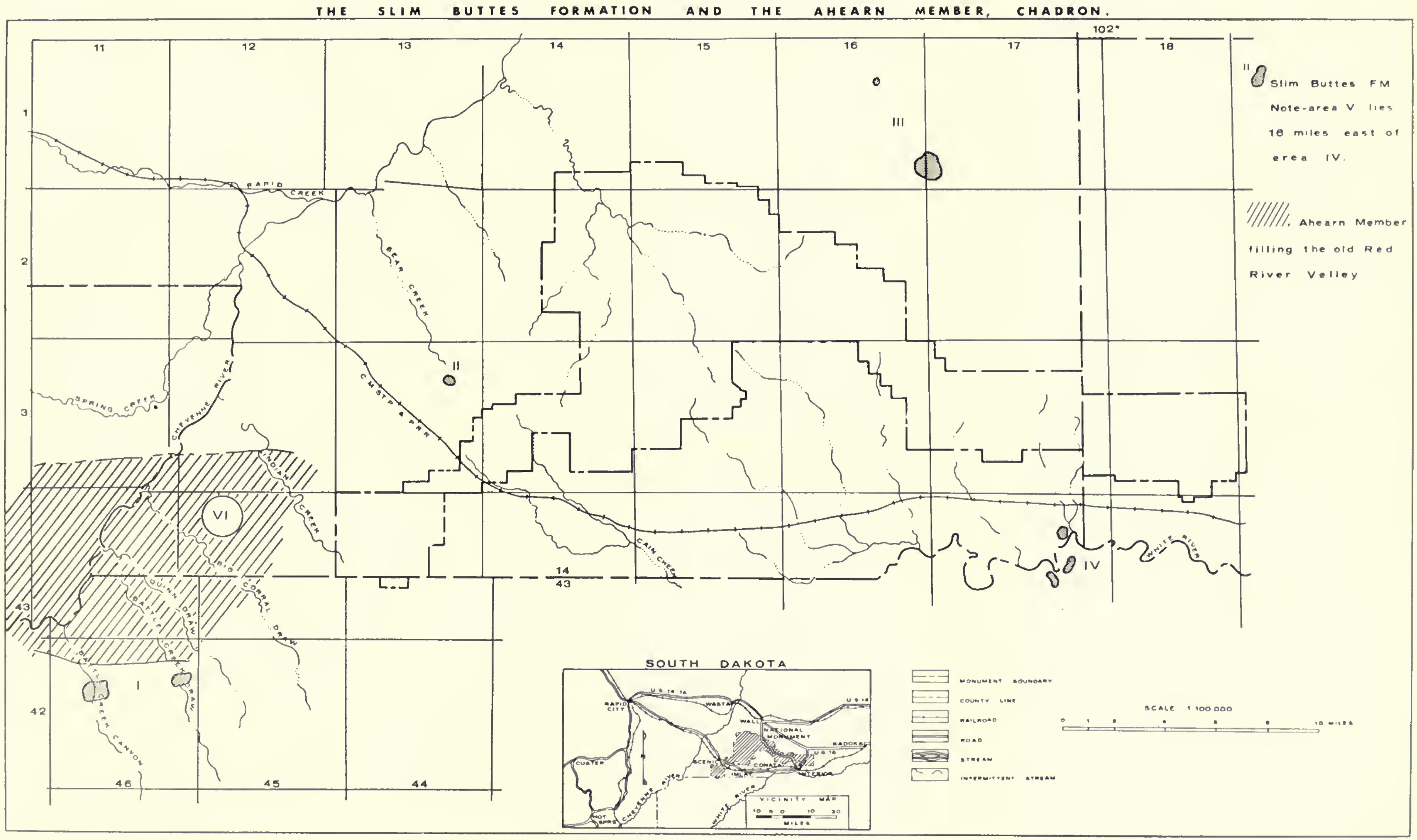


FIG. 4. The Slim Buttes Formation and the Ahearn Member, Chadron. In the area marked VI, the basal Ahearn sediments include much reworked Slim Buttes sand.

Fig. 5A. View of locality V, looking west at the SW ¼ of Section 2, T 3S, R. 20E, Jackson Co. Shows the Slim Buttes Formation (light colored with a dark band near the top) resting upon the Interior Zone soil (dark grassy gullies in foreground). The overlying Chadron cuts out the Slim Buttes in the middle of the picture. Slopes of both Chadronian channel-banks are visible, also Chadron resting on Interior in the middle of the picture.

Fig. 5B. Slim Buttes Formation resting upon Interior Zone soil and overlain by Chadron, which has penetrated cracks and joints in the Slim Buttes. In locality IV, Section 12, T 4S, R 17E, Jackson Co.

Fig. 5C. Inherited Slim Buttes sediments reconstituted as an Ahearn sandstone, in locality VI, Big Corral-Little Corral draw divide.

fine to medium-grained sand. The unit frequently includes a basal conglomerate.

The formation occurs as discontinuous lenses (Figs. 4, 5) sometimes several miles in extent, up to 40 ft. thick, resting disconformably upon the Interior zone. Most of these lenses wedge out with no visible indication of erosion by Chadron streams. However, a Chadron channel-fill clearly bisects a lens of Slim Buttes sandstone and even cuts somewhat into the underlying Interior zone, north of Weta (SW ½, Sec. 2, T. 3S., R. 20 E., Jackson Co.).

The sediments referred to the Slim Buttes formation are those previously described by Clark (1937, pp. 277–278) as "restricted white channel fills" of the Ahearn Member of the Chadron Formation.

Chadron Formation: Since the Chadron Formation will be the subject of Chapter V, only the briefest summary need be given here.

The lowest, or Ahearn Member, consists of 0–80 ft. of greenish and red-mottled sandstones with subordinate gray, green, and tan mudstones, occupying an east–west trough. There is usually a basal conglomerate, and conglomeratic channel-fills are common, especially in the lower two-thirds of the member.

The middle, or Crazy Johnson Member, is made up of greenish to gray conglomeratic channel-fills associated with gray, greenish, and bluish mudstones. It is 20–40 ft. thick.

A predominance of greenish, gray, and tan to orange mudstones characterizes the upper, or Peanut Peak Member, 20–30 ft. thick. Conglomeratic channel-fills are just as well-marked but smaller and much less numerous than those of the members below.

The Chadron-Brule contact consists of a zone 6 in. to 3 ft. thick, of limey layers intercalated with greenish and tan mudstones. Occasionally, the contact comprises a single limestone up to one foot thick. Characteristically, the limestones are partially to completely opalized.

Brule Formation: The Scenic Member of the Brule comprises 89–130 ft. of tan, yellow, gray, red, and greenish mudstones with some siltstones, thin beds of fine-grained sandstone, and channel fills some of which include coarse conglomerate and others which consist only of fine sand. Chapter VI will describe the Scenic Member in detail.

The Poleslide Member, 270 ft. thick, conformably overlies the Scenic Member. It consists of yellow-to-tan mudstones, with a considerable admixture of volcanic ash. Sandstone channel-fills occur approximately overlying similar channel-fills in the Scenic Member, but are much narrower, thinner, and usually finer-grained than their underlying predecessors.

Rosebud Formation: Use of this name for the basal Miocene formation of the Big Badlands has been disputed by MacDonald (1958). However, the type locality designated by Matthew and Gidley is almost in lithologic continuity with the basal Miocene of the area under discussion; deposition of sediments was generally outward from the Black Hills, the same source: Macdonald confuses the type section with beds "along the Niobrara River to the South in Nebraska," and then invalidates the name Rosebud by quoting an Oligocene date for the beds in Nebraska. For these reasons, it seems preferable to continue use of the name Rosebud for the basal Miocene beds of the Big Badlands.

The Rosebud consists of a basal member, named Rockyford by Nicknish (1957), up to 55 ft. thick, composed of water-deposited volcanic ash with minor clastic mud, which appears white in the field. The base of the ash has been used for decades as an arbitrary marker for the beginning of the Miocene. There is no evidence of disconformity at this horizon, merely a sudden increase in the amount of ash. Overlying the Rockyford Member is a series of bedded, gray to tan siltstones with a high ash content, the top of which is cut across by the Missouri Plateau surface.

B. *Regional Structural Setting*

The regional structural setting of the Big Badlands is much more complex and orderly than one might suppose from the outcrop map, or from a hasty field inspection. Figures 6 and 7 make clear that the structures consist of a series of parallel linear faults diminishing along their strike into low folds and domes, at intervals of a few miles, trending roughly N 70°W. The downthrown side is generally south except for the Pine Ridge Structure, which is downthrown some 1200 ft. on the north side. Regional dips between the Sage Fault on the north and the Pine Ridge Structure on the south trend south–southeast. The overall picture is an asymmetrical structural trough, hinged along its northeastern margin and downthrown to the southwest. Small structures within the trough parallel the bounding faults. Local sags and swells occur along all of the structures.

Since the Cretaceous shales and Tertiary mudstones involved are completely incompetent to transmit stresses a distance of tens of miles, these linear movements presumably constitute drape structures over displacements in the Precambrian-Paleozoic basement. They are part of a system extending south into Nebraska, where the direction changes to more nearly east-west.

Geomorphologic evidence suggests that the Badlands structures extend westward into the Paleozoics of the Black Hills. The drainage of the east flank of the Hills consist of a series of sub-parallel streams, tending ESE, each of which, from Elk Creek south, passes through the Paleozoic-Mesozoic strata via a structure-controlled gap.

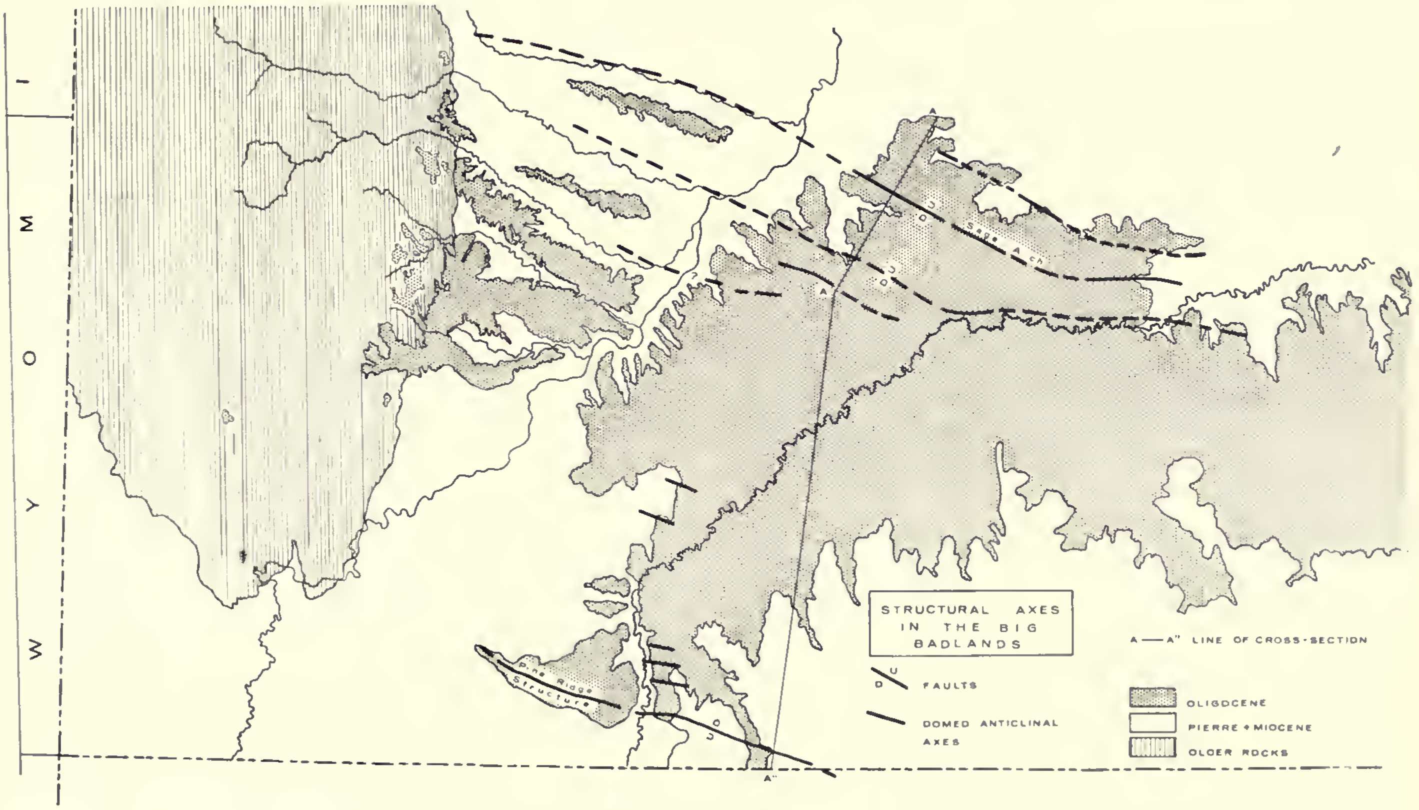


FIG. 6. Structural axes in the Big Badlands.

Furthermore, the five divides between Bear Butte Creek and Spring Creek are strongly asymmetrical, with short, steep north-facing slopes and long, gentle southern slopes. Plumley (1948, pp. 538–539) suggested that southward tilting of the whole area after the present drainages were established could have caused the asymmetrical drainages. This seems improbable for the following reasons:

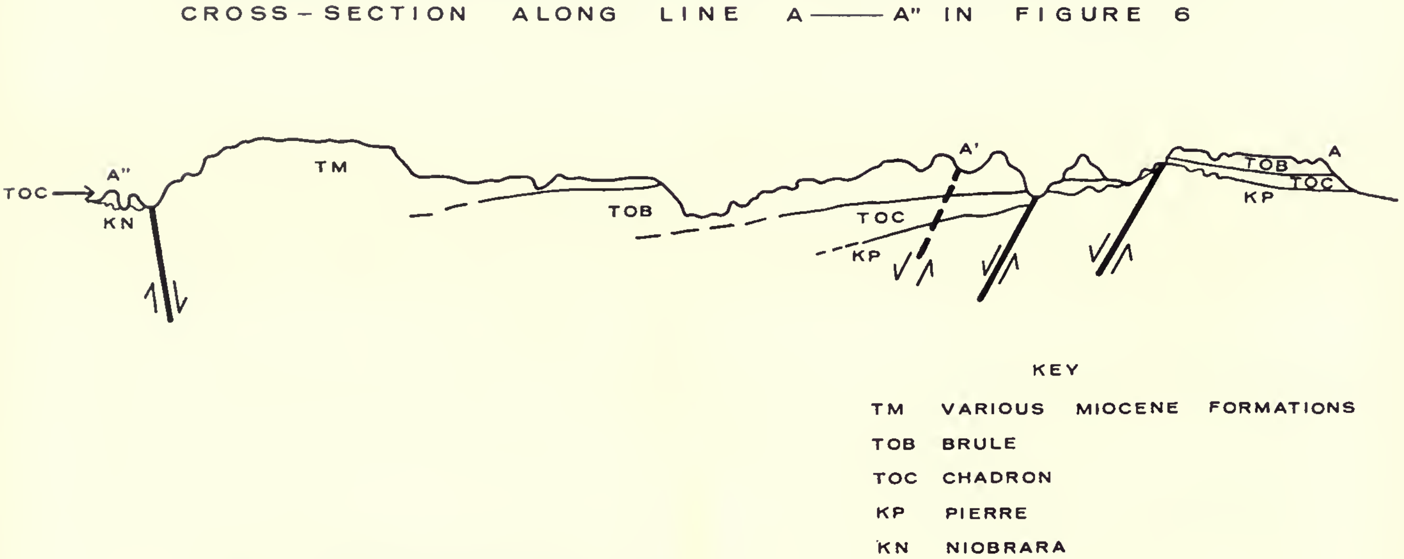


FIG. 7. Cross-section along line A–A, Figure 6.

1. Table-top gravels occurring east of the present upper course of Cheyenne River indicate that streams flowed eastward from the Black Hills at about the Missouri Plateau level during early Pleistocene time. Capture of the Black Hills drainage by Cheyenne River was a middle to late Pleistocene event.

2. The table-top remnants of the Missouri Plateau, scattered throughout the Big Badlands, show no sign of a southward tilt. Rather, they slope northwestward and southeastward from an apparent old divide trending ENE-WSW from the south end of Sheep Mountain to the Pinnacles.

3. Missouri Plateau remnants preserved on top of the Railroad Buttes (Sec. 6, 7, 8, T. 2 S., R. 11 E., Pennington Co.), west of Cheyenne River between Spring Creek and Rapid Creek, slope northward, not south. If the entire area had undergone a southward tilt, the plateau remnant on this asymmetrical divide should slope southward.

4. A southward tilt of even one degree would, in the 40 mile distance from Bear Butte Creek to Spring Creek, result in a vertical uplift of 3680 ft. north relative to the south. Actual elevations in the north average about 100 ft. lower than southern elevations of corresponding topographic situation and distance from the Hills.

5. Such an uplift would have caused notable displacement of the Cretaceous formations involved. No such displacements occur. Rather, the attitude and position of all beds exposed are geometrically explicable only in relation to the known major and minor structures along the east flank of the Hills, without regional tilting.

6. Regional tilting can cause lateral migration of streams only in the presence of alternately harder and softer beds. These asymmetrical divides are composed esentially of homogeneous Pierre Shale; some crests include remnants of Oligocene mudstones for part of their length, and frequently the crests consist of ?Pleistocene gravels a few feet thick. None of these materials shows measurable south dips, nor are there any layers significantly harder than the mass as a whole. Regional tilting of these sediments, even if it occurred, would not cause drainage migration.

7. The northward course of Cheyenne River above its junction with the Belle Fourche is known to be post-middle Pleistocene. It seems almost impossible that a northward-flowing stream could develop and capture the drainage of an area which was being actively tilted southward.

For these reasons, a Pleistocene southward tilting of the area east of the Black Hills seems most improbable.

Two alternative explanations remain for the asymmetrical divides between the parallel streams east of the Black Hills. First, they may be a response to climatic-vegetational controls. North-facing slopes at present are steeper, and develop more trees but poorer grass cover, than south-facing slopes. A combination of wind direction, snow accumulation, and insulation could cause vegetational differences which would favor more rapid erosion on north or south slopes, as the case might be. Many isolated buttes on the Tavaputs Plateau of Utah demonstrate this situation excellently, although under the Utah climatic regimen erosion is faster on south slopes.

However, this hypothesis for asymmetrical divides does not explain the general parallelism of the master streams with each other and with the known trend of regional structures in the Badlands. Also, it does not explain the fact that these streams flow east-southeastward rather than radially outward, normal to the mountain front and the regional strike. It seems reasonable, therefore, to propose as a structural hypothesis that the linear structures observed in the Badlands continue northwestward to the Black Hills. The major streams emerge through structurally-controlled gaps in the Hills and follow these old structural lines to the points of their relatively recent capture by Cheyenne River. Since the structures are draped normal faults and folds, generally downthrown a few feet or tens of feet south, the fault planes dip south. The streams may have migrated down the dip of the fault zones, producing asymmetrical divides, or recent tilting of the individual blocks between faults might have occurred, or climatic-vegetational control of tributary gullies might produce asymmetrical divides between structurally-controlled streams. The second of these hypotheses seems least probable, but I have not yet found evidence disproving it.

The question of whether the structural system evident in the Badlands extends westward to the Black Hills is of subordinate interest to the present study. The time or times of movement are of much greater significance. Clark (1937, p. 289) suggested that a pre-Chadron topographic ridge paralleling the Sage Fault was evidence of pre-Chadronian movement along the fault; displacement of early Miocene strata clearly indicates post-early Miocene movement. The Pine Ridge Fault brings the Niobrara Formation into contact with presumably middle Miocene beds. Absence of the entire Pierre indicates a pre-Chadron uplift of at least several hundred feet, erosion down to the Niobrara, deep weathering of the Niobrara, deposition of the Oligocene-Miocene group, then reactivation of the fault with at least 300 ft. of post-middle Miocene movement. The entire fault system has, therefore, undergone at least two periods of activity, one pre-Oligocene (probably Laramide) and one post-middle Miocene, probably part of the general late Tertiary movements farther west (Eardley, 1962, pp. 493–514).

Chadron and Brule sediments are known to have overlapped the Oligocene Sage Ridge to the north and the ridge to the south, which will be referred to as the Pine Hills, in order to differentiate the Oligocene topographic feature from the Recent Pine Ridge. The influence of these two features upon Oligocene sedimentation suggests, however, that the higher parts of the Sage Ridge were exposed at least through Orellan (early Brule) time. Evidence for this will be presented in Chapter VI.

Chapter IV

THE SLIM BUTTES FORMATION

In 1959, Malhotra and Teglund described a new Tertiary formation, the Slim Buttes Formation, with its standard section in the NW ¼ of the SW ¼ of Section 11, Township 16N, Range 8E, Harding County, South Dakota. This is in the northwest corner of South Dakota, approximately 100–120 miles north of the western part of the Big Badlands (Fig. 1). Since correlation of strata in the Badlands with this formation in its standard area is not certain, and since the original description of the Slim Buttes Formation was published in a journal of extremely limited distribution, I shall here paraphrase such of Malhotra and Teglund's description as applies to the suggested correlation:

The Slim Buttes Formation occurs as a lens 0 to 40 feet thick, several miles in diameter, which outcrops in the southern two-thirds of the Slim Buttes and in the East Short Pine Hills. It rests disconformably upon Paleocene sediments, and is overlain with apparent conformity by the Chadron. The formation consists essentially of white, cross-bedded sandstones. Thin gravel bands consisting of chert and quartz pebbles up to 19 mm diameter festoon the outcrops in many places. The upper contact of cliff-making, white Slim Buttes sandstone with overlying crumbly slopes of greenish-gray Chadron mudstones appears sharp at a little distance, but closer inspection of fresh exposures reveals that gradational zones a few inches thick are common. The standard section includes several strata of reddish, brown, and purple mottled mudstone which contain vertebrate fossils. Elsewhere, the sandstone is remarkably uniform, with only occasional thin laminae of pale greenish clay.

Microscopically, the light fraction of the sand consists of quartz and feldspar. Much of the latter has been partially altered, producing pure white grains which, with the pale greenish to white cementing clay, are responsible for the overall color of the rock.

The associated heavy minerals can be divided into several groups, according to source:

I. Autochthonous
    Barite
    Limonite
    Leucoxene
    Hematite
II. Reworked from sedimentary rocks
    Glauconite
    Highly rounded garnet, tourmaline, zircon
III. Ubiquitous
    Biotite, generally anhedral, but one specimen euhedral
IV. Igneous or contact metamorphic
    Magnetite, both euhedral and rounded
    Apatite
    Sphene
    Zircon, clear to violet-gray
    Tourmaline, black to clear, ranging from euhedral to subhedral
    Rutile, red, resinous, angular
V. Igneous or metamorphic
    Hornblende, black to dark green
    Garnet
VI. Metamorphic only
    Staurolite, brown and resinous
    Chlorite, green and platy

The tourmaline and garnet are abundant, hornblende and biotite uncommon.

Mudstones and concretionary sands at the standard section and within a mile to the east, south, and west have yielded a fairly large fauna, which is at present housed in the South Dakota School of Mines Museum of Geology. (Due to extremely hard matrix and soft bone, this collection was not fully prepared by the summer of 1964-J.C.). Preliminary observations indicate the presence of an undescribed tapiroid, a large species of *Epihippus*, *Megalamynodon*, *Eotrigonias*, and a titanothere the size of *Teleodus*. Assuming that these tentative identifications are correct, an Eocene-Oligocene transitional age is indicated.

This ends the paraphrase of Malhotra and Teglund's description, which contains much significant matter not included here.

My own observations indicate that a homogeneous mixture of fairly well-sorted sand with a white clay matrix characterizes the Slim Buttes formation in its standard area. Feldspar grains the same size as the quartz grains are all altered to a white clay, and some of the white matrix shows fragmentary ghosts of feldspar cleavages. It seems probable that this texture indicates syngenetic or epigenetic alteration of an originally well-sorted, highly arkosic sand. Neither the crossbedding nor the sorting resembles that of the known Tertiary fluvial deposits of South Dakota; I am therefore in agreement with Malhotra and Teglund that these sediments may well be lacustrine. However, I am not convinced by their evidence that the source of the clastics lay to the west or northwest, and at present consider a Black Hills source more probable.

Sediments which occupy the same relative stratigraphic position as the Slim Buttes Formation occur in five areas in the Big Badlands (see Fig. 4). In all cases they rest disconformably upon the Interior weathered zone of the Pierre Shale. In all cases they are overlain by the Chadron, but at least two localities offer definite evidence of a time lapse between deposition of the two formations.

The five localities differ sufficiently to require separate description.

LOCALITY I. Western Badlands, Exposed in upper Battle Creek Draw, in section 12, and in Battle Creek Canyon, sections 10 and 15, T 42N, R 46W, Shannon County.

Two lenses of coarse white sandstone up to 20 ft. thick and 400 yd. in diameter. A very coarse conglomerate of quartz and chert pebbles, up to 6 in. greatest diameter, lies at the base and crossbedded into the lower several feet of the thicker sections.

Individual pebbles of rose quartz and "Fairburn" agate plainly indicate a gravel with its source in the southern Black Hills ("Fairburn" agates are placer agates derived apparently from the Hell's Canyon agate nodules in the Pahasapa Formation, Mississippian, of the southern Hills.) The rose quartz clearly proves that the Precambrian pegmatites of the southern Hills had been exposed by the time these pebbles were eroded from their parent outcrops. Complete absence of granite and feldspar pebbles indicates active syngenetic weathering, producing a mature gravel within 30–40 miles of its source. The contrast with richly arkosic Chadron and Brule gravels exposed in the same area is striking.

The petrology of the sands in these lenses has not yet been studied.

No fossils, other than a few obviously transported pieces of silicified wood, have been collected from this locality.

The lenses are overlain by greenish Chadron mudstones, with a sharp contact.

LOCALITY II. Northeast of the town of Scenic, center of section 11, T3S, R 13E, Pennington County, (FMNH specimen G4007).

One lens, up to 8 ft. thick, of greenish-white to yellowish-white sandstone, with a basal conglomerate of chert pebbles up to 2 in. in diameter. The lens is exposed over an area of less than 100 yards; badlands gullies surrounding it reveal that this is about its maximum diameter. The overlying greenish Chadron consists of sandy siltstones, and rests with an erosional contact upon the fine-grained sandstone. There is no actual trenching or gullying, but the lens seems to feather out by erosion of its upper surface rather than by confinement within a small depositional basin.

The sandstone is homogeneous and well-sorted, but bimodal, with the principal mode at about 0.125 mm and the secondary mode in the clay sizes. Grains are generally sharply angular, with a few very well rounded and slightly frosted ones. These might be presumed to be inherited if the extreme wear were restricted to quartz grains, but such is not the case. Possible alternative hypotheses will be discussed after detailed description of localities has been completed.

The light fraction of the sand consists of quartz, angular chips of yellow, orange, gray, and brown chert, a small percentage of gray, sugary quartzite, and scattered grains of white, glossy material which is almost completely weathered feldspar.

Barite both euhedral and interstitial, dominates the heavy fraction. Next in abundance come magnetite and a black, metallic mineral which is not sufficiently magnetic to adhere to a hand magnet. Both of these last vary from very well-rounded, spherical grains to euhedral double pyramids and sharply angular fragments. Next in abundance are shards of pink garnet and small, euhedral crystals of colorless, pale yellow, and pink zircon. Smoky to olive tourmaline is the only other common heavy mineral. The rarer minerals include yellow-brown allanite; dark green, clear, well-rounded but usually columnar grains of actinolite; and red, columnar transparent grains, both well-rounded and angular, of either rutile or cassiterite. A few grains of blue, transparent indicolite have also been observed.

The quartz grains 0.125 mm and smaller fall into two sharply differentiated varieties; colorless, and pale to bright yellow citrine. Both varieties include both highly angular and well-rounded grains. The large-diameter fractions of the sample, above 0.125 mm, consist of limonite nodules, yellowish chert, and a very few angular quartz grains with slightly etched or abraded surfaces.

Petrologically, the assemblage is notable for immaturity, absence of micas, and a high percentage of minerals from igneous rocks as opposed to those from metamorphics or from older sediments. It differs from the Slim Buttes assemblage in the absence of leucoxene, glauconite, apatite, biotite, sphene, hornblende, and chlorite. Some of these differences may be due to overlooking of rare, single grains in the Scenic sample, but even if so, the relative proportions of the minerals named must be sufficiently lower to be significant.

Absence of feldspars from the gravel, deep weathering of the few feldspar grains remaining in the sand, and the homogeneous mixture of greenish-white clay, presumably derived from *in situ* weathering of feldspars, with otherwise well-sorted sand, are the only indication of active syngenetic or epigenetic chemical decay.

No fossils have been found here.

LOCALITY III. Southeast of Wall. A major area of exposure at the intersection of sections 25, 26, R. 16E., and 30 and 31, R. 17E., T. 1S., Pennington County. The total area of exposure is roughly two-thirds of a mile in diameter. A remnant outlier is exposed on the southwest flank of a butte, in the NE 1/4 of the SE 1/4 of the SE 1/4, Sec. 10, T. 1S., R. 16E. (FMNH specimen 4076).

The larger area comprises horizontally-bedded strata approximately 35 ft. thick. The lower portion is a white to yellowish green, fine-grained sandstone. Chert and some quartz pebbles up to 3 in. diameter make up a basal conglomerate, near the top of which the pebbles are not over 2 in. in diameter. This is overlain by a zone 1–2 ft. thick of a peculiar clinkery sediment which varies from an exceedingly impure limestone to calcareous, gritty, gray material with white flecks. Fifteen to twenty feet of pale yellow, pale gray, and brighter reddish-purple mudstones overly the clinkery zone. A second clinkery zone caps the formation, overlain directly by 40 ft. of grayish Chadron clays.

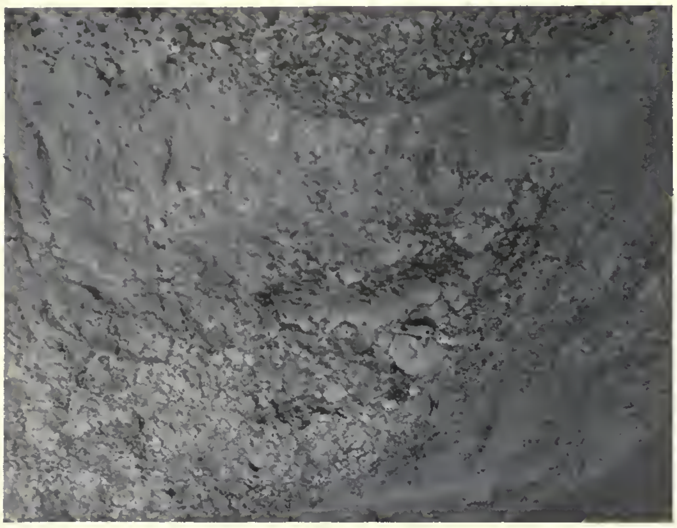


FIG. 8. Slim Buttes–Chadron contact zone, showing (middle of picture) darker Chadron clays penetrating joints and cracks in the light-colored Slim Buttes sandstones. Vertical white streaks are pick marks, made during removal of weathered surface material.

The outlier consists of 10 to 15 ft. of medium-grained, greenish-white sandstone including one stringer of purplish sand and clay. It also is overlain with apparent conformity by grayish Chadron clays.

The sediments of this locality have not yet been analyzed petrologically. No fossils have been found in them.

LOCALITY IV. Southwest of Interior, in Section 12, T. 4S., R. 17E., Jackson County and in Sections 23 and 24, T. 43N., R. 40W., Washabaugh County. This is the area described and figured by Clark (1937, p. 277, also Figs. 5B and 8).

The outcrops north of White River, in section 12, never exceed 10 ft. in thickness. They consist of a basal conglomerate of chert and quartz pebbles up to 2 in. in diameter, overlain by greenish-white, massive, poorly-cemented sandstone. The sandstone is fractured into angular blocks several inches in diameter; greenish clay from the overlying Chadron and purple clay from the underlying Interior zone have intruded the fractures, producing a mosaic effect.

The sandstone has a considerable content of white to greenish-white clay, which is high in kaolinite, montmorillonite and fine-grained quartz. A few identifiable feldspar grains remain, but many more are weathered almost beyond recognition.

The large outcrop area south of White River includes a basal conglomerate and cross-bedded to massive lenses of coarse to fine, greenish-white sandstones. Lenses up to 3 ft. thick of exceedingly plastic, pale gray clay, also characterize this locality. The clays consist of fine-ground quartz, kaolin, and subordinate quantities of montmorillonite and mixed-layer clay.

No fossils have been found at this locality, and the detailed petrology has not been adequately studied. (FMNH specimens G3729, G3730, G3731).

LOCALITY V. North of Weta; sections 1, 2, 3, 11, 12, 14, T 3S, R 20E, Jackson Co. and scattered localities to the east.

Erosion of the white sandstones previous to deposition of the overlying, typical Chadron sediments is clearly demonstrated at this locality. Figure 5, looking west from the road one-quarter mile north of the south edge of section 2, shows white sandstone north and south of a central gap, with sloping shoulders of Chadron cutting it out completely. Outcrops not visible in the picture have Chadron resting directly upon Interior Zone clays. The top of the white sandstone is fractured, and the fractures have been intruded by Chadron clay, as at Locality IV. Figure 8 shows the fracture zone as exposed by stripping off the weathered surface on the shoulder of the northern side of the pre-Chadron eroded gap in section 2.

The basal conglomerate reaches a thickness of 3 ft., with bands of smaller pebbles cross-bedded into the sandstones as much as 6 ft. above the main gravel mass. Red and yellow jasper, and "eye agates" of gray and black chert comprise the bulk of the gravel. The largest pebbles are about 3 in. in diameter. Less than 1% of the pebbles over 2 in., and less than 3% of the pebbles ½–2 in. in diameter, are composed of quartz. Rose quartz, Fairburn type agates, and black-and-white, banded, schistose quartzite are all absent here, in contrast with Locality I where they comprise the bulk of the gravel.

The white to greenish-white sandstone varies from coarse to fine, with more greenish color on the finer material. As elsewhere, the interstitial white clay and the white clay granules show ghosts of feldspar grains. Altered feldspar grains form an appreciable proportion of the larger-sized light sands, but are absent in the finer sizes.

Microscopically, the light fraction consists of quartz of two types, colorless and lemon-yellow citrine. Both types occur usually as sharply angular grains, with a few highly spherical, well-rounded and frosted ones. The grains show much less abrasion and frosting, especially in the sizes greater than 0.25 mm, than do those at Locality III. Subordinate quantities of yellow, orange, gray, and brown chert, and a few grains of gray, sugary quartzite, characterize the +0.25 mm fraction.

The heavy mineral suite differs notably in proportion from that of the outcrops near Scenic. Euhedral to subhedral barite is the principal constituent; apparently it is autochthonous and functions as a cement. Of the clastic heavy minerals, magnetite and a black, metallic, nonmagnetic mineral resembling it are most abundant; both include grains varying from euhedral double pyramids and freshly fractured granules to very well-rounded spheres. Euhedral zircons, colorless, pale yellow, and pink, are next in abundance. Pale orange to pink garnet and smoky-olive tourmaline (which would probably be black if seen in larger pieces) occur in roughly equal proportions. Clear, dark green, well-rounded prismatic grains of actinolite, and transparent red columnar grains of rutile (or cassiterite?) are uncommon. The rutile includes both angular and well-rounded grains. Very rare grains of yellow-brown allanite and glassy blue indicolite complete the list of minerals identified to date.

The Weta assemblage differs from that near Scenic in the absence of staurolite, abundance of magnetite and other metallics, relative decrease in tourmaline, and considerable decrease in garnet. However, changes of proportions of heavy minerals cannot be interpreted arbitrarily in this case, because the sample from Scenic occurred in a fine-grained sandstone and the sample from Weta in a much coarser-grained rock.

The abundance of magnetite, the presence of rutile and indicolite, the absence of biotite and of micas generally, the presence of smoky tourmaline in some quantity, and the presence of zircon in some quantity, are all features in which these rocks differ from the sandstones of the overlying Chadron. Smoky tourmaline occurs in abundance in many Chadron sands, but not associated with abundant magnetite.

The outcrops in section 2 include a bed of red-brown mudstone (see Fig. 5) near the top of the formation. This situation resembles that at the type section of the Slim Buttes formation. A very careful search was made for fossils and two partial ribs of an animal the size of a large *Trigonias* or small titanothere were discovered. No other fragments of vertebrates have been found.

The basal conglomerate in section 2 includes pieces of fossil wood up to 2 ft. long. Many of these have, unfortunately, been removed by local rock collectors, but a few are in the collection of the South Dakota School of Mines and Technology, and one, G3729, is in the Field Museum of Natural History. Since these specimens are many times larger than the largest clastic pebbles in the conglomerate, it is obvious that they were not mechanically transported as boulders from some other formation. The pieces of unfossilized wood must have floated in and lodged in their present positions, but whether they came from a neighboring or a distant source is not known. The wood has been tentatively identified as cedar, and of no value in precise age determination.

A sixth area (marked VI on the map, Fig. 4) consists of Slim Buttes sands reworked into the basal Chadron, with so little admixture as to suggest that the Slim Buttes material was transported only a very short distance.

General conclusions: Whatever their age, the present lenses seem to represent remnants of a formerly widespread sheet of clastics. They resemble each other and the Slim Buttes Formation in the following respects:

1. Distribution as scattered lenses.
2. Stratigraphic position.
3. Relatively good sorting.
4. Grain size generally within the limits of sand.
5. Much better sorting than other Oligocene sediments.
6. Bimodal size distribution, with maxima in the medium sand and clay sizes.
7. Material either massive or crossbedded, but only the rare beds of a really persistent mudstone flat-bedded.
8. White color, due to weathered feldspar grains and cement of kaolin.
9. Clays with relatively higher content of kaolin and silica, and lower montmorillonite and mixed-layer, than other Oligocene sediments.
10. Feldspars highly weathered, in contrast with other Oligocene sediments which contain predominantly fresh feldspars.
11. General absence or low percentage of micas.
12. Absence of fresh or weathered pumice shards.
13. General absence of fossils, except in the rare local, dark-colored mudstones.
14. Presence of both angular and highly rounded quartz grains.

In view of these points of similarity, and in the absence of any evidence to the contrary, the white lenses of the Big Badlands are tentatively correlated with the Slim Buttes Formation.

The sorting, bedding, and grade of sediment suggest that this formation is lacustrine. Also, the presence of both angular grains and well-rounded, spherical grains of quartz, citrine, and tourmaline at Locality V cannot be satisfactorily explained by assuming that the worn grains are inherited. Inheritance of well-rounded grains of the same varieties of quartz and tourmaline as occur in first-generation clastics at the same spot, within 75 miles of the source, would be almost impossible. A much more logical explanation would be that certain grains have been rounded by wind and wave action along beaches, while others were introduced immediately prior to final deposition and suffered no appreciable abrasion.

This does not mean that the Slim Buttes Formation represents one continuous lake covering most of western South Dakota. If the whole area were somewhat below grade, it might be expected that a series of lakes would form, each receiving sediment from its respective feeder stream. The similarities noted between the sediments at different localities are mostly attributable to coeval deposition in similar lacrustrine environments under a uniform climatic regimen, with the Black Hills as the source of clastics. Differences are consistent with differences in the local headwater districts of the Black Hills, plus small differences in the province of deposition.

Judging from the paucity of micas and montmorillonite, and the absence of glass shards, little or none of the Slim Buttes formation is composed of pyroclastics. This suggests that deposition occurred at a time either when vulcanism was relatively inactive or when the prevailing winds carried the major ash falls away from western South Dakota.

The deep weathering of feldspars, with the development of a high percentage of kaolinite relative to montmorillonite, suggests a climate more consistently humid and probably warmer than that of Chadron time.

It must be freely admitted that the presence of lacustrine deposits over so wide an area poses a serious paleogeographic problem. The extremely large size of pebbles in conglomerates many tens of miles from their source offers a second difficulty. Finally, the fact that lenses occur on both sides of the Sage Ridge, as well as on the upland bordering the Red River Valley (which was old by earliest Chadronian time), is not at present explicable. In the absence of any general interpretation which would bring these facts into accordance with Chadronian history, I have simply interpreted the sediments as they occur and let the anomalies stand. This seems a sure way of exposing my interpretations to searching analysis. Naturally, I intend to study these rocks further. It is hoped that this chapter will incite others to investigate them independently from fresh points of view.

Chapter V

GEOLOGY, PALEOECOLOGY, AND PALEOCLIMATOLOGY OF THE CHADRON FORMATION

by

John Clark and J. R. Beerbower

INTRODUCTION

The fauna of the early Oligocene Chadron formation of South Dakota represents a transition between the Eocene jungle forest faunas and the later plains faunas of western North America. Therefore, a study of this fauna is of particular importance in clarifying the nature of major faunal changes and in determining some of the factors controlling these changes. The senior author began this work with a detailed description of Chadron stratigraphy (Clark, 1937), but an adequate faunal characterization was possible only for the upper member of the formation at that time. In field studies during 1940, 1941, 1946, 1953, and 1954, the senior author obtained sufficient additional information and specimens to justify an extended interpretation of Chadronian paleogeography, paleoclimatology, and paleoecology, and of the relationships of South Dakota faunas to certain other Oligocene assemblages.

The Chadron Formation as now defined comprises three members (Clark, 1954):

Peanut Peak	20–30 ft.
Crazy Johnson	20–40 ft.
Ahearn	0–80 ft.

Within the Big Badlands, the formation ranges in thickness from 8 to 130 ft. The Ahearn is definitely absent and the two upper members are not separable in the area of minimum thickness; probably only the Peanut Peak member occurs there.

The known fauna includes a wide variety of mammals plus poorly-known fish, amphibians, and reptiles. In general, fossils are more fragmentary and less abundant than in the overlying Brule Formation; many species are known only from a few specimens.

This chapter was originally written to be published as a separate paper; it was completed in 1957. It has been withheld since that date, pending completion of the other chapters of this study. The authors have modified the 1957 manuscript only by bringing the taxonomy up to date and by modifying certain interpretations in view of pertinent studies by others. No attempt has been made to establish detailed correlations with formations and faunas unknown in 1957, or to include specimens collected since then. This would entail completely reorganizing the study, which would unduly delay the whole project.

ACKNOWLEDGMENTS

The Carnegie Museum of Pittsburgh sponsored field work in 1940, 1941, and 1946. Princeton University and the Yellowstone-Bighorn Research Association sponsored the field work in 1953 and 1954. The research was aided by Geological Society of America Grant 658–54. Messrs. A. D. Lewis, H. O. Woodbury, L. Stagner, H. Stoll, T. Harrison, and D. T. Taylor served most competently as field assistants.

Studies of Chadron paleogeography and sedimentary petrology were carried forward during 1963 and 1964, under the sponsorship of the Field Museum of Natural History; Mr. Kenneth K. Kietzke served as field assistant.

The authors greatly appreciate the co-operation of geologists of the staffs of Princeton University, Lafayette College, the Field Museum of Natural History, the University of Chicago, and Harvard University. These gentlemen have so freely given of their time and experience, through numerous informal conferences, that it is impossible to credit each with the ideas he has contributed. The authors also wish to thank Mr. E. H. Taylor and Mr. D. T. Taylor, of Scenic, South Dakota, for their hospitality in permitting the use of their ranch as field headquarters.

STRUCTURAL RELATIONSHIPS

The Ahearn Member of the Chadron fills an old valley 70–90 ft. deep and approximately four miles wide, cut in the Pierre Shale. The valley walls slope not over 2–5°, and consist of the Interior zone weathered to depths of 30–50 ft. (Figs. 2 and 4).

The Crazy Johnson and Peanut Peak Members can be distinguished from each other only where they overly this old valley. Laterally on both sides, they extend as a 25–40 ft. blanket of bentonitic mudstones to the structure-controlled Sage ridge and Pine Hills. The Chadron thins locally to 8 ft. over the crest of the Sage Ridge, and in one small area it fails to cover the crest of the Pine Hills ridge. It thickens again to over 30 ft., north of the Sage Ridge and south of the Pine Hills.

The Chadron is everywhere conformably overlain by the Brule.

Occasional sedimentary dikes a few inches in width and less than one-half mile long transect the Chadron. They occur singly and are too few to give satisfactory statistical evidence for or against a preferred orientation. The fill consists either of identifiable Chadron material from lower strata cut by the dike, or of material probably Chadron but not surely identifiable. Chalcedony veins extend downward from the lower Brule into the upper few feet of the Chadron at many places. Genesis of the fissures occupied by the dikes and veins is not known, but it probably is not a reflection of basement structures.

LITHOLOGY

This section is based upon field observations plus laboratory studies of the following specimens:

G 3635
G 3637
G 3638
G 3733
G 3734
G 3735
G 3736
G 3740
G 3741
G 3941
G 3942
G 3943
G 3944
G 3945
G 3946
G 4013
G 4019
G 4102

Ahearn Member

The basal conglomerate of the Ahearn member occupies the middle of the old Red River Valley, but thins to disappearance along the margins. It reaches total thickness of 3–4 ft., is poorly bedded, and usually very poorly sorted. Cementation is also usually poor; many of the sandier patches can be dug with the fingers. The cement is calcite, occasionally intergrown with a little silica. At several places the cement directly at the Pierre Shale contact is pyrite, apparently produced by the reaction of sulfates in the Pierre with acid Chadron waters.

The conglomerate comprises pebbles from three sources: (1) remanie chert and quartz pebbles reworked from the Slim Buttes basal conglomerate; (2) sand and gravel directly derived from the Black Hills; (3) occasional pebbles and limonite concretions from the underlying Pierre.

The pebbles over about 20 mm diameter are all, apparently, secondarily derived from the Slim Buttes conglomerate. All pebbles above that size consist of chert, quartz, and quartzite, while the smaller gravel in the same outcrops is richly feldspathic, with unweathered granite pebbles. Since it is impossible to distinguish primary from inherited chert and quartz grit or sand, the relative amounts of each in the finer grades cannot be estimated. Failure to recognize the dual source of sediment led the senior author in 1937 (p. 279) to believe that increase in percentage of feldspar upward in the Chadron section was climatically controlled. He now believes that this increase in feldspar reflects progressively less dilution with Slim Buttes material, upward in section.

Above the basal conglomerate is 0–10 ft. of poorly-cemented olive green sand, overlain by a red, silty clay, 0–12 ft. thick, which includes bands of intraformational, red shale-pebble conglomerate. This basal sequence generally totals about 20 ft. thick. It is not uniform in development and is by no means sharply separable from the superjacent beds.

The overlying strata consist mostly of cross-bedded, greenish silty sandstones, streaked with pink and lavendar. Cross-bedding dips up to 30° are not rare, but the general average is 20–25°. Individual cross-bed sets generally reach dimensions of 100–300 yards laterally and 5–15 ft. vertically. The cross-beds dip east and southeast; a few dip northwest or south. Most of these sands contain considerable muscovite. The bentonite content varies from large amounts to none. Interbedded with these are channel fills of arkosic conglomerate, which project as irregular ledges among the vertically fluted, organ-pipe columns of cross-bedded silty sandstones.

The upper 20 ft. of the Ahearn Member is made up of light tan to orange siltstones, mostly poorly cemented, with numerous scattered concretions less than 2 in. diameter, of mixed calcite and limonite cement. Greenish, conglomeratic channel-fill sandstones are much smaller and less common than in the underlying strata, and are, in general, finer grained. In general aspect, the upper Ahearn resembles the Peanut Peak Member. Fossils are more abundant than in the lower part of the Ahearn, and some coprolites occur. The top of the Ahearn was in some places slightly eroded to depths of 2–3 ft. before deposition of the overlying Crazy Johnson sandstones.

Each of these lithologic subdivisions coarsens westward, without altering the general vertical gradation from relatively coarser to finer materials. Thus, at Indian Creek the basal conglomerate of 3 in. pebbles is overlain by sandstone lenses containing ¾ in. pebbles and these by silty claystone. Five miles to the west in Big Corral Draw, the basal conglomerate of 6 in. pebbles is overlain by sandstone lenses with 1¼ in. pebbles and these by sandy siltstones.

Two lenses, both near the top of the Ahearn Member, merit separate description.

The first is a bed of pure ash, approximately 3 ft. thick and 150 ft. long, N–S, which is exposed beneath a sandstone ledge in the SE ¼ of SE ¼, Sec. 4, T. 4S., R. 10E., Custer Co. Bedding is non-evident; planes of parting develop upon breaking the rock out. Microscopically, the material consists of abundant biotite, quartz, and devitrified glass, with subordinate oligoclase and apatite. The biotite and feldspar are both perfectly fresh. No isotropic glass has been observed.

Rare, very small zircons complete the list of minerals identified.

The second is a lens 0–3 ft. thick, 20 ft. wide, and at least 1/2 mile long, outcropping in the NW 1/4 of NW 1/4, Sec. 13, T. 4S., R. 12E., Pennington Co., in the drainage of Indian Creek, approximately 12 miles east of the first lens. It consists of pure white bentonite with abundant biotite. The percentage of oligoclase to quartz is higher than in the ash lens, and zircon has not been observed. Apatite occurs about in the same proportion as in the first lens.

Presumably, these two lenses were formed by ash falls into temporary ponds or lagoons. The difference in mineralogy suggests that two falls are represented rather than one. The absence of clastics and the generally monolithic character of both deposits indicate that each was produced by a single fall. This gives a useful measure of the amount of fine ash deposited by single falls, as well as of the local relief on a late Ahearnian depositional surface. The climatological environment necessary for devitrification and bentonitization of the glass, without noticeable weathering of either biotite or feldspar, is not known.

Crazy Johnson Member

In its central area of outcrop, where it overlies the Ahearn, the base of the Crazy Johnson Member consists of sandstones or arkosic conglomerates. Where it rests upon the Interior zone, the base is usually either greenish mudstone or nodules of white calcium carbonate. Greenish to bluish bentonitic siltstones comprise the bulk of the member.

Cross-bedded sandy siltstones, resembling those of the Ahearn Member in all respects except that they lack red color, commonly occur in the central area, associated with numerous thin, flaggy sandstones and arkosic conglomerates. The conglomerates and sandstones decrease in grade eastward. Maximum diameter of pebbles in the conglomerates at Quinn Draw (Sec. 14, T. 4S., R. 11E.) is 2 in.; 5 miles east at Indian Creek (Sec. 2, 10, 11, T. 4S., R. 12E.), it is 3/4 in.; at Cain Creek (Sec. 21, T. 43N., R. 42W.), 18 miles farther east, about 1/4 in.; and east of Weta (Sec. 14, T. 3S., R. 20E.), 48 miles farther, the coarsest sand is 0.2 mm. This size diminution does not represent that along the course of a single stream, since the heavy-mineral content differs significantly (see below) between some of these localities. However, it does represent transportation at increasing distances by contemporaneous streams of comparable size with a common source, the Black Hills, and common regimen.

Pseudoconglomerates are a characteristic feature of the Crazy Johnson Member. They consist of structureless lumps of gray, impure calcium carbonate up to 10 in. in diameter, which are jumbled in a matrix of fine, sandy siltstone. The lumps resemble cobbles of soft, massive limestone rather than concretions, are rounded, lack ramifying extensions, and are never intergrown. Since the Crazy Johnson Member contains no other pebbles larger than 2 in. diameter, and since the matrix of the pseudoconglomerates is fine-grained, these lime cobbles are probably autochthonous rather than stream-transported boulders of an older limestone. Their roundness and soft surface suggest that they are chunks of calcium carbonate ooze, broken up before complete induration by flood invasion of the shallow swamps or ponds in which the ooze was accumulating. Unfortunately, no unbroken deposits of this type have been found: the known pond limestones show extensive algal structures and contain fossil snails or mussels. The origin of these cobbles is, therefore, obscure, and the term "pseudoconglomerate" is used for them in preference to the much more definitive "intraformational conglomerate." In any case, these pseudoconglomerates, more than any other sedimentary type, are associated with the famous "graveyards" of titanothere bone which occur at the base of the Member.

The senior author described in an earlier paper (Clark, 1937, p. 301) a humus zone in association with a titanothere graveyard and a pond limestone. Re-examination has shown that the supposed humus is a zone stained with diffused, powdery manganese dioxide. Study of the other known dark zones within the area has demonstrated that they all derive their color from manganese dioxide, and that no humus is preserved in the Chadron of the Big Badlands.

The Crazy Johnson Member thins westward to less than 20 ft.; in contrast, the Ahearn thickens to 80 ft., but the total thickness of the two remains approximately 100 ft.

Both north and south of its central area of coarser sediment, overlying the Ahearn Member, the Crazy Johnson sediments grade rapidly to pale bluish, greenish, and gray bentonitic mudstones with occasional impure limestones of small areal extent, a few inches thick. These sediments blend indistinguishably with those of the overlying Peanut Peak Member to form a single unit.

Peanut Peak Member

The Peanut Peak Member rests comformably on the Crazy Johnson Member; its thickness ranges from 20–30 ft. A pond limestone, flaggy sandstone, or channel fill conglomerate usually marks the base of the Peanut Peak in the central area of deposition; north and south of this district, as described above, the two members are not separable.

The Peanut Peak comprises light tan to greenish silty clays, mottled with orange in many places. In the western part of the central area, the entire member is orange for distances of more than a mile. Sandstones and channel fills are notably smaller, less numerous, and finer-grained than in the immediately underlying Crazy Johnson, over the entire area from Big Corral Draw eastward. To the west, a few major channel fills persist throughout the member, and into the overlying Brule, carrying pebbles as large as any in the underlying Crazy Johnson Member.

The upper few feet consist of silty mudstone interbedded with thin, discontinuous limestones. Some of the latter form definite lenses a few hundred feet in diameter, composed of algal limestone with associated snails and ostracods. Others are less than an inch thick, unfossiliferous, highly irregular, and anastomose from one local horizon to another. These apparently represent lime concentrations or caliches formed under semi-arid conditions, while the fossiliferous limestones are actual pond deposits. The contact with the overlying Brule is almost everywhere a pond limestone.

General Observations

The Chadron Formation exhibits foreset types of cross-bedding throughout most of its central area of deposition, exclusive of channel fills proper. The local depositional relief indicated is up to 10 or 12 ft. The average grade of clastic sediment is notably coarser than that of the succeeding formations, and finer than that of the Slim Buttes formation. The cross-bedding somewhat resembles that of the Slim Buttes, but differs from the horizontal bedding which characterizes the interfluve deposits of the succeeding formations.

Individual channel fills can be differentiated only rarely and for short distances. When they can, as at the standard section of the Crazy Johnson Member (SE 1/4, Sec. 10, T. 4S., R. 12E.), they exhibit cutbanks with a maximum slope of 60° and 5 to 10 ft. of relief. The great majority have banks which slope 1–5°, and a relief of 3–5 ft.

The channel fills show division on a scale of individual channelways 1–5 ft. wide, and usually 1–3 in. deep, immediately contiguous to each other. That is, a cross-section normal to the direction of flow transects any one stratification surface in a continuous curve reversing direction, like a series of open S-curves lying on their sides. The interchannel bars are neither flat-topped nor larger than the channels. The channel sediments usually form sand waves with rounded crests, of a few inches wave length, which V downstream. No deformed cross-strata, oversteepened dips, or recumbent folds have been observed. Figure 6 indicates directions of channel fills. No true meanders occur and only a few open bends of more than 45° change in direction have been noted.

The sands fall into two sharply different mineralogic groups. All of the Ahearn sands, and all but one of the Crazy Johnson-Peanut Peak sands in the main area of outcrop contain abundant black to smoky-olive tourmaline, pink to gray garnet, and brown staurolite, with subordinate glauconite, muscovite, and rounded, pearly chips of fossil bone. Pyrite, limonite, and barite may be absent to common, and seem to be authochthonous when they occur. Biotite is rare, although it occurs quite commonly, as does tourmaline, as tiny inclusions in quartz grains. This assemblage was determined by Seefeldt and Glerup (1958) to be typical of sediments derived from the southern Black Hills, from the Harney Peak area southward.

The light portion of the large sizes (above 250μ) consist of angular to subangular quartz grains; pink, yellow, and greenish feldspars; gray, quartzose schist; occasional yellow to gray chert; and greenish clay pellets.

In the smaller grades, some very well rounded, frosted quartz grains appear, presumably inherited from older sandstones in the Black Hills. The pink, cream-colored, and greenish feldspars show considerable alteration to white kaolin, increasing in the smaller sizes until very few recognizable feldspars remain. Colorless feldspar grains with a microperthite structure, whose optical properties place them in the oligoclase-sanidine range, show no alteration at all. The suggestion is that the clastic feldspars were altered during erosion and transport, while the volcanic feldspars underwent quick burial at the approximate site of their airborne arrival.

A second group of sandstones is represented by two outcrops: one channel fill 75 ft. wide and 15 ft. thick, trending S 20° E., at the top of the Crazy Johnson Member 2½ miles west of Scenic, NW ¼ of NE ¼, Sec. 19, T. 3S., R. 12E., Pennington Co.; and one channel fill trending SSE, in the SE ½ of Sec. 14, T. 3S., R. 20 ., Jackson Co., 1½ miles east of Weta, probably in the Crazy Johnson Member (individual members cannot be distinguished here).

The heavy minerals of this group are much more varied than in the southern-derived group. The list includes:

Epidote, greenish yellow
Magnetite, euhedral to rounded
Actinolite, greenish, acicular
Sphene, lemon yellow
Garnet, pink
A black, nonmagnetic, isometric mineral
Biotite (not common)
Limonite (not common)
Glauconite (not common).

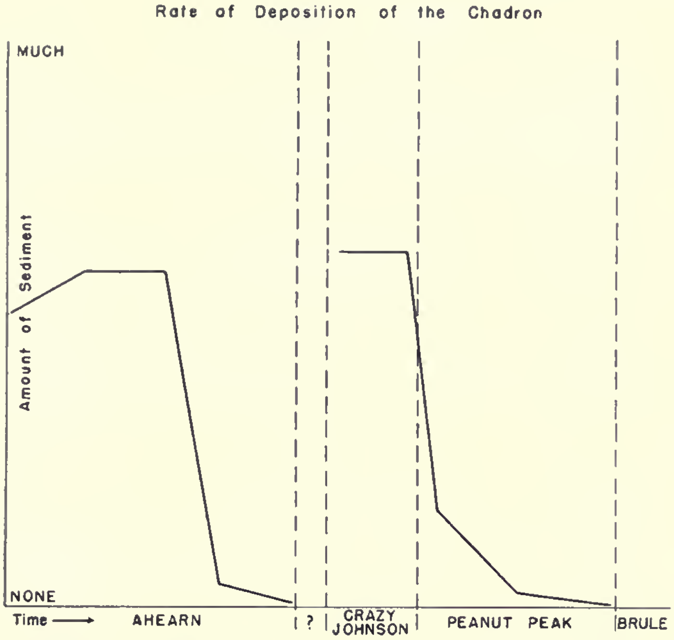
In addition to these, which are common to both localities, the Scenic locality contains:

Hornblende
Muscovite
Gypsum.

The Weta locality contains the following which have not been identified at Scenic:

Staurolite
Barite (autochthonous)
Black tourmaline
Colorless zircon
Rutile
Pyrite (autochthonous)
Waxy, red hematite
Columnar, colorless apatite
Gold (very rare).

Ritter and Wolff (1958) demonstrated that, in the Brule sandstones, a suite including abundant magnetite, lemon-yellow sphene, actinolite, and epidote is characteristic of sediments derived from the northern Black



This graph is approximate only. Time intervals of rapid deposition may be much shorter, and intervals of slow deposition to non-deposition longer, than shown here.

FIG. 9. Rate of Deposition of the Chadron Formation.

Hills. The staurolite and black tourmaline in the Weta sample may indicate an admixture of materials by confluent streams from two sources, or may indicate reworking of southern-Black Hills-derived sediments of Slim Buttes or Ahearn member age by these later Chadronian streams. It is not possible to determine whether the rutile and zircon of the Weta sample are primary or are inherited from the Slim Buttes formation in the immediate area, which is known to have been eroded by Chadronian streams (see Fig. 9).

The light minerals consist primarily of quartz and feldspars. The quartz comprises angular grains, both milky and clear, with minor quantities of citrine, but also many clear grains bearing yellow surface stains. A few of the larger grains contain biotite inclusions.

The feldspars are divisible, like those of the southern-derived sediments, into creamy to greenish plutonic feldspars, mostly deeply weathered, and fresh, sharp-edged oligoclase-andesine grains, presumably volcanic.

Abundant chert grains of several colors characterize the Scenic specimen, but the Weta sand includes only occasional grains of gray chert.

General Conclusions

The lithology of the Chadron Formation suggests that deposition occurred in two major episodes, one represented by the Ahearn Member, the other by the Crazy Johnson and Peanut Peak Members (see Fig. 9). In each case, deposition started with generally coarse sediments which became progressively finer, and apparently were deposited more slowly. During the periods of slow deposition in late Ahearn and Peanut Peak times, the interfluve sediments underwent mild, incipient lateritization, just sufficient to develop pale orange colors. In the later period, lateritization was confined to the immediate neighborhood of the stream channels, and formation of caliche was the more widespread surface process. We conclude therefore that Peanut Peak time was probably drier than late Ahearn time, and was characterized by seasonal groundwater fluctuations accordant with periodic changes in volume of stream flow. During late Ahearn time streams were much larger, so that no part of the valley plain lay far away from them, and lateritization may have occurred as a result either of seasonal, local rainfall or of seasonal increases in stream flow from the Black Hills.

The heavy mineral suites give clear indication of a shift in location of major drainages during Crazy Johnson time. Specimens G 3942 from the base of the Crazy Johnson northeast of Scenic, and G 3733, from the same horizon east of Imlay, are composed of clastics derived entirely from the southern Black Hills. The southward-trending channel fill west of Scenic, from the top of the Crazy Johnson, (specimen G 4019) is composed of sediments from the northern Black Hills. This represents a westward shift of at least 12 miles, of the southwesternmost stream from the northern Hills, at the expense of the southern Hills drainage (see map, Fig. 3).

SYSTEMATIC PALEONTOLOGY

Introduction

The known Chadron fauna of the Big Badlands comprises fish, amphibians, reptiles, birds and a variety of mammals. Although fossils other than titanotheres are not common in the Ahearn and Crazy Johnson members, a sufficient number have been found to provide a reasonable sample of the successive vertebrate faunas. Because the Peanut Peakian fauna was treated in an earlier paper (Clark, 1937) only a summary of those forms will be given here except where additional materials demand a reinterpretation, or where a restudy has shown that a modification of earlier opinions is proper. The "microfauna locality", in Peanut Peak sediments, lies in the north part of the SE ¼ of Sec. 3, T. 42N., R. 45W., Shannon Co., South Dakota. In general, we have assigned the various genera in accordance with the classification of mammals proposed by Simpson (1946).

Class Osteichthyes
Subclass Actinopterygi

The only fish materials known from the Chadron are a collection of small bones, probably in a non-evident coprolite, from the lower part of the Ahearn Member (PM 13601) and several ganoid scales from the Ahearn and Crazy Johnson Members.

Class Amphibia
Order Anura
Family Pelobatidae
Genus **Eopelobates**

Eopelobates grandis

Specimen.—PM 16441; partial skeleton; Ahearn member.

Discussion.—Close relatives of this frog now inhabit the typical lowlands in Indonesia and southern China, and the upland forests of the southeastern Tibetan rim.

Class Reptilia
Order Chelonia

Although turtle material from the Chadron is not of great systematic importance, it is of significance in interpretation of Chadron environments. Most of the following list is based on field identification of scrap.

Family Emydidae
Genus **Graptemys**

Graptemys cordifera

Specimen.—PM 13838; carapace and plastron; Crazy Johnson member.

Graptemys sp.

Specimens.—Scrap from Ahearn Member.

Genus **Trachemys**

Trachemys antiqua

Specimen.—PM 13839; plastron, right bridge, right posterior border of carapace; Crazy Johnson Member.

Trachemys sp.

Specimens.—Scrap from Ahearn Member.

Family Trionychidae
Genus **Amyda**

Amyda sp.

Specimens.—Scrap from Ahearn Member.

Family Dermatemydidae
Genus **Pseudanosteira** or **Anosteira**

Sp. indet.

Specimens.—Scrap from Ahearn Member.

Anosteirine, g. indet.

Specimens.—PM 16302; marginal plate; Crazy Johnson Member. PM 16303; two marginal plates; Crazy Johnson Member.

Discussion.—The discovery of anosteirine material in the Chadron represents an upward extension of the time range of a typically Eocene group.

Genus **Xenochelys**

Xenochelys formosa

Specimens.—PM 13686; skull; Crazy Johnson Member.

Discussion.—This specimen was described and figured by Williams (1952).

Order Squamata
Suborder Lacertilia
Family Anguidae
Genus **Peltosaurus**

Peltosaurus sp.

Specimen.—PM 16304; fragment of skull; Ahearn Member.

Peltosaurus

Specimen.—Maxillary; microfauna locality; Peanut Peak Member.

Discussion.—This specimen might represent *Glyptosaurus* rather than *Peltosaurus.*

Order Crocodilia
Family Alligatoridae
Genus **Alligator**

Alligator cf. *prenasalis*

Specimen.—PM 16273; skull and jaws; Ahearn Member. PM 13799; skeleton; Crazy Johnson Member. Fragmentary specimens from Ahearn and Crazy Johnson Members. Not collected.

Class Aves
Order Passeriformes
Genus indet.

Specimens.—Two scapulae, three ulnae, distal end of tarsometatarsus; microfauna locality: Peanut Peak Member.

Class Mammalia
Order Marsupialia
Family Didelphidae
Genus **Peratherium**

Peratherium sp.

Specimen.—One jaw with fragments of teeth; microfauna locality; Peanut Peak Member.

Order Insectivora
Family Apternodontidae
Genus **Apternodus**

Apternodus altitalonidus

Specimen.—PM 13774; fragment of left mandible with P_4-M_3; Peanut Peak member; microfauna locality.

Apternodus mediaevus

Specimen.—CM 8669; skull and jaws; Peanut Peak Member.

Genus **Clinopternodus**

Clinopternodus gracilis

Specimen.—PM 13835; mandibular ramus with C, P_{3-4}, M_1, Peanut Peak Member; microfauna locality.

Family Leptictidae
Genus **Ictops**

Ictops dakotensis

Specimens.—PM 13605; mandibular ramus; Peanut Peak Member. PM 13773; six partial maxillae and four mandibular rami; Peanut Peak Member; all from microfauna locality.

Family Metacodontidae
Genus **Metacodon**

Metacodon magnus

Specimen.—PM 13835A; partial lower jaw with P_4-M_3; Peanut Peak Member; microfauna locality.

Order Primates
Family Apatemyidae
Genus **Sinclairella**

Sinclairella dakotensis

Specimen.—PM 13585; crushed skull and lower jaws; Peanut Peak Member; microfauna locality.

Order Rodentia
Family Ischyromyidae
Genus **Ischyromys**

Ischyromys sp.

Specimen.—CM 9493; mandible; Ahearn Member.

Family Eomyidae
Genus **Adjidaumo**

Adjidaumo minutus

Specimen.—PM 13832; two lower jaws; Peanut Peak Member; microfauna locality.

Adjidaumo sp.

Specimen.—CM 9400; partial mandible with two molars; Crazy Johnson Member.

Genus **Paradjidaumo**

Paradjidaumo minor

Specimen.—PM 13831; eight lower jaws; Peanut Peak Member; microfauna locality.

Genus indet.

Specimen.—PM 16306; incisor; Ahearn Member.

Family Eutypomyidae
Genus **Eutypomys**

Eutypomys cf. *thomsoni*

Specimen.—Two molar teeth; (specimen not located 1956; see Clark, 1937); microfauna locality; Peanut Peak Member.

Order Lagomorpha
Family Leporidae
Genus **Megalagus**

Megalagus turgidus

Specimens.—Two sets of lower molars; no numbers; microfauna locality; Peanut Peak Member.

Order Carnivora
Suborder Creodonta
Family Hyaenodontidae
Genus **Hyaenodon**

Hyaenodon cf. *cruentus*

Specimens.—CM 9090; two milk molars, possibly DP_4-M_1; Crazy Johnson Member. PM 12745; mandibular ramus; Peanut Peak Member.

Hyaenodon cf. *montanus*

Specimens.—CM 9098; two upper molars, possibly P^4-M^1; Ahearn Member. PM 12970; skull and part of lower jaw; Peanut Peak Member.

Hyaenodon cf. *horridus*

Specimen.—PM 16288; M_3; Ahearn Member.

Suborder Fissipedia
Family Canidae
Subfamily Caninae
Genus **Hesperocyon**

Hesperocyon gregarius

Specimen.—PM 13630; mandibular ramus with P_4-M_3; Peanut Peak Member; microfauna locality. No number, Princeton; mandibular ramus with P_4-M_1; Peanut Peak Member.

Genus **Daphoenus**

Daphoenus sp.

Specimen.—CM 8799; fragment of right lower jaw with alveoli of P_4-M_1; Crazy Johnson Member.

Discussion: This fragment, about the same size as *D. hartshornianus* or *Daphoenocyon minor*, has a narrow, shallow jaw, and, as indicated by the alveoli, well-spaced narrow teeth. The specimen is a typical *Daphoenus* and cannot be referred to *Daphoenocyon*. This is the only specimen of *Daphoenus* from the Chadron, and we believe that *Daphoenus* was probably rare at this time. Certainly it was uncommon even during Brule time. Its place in the Chadron ecosystem was probably preempted by *Daphoenocyon* which resembles it closely in post-cranial osteology.

Subfamily Amphicynodontinae
Genus **Parictis**

Discussion.—The discovery of a new species of *Parictis* in the Ahearn Member poses a difficult taxonomic problem. The species (*P. parvus*) strongly resembles *P. dakotensis* and an undescribed species from Pipestone Springs but also shows very close affinities to *Campylocynodon personi* and indeed may be synonymous (see *Discussion* under *P. parvus* below). We believe that *Campylocynodon* is best relegated to the status of a subgenus of *Parictis* with *C. personi* as type species because recognition as a separate genus of slender-jawed parictines would require a taxonomic grouping of the two below the subfamily rank. *Parictis* then comprises two subgenera, *Campylocynodon* and *Parictis*, with a trend from early forms with trenchant sectorial but rounded tubercular dentition to later species with the entire dentition low, broad, and rounded.

Comparison with *Daphoenus*, *Hesperocyon*, *Daphoenocyon dodgei*, and the European genera *Cynodictis*, *Cynodon*, and *Cephalogale* demonstrates that the de-

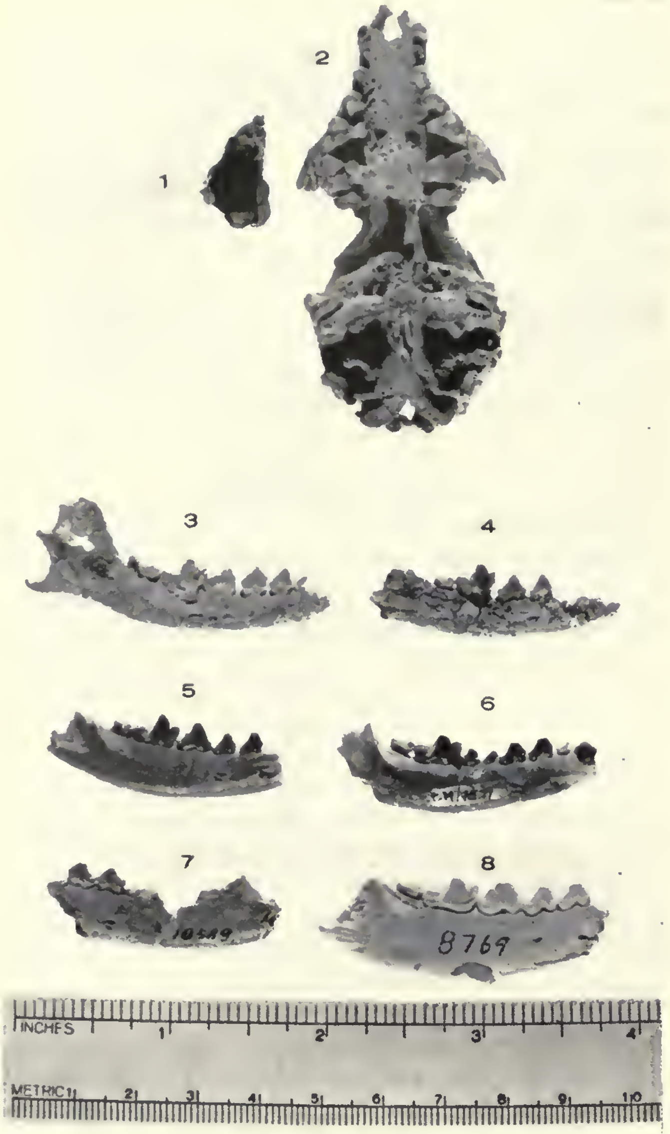


FIG. 10. The genus *Parictis:* lateral view of specimens. 1. Undescribed species from Montana. 2. Type specimen of *Parictis* (*Campylocynodon*) *personi*. 3. Type specimen of *Parictis* (*Campylocynodon*) *personi*. 4. Type specimen of *Parictis* (*Campylocynodon*) *parvus*. 5 & 6. Undescribed species from Montana. 7. Genotype specimen of *Parictis* (*Parictis*) *primaevus*. 8. Cast of type specimen of *Parictis* (*Parictis*) *dakotensis*.

velopment of an accessory cusp on the protoconulid of M_1 and the crowding of the trigonid of M_1 are valid characteristics distinguishing the genus *Parictis*. Figures 10 and 11 illustrate the known specimens of the genus.

Subgenus *Campylocynodon*

Parictis (*Campylocynodon*) *personi* Chaffee, type species.

Diagnosis.—Characteristics as for the genus, but the jaw is relatively slender and the sectorial dentition somewhat trenchant.

Parictis (*Campylocynodon*) *parvus*, n. sp. (Figs. 10–12).

Type.—PM 16265; right lower-jaw with P_3-M_2 and alveoli of C, P_{1-2}, M_3; red layer near base of Ahearn member; west flank of Quinn Draw, SW 1/4, sec. 25, T 43N, R. 46W, Shannon Co., South Dakota.

Description.—Ramus of jaw slender, mental foramina below anterior root of P_2 and posterior root of P_3; P_3 short, outline shaped like a parallelogram, principal cusp high with a ridge extending down to the postero-external angle of the tooth but with no accessory cusp; anterior and posterior cingula heavy, but not connected across labial and lingual faces of the principal cusp. Principal cusp set anteriorly, but directed vertically or slightly posteriorly. P_4 ovoid in plan, slightly larger than P_3. Principal cusp vertical, with a blade-shaped, well-developed accessory cusp half-way up the postero-external ridge. Cingula heavier than on P_3 but not meeting laterally. M_1 relatively low-crowned, shorter and broader than M_1 of *P.* (*Campylocynodon*) *personi;* trigonid with paraconid more lingually placed than in *P. personi,* but otherwise similar; pronounced cingulum across anterio-external face of trigonid. Talonid much shorter than in *P. personi;* hypoconid a cutting ridge; entoconid-hypoconulid forming a lingual ridge, separated from the hypoconid by a trench which notches the posterior rim of the tooth; small but marked cingulum on exterior face of hypoconid. M_2 two-rooted, broad, short, very low-crowned. Cusps of trigonid well-developed, stout, triangular, very closely crowded at the antero-internal corner of the tooth. A low, heavy accessory cusp on the postero-external corner of the protoconid lies directly posterior to the antero-external cingular shelf. Hypoconid slightly lower than in M_1; talonid broadly basined, with entoconid-hypoconulid very weakly developed. M_3 single-rooted.

Discussion.—This species may be synonymous with *P.* (*Campylocynodon*) *personi.* The dental characters of the type of *P. personi* are, unfortunately, almost indeterminable. Major differences between the two type specimens are: (1) *P. parvus* is smaller overall; (2) *P. parvus* has teeth that are shorter antero-posteriorly but equal in width and in height of crown; (3) talonid of M_1 is proportionally much smaller in *P. parvus.* Since only one specimen of each species is known, the range of variability of these characters cannot be determined at present. The tendency toward low-crowned teeth with heavy cingula is evident in *P. parvus,* but the proportionally heavy jaw characteristic of the subgenus *Parictis* is not apparent.

Subgenus **Parictis**

Parictis (*Parictis*) *dakotensis*

Diagnosis.—Characteristics as for the genus but with proportionally heavy jaw and low crowned, blunt dentition.

Parictis (*Parictis*) *dakotensis*

Specimen.—So. D. School of Mines; right mandible with P_{2-4} M_{1-2}; probably Peanut Peak Member.

Genus **Daphoenocyon** Hough

Daphoenocyon dodgei (Scott), type species.

Diagnosis.—Strongly brachycephalic; flaring zygomata; deep thick jaw. Molar series relatively long, 85–97% of premolar length as compared with 64–71% in *Daphoenus* and 78–89% in *Hesperocyon.* Canines verti-

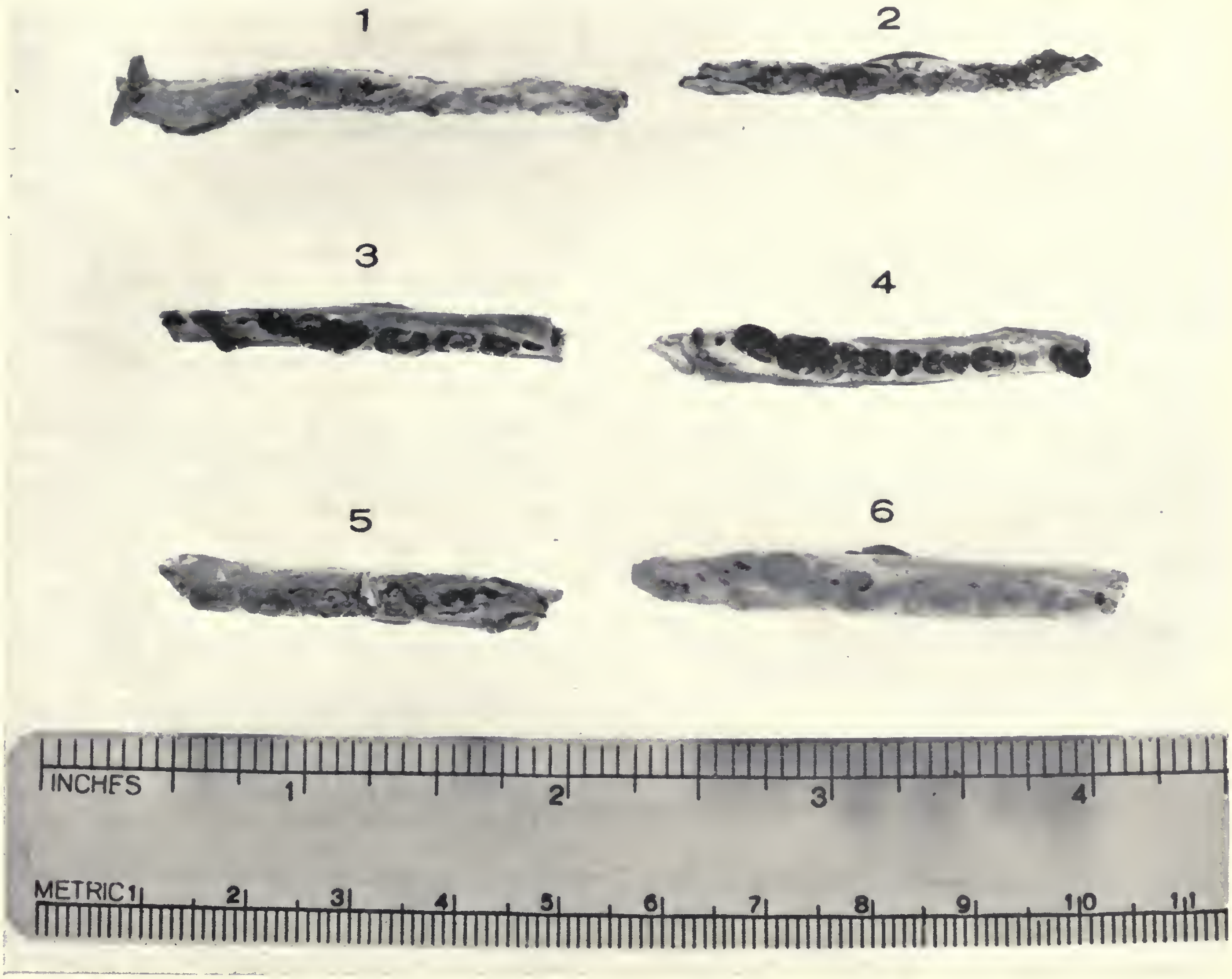


FIG. 11. The genus *Parictus:* crown view of mandibles. 1. Type specimen of *Parictis* (*Campylocynodon*) *personi*. 2. Type specimen of *Parictis* (*Campylocynodon*) *parvus*. 3 & 4. Undescribed species from Montana. 5. Genotype specimen of *Parictis* (*Parictis*) *primaevus*. 6. Cast of type specimen of *Parictis* (*Parictis*) *dakotensis*.

cal, trenchant. Pre-molars short and heavy. General facial character simulates that of felids (Figs. 14–16).

Discussion.—Hough, (1948) described the genus *Daphoenocyon* with *Daphoenus dodgei* as the type species. She based her description on the type material (PM 11422), which comprises three partial jaws from the Chadron formation, White Horse Creek, Nebraska, and on two skulls with lower jaws (USNM 17847 and Walker Museum 1456) from the Orellan. Restudy of the type material and of the specimens referred by Hough, and study of new material from the Chadron, demonstrates that this reference of USNM 17847 and WM 1456 is incorrect. Hough states (p. 594):

Measurements of *Parictis (Campylocynodon) parvus*

	Length	Width	Height
P_3	4 mm.	2.1	3.4
P_4	4.8	2.6	3.6
M_1	6.4	3.6	4.6
M_2	3.3	2.8	1.4

FIG. 12. Measurements of *Parictis* (*Campylocynodon*) *parvus*.

> "A brachycephalic, short-faced carnivore about the size of a large coyote but very differently proportioned. Frontal sinuses prominent, giving the upper profile of the skull something the appearance of that of a domestic dog. Basicranial region very short in comparison with other daphoenid genera. Auditory region short and narrow. Promontorium large. Mastoid produced into a rugose knob projecting downward. Facial nerve apparently leaving the skull through a groove posterior to the mastoid process.
>
> "Type species: *D. dodgei* Scott 1898
>
> "*Specific characters*: Lower jaw exceptionally short, maximum length 51 mm. Premolars crowded. P_2 and P_3 as well as P_4 with accessory cusps. M_1 much more primitive with anterior cusp (protoconid) more rounded than in other genera; metaconid also higher and more rounded, talonid with high median cusp."

Also, p. 578:

> "Genus *Daphoenocyon*
>
> "This genus, described below, is closely related to *Brachyrhynchocyon* but is larger and has a very short cranium as well as face.

> The basicranial region is also very short. The lower jaw is short and thick. The premolars are crowded but not reduced. The frontal sinuses are prominent and this together with the rounded cranium goes the skull some resemblance to that of a domestic dog. The promontorium is large and rounded. The mastoid produced into a rugose knob. The facial nerve apparently left the skull posteriorly of the mastoid process. Accessory cusps are present on P_2 and P_3 as well as P_4. The molars are triangular with little development of the internal cingulum. M_3 is a small rounded tooth situated in the angle of the jaw."

USNM 17847 has no lower teeth except the canine, P_1, and anterior half of P_2. The canine is long and slender as in *Daphoenus vetus* and utterly unlike the short, massive canine in the type of *D. dodgei*. Since P_1 is missing from the type, no comparisons of this tooth are possible. The anterior portion of P_2 is slender with the principal cusp over the middle of the tooth and the anterior ridge sloping. This is the typical structure of P_2 in *Daphoenus vetus* and *Daphoenus hartshornianus*, but in *Daphoenocyon dodgei* the tooth is broad with the principal cusp set forward and the anterior ridge almost vertical. The jaw in *Daphoenocyon dodgei* is deep and heavy; in USNM 17847, it is long and slender as in *D. vetus*. It must be concluded that there is no basis referring this specimen to *D. dodgei*.

Posterior Accessory Cuspule on Premolars
of *Daphoenus*

Key:
○ absent
⊗ present but very small
X present
— broken or worn: indeterminable

Species	Specimen Number	P_3	P_2
Protemnocyon inflatus (◇H) = *Daphoenus vetus*	CM 552	—	⊗
Daphoenus hartshornianus	CM 3697	—	○
	PM 12650	—	⊗
vetus (S & J list as *hartshornianus*)	PM 13580	L ⊗ R ○	L ⊗ R ○
	PM 13600	X	○
	PM 13792	⊗	○
(type *felinus*)	PM 11425	X	⊗
vetus (S & J list as *hartshornianus*)	PM 12635	—	⊗
	PM 12651	X	⊗

FIG. 13. Posterior accessory cuspule on premolars of *Daphoenus*.

The skull associated with the lower jaws in USNM 17847 is that of a small *Daphoenus vetus* with facial proportions, length of the basicranium, and details of basicranium and auditory area like those of *Daphoenus vetus*. Hough, in her description, mistook features produced by distortion and breakage for generic characters.

The lower dentition of WM 1456 resembles the type of *D. dodgei* only in the development of posterior accessory cuspules on P_2 and P_3. Accessory cuspules are, however, present in some typical *Daphoenus vetus* and *Daphoenus hartshornianus* as indicated in Figure 13, and so are not diagnostic of *D. dodgei*. The lower dentition otherwise is that of a typical *Daphoenus vetus*, with long slender premolars having a central principal cusp. The skull of WM 1456 is badly crushed, but the proportions are those of a normal, dolichocephalic *Daphoenus vetus*. The only basicranial character in which this specimen differs from typical *Daphoenus vetus* is enlargement of promontorium.

Since neither WM 1456 nor USNM 17847 can be assigned to *D. dodgei* and since they do not differ from *Daphoenus vetus* in any significant way, a complete redescription of the genus *Daphoenocyon* based on the Chadron specimens is necessary.

Description.—The lower jaw is thick with a deep, sharply-rimmed temporal fossa, a sub-triangular coronoid process shorter than in *Daphoenus*, a heavy, inflected angular process with a deep dorsal furrow, and a definite chin (Fig. 14). The anterior mental foramen is below P_2 and is large; the posterior below P_3 and small. The canine is vertical and heavy. P_1 has a single root, is vertical, and ovoid-cone-shaped. P_2 is sub-quadrangular and is inflated posteriorly, with a posterior accessory cusp. P_3 and P_4 are like P_2 but are successively larger with larger accessory cusps; P_4 is less inflated than P_3. The premolars are all vertical to slightly raked posteriorly and P_{1-3} are echeloned or are out of line. M_1 is like that of *Daphoenus* but heavier and with lower crown and a quite shallow, basined talonid. M_3 is missing from all specimens but was large and had a single to double root. The molar series is relatively long and the entire lower dentition is broad and massive.

The skull is strongly brachycephalic—the muzzle includes only P^1. The narial opening is large, with its anterior rim vertical. The nasals slope upward posteriorly at an angle of about 25° to the tooth row. The incisor row is moderately arched, the teeth vertical with posteriorly raked points, and not crowded. I^{1-2} are small and transversely spatulate with I^2 larger than I^1. I^3 is much larger and caniniform with short anteromedian and long postero-external ridge.

The canine is straight, heavy, and vertically directed. The surface between the antero-internal and postero-external ridges is nearly flat and blade-shaped, but the external face is cone-shaped with a slight flattening posteriorly. There is no diastema between the canine and P^1. The latter tooth is small, single rooted, and high, and was probably functional. P^2 is simple, quadrangular and massive. The principal cusp is high and directed posteriorly. The cingulum is complete. A faint ridge runs from the cusp to the postero-external angle of the tooth and another to the antero-internal angle. P^3 is like P^2 but is larger and more sharply quadrangular, has a tiny accessory cusp on the postero-external ridge, and a heavy postero-external cingulum. P^2 and P^3 are not in line with each other. P^4 is low and simple with the cingulum complete but weak antero-internally. The protocone is low and heavy; no cusp is present on the

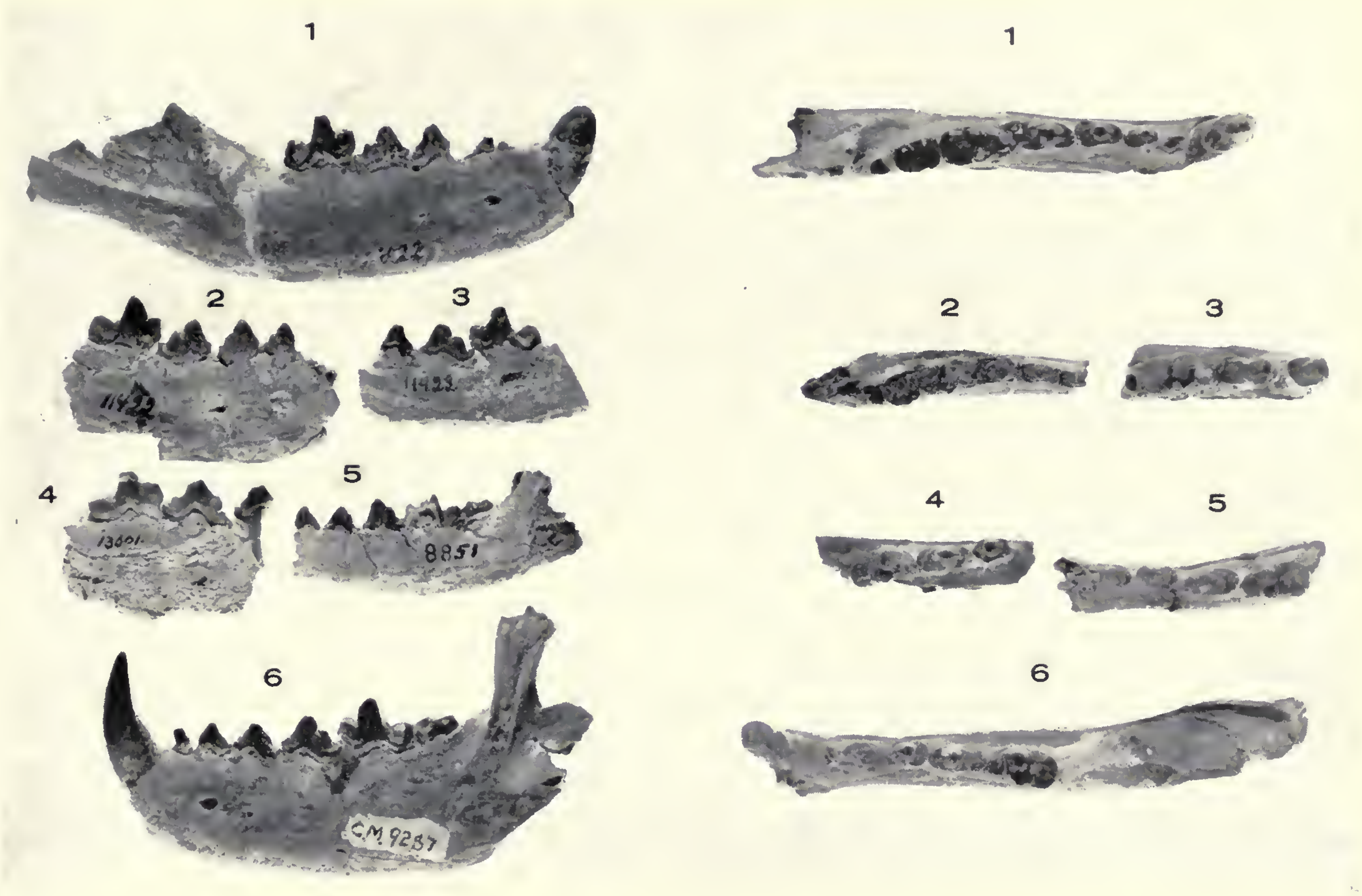


FIG. 14. The genus *Daphoenocyon:* mandibles.

antero-external cingulum; and the deuterocone is prominent with a low lateral crest extending to meet a similar crest on the protocone. M^1 is large and like that of *Daphoenus*. M^3 is small, narrow, and double-rooted. Occlusal surfaces show wear, indicating that it was functional.

Daphoenocyon dodgei (Scott)

Daphoenus dodgei Scott, 1898, Notes on the Canidae of the White River Oligocene, Trans. Am. Philos. Soc., **19**, (n.s.), p. 362.

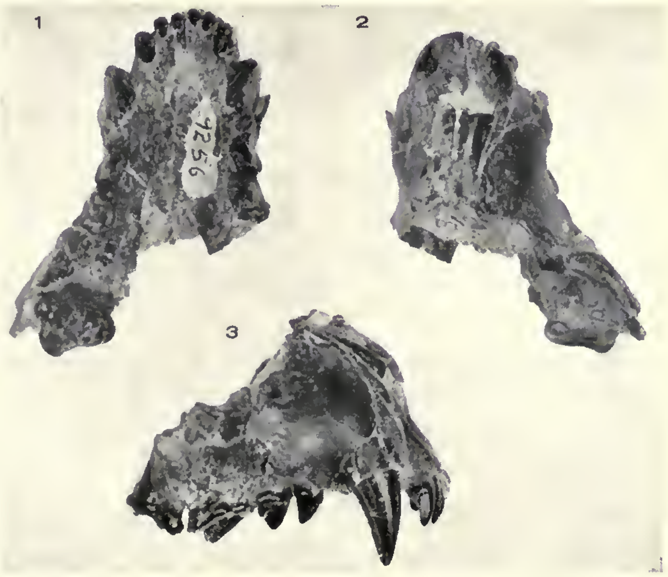


FIG. 15. The genus *Daphoenocyon* CM 9256, paratype specimen.

Daphoenocyon dodgei Hough, 1948, A Systematic Revision of *Daphoenus* and some allied genera. J. Paleo., **22**, pp. 578, 594.

Type.—PM 11422; Lower Jaw; Whitehead Creek, Nebraska; "Titanotherium Beds."

Paratypes.—CM 9256; anterior part of skull with I^1-M^1; Chadronian; Pipestone Springs, Montana. CM 9287; lower jaw; Chadronian; Pipestone Springs, Montana. CM 9508; pair of lower jaws; Chadronian; Spring Gulch, West of Sage Creek, Beaverhead Co., Montana.

Referred specimens: PM 13601; lower jaw; Peanut Peak Member. PM 16280; P_3-M_1; upper part of Crazy Johnson Member. CM 9825; lower jaw; Chadronian; Pipestone Springs, Montana. CM 9057; lower jaw broken and rehealed; Chadronian; Pipestone Springs, Montana. CM 9573; lower jaw with periostitis, Chadronian, Pipestone Springs, Montana. CM 9358B; lower jaw fragment, P_{3-4}; Chadronian; Hadcock Ranch, W. side of Missouri River, S. end of Sewell Lake, Broadwater Co., Montana. CM 673; lower jaw; Chadron Formation; Near Sugar Loaf, Sioux Co., Nebraska.

Diagnosis.—Large size, P_1-M_3 58–63 mm. Jaw very deep and heavy. Other characters as in description of genus.

Discussion.—*Daphoenocyon dodgei* apparently represented a highly variable population—specimens from Pipestone Springs show a variability of about 10% with little or no association between the varying characters. The *D. dodgei* specimens from South Dakota may repre-

Comparative Measurements of *Daphoenocyon*, *Daphoenus*, and *Parictis*

	Daphoenocyon *D. dodgei* type, PM 11422 A	B	C	*D. vetus* WM 1456	*D. vetus* PM 13580
P_2 length		6.5		8.5	8.4
P_2 width		4.3		3.8	3.6
$P_2\ \frac{W}{L}$		.661		.447	.429
P_3 length	8.2	8.2	8.1	9.9	9.9
P_3 width	4.9	5.3	4.9	4.4	4.2
$P_3\ \frac{W}{L}$	.597	.646	.605	.444	.424
P_4 length	11.1	10.7	11.1	12.4	12.0
P_4 width	5.2	5.5	5.2	4.6	4.7
$P_4\ \frac{W}{L}$	.468	.514	.468	.371	.392
M_1 length	14.3	14.5	14.4	16.0	16.2
M_1 width	7.3	7.2	6.9	7.5	7.7
$M_1\ \frac{W}{L}$	.510	.496	.479	.469	.475

A

	Daphoenocyon dodgei							*Parictis*			
	PIPE. 9287	PIPE. 9573	PIPE. 9825	COOKR. 9508	NEBR. 573	S.D. 9506	PIPE. 8851	S.D.	PIPE. 9068	PIPE. 9571	Oregon
MANDIBLE, DEPTH BELOW M_1 PROTOCONID	26.0	22.0	22.7	23.5	22.5	19.3	14.7	11.0	8.8	8.9	
DEPTH BELOW P_2	23.0	22.3	21.4	24.0	22.0	—	—	9.5	7.1	7.5	
THICKNESS BELOW P_3	11.0	10.7	11.0	L-14.0 R-10.5	9.2	10.4	7.6	4.9	3.9	4.5	10.0
$P_1 - M_3$	60.5	60.0	58.0	61.9	62.3	51.3	@44.8	37.1	29.0	30.7	32.0
$P_1 - P_4$	33.0	31.2	31.0	33.1	32.4	26.2	@24.3	21.5	16.5	17.7	
SECTORIAL DENTITION	42.0	—	38.5	41.0	41.0	35.8	31.7	28.0	20.5	21.7	
TUBERCULAR DENTITION	19.0	—	19.0	20.3	20.3	16.8	13.5	10.5	8.4	8.6	
$P_1\ \frac{L}{W}$	$\frac{3.3}{3.0}$	—	—	—	—	—	—	—	—	$\frac{2.4}{1.6}$	
$P_2\ \frac{L}{W}$	$\frac{6.7}{3.7}$	—	$\frac{7.3}{4.0}$	$\frac{7.5}{3.4}$	$\frac{6.5}{4.3}$	—	$\frac{5.5}{3}$	$\frac{5.5}{-}$	$\frac{4.1}{2.4}$	$\frac{4.5}{2.4}$	$\frac{5}{3}$
$P_3\ \frac{L}{W}$	$\frac{9.5}{5.3}$	$\frac{8.4}{4.8}$	$\frac{8.5}{4.8}$	—	$\frac{8.8}{4.8}$	—	$\frac{7.2}{3.8}$	$\frac{6}{-}$	$\frac{4.0}{2.6}$	$\frac{4.5}{2.4}$	
$P_4\ \frac{L}{W}$	$\frac{12.4}{5.9}$	$\frac{11.6}{6}$	$\frac{11.6}{5.7}$	$\frac{11.4}{6}$	$\frac{11.3}{5.3}$	$\frac{10.9}{4.8}$	$\frac{8.3}{4.4}$	7.5	$\frac{5.9}{3.0}$	$\frac{6.1}{2.7}$	
$M_1\ \frac{L}{W}$	$\frac{15.0}{7.6}$	—	$\frac{15.0}{7.9}$	$\frac{14.9}{7.4}$	$\frac{14.7}{7.4}$	$\frac{13.9}{6.5}$	$\frac{11.6}{6}$	9	$\frac{7.6}{4.0}$	$\frac{7.9}{3.8}$	
$M_2\ \frac{L}{W}$	$\frac{8.5}{6.3}$	—	$\frac{9.5}{7.3}$	$\frac{8.8}{6.3}$	$\frac{9.5}{6.0}$	—	$\frac{6.8}{5.2}$	5	$\frac{3.0}{2.7}$	$\frac{4.0}{3.2}$	
$M_1 - M_3$	29.0	29.3	29.3	29.6	29.8	25.6	—	17.0	13.0	13.8	
RATIOS:											
$\frac{\text{TUBERCULAR}}{\text{SECTORIAL}}$	.452	—	.493	495	.495	.469	.426	.404	.410	.397	
$\frac{M_1 - M_3}{P_1 - P_4}$	.879	.939	.945	.894	.920	.977	.856	.791	.791	.780	
$\frac{\text{THICKNESS}}{P_1 - M_3}$	.182	.178	.189	L-.226 R:170	.148	.207	.170	.132	.134	.150	
$\frac{\text{DEPTH AT } M_1}{P_1 - M_3}$	.430	.367	.391	.380	.361	.376	.328	.297	.303	.290	
$\frac{\text{THICKNESS}}{\text{DEPTH AT } M_1}$	423	486	.484	R:447	.409	.539	.517	.445	.443	.506	

B

FIG. 16A, B. C. Comparative measurements of *Daphoenocyon*, *Daphoenus*, and *Parictis*.

	Periostitis	*Daphoenocyon dodgei*			
	PIPE. 9573	PIPE. 9287	9508	PIPE. 9825	PIPE. 9057
DEPTH OF JAW BELOW PROTOCONID, M_1	22	26	23.5	22.7	broken
DEPTH OF JAW BELOW P_2	22.3	23	24.0	21.4	
MAXIMUM THICKNESS AT P_2	10.7	11	(14.0) 10.5	11.0	jaw
$P_1 - M_3$	60.0	60.5	61.9	58.0	
$P_1 - P_4$	31.2	33	33.1	31.0	31.0
$M_1 - M_3$	29.3	29	29.6	29.3	
$P_1\ \frac{L}{W}$	—	$\frac{3.3}{3.0}$	—	—	—
$P_2\ \frac{L}{W}$	—	$\frac{6.7}{3.7}$	$\frac{7.5}{3.4}$	$\frac{7.3}{4}$	$\frac{7}{4}$
$P_3\ \frac{L}{W}$	$\frac{8.4}{4.8}$	$\frac{9.5}{5.3}$	—	$\frac{8.5}{4.8}$	$\frac{9}{5.5}$
$P_4\ \frac{L}{W}$	$\frac{11.6}{6}$	$\frac{12.4}{5.9}$	$\frac{11.4}{6}$	$\frac{11.6}{5.7}$	$\frac{11.0}{5.2}$
$M_1\ \frac{L}{W}$		$\frac{15}{7.6}$	$\frac{14.9}{7.4}$	$\frac{15.0}{7.9}$	
$M_2\ \frac{L}{W}$		$\frac{8.5}{6.3}$	$\frac{8.8}{6.3}$	$\frac{9.5}{7.3}$	
$M_3\ \frac{L}{W}$		—	—	—	
$\frac{\text{SECTORIAL}}{\text{TUBERCULAR}}$		$\frac{42}{18.3}$ .436	$\frac{41}{20.3}$ .495	$\frac{38.5}{19.0}$ .493	
$\frac{P}{M}$	$\frac{31.2}{29.3}$ .939	$\frac{33}{29}$ .879	$\frac{33.1}{29.6}$ .894	$\frac{31}{29.3}$ .945	
$\frac{P_1 - M_3}{\text{THICKNESS}}$	$\frac{60}{10.7}$ .178	$\frac{60.5}{11}$ .182	$\frac{61.9}{14\text{-}10.5}$ .226 .170	$\frac{58.0}{11.0}$ .189	
$\frac{P_1 - M_3}{\text{DEPTH}}$	$\frac{60}{22}$ .367	$\frac{60.5}{26}$ .430	$\frac{61.9}{23.5}$ .380	$\frac{58.0}{22.7}$ .391	
$\frac{\text{DEPTH}}{\text{THICKNESS}}$	$\frac{22}{10.7}$ .486	$\frac{26}{11}$ .423	$\frac{23.5}{10.5}$ .447	$\frac{22.7}{11.0}$ .484	

C

sent a different species than the Montana material, with a more shallow jaw, but the samples are too small to justify such a division.

Daphoenocyon minor n. sp.

Type.—CM 9506; partial left mandibular ramus with P_4-M_1 and alveoli of C_1 P_{1-3} and M_{2-3}; two miles above main forks of Indian Creek, Pennington Co., S.D.; upper third of Ahearn Member (Fig. 19).

Referred Specimens.—PM 16284; partial right mandibular ramus with alveoli M_{2-3}; associated; base of Crazy Johnson Member. PM 16279; partial ramus with alveoli of P_2-M_1; upper part of Ahearn Member.

Diagnosis.—Smaller than *D. dodgei*, length P_1-M_3 51 mm. Jaw thick, heavy, but not deep. Tooth row almost straight.

Discussion.—*D. minor* appears to be near the ancestral population of both *D. dodgei* and a small species of *Daphoenocyon* from Pipestone Springs. *D. dodgei* then would represent a trend toward increased size and specialization and the small Montana *Daphoenocyon* a population diverging toward the carnivore size niche occupied by the present day Fisher.

Family Mustelidae

Genus **Mustelavus**

Mustelavus priscus

Specimens.—PM 13775; skull and lower jaws; Peanut Peak Member. PM 13776; partial lower jaw; Peanut Peak Member. PM 13777; maxillary fragment; Peanut Peak Member.

The genus *Mustelavus* is certainly very close to and may be synonymous with the European genus *Plesictis*.

However, the type species of *Plesictis* is late Miocene in age, and probably is generically distinct from the early Oligocene *P. pygmaeus*, which *M. priscus* closely resembles. Unravelling the tangled synonymy of *Plesictis* would require both access to European material and time, which are at present not available. We therefore retain *Mustelavus*, in the expectation that the species *M. priscus* will be declared a member of whatever genus the species *P. pygmaeus* is eventually assigned to.

Family Felidae
Subfamily Machairodontinae
Genus **Eusmilus**

Eusmilus sp.

Specimen.—PM 16271; fragment of left mandibular ramus with alveoli of P_4–M_1, Crazy Johnson Member (Fig. 17).

FIG. 17. Measurements of *Eusmilus* sp.

PU 16271	mm.
Depth of jaw below M_1	22.3
Maximum thickness of jaw below M_1	12.4
Length of P_4 alveolus	12.9
Length of M_1 alveolus	17.4

Discussion.—This specimen probably represents an undescribed species of *Eusmilus*, but it seems best to await the discovery of more complete material before erecting a new species. The size of the alveoli indicates that the teeth were as large as those of a small *E. sicarius* with the backward rake characteristic of the genus, but the jaw is little more than half as deep and, apparently, about two-thirds as long. Thus the animal had large teeth, fully specialized in the direction of *Eusmilus*, set in a small, relatively light jaw.

As this specimen and PM 16272 are the oldest known machairodontines, the high specialization of the dentition indicates that the major morphological evolution of the subfamily occurred much earlier.

Eusmilus?

Specimen.—PM 16272; Fragment of mandibular ramus with root of M_1; Ahearn Member.

Discussion.—Since the premolar alveoli are missing, assignment to the genus *Eusmilus* is questionable. The fragment is very slightly smaller than PM 16271.

Genus **Hoplophoneus**

Hoplophoneus sp.

Specimen.—PM 13596; right mandible with P_3; Crazy Johnson Member.

Holophoneus oharrai

Specimens.—S.D. School of Mines Museum No. 2417; partial skull; Crazy Johnson Member. PM 13593; partial skeleton; Peanut Peak Member.

Genus **Dinictis**

Dinictis fortis

Specimen.—PM 13638; assorted teeth; Peanut Peak Member.

Order Perissodactyla
Family Equidae
Genus **Mesohippus**

Nine species of *Mesohippus* have been described from the lower Oligocene:

M. celer Marsh, 1874, Nebraska
M. westoni Cope, 1889, Cypress Hills, Sask.
M. latidens Douglas, 1903, Thompson Creek, Mont.
M. montanensis Osborn, 1904, Pipestone Springs, Mont.
M. portentus Douglass, 1908, Pipestone Springs, Mont.
M. hypostylus Osborn, 1904, Big Badlands, S.D.
M. proteulophus Osborn, 1904, Big Badlands, S.D.
M. precocidens Lambe, 1905, Cypress Hills, Sask. Sask.
M. viejensis McGrew, 1956, Vieja, Texas.

These species were differentiated in the original descriptions on the following characters:

1) Size
2) Relative length and breadth of upper cheek-teeth
3) Presence and size of hypostyle
4) Degree of reduction of metaconule
5) Hypsodonty
6) Development of internal cingulum
7) Connection of metaloph to ectoloph
8) Connection of protoloph to parastyle
9) Angulation of ectoloph in upper molars
10) Development of metastyle

Preliminary study of a series of over 40 specimens from the Chadron formation has demonstrated, however, that these characters are highly variable at any one time level and that a complete review of Chadronian horses is necessary. In order to obtain an objective description of these animals a series of measures was employed, including the characters mentioned above and, in addition, anteroposterior length of the ectoloph, development of the external cingulum, angle of the external face of the ectoloph to the basal enamel line, and ratio of the transverse length of the protocone to transverse length of the paracone (Fig. 18). Those characters that could not be measured directly were ranked in a series of classes. Statistical tests of significance were used where necessary.

Of the group of 40 specimens, 13 are from the Ahearn, 23 from the Crazy Johnson, and 4 from the Peanut Peak Member; these were supplemented by the collections of *M. viejensis* (Field Museum of Natural History), of Montana *Mesohippus* from the Carnegie Museum, and of lower Brule (Lower Nodular zone) *Mesohippus* from the Princeton Museum. The measurements on this assemblage of specimens are reported in the accompanying tables (Fig. 18).

Analysis of these data supports these generalizations:

1) The internal cingulum is absent in early *Mesohippus* and in smaller individuals. Where present, it is best developed on M^3 and the premolars and is weak or absent on M^{1-2}. Conules are developed irregularly on

FIG. 18. Key

Protoloph
1. Cingulum to parastyle
2. Both to parastyle
3. Protoloph to parastyle
30. Protoloph connected, but interrupted by preceeding tooth

Crotchet
0. Absent
1. Slight
2. Marked

Height (H on graphs)
Median space present—M
absent —O

Internal cingulum
1. Present 1 cone; or does not close valley
2. Closes valley but not on tooth valls
3. Complete

Metaconule
1. Completely separate
2. Part of metaloph, but large and round
3. Slight swelling on metaloph
4. Absent

Metastyle
0. Cingulum does not reach tooth crown
1. Cingulum reaches crown as enamel ridge only
2. Dentine included in laterad cingular ridge
3. As above, plus posterior extension

Hypostyle
0. Absent

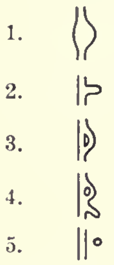


FIG. 18. I.—Measurements of Type Specimens of Chadron *Mesohippus*.

Species		*celer* 1874	*westoni* 1889	*latidens* 1903	*montanensis* 1904	*porentus* 1908	*hypostylus* 1904	*proteulophus* 1904
Locality		Nebraska	Cypress Hills	Thompson Cr., Mont.	Pipestone Springs	Pipestone Springs	South Dakota	South Dakota
$P^1 - M^3$							75	$P^4 - M^2$ 37
$P^2 - M^3$								
$P^1 - P^4$								
$M^1 - M^3$		27		32			32	
$\frac{P^{2-4}}{M^{1-3}}$								
P^1	L							
	W							
P^2	L							
	W							
	H							
	Hy							
	Int. cingulum						3–	
	Metaconule						2	
	Metastyle						0	
	Hypostyle						2	
	Protoloph connected						1	
	Crotchet						0	
P^3	L							
	W							
	H							
	Hy							
	Int. cingulum						3–	
	Metaconule						2	
	Metastyle						0	
	Hypostyle						2	
	Protoloph connected						2	
	Crotchet						0	
P^4	L							
	W							
	H							
	Hy							
	Int. cingulum	2		2			2	
	Metaconule			2			2	
	Metastyle	0		0			0	
	Hypostyle			1			2	
	Protoloph connected						2	
	Crotchet			0			0	
M^1	L	10		10	10.5		10	
	W	15		16	14		13.5	
	H							
	Hy							
	Int. cingulum	0		?	0		0	
	Metaconule			3	2		3	
	Metastyle	0		0	0		0	
	Hypostyle			1	1		2	
	Protoloph connected			1	?		2	
	Crotchet				0		0	

Fig. 18. I.—Measurements of Type Specimens of Chadron Mesohippi—*Continued.*

Species		*Celer* 1874	*Weston* 1889	*Latidens* 1903	*Montanensis* 1904	*Porentus* 1908	*Hypostylus* 1904	*Proteulophus* 1904
Locality		Nebraska	Cypress Hills	Thompson Dr., Mont.	Pipestone Springs	Pipestone Springs	South Dakota	South Dakota
M^2	L		9.5–10.2			13.3		
	W		12–13			18		
	H							
	Hy							
	Int. cingulum	0	3	2		2	1	
	Metaconule	2–3	2	3+		4	3	
	Metastyle	0	0	0		0	0	
	Hypostyle	0	0–1?	1		5	2	
	Protoloph connected		1	2		3	3	
	Crotchet			0		1	0	
M^3	L	8.5						
	W	12						
	H							
	Hy							
	Int. cingulum	1		3		3	2	
	Metaconule	3		4		4	3	
	Metastyle	0		0–1		1	1	
	Hypostyle	0		1		1	2	
	Protoloph connected			3		3	3	
	Crotchet			0		1	0	

Fig. 18. II.—Vieja Specimens

Species		FM–PM 107	PM 151	PM 142	PM 108	PM 42	PM 35
Horizon							
$P_1 - M_3$							
$P_3 - M_3$		57.3					
$P_2 - P_4$		27					
$M_1 - M_3$		30.4					
$\frac{P_{2-4}}{M_{1-3}}$		.888					
P_1	L						
	W						
P_3	L	8.9					
	W	5.4					
	H						
	Hy						
	Cingulum	0					
P_3	L	9.7	9.3				
	W	7.1	7.2				
	H						
	Hy						
	Cingulum	1	1				
P_4	L	9.6			9.6		10.6
	W	7.8			6.4		7.7
	H						
	Hy						
	Cingulum	1			2		
M_1	L	9.1			9.7	11.5	9.9
	W	7.0			6.4	8.8	6.9
	H						
	Hy						
	Cingulum	1			2	3	
M_3	L	9.4	9.1	9.6	9.8	12.0	10.5
	W	7.2	7.0	6.5	7.0	8.6	7.3
	H					6.6	5.6
	$\frac{H}{W}$					70.9	76.6
	Cingulum	1	1	3	3	3	
M_3	L	12.3	11.9	12.3			
	W	6.2	6.1	6.3			
	H	5.1					
	$\frac{H}{W}$	82.3					
	Cingulum	1	1	3			

Fig. 18. III.—*M. viejensis–celer* Group

		M. v. viejensis			M. v. ahearn			M. celer	
Species		FM-PM 36	FM-PM 56	FM-PM 121	PU 16245	CM 9496	PU 13829	CM 9394	PU 16257
Horizon									
Peanut Peak									x
Crazy Johnson									
Ahearn		x	x	x	x	x	x	x	
$P^1 - M^3$									
$P^2 - M^3$									
$P^1 - P^4$				35.6		37.0		31.5	32.8
$M^1 - M^3$									
$\frac{P^{2-4}}{M^{1-3}}$									
P^1	L			6.3		6.5			
	W			4.0		5.2			
P^2	L			10.3		11.0	10.3		
	W			9.5		11.8	10.5		
	H					M	M		
	Hy								
	Int. cingulum			0		2	2		
	Metaconule			3		2	2		
	Metastyle			0		0+	0		
	Hypostyle			1		5	1		
	Protoloph connected			0		1	1		
	Crotchet			0		0	0		
P^3	L			9.9		10.7	10.3	10.8	
	W			11.9		13.0	12.5	13.7	
	H			0		M	M	M	
	Hy								
	Int. cingulum			2		2+	2	2	
	Metaconule			2−		2	2	2	
	Metastyle			1		0	0	0	
	Hypostyle			1		1		4	
	Protoloph connected			1		1	1	2	
	Crotchet			0		0	0	0	
P^4	L			9.7		11.3	10.2	11.3	11.1
	W			13.1		12.7	13.4	14.4	14.1
	H		M	M	M	M	0	0	0
	Hy								
	Int. cingulum			2	2	2	2	2	2
	Metaconule		1	2	2	2	2	2	—
	Metastyle			1	0	0	0	0	
	Hypostyle			0	1	0	5	4	2
	Protoloph connected		1	1		1	1	2	30
	Crotchet		0	0	0	0	0	0	0
M^1	L			9.6				10.7	11.4
	W		10.0	11.9				13.9	14.1
	H		M	M		M		0	0
	Hy								
	Int. cingulum	2		0		0		2	0
	Metaconule	2	2	2				2	3
	Metastyle		1	0				0	0
	Hypostyle	0	1	0				4	
	Protoloph connected	1	2	1				2	3
	Crotchet	0	0	0		0		0	0
M^2	L		10.6	9.3				11.0	11.4
	W		12.3	12.6				14.8	14.5
	H	M	M	M				0	0
	Hy								
	Int. cingulum	2	2	0				2	0
	Metaconule	2	2	2				2	3
	Metastyle			1				0	0
	Hypostyle	1	1	1				3	2
	Protoloph connected	1	3	3				3	2
	Crotchet	0	0	0				0	0
M^3			L R						
	L	10.0	9.7–9.0					10.2	11.2
	W	12.8	11.9					14.3	13.5
	H		M					0	0
	Hy								
	Int. cingulum	3	2	2				2	2
	Metaconule	3	2	3				2	4
	Metastyle	2	3					1	1
	Hypostyle		0					3	2
	Protoloph connected	1	2					3	3
	Crotchet	0	0					0	0

FIG. 18. III (*Continued*).—Lower Jaws

						M. celer		
Species		PU 16248	PU 16244	PU 16246	PU 16247	CM 9392	PU 16251	CM 9394
Horizon								
Ahearn		x	x	x	x	x	x	x
P_1-M_3		66	64.5	65.6	63.8			
P_2-M_3		62.4	60.6	62.8	60.0	70.0		67.5
P_1-P_4		33.5	33.4	32.9	32.2		37.4	
M_1-M_3		33.4	32.0	33.5	31.9	38.3	35.3	36.2
$\frac{P_{2-4}}{M_{1-3}}$		.895	.862	.854	.893	.843	.918	.878
P_2-P_4		29.9	28.8	29.8	28.5	32.3	32.4	31.8
P_2	L	10.0		10.0	9.5		10.5	
	W	6.9		6.3	6.4		6.8	6.6
	H							
	$\frac{H}{W}$							
	Cingulum	2	2	1	2		2	
P_3	L	10.6	10.0	10.0	10.0	11.7	11.2	10.2
	W	7.8	7.5	7.8	7.3	8.1	8.2	7.8
	H	5.4+						
	$\frac{H}{W}$	69.2						
	Cingulum	3	3	1	3		3	
P_4	L	10.5	9.7	10.4	9.7	11.6	11.0	10.6
	W	8.6	8.1	8.4	7.8	10.4	9.1	8.6
	H	5.4						
	$\frac{H}{W}$	63.9						
	Cingulum	3	3	3	3		3	3
M_1	L	10.0	9.4	10.5	9.7	11.1	11.3	10.8
	W	7.6	7.2	7.5	7.1	9.0	7.9	8.2
	H							
	$\frac{H}{W}$							
	Cingulum	2	2	3	3	2	2	2
M_2	L	10.5	9.4	10.4	9.8	11.9	10.9	10.9
	W	7.2	6.9	7.3	6.9	9.0	7.2	8.0
	H							
	$\frac{H}{W}$							
	Cingulum	2	2	2	2	2	2	3
M_3	L	12.7	13.0	13.5	12.7	15.5	13.0	14.6
	W	6.5	6.6	6.5	6.6	7.8	6.3	7.5
	H	5.7		4.8	5.0		5.8	
	$\frac{H}{W}$	87.7		73.8	75.7		92.0	
	Cingulum	1	1	1	2	2	2	2

FIG. 18. IV.—*Mesohippus latidens*

Species		CM 9078	CM–FY	PU 13830
Horizon				
Peanut Peak				x
Crazy Johnson		x	x	
Ahearn				
P^1-M^3		67.9		
P^2-M^3		63.2		
P^1-P^4		38.3		
M^1-M^3		32.3		
$\frac{P^{2-4}}{M^{1-3}}$		1.01		
P^1	L	7.0		
	W	5.4		
P^2	L	10.6		
	W	12.7		
	H	0		
	Hy			
	Int. cingulum	2		
	Metaconule	1		
	Metastyle	0		
	Hypostyle			
	Protoloph connected	30		
	Crotchet	0		
P^3	L	11.4		
	W	14.4		
	H	0		
	Hy			
	Int. cingulum	2		
	Metaconule	1		
	Metastyle	0		
	Hypostyle			
	Protoloph connected	30		
	Crotchet	0		
P^4	L	12.2		12.0
	W	15.0		15.9
	H	0		0
	Hy			
	Int. cingulum	0		2
	Metaconule	3		2
	Metastyle	1		1
	Hypostyle	1		1
	Protoloph connected	30		30
	Crotchet	0		0
M^1	L	11.2		
	W	14.7		
	H			
	Hy			
	Int. cingulum	0		
	Metaconule	2		
	Metastyle	0		
	Hypostyle			
	Protoloph connected	30		
	Crotchet	0		
M^2	L	11.0	11.7	11.9
	W	15.4	15.3	16.4
	H	0	0	0
	Hy			
	Int. cingulum	2	3	2
	Metaconule	3	3	3
	Metastyle	1	3	1
	Hypostyle	1	2	1
	Protoloph connected	3	3	30
	Crotchet	0	1	0
M^3	L	11.1	12.9	11.4
	W	15.3	15.9	15.8
	H	0	M	0
	Hy			
	Int. cingulum	2	3	3
	Metaconule	2	4	4
	Metastyle	2	3	1
			L R	
	Hypostyle	1	5 2	1
	Protoloph connected	3	30	30
	Crotchet	1	1	0

FIG. 18. V.—Ahearn Specimens

		M. v. ahearn		*M. celer*	*M. h. hypostylus*		
Species		PU 13829	CM 9496	CM 9394	CM 9392A	CM 9478	CM 9390
Horizon							
Peanut Peak							
Crazy Johnson							
Ahearn		x	x	x	x	x	x
$P^1 - M^3$							
$P^2 - M^3$							
$P^1 - P^4$			37.0				
$M^1 - M^3$				31.5			
$\frac{P^{2-4}}{M^{1-3}}$							
P^1	L		6.5				7.5
	W		5.2				5.4
						DP^2	
P^2	L	10.3	11.0			15.0	13.8
	W	10.5	11.8			11.8	14.1
	H	M	M			M	
	Hy						
	Int. cingulum	2	2			3	3
	Metaconule	2	2			2	
	Metastyle	0	0+			0	0
	Hypostyle	1	5			2	
	Protoloph connected	1	1			1	1
	Crotchet	0	0			0	0
P^3	L	10.3	10.7	10.8			12.8
	W	12.5	13.0	13.7			15.7
	H	M	M	M			0
	Hy						
	Int. cingulum	2	2+	2			3
	Metaconule	2	2	2			
	Metastyle	0	0	0			0
	Hypostyle		1	4			
	Protoloph connected	1	1	2			3
	Crotchet	0	0	0			0
P^4	L	10.2	11.3	11.3			12.8
	W	13.4	12.7	14.4	13.9		15.8
	H	0	M	0	0		
	Hy						
	Int. cingulum	2	2	2	3		3
	Metaconule	2	2	2	2		
	Metastyle	0	0	0	0		0
	Hypostyle	5	0	4	2–5		
	Protoloph connected	1	1	2			
	Crotchet	0	0	0	0		0
M^1	L			10.7	13.4	14.0	
	W			13.9	15.2	14.6	
	H		M	0	0	0	
	Hy						
	Int. cingulum		0	2	2	3	
	Metaconule			2	3	2	
	Metastyle			0	0	3	
	Hypostyle			4	5	1	
	Protoloph connected			2	3	2	
	Crotchet		0	0	0	0	
M^2	L			11.0			
	W			14.8			
	H			0		0	
	Hy						
	Int. cingulum			2		1	
	Metaconule			2		3	
	Metastyle			0		3	
	Hypostyle			3		1	
	Protoloph connected			3			
	Crotchet			0		0	
M^3	L			10.2			
	W			14.3			
	H			0			
	Hy						
	Int. cingulum			2			
	Metaconule			2			
	Metastyle			1			
	Hypostyle			3			
	Protoloph connected			3			
	Crotchet			0			

FIG. 18. VI.—Base of Crazy Johnson Member

Mesohippus hypostylus and *latidens*

Species		CM 9395	CM 9078	CM 8775	CM–FY	CM–FA
Horizon						
Peanut Peak						
Crazy Johnson		x	x	x	x	x
Ahearn						
$P^1 - M^3$			67.9			
$P^2 - M^3$			63.2			
$P^1 - P^4$			38.3			
$M^1 - M^3$			32.8			
$\frac{P^{2-4}}{M^{1-3}}$			1.02			
P^1	L		7.0			
	W		5.4			
P^2	L		10.6			
	W		12.7			
	H		0			
	Hy					
	Int. cingulum		2			
	Metaconule		1			
	Metastyle		0			
	Hypostyle					
	Protoloph connected		30			
	Crotchet		0			
P^3	L		11.4			
	W		14.4			
	H		0			
	Hy					
	Int. cingulum		2			
	Metaconule		1			
	Metastyle		0			
	Hypostyle					
	Protoloph connected		30			
	Crotchet		0			
P^4	L		12.2			
	W		15.0			
	H		0			
	Hy					
	Int. cingulum		0			
	Metaconule		3			
	Metastyle		1			
	Hypostyle		1			
	Protoloph connected		30			
	Crotchet		0			
M^1	L	13.4	11.2			
	W	16.0	14.7			
	H	0				
	Hy					
	Int. cingulum	0	0			
	Metaconule	3	2			
	Metastyle	0	0			
	Hypostyle	5				
	Protoloph connected	30	30			
	Crotchet	0	0			
M^2	L	13.3	11.0	12.8	11.7	13.5
	W	16.3	15.4	16.1	15.3	16.6
	H	0	0	M	0	0
	Hy					
	Int. cingulum	0	2	3	3	1
	Metaconule	3	3	3	3	3
	Metastyle	0	1	0	3	0
				L R		
	Hypostyle	2–5	1	1 2	2	4
	Protoloph connected	30	3	2	3	3
	Crotchet	0	0	0	1	1
M^3	L	11.6	11.1	12.9		13.9
	W	15.5	15.3	15.9		16.9
	H	0	0	M		0
	Hy					
	Int. cingulum	2	2	3		3
	Metaconule	3	2	4		4
	Metastyle	1	2	3		3
				L R		
	Hypostyle	1	1	5 2		4
	Protoloph connected	3	3	30		30
	Crotchet	0	1	1		0

FIG. 18. VI (*Continued*).—Lower Jaws

Species		CM 9395	CM 9078	PU 16255	PU 16254
Horizon					
	Peanut Peak				
	Crazy Johnson	x	x	x	x
	Ahearn				
$P_1 - M_3$					
$P_2 - M_3$			65.3	70.4	70.4
$P_1 - P_4$					35.9
$M_1 - M_3$			36.2	38.7	38.5
$\frac{P_{2-4}}{M_{1-3}}$			.842	.832	.836
$P_2 - P_4$			30.5	32.2	32.2
P_2	L		9.8	10.5	10.2
	W		7.2	7.0	6.9
	H				
	Hy				
	Cingulum		1	1	1
P_3	L		10.0	10.6	11.1
	W		8.7	8.7	9.1
	H				
	Hy				
	Cingulum		1	1	2
P_4	L	11.9	10.8	11.0	11.9
	W	10.0	9.5	9.1	10.1
	H				
	Hy				
	Cingulum		2	1	3
M_1	L	11.8	9.9	11.7	11.9
	W	9.0	8.4	8.7	9.3
	H				
	Hy				
	Cingulum		1	2	2
M_2	L		11.2	11.6	11.4
	W		7.6	8.4	8.9
	H				
	Hy				
	Cingulum		2	1	2
M_3	L		15.8	16.6	14.9
	W		7.4	8.2	8.0
	H				
	Hy				
	Cingulum		1	2	3

FIG. 18. VII.—Top of Crazy Johnson Member

Species		CM 9089	PU 16256	CM 9034A	CM 9034B	CM 9034C	PU 16258	PU 16258A	CM 9036
Horizon									
Peanut Peak									
Crazy Johnson		x	x	x	x	x	x	x	x
Ahearn									
$P^1 - M^3$		73.2							
$P^2 - M^3$		67.5							
$P^1 - P^4$		41.2							
$M^1 - M^3$		34.4						38.7	
$\frac{P^{2-4}}{M^{1-3}}$		1.02							
P^1	L	7.5							
	W	5.8							
P^2	L	12.2	12.5		12.7				
	W	12.0	13.2		12.5				
	H	0	0		0				
	Hy								
	Int. cingulum	2	3		3				
	Metaconule	2	2		2				
	Metastyle	0	0		0				
	Hypostyle	2	2		2				
	Protoloph connected	1	1		1				
	Crotchet	1–	0		0				
P^3	L	12.6	13.0						
	W	13.8	15.0						
	H	0	0		0				
	Hy								
	Int. cingulum	2	1		3				
	Metaconule	2	2		2				
	Metastyle	0	1		0				
	Hypostyle	2	2		2				
	Protoloph connected	2	1						
	Crotchet	0	0		0				
P^4	L	12.8	12.8		13.0		14.0		
	W	15.0	15.7		15.8		16.0		
	H	0	0		M–		0		
	Hy								
	Int. cingulum	2	1		3		2		
	Metaconule	3	3		3		4		
	Metastyle	0	1		0		1		
	Hypostyle	2	2		2		2–4		
	Protoloph connected	20	1		3				
	Crotchet	0	0		0		0		
M^1	L	12.6	13.5	13.8	13.4	13.0		14.5	
	W	14.5	14.0	15.6	16.9	14.7		15.0	
	H	0	0	0	0	0		0	
	Hy								
	Int. cingulum	2	0	0	3	1		2	
	Metaconule	3	3	3	3	3		3	
	Metastyle	0	1	0	0	1		0	
	Hypostyle	2	2	2–5	2	2		2	
	Protoloph connected	30		10	3	3		30	
	Crotchet	0	0	2	0	1		1	
M^2	L	12.3	13.8			11.9			
	W	15.0	16.3			15.2			
	H	0	0			0			
	Hy								
	Int. cingulum	1	1			1	0	2	0
	Metaconule	3	3			3	4	4	3–4
	Metastyle	0	1			1	0	1	1
	Hypostyle	2	2			2	4	2	2–5
	Protoloph connected	30	30				2	30	
	Crotchet	0	0			0	0	2	0
M^3	L	11.8					13.2	12.9	13.8
	W	14.3					15.9	14.8	15.3
	H	0					0	0	0
	Hy								
	Int. cingulum	2					2	3	3
	Metaconule	4					4	4	4
	Metastyle	1					1	1	1
	Hypostyle	2					3	3	2–5
	Protoloph connected	30						30	30
	Crotchet	0					0	1	0

FIG. 18. VII (*Continued*).—Lower Jaws

Species		CM 9087	PU 16256	CM 9034A	CM 9034B	CM 9034C	CM 9036
Horizon							
	Peanut Peak						
	Crazy Johnson						
	Ahearn						
$P_1 - M_3$							
$P_2 - M_3$							
$P_1 - P_4$							
$M_1 - M_3$		37.5					38.0
$\frac{P^{2-4}}{M^{1-3}}$							
$P_2 - P_4$	L						
	W						
P_2	L	11.2					
	W	7.7					
	H						
	Hy						
	Cingulum	1					
P_3	L	11.7					
	W	9.2					
	H						
	Hy						
	Cingulum	2					
P_4	L		14.0				
	W		11.3				
	H						
	Hy						
	Cingulum		3				
M_1	L	11.5	12.6	12.5		12.3	11.6
	W	9.0	9.5	9.6		8.0	8.6
	H						
	Hy						
	Cingulum	2	3	3		2	1
M_2	L	11.2	14.0	12.0	12.1	11.6	11.7
	W	8.4	9.9	9.0	8.8	7.9	8.7
	H						
	Hy						
	Cingulum	2	3	3	3	2	2
M_3	L	15.5			15.5		
	W	8.0			8.0		
	H						
	Hy						
	Cingulum	2			3		

FIG. 18. VIII.—Crazy Johnson Member, General

Species		*M. hypostylus*			
		PU 13828	PU 13827	CM 8777	CM 8778
Horizon					
Peanut Peak					
Crazy Johnson		x	x	x	x
Ahearn					
$P^1 - M^3$					
$P^2 - M^3$					
$P^1 - P^4$					
$M^1 - M^3$		41.5			
$\frac{P^{2-4}}{M^{1-3}}$					
P^1	L	9.6			
	W	6.5			
			DP?		
P^2	L	14.5	14.5		12.8
	W	13.8	15.3		13.2
	H	0	M		M
	Hy				
	Int. cingulum	3	2		2
	Metaconule	3	3		2
	Metastyle	0	0		0
	Hypostyle	4	2		2
	Protoloph connected	1	1		1
	Crotchet	1	0		0
P^3	L	15.0	14.6	14.8	13.1
	W	15.1	16.1	15.3	15.3
	H	0	0	M	M
	Hy				
	Int. cingulum	3	3	0	3
	Metaconule	3	3	3	3
	Metastyle	0	0	1	0
	Hypostyle	2	2	1	1
	Protoloph connected	3	3	1	1
	Crotchet	1	1	0	0
P^4	L		15.6	13.5	13.7
	W		17.0	17.0	16.0
	H		0	0	0
	Hy				
	Int. cingulum		2	3	2
	Metaconule		3	2	4
	Metastyle		0	1	0
	Hypostyle		2	2	0
	Protoloph connected		3	1	1
	Crotchet		1	0	0
M^1	L	15.0	14.1		
	W	16.8	18.0		
	H	0	0		
	Hy				
	Int. cingulum	0	0		
	Metaconule	4	4		
	Metastyle	0	0		
	Hypostyle	4	2		
	Protoloph connected	2	2		
	Crotchet	0	0		
M^2	L	15.0		12.5	
	W	17.4		15.8	
	H	0		0	
	Hy				
	Int. cingulum	1	2	2	
	Metaconule	4		4	
	Metastyle	0		0	
	Hypostyle	2	2–5	1	
	Protoloph connected	30		3	
		R L			
	Crotchet	0 1		0	
M^3	L	14.3	14.8		
	W	16.8	18.3		
	H	0	0		
	Hy				
	Int. cingulum	2	2		
	Metaconule	4	4		
	Metastyle	1	0		
	Hypostyle	2	2–5		
	Protoloph connected	30	3		
		L R			
	Crotchet	1 0	0		

FIG. 18. IX.—Peanut Peak Member

Species		*M.latidens* PU 13830	PU 16257
Horizon			
	Peanut Peak	x	x
	Crazy Johnson		
	Ahearn		
$P^1 - M^3$			
$P^2 - M^3$			
$P^1 - P^4$			
$M^1 - M^3$			32.8
$\frac{P^{2-4}}{M^{1-3}}$			
P^1	L		
	W		
P^2	L		
	W		
	H		
	Hy		
	Int. cingulum		
	Metaconule		
	Metastyle		
	Hypostyle		
	Protoloph connected		
	Crotchet		
P^3	L	12.4	
	W		
	H		
	Hy		
	Int. cingulum		
	Metaconule		
	Metastyle		
	Hypostyle		
	Protoloph connected		
	Crotchet		
P^4	L	12.0	11.1
	W	15.9	14.1
	H	0	0
	Hy		
	Int. cingulum	2	2
	Metaconule	2	
	Metastyle	1	
	Hypostyle	1	2
	Protoloph connected	30	30
	Crotchet	1	0
M^1	L		11.4
	W		14.1
	H		0
	Hy		
	Int. cingulum		0
	Metaconule		3
	Metastyle		0
	Hypostyle		
	Protoloph connected		30
	Crotchet		
M^2	L	11.9	11.4
	W	16.4	14.5
	H	0	0
	Hy		
	Int. cingulum	2	0
	Metaconule	3	3
	Metastyle	1	0
	Hypostyle	1	2
	Protoloph connected	30	20
	Crotchet	0	0
M^3	L	11.4	11.2
	W	15.8	13.5
	H	0	0
	Hy		
	Int. cingulum	3	2
	Metaconule	4	4
	Metastyle	1	1
	Hypostyle	1	2
	Protoloph connected	30	3
	Crotchet	0	0

FIG. 18. IX (*Continued*).—Lower Jaws

		M. grandis			
Species		CM 9157	CM 9158	CM 8743	CM 8744
Horizon					
Peanut Peak		x	x	x	x
Crazy Johnson					
Ahearn					
P_1-M_3					
P_2-M_3		89.5	89.0		
P_1-P_4					
M_1-M_3		47.6	49.0		
$\frac{P_{2-4}}{M_{1-3}}$					
P_2-P_4		43.3	42.0		42.6
P_2	L	13.8		14.6	13.7
	W	8.6		9.1	9.4
	H				
	Hy				
	Cingulum	2			
P_3	L	14.0	14.5	14.2	13.8
	W	11.2	11.0	10.0	10.8
	H				
	Hy				
	Cingulum	3			
P_4	L	14.8	15.0	14.6	14.2
	W	12.0	11.5	10.3	11.7
	H				
	Hy				
	Cingulum	3			
M_1	L	13.6	14.0		13.7
	W	9.9	10.2		10.2
	H				
	Hy				
	Cingulum	3			
M_2	L	14.7	16.8		13.5
	W	9.7	10.6		10.3
	H				
	Hy				
	Cingulum	3			
M_3	L	17.9			
	W	9.1			
	H				
	Hy				
	Cingulum	3			

the cingulum, varying from tooth to tooth in a single maxilla.

2) The external cingulum is relatively heavy in the smaller and earlier forms.

3) The hypostyle, if present at all, is developed in all the cheek-teeth, but the shape varies irregularly from tooth to tooth in a single maxilla.

4) The metaloph attaches to the ectoloph in only a few individuals and may do so in only a single tooth in a maxilla.

5) The metaconule is relatively least developed on M^3.

6) The metastyle is relatively best developed on M^3.

7) Considerable wear is apparent between adjacent teeth, affecting in particular the metastyle and the connection between parastyle and protoloph. Since most of this wear takes place shortly after the tooth is erupted, teeth with slightly worn crowns differ very much from unworn teeth in these characters.

8) Apparently hypsodonty did not increase in Chadron *Mesohippus*. Early Chadron horses show a flat space between the bases of the three lophs and another between the metaloph, ectoloph, and posterior cingulum. The bases of the metaloph and protoloph expand to fill these spaces; the tips of the protocone and hypocone rise slightly and thus increase the angle of slope of their internal faces; and the internal faces of the ectoloph change from planes set at a slight angle to concave vertical surfaces. These changes, however, occur independently of one another. The apparent hypsodonty in the molars of later forms results from an increase in overall size.

9) The following characters vary independently from specimen to specimen:

a. development of metaconule
b. hypostyle, presence and form
c. attachment of protoloph to parastyle
d. development of internal cingulum
e. development of external cingulum
f. development of metastyle
g. connection of metaloph to ectoloph
h. hypsodonty

i. angulation of ectoloph to antero-posterior direction
j. antero-posterior length of ectoloph
k. angle of external face of ectoloph
l. ratio of $\frac{\text{transverse length of paracone}}{\text{transverse length of protocone.}}$

10) The mesohippi from the Lower Nodular Zone, Orellan age, vary in the same characters and through the same range of characters.

Since these observations invalidate most of the criteria used previously in the diagnosis of Chadronian horses, a revision of these species is necessary. If the specimens from one member are examined and the variability of the population or populations from which they came is estimated, several distinct populations can be discerned. Comparison among the populations from all three members then reveals that these populations fall into a few groups and that the successive populations within a group intergrade. Since the populations from the various groups are specifically distinct in the defined time segments, the population groups are described as separate species. Those population groups in which the difference between the end populations exceeds the differences "normal" between subspecies of a neontologic species are divided into two or more species. Distinct populations within any one species are named informally, employing the specific name and the name of member from which the sample was collected.

Whenever practicable, boundaries between species are set at breaks in the stratigraphic record, but single specimens without stratigraphic assignment may be indeterminable because the successive populations overlap in morphology. Fortunately, the gaps between species as here defined are such that the old species types could be determined and assigned at the species level. Therefore the species are named on the basis of previously described types that fell within the limits of variability of the redefined species.

Mesohippus viejensis McGrew

Mesohippus viejensis McGrew, P., in press.

Type.—Not yet declared.

Referred specimens.—PM 16244; lower jaw; base of Ahearn. PM 16250, 16248, 16246, 16247; mandibles; base of Ahearn member. PM 13829, CM 9496; partial maxillaries; base of Ahearn Member.

Diagnosis.—Primitive mesohippi with large median space in molars; molars rectangular to ovoid. Size range indicated by length of M_2: 9.1 to 12.0 mm.

Discussion.—Mesohippus viejensis is clearly a distinct species (except from the succeeding population of the group, *M. celer*), but further subdivision is extremely difficult. The specimens of *M. viejensis* from the Vieja Formation of Texas appear to fall into two morphological groups, and the coefficients of variability of dental measurements likewise suggest that we have samples from rather distinct populations. The majority of the Vieja specimens are relatively small Mesohippi and somewhat smaller than the *M. viejensis* specimens from the Ahearn, but a few large individuals, as large or larger than any from the Ahearn, are also known. Until further information can be obtained on the stratigraphic occurrence of these individuals, it is impossible to determine whether they represent two contemporaneous subspecies which occupied the area alternately during Vieja time, or whether they represent successive populations in an evolving series.

Although the *M. viejensis* specimens from the Ahearn overlap those from Texas in size and in details of dental variation, a separation seems appropriate because the small differences that do occur foreshadow further changes in this phyletic line. Therefore we recognize two populations, *M. viejensis*-Vieja and *M. viejensis*-Ahearn.

The *viejensis*-Vieja population consists of small, generally primitive mesohippi. Size is quite variable as indicated by variation in the length of M_2 (range, 9.1–12.0 mm; mean, 10.07 mm; standard deviation 1.06 mm; coefficient of variability, 10.5). So far as known, this population is limited to Vieja time (see below, *Stratigraphic Paleontology*).

The *viejensis*-Ahearn population gives an impression of somewhat greater size than the *viejensis*-Vieja although this is not shown by the statistics (range in length of M_2, 9.4–10.5 mm; mean, 10.02 mm; standard deviation, .519 mm; coefficient of variability, 5.16). In addition, there are very minor differences in the details of the upper molars. The known stratigraphic range of this population is early Ahearnian.

Mesohippus westoni lies within the *M. viejensis* size range, but the type is indeterminable because of its fragmentary condition. The topotype (Ottawa Museum 6293) is almost certainly from a *M. viejensis* population, but since the topotype is not a name bearer, *M. viejensis* is the only available name.

Mesohippus celer (Marsh)

Anchitherium celer Marsh, O. C., 1874. Notice of new equine mammals from the tertiary formation. Am. Jour. Sci., (3) 7, no. 39, Mar. 1874, p. 251.

Type.—Yale Museum 11302, right maxillary with P^4–M^3; "Miocene" of Nebraska.

Referred Specimens.—PM 16251; mandible; Ahearn Member. PM 13829; right maxilla with P^3–M^1; Ahearn Member. CM 9394; partial maxillary; Ahearn Member. PM 16257; partial maxillary; Peanut Peak Member.

Diagnosis.—Molars with median space very much reduced. Size range, M^{1-3}, 29.5–32.8 mm. Upper molars approximately quadrangular, slight lateral expansion, posterior borders straight or slightly convex posteriorly, metastyle not expanded posteriorly, parastyle very little anterior to anterior edge of tooth; protoloph and metaloph developed.

Discussion.—The dentition of *M. celer* is very similar to that of *M. viejensis*, and *M. celer* was probably derived directly from a *M. viejensis* population. The *M. viejensis-celer* species group thus consists of successive segments in a continuum of populations, the *viejensis*-Vieja population from the late Duchesnean, the *viejensis*-Ahearn population from the earliest Chadronian, and *M. celer* from the remainder of the Chadron.

Mesohippus latidens

Mesohippus latidens, Douglass, E., 1903. New vertebrates from the Montana Tertiary. Ann. Carnegie Mus., **2**, pp. 161–162.

Type.—CM 751; left P^4–M^3; Thompson's Creek near Three Forks, Montana; "Lower White River Beds."

Referred specimens.—CM 9078; complete upper and lower dentition; base of Crazy Johnson Member. PM 13830; P^3–M^3; Peanut Peak Member.

Diagnosis.—Upper molars extremely broad laterally, short antero-posteriorly; anterior and posterior borders of teeth straight. Teeth not expanded externally.

Discussion.—These specimens are distinctly different from the other Chadron species lines and show no particular affinities to any one of them. CM 9087 from the base of the Crazy Johnson is somewhat smaller and has the ectoloph less angulated than PM 13830 from the Peanut Peak or CM 751 from the Thompson Creek, Montana. The sample is so small, however, that the difference cannot be considered significant.

Mesohippus hypostylus Osborn, 1904.

Mesohippus hypostylus Osborn, H. F., 1904. New Oligocene horses. Bull. Am. Mus. Nat. Hist., **20**, pp. 170–171.

Mesohippus portentus Douglass, E. 1908. Fossil horses from North Dakota and Montana. Ann. Carnegie Mus., **4**, pp. 268–269.

Mesohippus proteulophus Osborn, H. F. 1904. *ibid.*, pp. 171–172.

Mesohippus montanensis Osborn, H. F. 1904. *ibid.*, p. 170.

Type.—AMNH 1180; anterior portion of skull with palate and complete P^1–M^3 on both sides; Cheyenne River, S.D.; "Upper Titanotherium zone."

Referred specimens.—*hypostylus*-Ahearn (see discussion below). CM 9390. CM 9392A. CM 9478.

Diagnosis.—Upper molars not expanded laterally or only slightly expanded; ectoloph longer than internal antero-posterior dimension of tooth; hypostyle always present; molars without median space; posterior borders of molars straight to posteriorly concave.

Discussion.—The *M. hypostylus* population group probably branched from *M. viejensis* during late Duchesnean time, divided into two population groups during the latter Chadronian, and gave rise through one of these branches to *Mesohippus bairdi* of early Orellan time. Within the *M. hypostylus* population groups two populations can be distinguished, *hypostylus*-Ahearn and *hypostylus*-Crazy Johnson. These populations overlap in morphology but show a progressive shift in the population means.

A.) *hypostylus*-Ahearn population: The specimens of *M. hypostylus* from the Ahearn member are, as a group, distinctly smaller than the specimens of this species from the Crazy Johnson Member. In addition, the average of ectoloph angle is less in the Ahearn specimens than in the Crazy Johnson. The populations, however, overlap in all characteristics and individual specimens cannot be assigned without knowledge of their stratigraphic occurrence.

The species *Mesohippus montanensis* Osborn is within the limits of variation of the *hypostylus*-Ahearn population.

B.) *hypostylus*-Crazy Johnson population: *Referred specimens*: CM 9035A, 9035B, 9035C, 9093, 9037, PM 13827, 13828. The average size of individuals in this population is somewhat greater than *hypostylus*-Ahearn and the ectoloph of the upper molars is relatively longer and is set at a larger angle to the anteroposterior direction. The molar therefore narrows sharply posteriorly and is much longer at the outside margin than at the inside margin. The metaconule is more reduced and metastyle more developed than in *hypostylus*-Ahearn. Most lower teeth have a complete, heavy cingulum. The range in size is relatively great as exemplified by the length of M^2; range, 11.0–15.0 mm; mean, 12.92 mm; standard deviation, 1.06 mm; coefficient of variability, 8.21.

The rather high variability of the *hypostylus*-Crazy Johnson sample may have resulted from one of several factors: 1) high variability of the local population, 2) sampling from two or more subspecific populations which occupied the area at various times, 3) fluctuations in the local population through time, and 4) sampling error.

The largest specimens approach the Peanut Peak *M. grandis* (see below) in size and are otherwise similar to that species. These individuals may represent a separate population evolving in the direction of *M. grandis.* The stratigraphic range of this population in South Dakota is through Crazy Johnson time, but may extend to early Peanut Peak time in Montana (Pipestone Springs, see below, *Stratigraphic Paleontology*).

M. proteulophis Osborn falls within the *hypostylus*-Crazy Johnson population limits since the type is near the mean size of the population and the fusion of the metaloph with the ectoloph is not a significant character. Although described as diagnostic by Osborn this character does not appear to be associated with any other character difference; it is present on P^4 in the *M. proteulophus* type but nowhere else in the dental series and on P^3 and M^3 in CM 8775 but nowhere else in that specimen; it is present on an *M. celer* specimen from the Ahearn member on P^3 and M^3; and it is unknown on specimens from the lower Brule. Together these facts indicate that the character was not fixed in any *Mesohippus* population and hence is not of taxonomic significance.

Mesohippus grandis, n. sp.

Type.—CM 9157, lower jaw with P_2–M_3, left (Figs. 19, 20).

Horizon.—Peanut Peak Member, Chadron Formation.

Locality.—West flank of Quinn Draw, Washington Co., South Dakota.

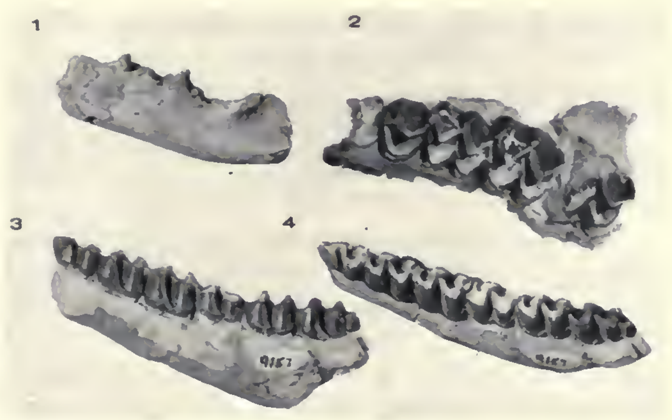


FIG. 19. The type specimens of *Daphoenocyon minor* (1) and *Mesohippus grandis* (3–4), also an unnamed species of *Merycoidodon* (2).

Referred Specimens.—CM 9158, CM 8743, CM 8744.

Diagnosis.—Animals of large size, length P_2–M_3 equals 89.5 mm. The external cingulum on the lower teeth is very heavy. Characteristics otherwise as in the *M. hypostylus*-Crazy Johnson population (see above).

FIG. 20.—Measurements of *Mesohippus grandis*

	CM 9157	CM 9158	CM 8743	CM 8744
P_2—M_3	89.5 mm.	89.0*		
$P_{2—4}$	43.3	42.0*		42.6
$M_{1—3}$	47.6	49.0		
P_2 L	13.8		14.6	13.7
P_2 W	8.6		9.1	9.4
P_3 L	14.0	14.5	14.2	13.8
P_3 W	11.2	11.0	10.0	10.8
P_4 L	14.8	15.0	14.6	14.2
P_4 W	12.0	11.5	10.3	11.7
M_1 L	13.6	14.0		13.7
M_1 W	9.9	10.2		10.2
M_2 L	14.7	16.8		13.5
M_2 W	9.7	10.6		10.3
M_3 L	17.9			
M_3 W	9.1			

Discussion.—Since these specimens are markedly larger than *M. hypostylus* they may properly be ranked as a separate species. This population however is closely affiliated with *M. hypostylus* and apparently represents a continuation of the trend toward greater size shown by some members of the Crazy Johnson population. The species so far as is known is limited to Peanut Peak time.

EVOLUTION OF *Mesohippus* DURING CHADRONIAN TIME: Although most Chadron horses are poorly known, we feel that sufficient material is available to justify discussion of their evolution. The early *M. viejensis* populations represented by the *M. viejensis*-Vieja population appear to be suitable ancestors for most of the Chadronian *Mesohippi* (Fig. 21). The *M. viejensis*-Ahearn sample is distinct from *M. viejensis*-Vieja only in slightly larger size (although the difference is not significant statistically) and minor characters of the upper molars. *Mesohippus celer* specimens known from the upper Ahearn and from the Peanut Peak differ by a very slight increase in size and by the reduction of the median space in the upper molars. The *M. viejensis*-Vieja sample is quite variable with respect to size (length of M_2, V = 8.9, N = 6) and thus it is difficult to demonstrate any size changes between *M. viejensis*-Vieja and *M. celer*. The successive populations in this line were quite conservative in tooth evolution and in size.

Mesohippus hypostylus is distinct from *M. viejensis* when the species appears in the Ahearn but might well have been derived from early *M. viejensis* populations. The samples are so small as to preclude a meaningful statistical test, but *M. hypostylus* was probably somewhat larger than *M. viejensis* by Ahearnian time. Further, *M. hypostylus* lacks the median space characteristic of *M. viejensis*, but this feature cannot be taken as debarring *M. viejensis* from an ancestral position since the *viejensis-celer* line also reduced this character, though at a somewhat later time. If *M. hypostylus* was not derived from *M. viejensis* it must have come from a closely related species, and this would be effectively the same so far as interpretation of evolutionary patterns is concerned.

The Crazy Johnson specimens of the *M. hypostylus* group are on the average slightly larger than those from the Ahearn, but the overlap is complete. In the *M. hypostylus*-Crazy Johnson population variability of dental minutiae was considerable. The shape of the hypostyle, reduction of the metaconule, development of the metastyle, attachment of metaloph to ectoloph, attachment of protoloph to parastyle, development of internal cingulum, and angulation of the ectoloph all vary considerably in detail and appear in all conceivable combinations. This suggests a considerable amount of

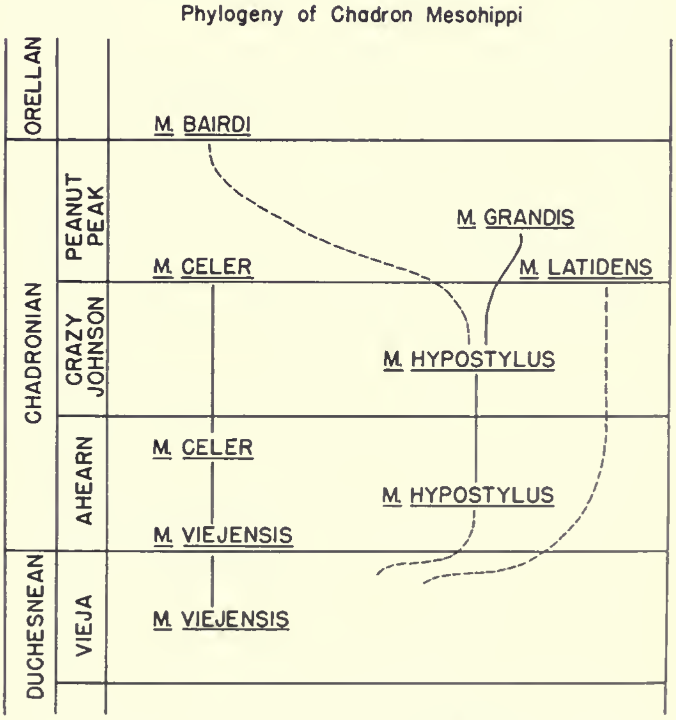


FIG. 21. Phylogeny of Chadron *Mesohippi*.

underlying genetic variabliity and low selection pressures for these details and for different combinations of them. The expression of some of these characters, such as internal cingulum and the metaconule, differs consistently in M^{1-2} from that in P^{2-4} and M^3. A similar order is also exhibited in *M. bairdi* from the lower Brule. This phenomenon seems to be related to the different period of development and time of emplacement for the two sets, M^{1-2} and P^{2-4}–M^3, but might be either an "accident" of development or the result of selection for developmental correlation in those units, M^{1-2}, which have somewhat similar periods of utilization.

Certain other characters such as the attachment of the metaloph to the ectoloph, the crotchet, and the shape of the hypostyle vary irregularly from tooth to tooth within the individual. The hypostyle, however, if it is present at all, is present in all the teeth of an individual, but the pattern of the style will differ from tooth to tooth. This observation suggests that hypostyle development was controlled by a single gene which affected the developmental field of all the teeth but whose expression was modified by the particular developmental pattern of individual teeth.

The known late Chadronian representatives of the *M. hypostylus* line are all large mesohippi included within *M. grandis* and represent the apparent culmination of one evolutionary trend in *M. hypostylus.*

Available material of the Chadron horses is insufficient to demonstrate with certainty the origins of the Brule horse *M. bairdi.* The smaller *M. hypostylus* specimens cannot be distinguished from *M. bairdi* on dental characters, but no small *hypostylus* are known from the late Chadron. On the other hand, *M. celer* is also quite similar to *M. bairdi* in both dental characters and size and is known from the late Chadron. Therefore we can make alternative hypotheses pending discovery of skeletal material:

1) The *M. bairdi* population of early Brule time was derived from a *M. hypostylus* population—either from a population of small *M. hypostylus* that lived in an area other than South Dakota during late Chadron time or by a reversal of size trends represented in the *M. grandis* population. The first seems more likely.

2) *M. bairdi* was derived from *M. celer* as a continuation of the evolutionary trend that increased size and reduced the median molar space in the *viejensis-celer* line.

A distinct line is represented by *M. latidens,* known from the base of the Crazy Johnson (1 specimen) and from the Peanut Peak (1 specimen). *M. latidens* resembles *M. hypostylus* somewhat more than it does *M. celer,* but might have been derived from some earlier species (possibly *M. viejensis*) or from an unknown species.

The probable phylogenetic relationships of Chadron horses are summarized in Figure 21. Alternate interpretations are possible, but this is offered as the most probable and conservative.

Family Menodidae (=Brontotheriidae Marsh 1873)

Genus **Menodus**

Menodus giganteus Pomel, 1846

Synonyms.—*Titanotherium* Leidy, *Megacerops* Cope, *Brontotherium* Marsh, *Symborodon* Cope, *Brontops* Marsh, *Diploclonus* Marsh, and *Allops* Marsh.

Specimens.—PM 16266, 16267, 16268, 16269; horn cores of four individuals; Crazy Johnson Member. PM 16270; horn core, nasals, and frontal sinuses; top of Crazy Johnson Member. Uncollected partial skulls and scraps observed in the Ahearn, Crazy Johnson and Peanut Peak Members.

Description.—The Ahearn *Menodus* are generally small- to medium-sized titanotheres. The largest horn found was 7 in. long, with an ovoid cross-section 3 by 5.5 in. The smallest specimen found was the skull of an immature individual in which M^3 had not erupted. Horns of this specimen were 2 in. long, and circular in cross-section with a diameter of 2 in. at the base.

The specimens from the Crazy Johnson include: PM 16267, a horn core with subtriangular cross-section, 3 in. long and 3.5 in. greatest transverse diameter; PM 16266, a horn core with subtriangular cross-section, 6 in. long, and 4.5 in. greatest transverse diameter; PM 16268, a horn core with ovoid cross-section, 8 in. long and 5 in. greatest transverse diameter; and PM 16269, a horn core with flat cross-section over 8 in. long (at least 2 in. missing), cross-sectional dimensions 5 in. by 2 in.

Specimen 16270 consists of the complete right horn core, the nasals, and both frontal sinuses. The transverse ridge between the horns is very high and the horn is low and tapering with a shape in cross-section of a blunt isosceles triangle with the base posteriad. The horn and transverse ridge are produced vertically with their posterior surface sloping up to 85° from the plane of the roof of the nasal passage, but the horns themselves are relatively reduced. The frontal sinuses are a pair of subhemispherical pockets, 2.75 in. in diameter and flattened posteriorly; apparently they opened ventroposteriorly into the nasal cavity.

Discussion.—The four specimens of *Menodus* from the Crazy Johnson (PM 16266 through PM 16269) were collected from a single "graveyard" in a layer 1 ft. thick and within 30 ft. of each other horizontally. Thus they demonstrate the marked variation in horn development in a contemporaneous population of titanotheres. It is difficult to believe that each individual represents a separate species, and we are inclined to the view that they are simply variants within a single species population, indeed perhaps even in a single local interbreeding unit. We offer therefore the following hypothesis for Oligocene titanothere taxonomy and phylogenetics:

1) Development of horns in *Menodus* was the result of generalized bone growth in the nasal region.

2) The developmental system that controlled this growth was not a highly homeostatic system but relatively indeterminate.

3) Minor disarrangements in the genetic background or "accidents of development" would thus profoundly modify the shape of the horns. Sexual dimorphism would similarly produce major variations.

4) Differences in species might then show in the horns with respect to: (a) kind of variability; (b) amount of variability.

5) Phylogenetic changes might also be of the same kind. Such differences are impossible to demonstrate without a large series of specimens with accurate, detailed stratigraphic assignments. Until such a series becomes available, it seems proper to regard all specimens as cospecific with the first-named species adequately described from the same formation and locality, which lies within the range of variation of the specimens at hand.

We recognize but two genera of titanotheres from the Oligocene of North America: *Menodus* and *Teleodus*. The diagnostic characters of the two genera are:

	Menodus	*Teleodus*
(1)	$\frac{I}{0\text{–}2}$	$\frac{I}{3}$
(2)	Horns small to large, subconical to cylindrical or flat in longitudinal section.	Horns small, subconical in longitudinal section.
(3)	Top of skull always concave upward.	Boss on top of male skulls.

With the exception of Marsh's type, no specimen referable to *Teleodus* has ever been collected from the Big Badlands. All of the abundant *Teleodus* specimens collected since 1930 have come from formations known to be somewhat older than the typical Chadron of South Dakota. This suggests that possibly either Marsh's type was collected from the Slim Buttes Formation in the Badlands, or that the locality data were confused in some manner and the specimen is not from the Big Badlands.

Selection of names for the genus and species embracing all other Chadron titanotheres has been most difficult. *Menodus giganteus* Pomel, 1846, has obvious priority. However, the type specimen, which has been lost, consisted of a fragment of a lower jaw, with RM_{2-3}. Except for its size, the type did not include characters which would exclude it from *Teleodus* or from some of the larger species of the Eocene *Protitanotherium*. Fortunately, Osborn (1929) designated a neotype skull, AMNH 505, which does possess diagnostic characters. The designation seems to be in accord with all of the rules of the International Code of Zoological Nomenclature for neotypes. The name is, therefore, available, and the genus and species are adequately diagnosed. Our characterization is an emendation of previous descriptions, in order to include within this genus and species the various Oligocene forms described as separate genera.

PM 16270 lies somewhat outside the accepted limits of *Menodus* variants, and the reduced horn cores, vertically produced frontal area, reduced nasals, and expanded frontal sinuses suggest specializations like those of the Asiatic embolotheres. Because of the fragmentary nature of the specimen, this can, however, be no more than a suggestion.

Family Helaletidae

Genus **Colodon**

Colodon occidentalis

Specimen.—CM 9482; lower jaw with P_2–M_2; Ahearn member.

Family Hyracodontidae

Genus **Hyracodon**

Hyracodon cf. *priscidens*

Referred Specimens.—CM 9129; partial skull, face crushed laterally and brain-case crushed dorso-ventrally, includes DP^{1-4}, M^{1-2} with M^2 only partly erupted. Base of Crazy Johnson Member. PM 13395; palate with I^1–M^1, jaw with P_2–M_3; Peanut Peak Member. CM 8717; two lower molars; Ahearn Member. CM 8787; associated P_2–M_1; Crazy Johnson Member. CM 8716; partial mandible with DP_4–M_2; Ahearn Member. CM 8715; maxillary fragment with P^{2-4}; Ahearn Member. PM 14026; fragments of maxilla, P^3–M^3; Ahearn Member. PM 16275; mandible, DP_3–M_1; Ahearn Member. PM 16305; DP^{3-4}, Ahearn Member. CM 9091; mandibular fragments with symphysis, DP_{2-4}, alveoli of I, C and DP_1, rudimentary P_2; Crazy Johnson Member. CM 9099; jaw fragment with DP_{2-3} and alveolus, DP_1; upper part of Ahearn Member.

Discussion.—All of the Chadron *Hyracodon* appear to belong to the small species, *H. priscidens*. CM 9129 is referred to this species because M^{1-2} are almost identical with those of the type (Lambe, 1905). CM 8787 is similarly referred since the size of teeth (P_{2-4} M_1) is very small for *Hyracodon*; PM 16275 has only one tooth (M_1) that can be compared with the type material but it is of the same size; CM 9091 and CM 9099 have only the deciduous premolars but these are sufficiently similar to the same teeth in PM 16275 that these are likewise referred to *H. priscidens*.

CM 9091 and 9099 are also of interest because they show the alveoli for DP_1. This tooth is absent in the Orellan *Hyracodon* juveniles (Scott and Jepsen, 1941) but apparently was still present as a vestigal structure in some Chadronian individuals.

The deciduous premolars were retained for a relatively long period in some individuals of this genus. In CM 9129 DP^{1-4} have long, firm roots with no traces of P^{1-2} behind the milk teeth, although M^2 has started to erupt. The full set of deciduous teeth is also present in CM 9091, in which the mandibular symphysis is completely fused. A specimen of *H. nebraskansis* (CM 3523) from the Orellan of Sand Creek, Sioux Co., Nebraska, also has DP $^{1-4}$ firmly rooted with M^2 partly erupted. In both CM 9129 and 3523 DP^{2-4} are fully molariform and DP^1 is submolariform. Wear has removed approximately one-half of the crown height in CM 9129 and about three-fourths in CM 3532. A fully adult specimen (CM 11723) of *H. nebraskansis* has P^{3-4} about as much worn as M^3 and much less worn than M^2, but two other members of this species from the Carnegie Museum collection have P^{3-4} as worn as M^2. This would indicate considerable variation in time of premolar replacement but more extended studies would be necessary to determine whether this is of taxonomic significance. In every adult specimen examined the entire premolar series was uniformly worn, suggesting that emplacement of the series was nearly simultaneous.

Hyracodon sp.

Referred Specimen.—PM 16287, right P_4; Crazy Johnson Member.

Family Rhinocerotidae

Genus **Caenopus**

Caenopus mitis

Referred Specimens.—CM 9153; complete mandible with P_2–M_3 of both sides and single small alveolus for P_1; Peanut Peak Member. CM 9396; left mandibular ramus with P_3–M_3; Peanut Peak Member. PM 16274; mandible with P_2–M_3; Crazy Johnson Member. CM 9100; mandible including P_1–M_2; Ahearn Member.

Discussion.—The teeth in CM 9153 and 9396 are quite similar, differing only in the vestigial P_1 in 9153 and a tiny antero-posterior ridge across the posterior valley of P_4 that is present only in 9396. The jaws, however, are quite different: that of CM 9153 decreases continuously in depth from the rear of M_3 to the chin; that of CM 9396 maintains the same depth from the rear of M_3 to below P_4 and tapers rapidly forward of P_4. The jaw of PM 16274 resembles that of CM 9396. All three of these specimens are larger than expected in *Caenopus mitis* (Wood, H. E., 1927; Scott and Jepsen, 1941) but are considerably smaller than *Subhyracodon*. The type of *C. mitis* does not include the lower teeth, so direct comparison is impossible and none of the characters used by H. E. Wood (1927) to differentiate *Caenopus* from *Subhyracodon* occur on the lower cheek teeth. Since *C. mitis* is a Chadronian species and since these specimens cannot be excluded from *C. mitis* on characteristics of the lower dentition, we feel that the most conservative position is to assign them to *C. mitis*. These specimens may not be congeneric, much less cospecific, but the differences in jaw depth and minor dental characters do not appear to justify their separation. CM 9100 is apparently a typical *C. mitis*, at least with respect to size.

Caenopus sp.

Indeterminable *Caenopus* material includes three single teeth from different localities in the Crazy Johnson, and an M^1, CM 9467, from the Ahearn Member.

Genus **Trigonias**

Trigonias osborni

Rererred specimens.—CM 9399; jaw fragment with M_{1-3}; Crazy Johnson Member. CM 9398; assorted upper and lower teeth from at least two individuals; Crazy Johnson Member. CM 9397; P_1–M_3; Crazy Johnson Member.

Discussion.—In view of the known variability in dental characters of *Trigonias*, both from specimen to specimen and from tooth to tooth within one jaw, we regard *T. osborni* as the only species satisfactorily established at present. We therefore refer these fragmentary specimens to *T. osborni*.

Trigonias sp.

In addition to the material referred to *T. osborni*, an incisor from the Crazy Johnson and a second upper premolar from the Ahearn are assigned to this genus.

Order Artiodactyla

Family Entelodontidae

Genus **Archaeotherium**

Archaeotherium cf. *scotti*

Referred Specimens.—PM 16281; lower canine tip and root, broken; antero-posterior length at base of enamel, 19 mm.; upper Ahearn. PM 16282; left M^2; upper Ahearn Member.

Archaeotherium cf. *mortoni*

Referred Specimens.—PM 16286; anterior part of right M_2; middle Ahearn Member. CM 9412; right mandibular ramus with M_{1-3}; Ahearn Member. CM 9097; left M^1; Ahearn Member.

Archaeotherium cf. *coarctatum*

Referred Specimens.—PM 16285; partial left M^3; middle Ahearn Member. PM 16283; partial left P_4; upper part of Ahearn Member.

Family Tayassuidae

Genus **Perchoerus**

Perchoerus cf. *minor*

Referred Specimen.—CM 9492; fragments of mandible with heel of right M_3; Ahearn Member.

Discussion: The size of this specimen (antero-posterior length of M_3, 15.5 mm and depth of jaw below anterior part of M_3, 19 mm) would place it within the range of *P. minor* and *P. nanus*. Since the type of *P. minor* is from the Chadron of Nebraska, CM 9492 is referred to this species. The type of *P. nanus* was collected from the "White River Miocene" of Nebraska, and Scott assigned the specimen to the lower Brule because of the similarity of the matrix to lower Brule lithology. Parts of the Nebraska Chadronian, however, resemble the Brule and the time and specific relationships of *P. minor* and *P. nanus* are problematical.

Family Anthracotheriidae

Genus **Bothriodon**

Bothriodon cf. *americanus*

Referred Specimens.—CM 9405; pair of lower jaws with P_2–M_3; Crazy Johnson Member. CM 9096; palate with P^2–M^3; Crazy Johnson Member.

Bothriodon sp.

Referred Specimens.—CM 9498; jaw with P$_2$, M$_{1-2}$; Ahearn Member. CM 9500; P^3, M$^{1-2}$ associated; Ahearn Member. PM 16298; jaw fragment with partial molar; Ahearn Member. PM 16433; skull and skeleton, juvenile; Peanut Peak Member.

Discussion.—These specimens are within the size range of *Bothriodon* and are the earliest anthracotheres recorded from North America.

Genus **Heptacodon**

Heptacodon

Referred Specimens.—CM 8779; jaw fragment with P$_{2-3}$, DP$_4$, M$_1$; Crazy Johnson Member. PM 16299; M$_1$; Crazy Johnson Member. PM 16300; M$_2$; Crazy Johnson Member.

Family Agriocheridae

Genus **Agriochoerus**

Agriochoerus cf. *antiquus*

Referred Specimens.—PM 16278; partial upper dentition; middle of Ahearn Member. PM 16277; pair of maxillae and partial lower jaw; upper part of Ahearn Member. CM 9128; upper molars and associated lower jaws; base of Crazy Johnson Member.

Discussion.—The two specimens from the Ahearn (PM 16278 and 16277) are not distinguishable from a small *A. antiquus* (PM 12538), from the lower Brule. The P^3 of 16277 has the deuterocone well-developed and internal to the protocone, so that the tooth is almost an isosceles right triangle with the hypotenuse antero-internal; P^3 of 16278 has the inner side of the tooth compressed with the deuterocone directly posterior to the internal buttress of the protocone, and the external face of the tooth indented between the roots. P^4 of 16277 has a tiny swelling on the postero-internal cingulum, with a single small ridge projecting from it toward the center of the tooth, like the leg of a T. P^4 of 16278 has the bunodont conule on the cingulum, but a tiny, trifid crest, unconnected with any of the cones, lies in the position of the small ridge of 16277. However, the lower Brule specimens of *Agriochoerus* in the Princeton collection show great individual variation in P^3 and P^4, so these characters may be of no significance.

Possibly these two specimens are not cospecific with the Brule forms, but more adequate material would be necessary to demonstrate any difference.

The Crazy Johnson specimen, CM 9128, is slightly smaller than the two specimens from the Ahearn Member, but otherwise indistinguishable from them.

Agriochoerid, gen. and sp. indet.

Referred Specimen.—CM 9092; maxillary fragments with DP^4–M^1; Crazy Johnson Member.

Discussion.—This specimen is within the size range of *Mesagriochoerus,* but the protoconule is absent as in *Merycoidodon* and the mesostyle is quite low as in *Agriochoerus.* The M^1 as a whole suggests a very small *Agriochoerus,* but the fragmentary condition of the specimen prevents definite reference to that genus.

FIG. 22. A, Type specimen of *Merycoidodon lewisi,* CM 9105, crown views of skull and mandible. B, Type specimen of *Merycoidodon lewisi,* CM 9105, lateral view of skull.

Family Merycoidodontidae

Subfamily Merycoidodontinae

Genus **Merycoidodon**

Merycoidodon lewisi[1] n. sp.

Type.—CM 9105; skull, jaws, and skeleton except fore limb and part of tail; Peanut Peak Member 12 ft. below Chadron-Brule contact; Big Corral-Quinn Draw divide, NW-1/4 sec. 30, T. 43N, R 45W, Shannon Co., S. D.

Referred Specimens.—PM 16289; skull and jaws; Peanut Peak Member. PM 16434; left lower jaw with I$_1$–M$_2$; Peanut Peak. PM 16435; symphysis with I$_1$–P$_3$; Peanut Peak Member. PM 16436; crushed skull with P^1–M^3; Peanut Peak Member. PM 16437; skull with C–M^3; Peanut Peak Member. PM 16438; skull with P^3–M^3; Peanut Peak Member.

Diagnosis.—Skull typically *Merycoidodon* in basicranial structures, but large, robust, with heavy canines,

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[1] The species is named for Mr. Arnold D. Lewis, who collected the type specimen.

FIG. 23.—Measurements of Skull of *Merycoidodon lewisi*, CM 9105, in mm.

I. SKULL

Length, dorsal, along midline	225.5
Width, altered to remove crushing	128.0
Depth, M^2 alveolus to top of skull	66.0
Width at infraorbital foramen	45.5
Length, prosthion-basion	206.5
Length, prosthion-choana	120.5
Length, bregma-inion	73.0
Height, canine alveolus-naso-premaxillary suture	39.0
Palate, width between canines	28.5
Palate, width between M R and L	32.0

II. UPPER DENTITION

$P^1 - M^3$		96.3
$P^1 - P^4$		46.4
$M^1 - M^3$		50.5
P^1	L	11.3
	W	6.5
P^2	L	12.5
	W	7.9
P^3	L	12.4
	W	11.9
P^4	L	9.4
	W	14.2
M^1	L	15.2
	W	16.7
M^2	L	18.5
	W	20.1
M^3	L	20.2
	W	20.2

III. MANDIBLE

Greatest length	182.0
Length of symphysis	49.5
Depth at P_3	33.0
Depth at anterior edge of M_3	39.0

IV. LOWER DENTITION

$P_1 - M_3$		100.0
$P_1 - P_4$		46.8
$P_2 - P_4$		35.4
$M_1 - M_3$		52.3
P_2	L	11.4
	W	5.7
P_3	L	11.3
	W	7.4
P_4	L	13.1
	W	9.3
M_1	L	13.2
	W	10.6
M_2	L	15.5
	W	12.7
M_3	L	23.6
	W	14.4

long palate, almost straight transverse row of incisors, strong postorbital construction, and flaring zygoma.

Description.—The bullae are absent from the type specimen and if present in life must have been small. The paroccipital processes are long and slender with antero-internal ridge; postglenoid processes small; squamosal root of zygomatic arch narrow antero-posteriorly, and the zygomatic arch is straight. Skull mesocephalic with greatest width immediately anterior to glenoid; palate long; and zygomatic arches angulated so that their anterior extensions would meet about 1 in. in front of the incisors. Postorbital constriction very narrow, braincase flaring posteriorly to a triangular shape; foramen rotundum reduced to one-half the diameter of foramen ovale; nasal bones posteriorly rounded, not acute; naso-frontal suture nearly a transverse line.

Upper canines and P^1 massive and long; upper incisors ranged in almost straight transverse row; back of I^1 posteriad to front of I^3. Mandible long with very long symphysis; massive P_1 and relatively small P_4.

Discussion.—Of the characters listed above, the basicranial characters are typical for *Merycoidodon*, but the remainder of the skull suggests *Eporeodon*. The basicranial characters seem adequate to refer this species to *Merycoidodon*—the robust build, long palate, heavy canines, etc., might be a function of size or very possibly of sex rather than indicating a relation to *Eporeodon*.

This species is probably not ancestral to any Orellan species of *Merycoidodon*, but it might be ancestral to *Eporedon*. The reduction of the foramen rotundum and the shape and position of the naso-frontal suture are so variable in *Merycoidodon* and *Eporeodon* that they are probably not significant in evaluating phyletic relationship.

Merycoidodon sp.

Specimen.—PM 16276; maxillary fragment with P^4, M^{1-2}, partial P^3, M^3; Ahearn Member; Big Corral Draw, main fork about 1 mile north of the Pennington-Washington County line, Pennington Co., S. D. This specimen probably represents an undescribed species, but its fragmentary nature precludes using it as a type.

Description.—Tooth structure typically *Merycoidodon* except that internal cingulum on P^4–M^3 and probably on P^3, also, is unusually strong and denticulate; two internal crescents of molars join each other rather than remaining distinct; anterior end of external crescent of P^4 forked, the internal fork supported by a stout pillar which reaches the anterior face of the tooth but does not unite with the internal crescent.

The tooth row is moderately arched laterally rather than straight as in other species. P^4 is set one-third of its width mesially to M^1, producing a sharp angulation along both the internal and external row of tooth faces. The posterior rim of the zygomatic root lies opposite the posterior edge of M^3 rather than opposite the middle of M^3.

Discussion.—Although the specimen is incomplete, it is markedly different in the described characters from any other species of *Merycoidodon*, lying well outside the range of variation of the other Chadron species and also of the Brule species. More complete specimens may demonstrate that this species is not referable to *Merycoidodon*, but the fragmentary nature of the specimen makes this reference advisable at present. None of these characters resemble those of *Protoredon*, with the exception of the posteriorly-placed zygoma. This species, whatever its affinities, is as highly evolved in the parts preserved as is *M. culbertsoni*.

Its apparent rarity is probably real rather than an accident of collection. The relative abundance of other small artiodactyls in the Ahearn collections, plus the fact that for several seasons the senior author has collected every generically identifiable scrap discovered, makes it seem probable that *Merycoidodon* was rare in South Dakota during Ahearnian time.

Merycoidodon sp.

Referred Specimen.—CM 9391; fragments of lower jaw with M_{1-3}, poorly preserved; Ahearn Member.

Discussion.—The specimen is of the size and general character of *M. lewisi.* Since it is indeterminable, it serves only to suggest the presence of *M. lewisi* or a related species in the Ahearn Member.

Family Camelidae
Subfamily Poebrotheriinae
Genus **Poebrotherium**

Poebrotherium cf. *andersoni*

Referred Specimens: PM 16260, two tibiae, one complete and one partial pes, one fore limb, partial scapula, and pelvis; Ahearn Member. PM 16261; upper right P^4–M^3, Ahearn Member. PM 16262; jaw with P_{1-2}, DP_4, M_{1-2}, M_{2-3} and fragments of other teeth; Ahearn Member.

Discussion.—These specimens may all be parts of the same individual inasmuch as they were collected from a 2-in. lamina within 6 ft. of each other. They were, however, part of a mechanical association including four *Mesohippus*, a hypertragulid, *Parictis* (*Campylocynodon*) *parvus*, and another camelid, and so could be from different individuals.

The limb bones are somewhat larger than those of the described species of *Poebrotherium* but are otherwise typical. The metatarsus and metacarpus are about the same length. The humerus measures 134 mm, but a portion of the proximal end is missing. Allowing 10 mm loss, which is very generous, the length of the humerus becomes 145 mm; the metacarpus is 140 mm and the metatarsus 145 mm. This is about the limb proportion of the modern camel and llama. Since these specimens are from the base of the Chadron formation, they are the oldest known *Poebrotherium.* That the oldest known specimen of the genus is the largest and is also the "most advanced" in limb proportions is a sure indication that the actual evolution of the genetic line is still unknown. Many of the really significant steps in camelid evolution had already been accomplished before earliest Chadronian time, when these specimens lived. Only fusion of the already-appressed metapodials, development of hypsodonty, and increase in size remained to be accomplished.

Camelid, n. g. and sp.

Specimens.—PM 16313; right maxilla with DP^{3-4}, M^{1-2}; PM 16263; left forelimb with humerus, partial radius and ulna, left hind limb with femur, tibia, pes; Ahearn Member.

Discussion.—A more complete specimen from McCarty's Mountain, Montana, congeneric with these, is being studied at the Frick Laboratory and so this material will be left unnamed pending publication on the McCarty's Mountain specimen. These two Dakota specimens, which are probably from the same individual, are of an animal about the size of *Eotylopus* but with four complete metatarsals and four toes on the hind foot. The tibia is slightly longer in proportion to the humerus than in *Poebrotherium* and the metatarsus is much shorter in proportion to both the humerus and tibia. This camel is very apparently adapted to a moist, forested or brushy habitat in contrast to the dry plains adaptations of *Poebrotherium.*

Camelid, genus indet.

Specimen.—CM 9023; M_{1-2}; Crazy Johnson Member.

Discussion.—This specimen although generically indeterminable is in the *Eotylopus* size range.

Superfamily Hypertraguloidea

Several species of small selenodont artiodactyls are common in the Chadron of South Dakota. The taxonomy of the hypertraguloids is, however, so badly confused that we are reluctant to assign these specimens to the recognized species and genera of hypertraguloids. Until an extensive review of these Chadronian artiodactyls is made, based on modern taxonomic principles, it seems best simply to refer them to the superfamily. For the present study, the most significant points are: 1) the abundance of medium to large hypertraguloids in the Ahearn and Crazy Johnson Members; 2) absence of these types from the Peanut Peak Member; 3) presence of a few small hypertraguloids in the Peanut Peak and Crazy Johnson Members.

The following specimens have been collected from the South Dakota Chadronian: Ahearn Member: PM 16290; PM 16291; CM 9490; PM 16292; PM 16293; PM 16295; PM 16294; CM 9468; CM 9491; PM 16296; CM 8707; CM 8708; CM 8709; CM 8710; CM 8711; CM 8712; CM 8713; CM 8714.

Crazy Johnson Member: CM 9393; CM 9033; CM 9022; CM 9032; CM 9088.

Peanut Peak Member: PM 13834; CM 8703; CM 8704.

STRATIGRAPHIC PALEONTOLOGY

INTRODUCTION

The faunules of the three members of the South Dakota Chadron Formation are now sufficiently known to allow detailed correlation of other Chadronian deposits with this standard section. Unfortunately, one large element in these faunules, the small artiodactyls, needs taxonomic revision before it can be used in correlation, and so is not now available as evidence. In addition, the rodents and some genera and species in other orders are so extremely rare in the Chadron that their occurrence in one member does not give satisfactory evidence of their stratigraphic range.

In general, correlations are based on the relative numbers of identical species. In making correlations of deposits that accumulated within these relatively brief intervals of time, however, we recognize that local ecological differences are likely to modify significantly the local stratigraphic ranges. This effect is most apparent among the reptiles, whose geographic distribution is sharply limited by temperature, but it must also exist in most mammalian species.

On the basis of general environmental requirements and associations, two groups of mammals can be distinguished within the Chadronian faunas. One of these consists of elements derived from a pre-Chadronian wet-forest chronofauna (see p. 68). The other group consists of invading elements from a savannah-savannah forest[1] chronofauna. It seems probable that the wet-forest chronofauna or a large number of its elements might survive longer in some areas than in others and that the invading species would appear at different times in different areas responding to changes in the local environment. Therefore, major faunas as well as individual species would overlap in time.

If the interdependence of species in a chronofauna were complete, then this chronofauna would behave as a unit and the species that compose it would always be found in association. If, as seems more likely, the species are only partially dependent on one another they would be associated in most occurrences but not invariably. Further, in this more flexible chronofauna, some species might be replaced either through evolution into new species or by immigration of a different species. In highly integrated (interdependent) chronofaunas, this replacement would probably be almost simultaneous through the area occupied by the chronofauna.

Therefore, although neither the appearance or disappearance of chronofaunas nor of species independent of the local chronofaunas forms a critical time-marker, the replacement of species within the local chronofaunas does constitute such a marker. In addition, we accept the first appearance of a species as a critical time-marker if the chronofauna of which it is part has previously occupied the local area, and the disappearance of a species if the chronofauna of which it is a part persists locally. The latter two types of occurrence, however, are considered less significant than the replacement of a species within a chronofauna.

Relation to Pre-Chadronian Faunas

The known fauna of the Ahearn Member differs strikingly from that of the Duchesne River and Sespe Formations, and there can be little doubt that the previous concensus (Simpson, 1946; Scott, 1945; etc.) was correct in considering the oldest Chadronian appreciably younger than the Duchesnean. (Fig. 24).

The Vieja fauna, however, is much closer to that of the Ahearn. Although much of the Vieja fauna has not been studied critically (as of 1957), *Agriochoerus* and the horse, *Mesohippus viejensis*, are common to both the Vieja and the Ahearn. On the other hand, the mesohippi differ at the intra-specific level; the agriochoerids may be of different species; and *Teleodus*, though present in the Vieja, is unknown from the Ahearn. Therefore, the Ahearn is probably a little younger than the Vieja.

Comparison of Yoder and Ahearn faunas supports the belief, expressed previously by the senior author, that the Yoder is the time equivalent of the Ahearn. Those species which have been described as distinct are based upon fragmentary specimens, at best doubtfully determinable, and in our opinion within the range of variation of known Chadronian species. Preliminary studies of the small artiodactyls of the two formations supports the idea of contemporaneity, and Wood (1955) concluded from a study of the rodents that the Yoder was slightly younger than Vieja—an assignment that might correlate the Yoder with the Ahearn. Studies on the Yoder collections of the South Dakota School of Mines should test this correlation and establish the age of the Yoder more definitely.

Relation of the Pipestone Springs Fauna

Figure 25 makes apparent the similarity of the Pipestone Springs fauna from Montana to the Peanut Peak fauna. Five species, based on good material, are limited to these faunas and are unknown from pre-Peanut Peak members or from the Brule Formation. These are *Apternodus mediaevus*; *A. altitalonidus*; *Metacodon magnus*; *Daphoenocyon dodgei*; and *Merycoidodon lewisi*. *A. altitalonidus* and *M. magnus* are known in South Dakota from the microfauna locality in the Peanut Peak member; *Apternodus mediaevus* from a single specimen in the Peanut Peak; and, therefore, these limited stratigraphic ranges may be accidents of sampling. They, however, along with the more common *D. dodgei* and *M. lewisi* do indicate that the Pipestone Springs formation and the Peanut Peak member are of approximately the same age.

Four other species, *Hyaeonodon horridus*, *Mesohippus latidens*, *Hyracodon priscidens*, and *Caenopus mitis*, are known from good specimens in both Peanut Peak and Pipestone Springs deposits but are also known from either middle and lower Chadron or from the Brule. Hence they indicate a general age similarity but are not as definitive as the foregoing species.

The Peanut Peakian *Mesohippus grandis* is unknown from Pipestone Springs, though large individuals of the closely related species *M. hypostylus* are found there. In itself this might suggest a younger age for the Peanut Peak Member, but because the Brule horse, *M. bairdi*, apparently represents a continuation of the *M. hypostylus* line, we conclude that *M. hypostylus* persisted through Peanut Peakian time though unknown from South Dakota during this time. Therefore, *Mesohippus hypostylus* cannot be used for precise correlation within the Chadron; the less common *M. grandis*, however, indicates Peanut Peakian age.

On the other hand, the dog, *Daphoenocyon dodgei*, succeeds the ancestral and more primitive *Daphoenocyon minor* in the savanna chronofauna from the Peanut Peakian of South Dakota. Thus its appearance in the Pipestone Springs fauna and the absence of *D. minor* suggests very strongly that the Pipestone Springs fauna is very little, if any, older than Peanut Peakian.

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[1] Henceforth in this paper, the term "savannah" will be used to include true savannah and the associated savannah-forest environment.

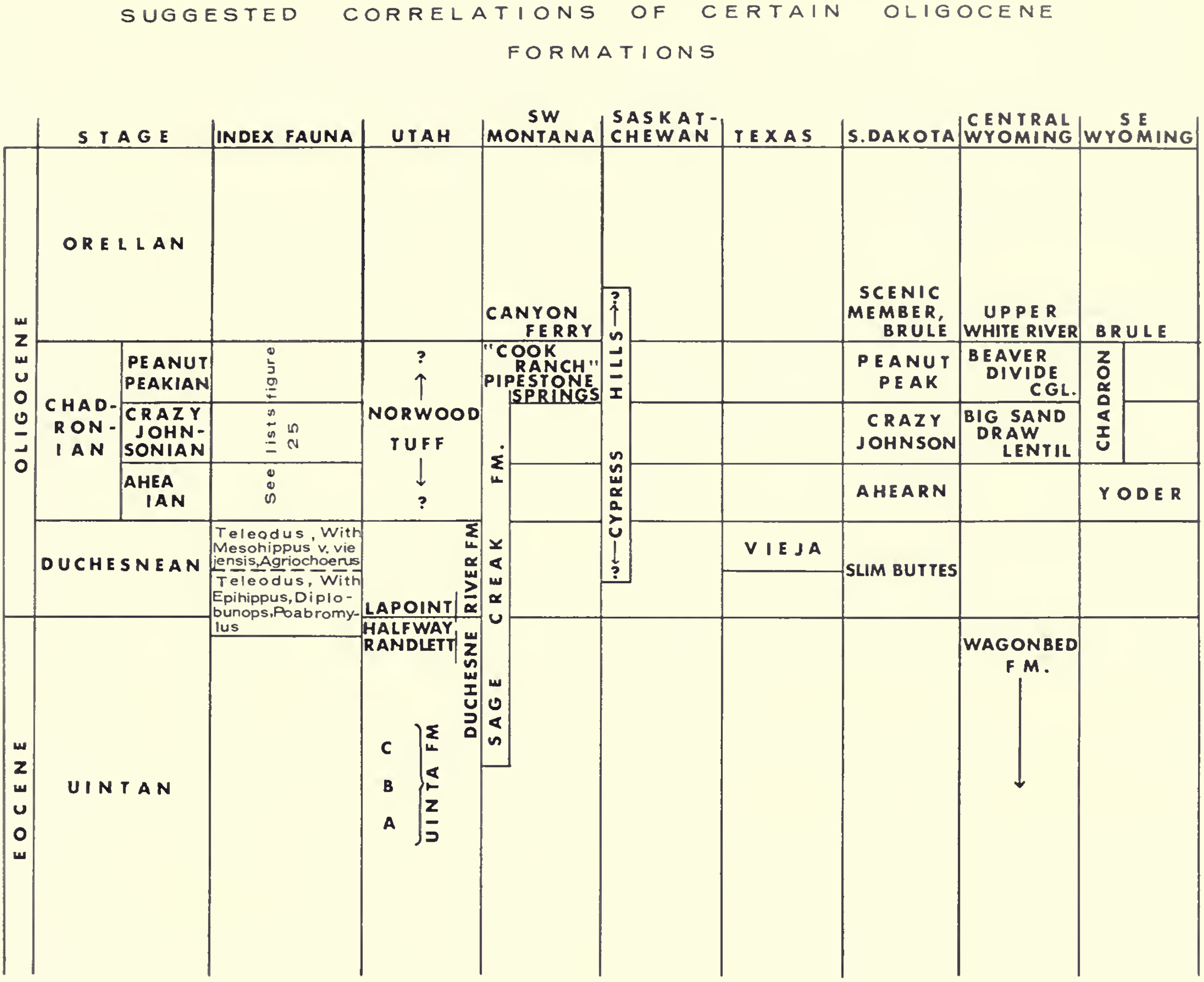


FIG. 24. Suggested correlations of certain Oligocene formations.

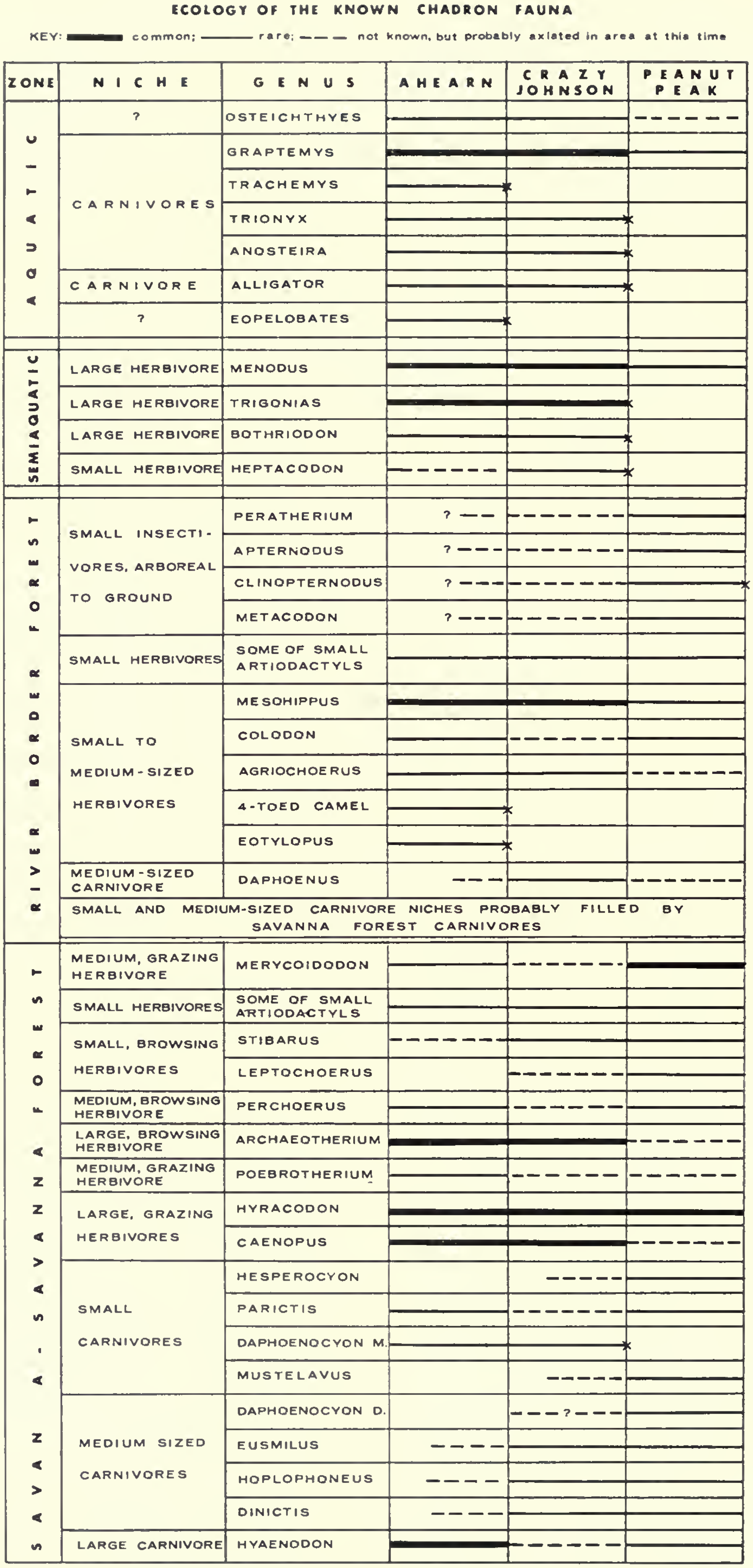
The oreodont, *Merycoidocon lewisi*, is common in both Peanut Peak and Pipestone Springs deposits, and the only earlier oreodont is known from a single specimen from the Crazy Johnson.

The replacement of *M. lewisi* by *M. culbertsoni* (replacement rather than succession as *M. lewisi* probably did not give rise to *M. culbertsoni*) in this chronofauna at the beginning of Orellan time suggests that the replacement is a critical time-marker and thus that the Pipestone Springs fauna is no later than Peanut Peakian.

Parictis parvus from the Ahearn is probably ancestral to *P. personi*, from Beaver Divide and Pipestone Springs, and to *P. dakotensis*, from the Peanut Peak. *P. personi* in turn is more primitive than *P. dakotensis* and is close, structurally at least, to the ancestry of *P. dakotensis*. This relationship suggests that the Pipestone Springs is older than the Peanut Peakian but since *Parictis* is rare as a fossil and since nothing is known of the group during the middle Chadron, the two species might well have had a common middle Chadronian ancestor from which *P. dakotensis* diverged more rapidly.

Peratherium, *Ictops*, *Menodus*, *Hopophoneus*, *Dinictis*, and *Paleolagus* occur both in the Pipestone Springs Formation and in the Peanut Peak Member. The ranges of these genera, however, are too long for precise correlation, and the species taxonomy of *Ictops* and *Peratherium* is too confused or the specimens too inadequate to allow specific determinations. The few rodents known from the Chadron Formation appear to be conservative groups with high dental variability within the species. Therefore, they are of little value as guide fossils for restricted time zones. The taxonomy of the small artiodactyls is also too confused at present to allow their use in correlation.

The sum total of the faunal evidence favors a correlation of the Pipestone Springs Formation with the Peanut Peak member. Certainly the Pipestone Springs is older than Orellan and almost as certainly much younger than Ahearnian (see also Wood, A. E., 1955.)



ECOLOGY OF THE KNOWN CHADRON FAUNA

KEY: ━━━ common; ——— rare; - - - not known, but probably existed in area at this time

ZONE	NICHE	GENUS	AHEARN	CRAZY JOHNSON	PEANUT PEAK
AQUATIC	?	OSTEICHTHYES	———	———	- - -
	CARNIVORES	GRAPTEMYS	━━━	━━━	———
		TRACHEMYS	———×		
		TRIONYX	———	———×	
		ANOSTEIRA	———	———×	
	CARNIVORE	ALLIGATOR	———	———×	
	?	EOPELOBATES	———×		
SEMIAQUATIC	LARGE HERBIVORE	MENODUS	━━━	━━━	———
	LARGE HERBIVORE	TRIGONIAS	━━━	━━━×	
	LARGE HERBIVORE	BOTHRIODON	———	———×	
	SMALL HERBIVORE	HEPTACODON	- - -	———×	
RIVER BORDER FOREST	SMALL INSECTIVORES, ARBOREAL TO GROUND	PERATHERIUM	? - - -	- - -	———
		APTERNODUS	? - - -	- - -	———
		CLINOPTERNODUS	? - - -	- - -	———×
		METACODON	? - - -	- - -	———
	SMALL HERBIVORES	SOME OF SMALL ARTIODACTYLS	———	———	———
	SMALL TO MEDIUM-SIZED HERBIVORES	MESOHIPPUS	━━━	━━━	———
		COLODON	———	- - -	———
		AGRIOCHOERUS	———	———	- - -
		4-TOED CAMEL	———×		
		EOTYLOPUS	———×		
	MEDIUM-SIZED CARNIVORE	DAPHOENUS	- - -	———	- - -
	SMALL AND MEDIUM-SIZED CARNIVORE NICHES PROBABLY FILLED BY SAVANNA FOREST CARNIVORES				
SAVANA - SAVANNA FOREST	MEDIUM, GRAZING HERBIVORE	MERYCOIDODON	———	- - -	━━━
	SMALL HERBIVORES	SOME OF SMALL ARTIODACTYLS	———	———	———
	SMALL, BROWSING HERBIVORES	STIBARUS	- - -	———	———
		LEPTOCHOERUS		- - -	———
	MEDIUM, BROWSING HERBIVORE	PERCHOERUS	———	- - -	———
	LARGE, BROWSING HERBIVORE	ARCHAEOTHERIUM	━━━	━━━	- - -
	MEDIUM, GRAZING HERBIVORE	POEBROTHERIUM	———	- - -	- - -
	LARGE, GRAZING HERBIVORES	HYRACODON	━━━	━━━	━━━
		CAENOPUS	━━━	━━━	- - -
	SMALL CARNIVORES	HESPEROCYON		- - -	———
		PARICTIS	———	- - -	———
		DAPHOENOCYON M.	———	———×	
		MUSTELAVUS		- - -	———
	MEDIUM SIZED CARNIVORES	DAPHOENOCYON D.		- - ? - -	———
		EUSMILUS	- - -	———	———
		HOPLOPHONEUS	- - -	———	———
		DINICTIS	- - -	———	———
	LARGE CARNIVORE	HYAENODON	━━━	- - -	———

FIG. 25. Ecology of the known Chadron fauna.

The persistence of several primitive species in the Pipestone Springs fauna might suggest that the fauna is slightly older than Peanut Peakian but might equally well be ascribed to local survival of these species in a more favorable environment.

Correlations with Other Chadronian Formations

The scattered and localized Chadronian deposits of Wyoming, Montana, and Saskatchewan present difficult problems in correlation because of the rarity of specimens, the local occurrence of many otherwise unknown species, or the difficulty in establishing the local stratigraphic sequence.

The relative ages of the various Chadronian formations and "local faunas" from southwestern Montana will be studied by the senior author in the future. Since these faunas resemble the Pipestone Springs fauna ecologically, they are best compared with that fauna rather than with the South Dakota faunules.

The Beaver Divide Conglomerate of central Wyoming may be middle or late Chadronian on the basis of occurrence there of *Parictis personi*; probably it is no older. The Big Sand Draw Lentil may be earlier Chadronian, but the known fauna does not definitely suggest such a dating.

The Cypress Hills fauna from Saskatchewan includes *Teleodus*, (a characteristic Duchesnean genus), *Mesohippus celer* (Chadronian), *Hesperocyon lambe* (late Chadronian), and several Orellan species. We suspect that this is a mixed fauna resulting either from reworking of the fossils or from continuous deposition with cross-bedding and channeling which would preclude zoning.

The complex stratigraphy at Sage Creek, Montana, will be discussed at length when studies on Montana Chadronian deposits are completed, but the bulk of this section is Uintan and Chadronian with a thin stratum which has yielded *Teleodus* and is probably Duchesnean.

Conclusions

The Chadron includes three distinct rock-time units with characteristic faunal associations (see Fig. 25). The oldest, the Ahearn, is apparently younger than the Vieja which may be regarded as late Duchesnean. The youngest, the Peanut Peak, is distinct faunally from the typical Orellan and underlies the Orellan Brule formation in the Big Badlands.

The late Eocene-early to middle Oligocene time sequence in western North America thus comprises the Uintan, Duchesnean, Chadronian, and Orellan (see Fig. 24.) The Uinta formation includes three distinct members, A, B, and C,[1] which represent the bulk of Uintan time. The lower two members of the Duchesne River Formation, however, are probably Eocene and include the typical Eocene species of *Protoreodon* and *Diplobunops* but are somewhat younger than Uinta C. The upper Duchesne River, the La Point, includes the titanothere, *Teleodus*, which is associated with *Mesohippus viejensis* and *Agricochoerus* in the Vieja and with *Mesohippus* in the Cypress Hills. The rest of the known La Point fauna is either transitional between Uintan and Chadron forms or is represented by specimens so inadequate that their relationships cannot be precisely determined.

The La Point Member of the Duchesne River Formation may then be properly considered typical of Duchesnean time (type locality, 12 miles west of Vernal, Utah—Kay, 1934) with the understanding that no rock section described up to the present represents all of Duchesnean time, that the La Point fauna is early Duchesnean, and that the Vieja Formation of Texas (Stoval, 1948) is late Duchesnean and should be considered the type for this part of Duchesnean time. *Teleodus* then becomes the index fossil for the Duchesnean. *Teleodus*, associated with *Poabromylus*, *Epihippus uintensis*, and *Diplobunops*, indicates La Pointian or early Duchesnean; and the *Teleodus-Agriochoerus-Mesohippus viejensis* association indicates Viejan or late Duchesnean age.

PALEOGEOGRAPHY

Topography

The character and distribution of Chadron deposits in South Dakota demonstrate the paleogeographic and and topographic relationships of that time. The Black Hills were the dominant element in the Chadron landscape and were the source of all the Chadron clastic deposits in the area. Their topography apparently was very similar to that of the present time, since the pre-Chadron valleys are aligned with notches in the hogbacks, and later Oligocene valley-fills extend up these valleys through the hogbacks and into the Triassic "Racetrack." The petrologic character of the Chadron sediments also indicates sources in the present watershed areas.

The Chadron formation was deposited on a surface of gentle to moderate relief cut into deeply-weathered Pierre shale. This pre-Chadron surface consisted of three major elements:

1. The valley of the "Red River", which was about 5 miles wide and some 70 ft. deep and trended approximately ESE.
2. The level upland surface into which the Red River Valley was cut, which ranged in width from 6–15 miles.
3. Low ridges that formed the divides to the north and south of the "Red River." These ridges were about three-quarters of a mile wide; the northern ridge or Sage ridge rose about 70 ft. above the upland surface; the southern about 40 ft.

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[1] Wood's (1934) division of the Uinta into Myton member (C) and Wagonhound member (A and B) is not followed here because we feel that the A and B members are much more distinct, both lithologically and faunally, than the B and C.

During Ahearnian time deposition was limited to the "Red River" valley but thereafter spread onto the upland, and in Peanut Peakian time extended over the whole upland area. Figure 4 summarizes the topography of the pre-Chadron surface and the general drainage pattern.

Climate

A fairly precise estimate of average temperature immediately preceeding Chadron time can be made. Since lateritic weathering of rocks other than limestone requires an average annual temperate of 60° F or higher (Krynine, 1949), the slight to moderate lateritization of the underlying Pierre shale and the slight lateritization of some Chadron sediments suggests a temperature of 60° F or very little higher. A mean annual temperature of 60–65° corresponds with the present situation in southeastern United States.

Comparison of the pre-Chadron weathering in South Dakota with that in Montana throws light on the vertical temperature gradient. Near Whitehall, Montana, at present elevations of 4000–4500 ft., the Paleozoic limestones show pre-Chadronian lateritization, but all other rock types were weathered to limonitic or kaolinitic debris. This indicates (*fide* Krynine) a mean annual temperature of about 55–60°, like that of West Virginia or of Cairo, Illinois. Assuming the average annual temperature in Montana to have been 57–58°, and the difference in elevation between the two stations to have been the same as at present, 1300 ft., the vertical temperature gradient in pre-Chadronian time would be about 3° per 1000 ft., or the same as the present gradient. Since the adiabatic gradient depends upon unchanging laws of physics, the accordance of the estimated temperatures to the gradient supports the accuracy of the estimates.

The presence of small alligators in the Ahearn and Crazy Johnson Members can be taken to mean that winter minimum temperatures did not long remain below freezing during much of Chadron time. It does not, however, indicate that the average annual temperature was as high during Chadron time as it had been before. The very incomplete lateritization of Peanut Peak sediments in the neighborhood of the major Chadron stream courses, and the lack of oxidation in Chadron sediments away from those stream courses, indicates that temperatures were not as high during Chadronian time as they had been before. Furthermore, the decrease in amount of weathered upland debris deposited in Peanut Peak sediments as contrasted with that in the upper Ahearn suggests that weathering processes in the uplands progressively declined through Chadronian time. This would suggest a drop in temperature, or precipitation, or both. Dorf (1959, pp. 185–189) cites paleobotanic evidence indicating that the later Oligocene was cooler than late Eocene.

An estimate of annual precipitation is much more difficult. Lateritization is accomplished under conditions of abundant but highly seasonal precipitation—40 in. or more, with an alternation of rainy and dry seasons. It may be safe to assume a pre-Chadronian annual rainfall of over 40 in.

The Chadron sediments themselves include algal limestones, casts of *Unio* and pond snail shells, bentonitized ash, and predominately reduced disseminated iron (greenish to bluish color), all of which indicate abundant water. They also contain scattered zones of gypsum crystals, manganese dioxide, and, especially in the Peanut Peak member, light tan sediments and calcereous nodules or zones, which suggest aridity. The fauna is a mixture of wet-forest forms such as alligators, small artiodactyls, insectivores, and *Mesohippus* with such dry-plains animals as the camel, *Poebrotherium.*

This apparently conflicting evidence resolves itself into a co-ordinated picture when it is noted that the indications of moisture occur generally near the bottom of the section or concentrated in the vicinity of the channel fills. The evidences of aridity, on the other hand, are to be found away from the channel fills and near the top of the section. Abundant run-off from the Black Hills, with the streams passing through a relatively dry plains area, could produce this pattern of evidence, especially if desiccation became progressively more severe.

INTERPRETATION OF CHADRONIAN SEDIMENTATION

General Review of Tertiary Sedimentation

A. Description.

The Oligocene epoch was a time of transition—this concept has been well documented by faunal studies, but the evidence to be derived from study of major lithologic changes has not been systematically presented. Figures 26 and 27 review the senior author's observations on Tertiary continental deposits and include distribution, thickness, lithology, and evidence of depositional environments of most of these sediments from the High Plains west to the Nevada-Utah boundary and from the San Juan basin north to the Canadian boundary. Much of the data on which this chart is based can be verified in the literature. However, we have omitted data which could be gleaned from the literature but which have not been personally observed because it seems unfair to quote in this context descriptions made without anticipation of this interpretation.

The chart shows that Upper Paleocene and Wasatchian sediments are primarily fluvial, of wide distribution and moderate thickness. Sediment colors are generally dark reds, greens, and purples, and the fossil bones are heavily impregnated with iron and manganese oxides. Middle and upper Eocene deposits on the other hand occur in only a few of the intermontane basins, are usually thicker than the underlying Tertiaries, and contain a large proportion of lacustrine sediments. Middle Eocene sediments are generally pale greenish to grey or tan, with bones colored pale tan by limonitic impregnation or black with manganese dioxide. The color of upper Eocene rocks and impregnation of the fossils is generally similar to that of the Wasatchian. Deep pre-

Chadronian weathering in South Dakota, Nebraska, eastern Wyoming, and Montana suggests that these areas were exposed surfaces during late Eocene time and that there were no late Eocene sediments deposited in this region.

In contrast, Chadronian sediments occur in northeastern Colorado, western Nebraska and the Dakotas, many of the basins of Wyoming, and most of the intermontane valleys of Montana. They rest discomformably on eroded, deeply weathered older rocks—only at two places, Beaver Divide and Sage Creek, were they deposited conformably on late Eocene beds. Bentonitized ash is always present in the Chadronian sediments and increases in amount and freshness toward the top of the section. The Chadronian sediments are thin, commonly less than 200 ft. thick, and occur only on the eastern side of the Continental Divide. The sediments are primarily fluvial and have relatively pale colors. Fossil bone is slightly impregnated, but sometimes heavily coated, with limonite.

Post-Chadron deposition in general parallels that of the Chadron in distribution and characteristics. The color of Orellan rocks is somewhat paler and more tan than Chadronian; the ash content is relatively higher; and fossil bone occasionally has a coating of hematite but otherwise shows little more iron-manganese impregnation than modern bone found on the surface of the High Plains. In Figure 26 these changes from the Paleocene through the later Tertiary are summarized and the transitional nature of Chadronian deposits is demonstrated. The development of reddish tan sediments, immediately followed by non-deposition, at the close of Chadron time, should be noted.

B. INTERPRETATION

The thickness and distribution of the deposits must reflect both tectonic and climatic controls. The proportion of lacustrine to fluvial beds must be the result primarily of tectonic activities by which the basins were blockaded to form lakes. On the other hand, sediment color if syngenetic, and bone impregnation, should be functions of climate rather than of tectonics.

Sediments may, of course, inherit their color from the parent rock or weathering of that rock, or may develop it epigenetically. The senior author has determined certain field criteria for the recognition of derived, epigenetic and syngenetic colors (Clark, 1962), and we limit our discussion to the latter, since they alone are significant in climatologic interpretations. Highly colored fluvial sediments are generally deposited under conditions of high temperature and humidity with abundant vegetation; pale fluvial sediments indicate aridity but not necessarily cool temperatures.

The nature of impregnation of fossil bone is also partially controlled by local climate. The senior author has found that in most semi-tropical to tropical forest environments fossil bone is heavily impregnated with hematite, limonite, (in general, hydrous iron oxides) and manganese oxides. In moist and somewhat cooler environments there is an impregnation of brown limonite. Several horse skeletons buried for 35 years in forest mould near Princeton, New Jersey, showed such impregnation to depths of one-eighth inch. Burial under somewhat drier conditions seems to produce incrustation without impregnation; for example, a woodchuck skull recovered from swamp mould in northeastern Illinois was heavily encrusted. In contrast, burial on the semi-arid high plains in Dakota and Colorado produces no iron impregnation. The precise factors that control impregnation are not known but are probably related to the acidity of the local ground water, and will vary with the nature of entombing sediments, porosity of the bone, and speed of burial. However, the generalization as to climatic conditions fits all the available evidence.

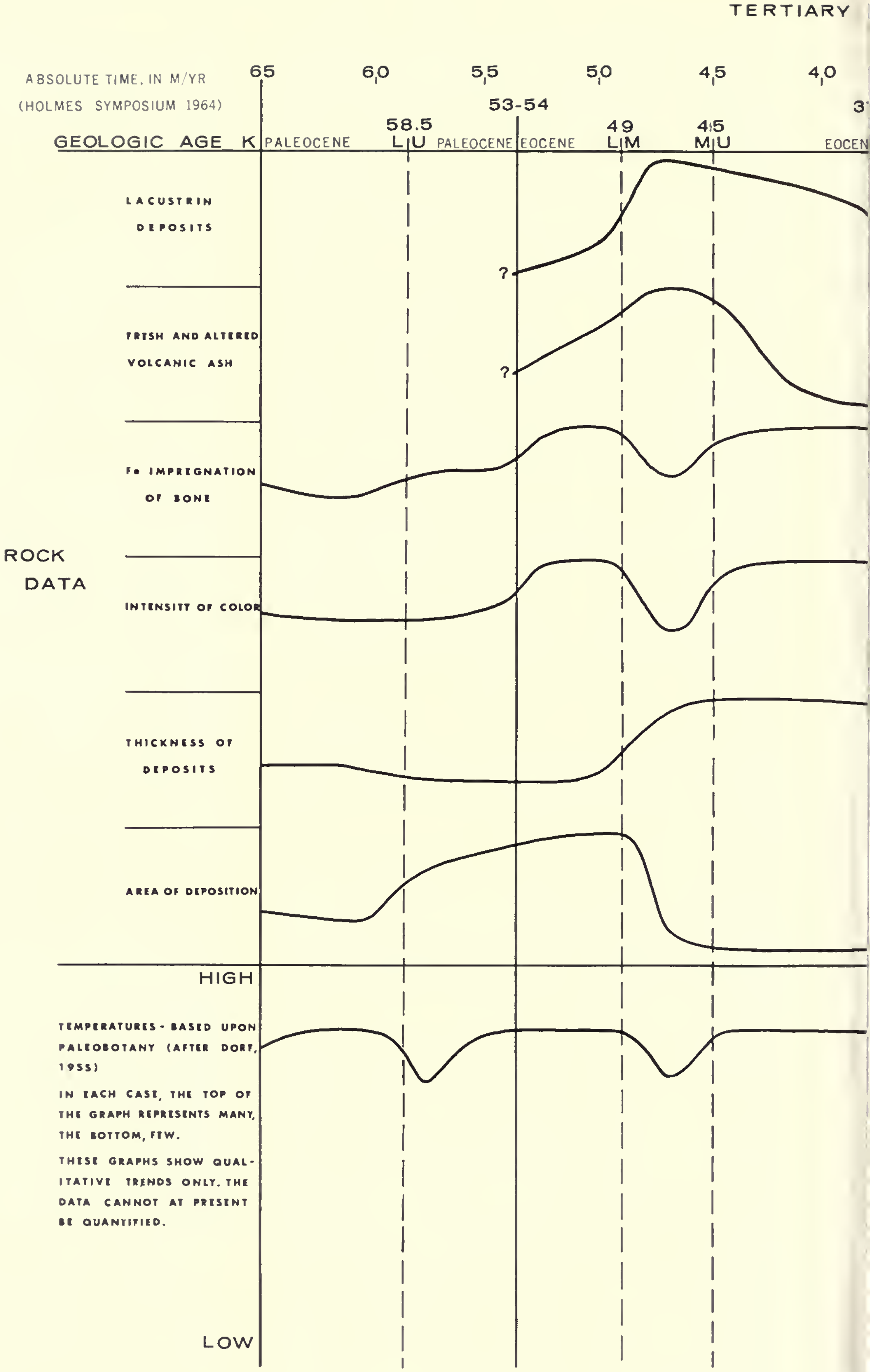
On the basis of the evidence cited above, a general interpretation of early and middle Tertiary sedimentary environments can be made. The thickness and wide distribution (on the plains and in all of the basins on either side of the divide) of late Paleocene and early Eocene rocks suggests widespread uplift of the positive units with respect to the intermontane basins and the high plains. The restricted distribution of middle and late Eocene beds and the development of deep weathering profiles elsewhere indicates cessation of general tectonic activity and a long period during which the streams were at grade or cutting shallow valleys in the basins and on the High Plains. The high proportion of lacustrine sediments presumably results from local tectonic adjustments which blocked egress from the intermontane basins. The geographic association of most of these basins with the Uinta Mountains suggests that these local movements were related to that tectonically active unit. Color of sediments and mode of bone impregnation suggests a middle Eocene cool episode followed by a late Eocene warm, moist climate. Paleontological evidence supports but does not prove this conclusion.

Resumption of widespread deposition in Chadron and post-Chadron time indicates the operation of a factor or factors of regional extent which resulted in overloading of streams east of the continental divide and in intermittent deposition over this area throughout the later Tertiary. The paler sediments, the change in type of fossil impregnation, and faunal evidence demonstrate rather conclusively a change toward a drier and somewhat cooler environment. It may well be that the reddish color of latest Chadron sediments, followed by non-deposition with abundant swamps, represents a temporary warming; this is possible but no satisfactory evidence is known.

Factors Controlling Chadronian Sedimentation

As indicated above, local or regional tectonic factors apparently controlled pre-Chadronian sedimentation. On the other hand, Oligocene and Miocene beds are not so clearly related to tectonic movements and further discussion of their origin is necessary.

Any one of five possible hypotheses or some combination of these hypotheses may be the true explana-

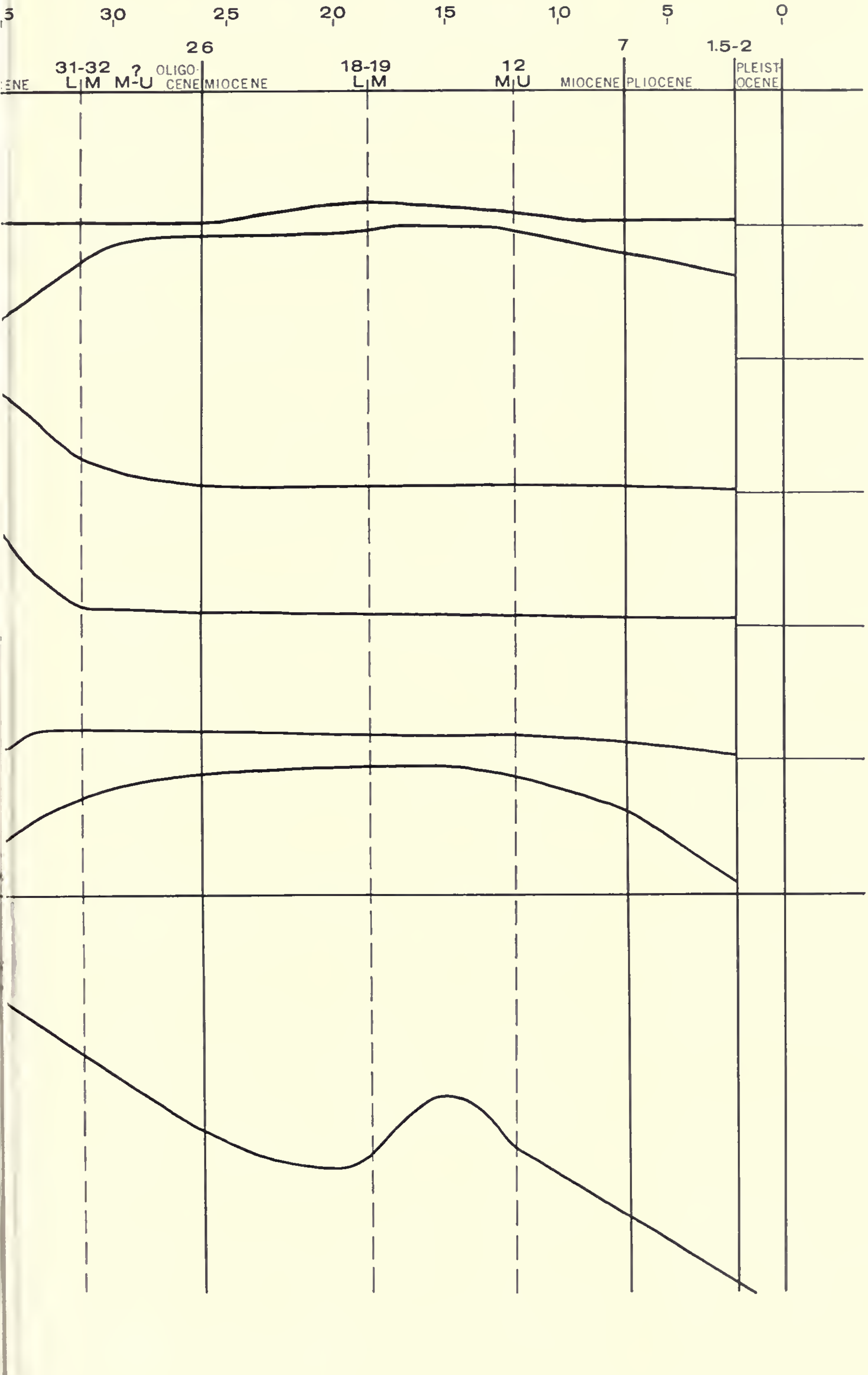


IN EACH CASE, THE TOP OF THE GRAPH REPRESENTS MANY, THE BOTTOM, FEW.

THESE GRAPHS SHOW QUALITATIVE TRENDS ONLY. THE DATA CANNOT AT PRESENT BE QUANTIFIED.

Fig. 26. Tertiary Paleogeographic Data-Sedimentary.

EOGEOGRAPHIC DATA - SEDIMENTARY



tion of the thin, widespread deposits across the central High Plains. These are:

1. eustatic rise of sea level;
2. uplift of a structural barrier across the lower reaches of the depositing streams;
3. down-warp of the entire region;
4. overloading of streams with volcanic ash; and
5. climatic change sufficient to cause a shift in stream regimen.

Eustatic rise of sea level can be eliminated as a possible cause for several reasons. First, the coastal Plain stratigraphy gives no evidence in favor of it, and suggests rather that Oligocene sea level was lower relative to the land than was Eocene sea level. Second, the Atlantic drainages south of central Colorado did not begin deposition simultaneously with those to the north, as they should have done had there been a change in sea level. Third, the Chadron of South Dakota thins both mountainward and seaward from its maximum thickness about 20 miles east of the rim of the Black Hills. A rise in sea level might be expected to result in a deposit thinning progressively upstream from the river mouth.

Uplifting of a structural barrier across the lower reaches of the depositing streams would also produce a lens of sediment thickest near the downstream shore of the resulting lake and thinning upstream. Further, the Oligocene streams of southwestern Montana probably did not enter the same master stream as did those of central Colorado. Therefore, a tremendously long structure, no trace of which is known, must be called into being. This second possibility can also be discarded.

A gradual downwarp of the entire area from Idaho to the Break of the Plains and from the Canadian border to central Colorado, has been postulated in oral discussions as the cause of mid-Tertiary (Oligocene-Miocene) deposition. Three main points of evidence have been regarded as supporting this hypothesis:

1. Presence of Oligocene and Miocene outliers at elevations up to 7500 (Montana) and 9000 ft. (Big Horn Mts.). If these levels are projected out into the intermontane basins, the late Miocene bottoms of the basins as reconstructed would lie 3500–4000 ft. higher than the present ones. Such great masses of fill, in every basin and trough, could only be explained by filling of a downwarped area.

2. The small amount of erosion of mountain slopes since early Oligocene time. Basal Chadronian sediments everywhere contain pebbles derived from rocks exposed in the present cores of the adjacent ranges. Chadronian sediments choke the mouths of present canyons debouching from the various mountain ranges, and thus indicate that early Chadronian mountain topography must have been like the present topography. This preservation of an ancient surface can be explained by assuming burial under thick mid-Tertiary sediments, which were then removed during Quaternary time.

3. Widespread superposition of streams on low ranges or near the ends of long ranges can be explained by assuming a cover of Tertiary sediments on which the streams meandered before their recent incision.

These are strong evidence, but other reasoning, equally cogent, opposes them:

1. There is no direct structural evidence of any such downwarping.

2. There are no known angular unconformities within the mid-Tertiary section (except in the Slim Buttes, where the movement is either non-tectonic or extremely local). If such extensive downwarping occurred, differential movements causing angular unconformities would be expected.

3. Basal Chadron sediments are everywhere (except at Beaver Divide) composed of reworked, deeply weathered material, but later clastics usually consist of fairly fresh rock, showing that once the pre-Chadron soil had been stripped, weathering did not keep pace with erosion. An area undergoing downwarp would certainly not be expected to show accelerated erosion.

4. Depositional dips of 3–5° are usual in the montane mid-Tertiary sediments, and demonstrably initial dips of up to 25° have been noted. Deposition of uniform, thin strata on a porous surface at even greater dips can be demonstrated experimentally.

If average depositional dips of 2° are presumed, which is conservative judging from the observed dips, then the mid-Tertiary fill of the Big Horn, Powder River, and other major basins need not have been more than 1500 ft. thick. This thickness accords roughly with the thickest preserved sections, and, further, the depositional structure would accord with that of the observable sediments. It is our belief that, with the exception of a few locally downfaulted areas in Montana, none of the basins of this area ever contained more than 1500 ft. of mid-Tertiary sediment.

5. The cases of stream superposition do not demonstrate a fill deeper than 1500 ft. Several streams are superposed over very low ranges, with much higher mountains nearby. Others traverse the lower reaches of higher ranges. In no case is the top of the ridge at the watergap more than 1500 ft. higher than the reconstructed pre-Oligocene surface.

6. Since pre-Chadron topography was probably very much like that of the Recent, the major stream systems would have filled rapidly to grade with clastic materials from the mountains during downwarp. Yet the post-Chadronian sediments contain smaller clastic constituents with the major proportion consisting of ash. Therefore, post-Chadronian deposition may have been partially controlled by the supply of volcanic ash and might be expected to show a different distribution than the Chadronian deposits.

7. Downwarp might be expected to cause Chadronian deposition on both sides of the Continental Divide rather than on one side.

8. Progressive downwarp should cause the youngest sediments to be thickest near the center of downwarp but these later Oligocene and Miocene sediments are

thickest near the base of the local mountain range that formed the watershed of the streams depositing each series. The only regional trend in thickness appears to be related to an increase in volume of volcanic ash toward northwestern Wyoming.

These eight lines of evidence weigh against the probability of a regional downwarp as the basic cause of deposition.

The fourth hypothesis, the overloading of the streams by volcanic ash, has two points in its favor. First, the ash occurs in large volume throughout the upper part of the section and increases in amount, proportion, and average grain size toward the volcanic center. Second, Chadron deposits are absent west of the volcanic center, and south beyond the zone where prevailing westerlies might be expected to carry ash.

Several strong lines of evidence militate against ash as a primary cause of mid-Tertiary deposition. First, the basal 20 ft. of Chadron sediment nowhere include volcanics. In South Dakota, ash first becomes an important part of the sedimentary mass in the Crazy Johnson member, and does not become dominant below the Peanut Peak Member. Overloading with ash cannot reasonably be regarded as the primary cause of an episode of sedimentation which began without ash and did not receive significant quantities of ash until the old topography had been buried. Therefore, increase in volume of ash in the streams could not have been the initial or the primary cause of deposition, but it probably influenced the rate of deposition.

The remaining hypothesis, that of climatic control of stream regimen, is thus supported by the default of the other four suggested; furthermore, the positive evidence for this interpretation is substantial.

The occurrence of a major climatic change at the beginning of Oligocene time has been demonstrated adequately in this and other papers. The change from a moist, warm, and possibly monsoonal climate to a semi-arid, cool climate would profoundly alter vegetational cover, weathering, and stream discharge and consequently would modify stream regimen.

In late Eocene time weathering must have been primarily chemical and resulted in a predominance of clays and solutes. The heavy vegetational cover would restrict surface run-off and thus reduce the amount of sediment relative to stream discharge. The master streams—adjusted to this comparatively small sediment load—would have low gradients over all outcrops susceptible to chemical weathering.

On the other hand, the rocks resistant to chemical weathering in the mountain cores would rise abruptly as sharp ridges, and consequently stream profiles would change rather abruptly near the divides. (Cotton, 1941 p. 155–156; Davis, 1923 p. 21; Lawson, A. C., 1932 p. 706). The landscape would then comprise two sets of features; broad river valleys with gentle gradients developed on the shales and weakly cemented sandstones, and bold mountain ranges on the more resistant rocks.

In Chadron and post-Chadron time the cooler, drier climate must have produced a relative increase in mechanical weathering with a resultant increase in supply of coarser clastics. The vegetational cover must also have been reduced, and surface run-off consequently increased in relation to total run-off. In turn, increased surface run-off would increase slope wash and gullying on steeper slopes. The effective load of main streams would therefore be relatively large at the same time total water discharge was decreasing considerably. The net result would be erosion of upland slopes, removing weathered mantle first and then relatively fresh rock fragments, and deposition in the major stream valleys extending out into the adjacent plains.

The effects of the climatic change would be regional and thus the pattern of erosion and deposition would be similar over a wide region. On the other hand, the boundaries of the area of deposition might be rather sharp and controlled by the major topographic elements and by boundaries of wind systems (see p. 66).

The protracted depositional episode (Oligocene and Miocene) cannot, however, be ascribed simply to a single brief period of climatic change. If such a change were the only control, rapid filling following the change would be succeeded by a long period of equilibrium and concluded by an even longer period of slow erosion as the supply of clastics from the uplands decreased. Therefore, if the climatic hypothesis is generally correct, one or more modifying factors must also have operated. The most probable factors are:

1. Small supply of material relative to the area of deposition. The stream profiles then would be adjusted very slowly. The evidence of numerous hiatuses and cut-bank erosion within the Chadron suggests, however, that the streams were never very greatly out of equilibrium and that the supply of material for deposition was an incidental factor.

2. Regional uplifts. Downstream parts of the channels would be above grade and would actively downcut. Deposition would then cease or slow as the knick points shifted upstream. The overall consequences of such changes are somewhat difficult to visualize but it seems probable that the streams would come to equilibrium more rapidly rather than more slowly.

3. Overloading by volcanic ash in post-Chadron times. The increase in ash-falls in late Chadron and post-Chadron time was undoubtedly a factor in Oligocene and Miocene deposition. It could be the controlling factor only if the amount of ash increased progressively, since *a*) the streams were never far from equilibrium, and *b*) the streams would tend to come to equilibrium with the amount of ash in their load and any great reduction in amount of ash would result in trenching. The percentage of ash does increase in the later Chadron and through the Oligocene and Miocene, but it seems unlikely that this increase is solely responsible for continued deposition.

4. Progressive climatic change. Further decrease in rainfall would decrease volume of the streams, both

absolutely and relative to available load. With an abundant supply of ash largely independent of regional climate and with progressive decrease in stream discharge, continued deposition would be expected. Such a progressive overall deterioration of climate is indicated by: *a*) paleobotanical evidence; *b*) increasing dominance of a savanna fauna during the later Tertiary; and *c*) general characteristics of the sediments.

We conclude, therefore, that climatic change initiated deposition in the Oligocene, that it was the primary factor in continuance of this deposition, and that the supply of volcanic ash was a major but accessory factor in later Oligocene and Miocene deposition. The fluctuations in deposition then may have been the result of either climatic fluctuations imposed on the general trend or of fluctuations in supply of ash.

Climatic Patterns of the Eocene and Oligocene

The distribution of fossil plants, (Dorf, 1955), of invertebrates, and of vertebrates, as well as petrologic evidence, indicates that late Eocene climates were warm and equable. The temperature differential between the Equator and the North Pole must have been low. Under such conditions hemispheric wind current systems would be weak, of small horizontal extent, and much influenced by local or regional temperature differentials.[1]

Assuming the present prevailing westerlies, the Eocene jungle-forest environments in the intermontane basins are extremely difficult to account for as the basins at present are arid or semiarid. All available evidence indicates that during the Eocene the mountains maintained, in general, approximately their present elevations above these basins (although the entire area was nearer sea level) so that an explanation based on changes in local or regional topography is inadequate. If, however, the westerlies were much weaker, local temperature differences between the Western Interior and the two major adjacent seaways, the Gulf of Mexico and Hudson's Bay, might be expected to produce a monsoonal climate.

The area of the southwestern and central United States must have been quite warm during the summer and thus would function as a thermal low. (Trewartha [1954, p. 99] describes the occurrence of such a summer thermal low at present). The Gulf of Mexico would be somewhat cooler, and Hudson's Bay or the Arctic would be considerably cooler. They would become thermal monsoonal highs. A summer monsoon, with prevailing northerlies, would bring moist air in from Hudson's Bay to cause heavy monsoon rains throughout the Northern and Middle Rockies. (There was probably also a southeast monsoon across Texas, but that does not enter into the present problem.) Heavy rains probably fell on all places above 1000 ft. elevation, as they do in the Punjab today.

The winters were probably dry and cool, with almost no wind. It is possible that the slightly stronger winter westerlies may have modified the winter monsoon, but no evidence of this is known at present.

Bradley (1948) noted the evidence of alternately wet and dry seasons in the middle Eocene Green River Shales, and suggested that the climate was monsoonal. He lacked, however, the supporting evidence given by modern knowledge of convectional dynamics, and supposed the summers to be dry and warm, the winters cool and wet. The present hypothesis makes necessary warm, wet summers and cool, dry winters.

Additional evidence of prevailing northerlies in Wyoming is offered by the distribution of volcanic ash. Ash constitutes a high proportion of the mass of middle Eocene sediment in the Green River and Washakie basins, and a much smaller proportion of middle and late Eocene sediment in the Uinta Basin to the south. Houston (1964, p. 18) considers that the volcanics of the Green River and Washakie Basins "may have come from the Absoroka source but the petrography is not definitive. . . . Petrographically these units equate to the acid breccia of the Yellowstone-Absaroka source, but in fine-grained rocks this far from source one might expect some loss of heavier more mafic minerals especially if the major transport was aerial." We consider that the Yellowstone-Absaroka district is the most probable source, because: (1) it is less than half as distant as the next nearest possible sources in Oregon and Nevada; (2) the proportion of ash decreases notably from the Green River Basin southward to the Uinta Basin, as it should if the source lay to the north, and should not if the source lay to the west; and (3) as Houston has pointed out, the petrography of the volcanic sediments in the Green River and Washakie Basins is compatible with Yellowstone-Absaroka volcanics. If this is the case, the tremendous volume of ash in the two basins, 300 miles from the source, indicates that the prevailing winds during late Eocene time were northerly.

The authors feel that the evidence justifies the hypothesis that during late Eocene time the climate was warm and equable, with a low temperature differential between the Equator and the North Pole. Consequent weakening of the prevailing westerlies permitted a monsoonal circulation to develop, with prevailing northerlies bringing moist air from Hudson's Bay and the Arctic toward the thermal low in southwestern United States.

The rainfall pattern produced by a monsoonal circulation with prevailing northerlies would be strikingly different from the present rainfall map. By analogy with

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[1] Communication from Dr. David Fultz, Department of Meteorology, University of Chicago: "A number of qualitative considerations, both theoretical and empirical, such as the observed seasonal differences in circulation between summer and winter, suggest that the smaller the general horizontal temperature differential in a rotating convective fluid system like the atmosphere, the weaker will be the currents and the smaller the horizontal dimensions of the predominant current systems. The more this is the case, the more such systems will be influenced by purely local temperature gradients. Laboratory experiments over a wide range indicate by comparison with the present 20-30° C between tropical and polar regions that if the differential were, say 2° C, the current systems would be of the order of size of a few degrees of latitude."

the present situation in the Punjab, one may presume that little precipitation would occur below elevations of 1000 ft. This means that most of the Central Lowlands would be dry plains or even desert, analogous to Delhi or the Sind, while the northern High Plains and the Wyoming basins enjoyed heavy summer rainfall. There is, of course, no evidence bearing on Eocene climates in the Central Lowlands, but the deeply-weathered, lateritic pre-Chadron surface in South Dakota certainly suggests warm, highly seasonal rainfall.

The general lowering of temperatures in the Oligocene and early Miocene (Dorf, 1959, and preceding sections of this paper) would represent an increase in the Equatorial-Polar temperature differentials and thus would increase the strength and extent of the hemispheric wind system. The monsoonal system would be greatly modified or destroyed, and replaced by prevailing westerlies and a cyclonic storm system similar to the recent pattern. Rainfall distribution would then come to approximate the Recent with a marked decrease in total rainfall on the eastern slopes of the central and northern Rockies. This area is, of course, precisely that in which stream regimen was profoundly changed at the beginning of Chadron time.

The relationship of this early Oligocene climatic change to the general pattern of Cenozoic climates has significant bearing on the causes of that change. A brief review of Cenozoic climatic fluctuations is needed to understand this.

Dorf (1955, p. 587) has published a series of geologic thermometers based upon studies of paleobotany. Figure 26 shows his temperature data graphed on the most recent absolute time scale (Phanerozoic Time Scale: Symposium; 1964, pp. 179–191). Parallels between temperature changes and the lithologic and paleontologic changes shown in the graph suggest a causal relationship. Three major warm (and presumably equable) episodes have occurred: 1. late Paleocene-early Eocene; 2. late Eocene; and 3. middle Miocene. Four intervening cool periods are represented by: 1. middle Paleocene; 2. middle Eocene; 3. Oligocene-early Miocene; and 4. late-Miocene-Recent.

A periodicity of about 10 million years of warmth, with shorter, intervening cool episodes, seems to have obtained until the beginning of Oligocene time. A general cooling trend began at that time and continued until its nadir in the Pleistocene glaciations, interrupted only by the partial warming of mid-Miocene time. This suggests a rough periodicity of about 20 million years, during the cooling trend. It is possible either that the evidence for warm episodes in about mid-Oligocene and late Pliocene times has been obscured by the general cooling, or alternatively that the 10-million-year periodicity was suppressed by the longer trend cooling. The senior author intends to investigate this problem further.

The Pleistocene glacial and interglacial episodes represent temperature fluctuations on a lesser order of magnitude. Estimates of the absolute length of the Pleistocene vary from 1,000,000 to 2, 700,000 years and estimates of the absolute length of the various stages depend upon the basis used. Whatever absolute time scale is used, these stages are fairly rhythmic fluctuations with a periodicity of a few thousands (cold) to many tens of thousands (warm) of years.

Brooks (1948) and Ahlman (1953) have summarized the evidence for a series of climatic fluctuations of the order of magnitude of 150–500 years. These plainly represent a third mode of temperature fluctuation not related to known Chadronian phenomena.

Finally, the 13 to 22-year cycle presumably related to sunspots is apparent in most weather records but is not evidenced in Chadron sediments.

It appears, therefore, that temperatures have fluctuated on four modes:

1. 10,000,000 year, and possibly a 20,000,000 year during long-term cooling;
2. 10,000–100,000 year;
3. 150–500 year;
4. 22 year, approximately.

The Chadronian cooling plainly represents the initiation of the cool phase of a 10,000,000 year fluctuation. It is not the equivalent of a Pleistocene glacial epoch, because the time involved is too long. The Oligocene is now generally regarded as having a duration of about 7–10 million years. Chadronian time was a major portion of this, and potassium-argon dating indicates that the Chadron probably represents 3–5 million years. That is, Chadronian time was longer than the entire Pleistocene.

Dorf's graph (Fig. 26 of this paper) makes apparent an even greater significance of the Chadronian cooling. At this time, the entire series of long-term fluctuations began to grow cooler, as mentioned above. Whether or not this very long-duration cooling is part of a fifth series of temperature fluctuations on a mode of more than 100 million years is not known. It is, however, of importance that coincidences of minima in the 10 million year mode and the 10,000–100,000 year mode, plus this very long-duration temperature depression, were required to produce glaciation in middle latitudes.

The Chadronian cooling should, therefore, be studied carefully, with the understanding that it may represent a simultaneous, coincidental cooling on two different systems. Once the modes of fluctuation are recognized, geologic and geophysical research can be devoted to determining their history and causes.

PALEOECOLOGY

Introduction

The rarity of fossils, the absence of paleobotanical materials, and the usual difficulties of determining habits and habitat from occurrence and morphology restrict interpretation of Chadron paleoecology. Interpretation is further complicated by the apparent geographic proximity of quite different major communities among which many of the mammalian species probably ranged at will. Figure 25 summarizes our knowledge of Chadron paleoecology and includes our interpretation of habits and environment preference of some forms. As is obvious from the table, only a few species can be assigned with certainty in this fashion. Other interpretations are less certain but probable, and many are extremely dubious. In constructing this table and the lists that follow, we have been guided by the following priorities in evidence:

1. Adaptations for particular modes of life evident in skeleton and teeth;

2. Lithologic associations and our interpretation of the environment of sedimentation:

3. Association with other species whose ecology is relatively clear from 1 above.

4. Taxonomic affinities to contemporaneous populations whose ecology is more certain.

5. Ecology of ancestral and/or descendant populations.

Points 2 and 3 involve major risks because of transportation of the animals after death and because of the likelihood that they have died in a place other than their normal range, e.g., plains animals along a stream or near a waterhole. In general, if a species is numerous in channel fills and/or channel margin deposits and is absent elsewhere, we interpret it as living in an aquatic or riparian environment; if a species is found commonly in the flood plain clays, we interpret it as living in a flood plain-upland environment. Since the temporary movement of animals from one local habitat into another is an important ecological factor, it has been considered separately in making our evaluations.

Points 4 and 5 possess an even greater uncertainty, particularly when the affiliated populations are relatively distinct species of different genera. We have attributed little weight to these taxonomic or phyletic affinities except where they tend to substantiate interpretations based on other evidence.

Environments of Deposition

Four distinct environments of deposition and of fossil occurrence can be distinguished in the Chadron Formation:

1. Streams, represented by channel fills of the "Red River" and its tributaries;

2. Ponds, usually represented by limestones near channels and channel margin facies;

3. River banks, composed of channel-margin sands and silts, including a chemically reduced zone of sediments from 100 yards to one-half mile in width, marginal to the channel fills;

4. Flood plains, represented by massive to bedded clays and silts.

Flood plain deposition did not begin until late Ahearnian time, but the remaining facies are recognized in all three members. The width of the channel fills and channel-margin zone is reduced in Peanut Peak sediments. Fossils are rare in the flood plain deposits below the Peanut Peak Member, where they are relatively common.

General Biotic Structure

Four more or less distinct ecological habitats, the aquatic, the semi-aquatic, the river-border forest, and the savanna forest-savanna, can be distinguished within the Chadron vertebrate fauna. Some species were probably restricted to one habitat; others, such as some of the carnivores, ranged through several; and still others, although largely limited to one habitat, must have spent some time in other habitats.

The aquatic habitat is defined as comprising those vertebrates limited to streams, ponds, and their banks. The following genera are characteristic of this habitat: Indet. osteichthyes, *Graptemys*, *Trachemys*, *Amyda*, Anosteirids, and *Alligator*. These genera are found almost exclusively in the channel fills, show aquatic adaptations, and their closest living relatives are aquatic.

The fauna of the semi-aquatic habitat includes those species which probably spent a large portion of their time in the water, but which also foraged in the swamp and river-border forest areas adjacent to the streams and ponds. Four genera are assigned to this habitat, *Menodus*, *Trigonias*, *Heptacodon*, and *Bothriodon*, and the assignments are based on absence from flood-plain deposits, on abundance in channel fills, pond deposits, and channel-margin beds, and on their short, heavy limbs which suggest semi-aquatic or swamp habitats.

The river-border forest habitat is more difficult to define sharply. Stratigraphically it consists of the reduced zones adjacent to the channels, and probably represents a wet-forest habitat. The occurrence of some forest-adapted animals, *Agriochoerus*, *Peratherium*, *Colodon*, *Eotylopus*, and the four-toed camel, suggest this conclusion, as do the nodular limy algal deposits, the chemical reduction of the sediments, and the frequent occurrence of the semiaquatic genera in these channel-margin beds. In addition to the genera named above, *Mesohippus*, *Hesperocyon*, and possibly *Daphoenocyon* are characteristic of this habitat. The association of these genera with the river-border forest is based largely on occurrence within the channel margin deposits in association with forest animals, and on their rarity or absence from the flood-plain deposits. The general adaptations of these later genera are also such as would fit them to a forest life (though not exclusively). Very possibly they also ranged in some numbers into the savanna, and almost certainly the larger carnivores of the savanna hunted also in the river-border forest.

The fauna of the savanna cannot be sharply delimited from that of the river-border, although some elements can be clearly assigned to one or the other. In general, the habitat is defined by occurrence in flood-plain clays, by subcursorial (*Hyracodon, Caenopus, Perchoerus*) or cursorial (*Poebrotherium, Archaeotherium*) habitus, by tooth adaptations to mixed browsing and grazing (*Hyracodon, Caenopus, Merycoidodon, Poebrotherium*) and by the abundance of many of these forms in the fauna of the Brule. The following genera are considered to belong to the savanna habitat: *Hyaenodon, Parictis, Daphoenocyon, Mustelavus, Eusmilus, Hoplophoneus, Dinictis, Hyracodon, Caenopus, Archaeotherium, Leptochoerus, Stibarus, Merycoidodon,* and *Poebrotherium.* The influence of the carnivores from this habitat on the river-border forest habitat must have been very great.

Figure 25 summarizes the various faunal habitats and indicates the probable overlap of genera into different habitats. Because of this overlap nearly all larger mammals were parts of a single natural community at any given time and may therefore be considered as a unit which we shall term "forest-savanna." The microfaunal elements and some of the small selenodont artiodactyls might be more definitive of the habitats, but the former (insectivores and rodents) are so rare as to be useless and the taxonomy of the latter is so confused as to obscure their ecologic relationships.

Evolution of the Biotic Structure

It is probable that, in common with modern biotas, the successive forest-savanna faunas had a degree of internal integration, that the elements of a fauna interacted, and that as a consequence of integration and interaction the fauna had a structure of occupied niches. Figure 25 summarizes our concept of that structure and of the position of the various genera within it for these three successive times—Ahearnian, Crazy Johnsonian, and Peanut Peakian. The figure also includes an estimate of the relative abundance of these genera during these periods.

Figure 29 shows a marked change in the abundance and variety of animals from the various ecologic habitats during Chadron time. The differences are shown in the number of genera present in each habitat, and in an "index" based on generic occurrence and abundance. In calculating the index, each genus known from large numbers of specimens was weighted by a factor of three; and those genera which are unknown from the member but which have known or probable stratigraphic ranges extending through this member are weighted by a factor of one. In general, the first or last occurrence of genus is not taken as its maximum stratigraphic range but in calculating the index that genus is given a weight of one in the preceding or succeeding member. The index thus tends to minimize large differences in fossil abundance, part or most of which may be due to differential preservation, and also to minimize the effects of non-occurrence which might well be due to sampling error.

The Ahearn is marked by a relative variety and abundance of aquatic (6 genera comprising 27% of the fauna and an index of 13), semi-aquatic (3 genera, 21%, index of 11), and river-border forest forms (5 genera, 23%, index of 12). The savanna fauna is varied but includes a smaller percentage of the total fauna (9 genera, 40%, index of 26). The Crazy Johnson member includes four aquatic genera (21%, index of 11), four semi-aquatic genera (21%, index of 10), three river-border forest genera (16%, index of 10), and nine savanna genera (47%, index of 28). The fauna of the Peanut Peak member consists of one aquatic (7%, index of 5), one semi-aquatic (7%, index of 5), two river-border forest (13%, index of 6), and twelve savanna genera (73%, index of 31).

Inasmuch as the fauna of the Ahearn member, which consists primarily of channel-fill and river-border facies, does not differ greatly from the fauna of the Crazy Johnson member, which includes flood-plain deposits, and because the Peanut Peak member includes all three sedimentary facies, the differences in fauna between the Peanut Peak and the earlier members cannot be attributed to general sedimentary facies differences. Therefore, they must result either from changes in the physical environment, evolution within the Chadron fauna, immigration, or most probably, a combination of these three processes.

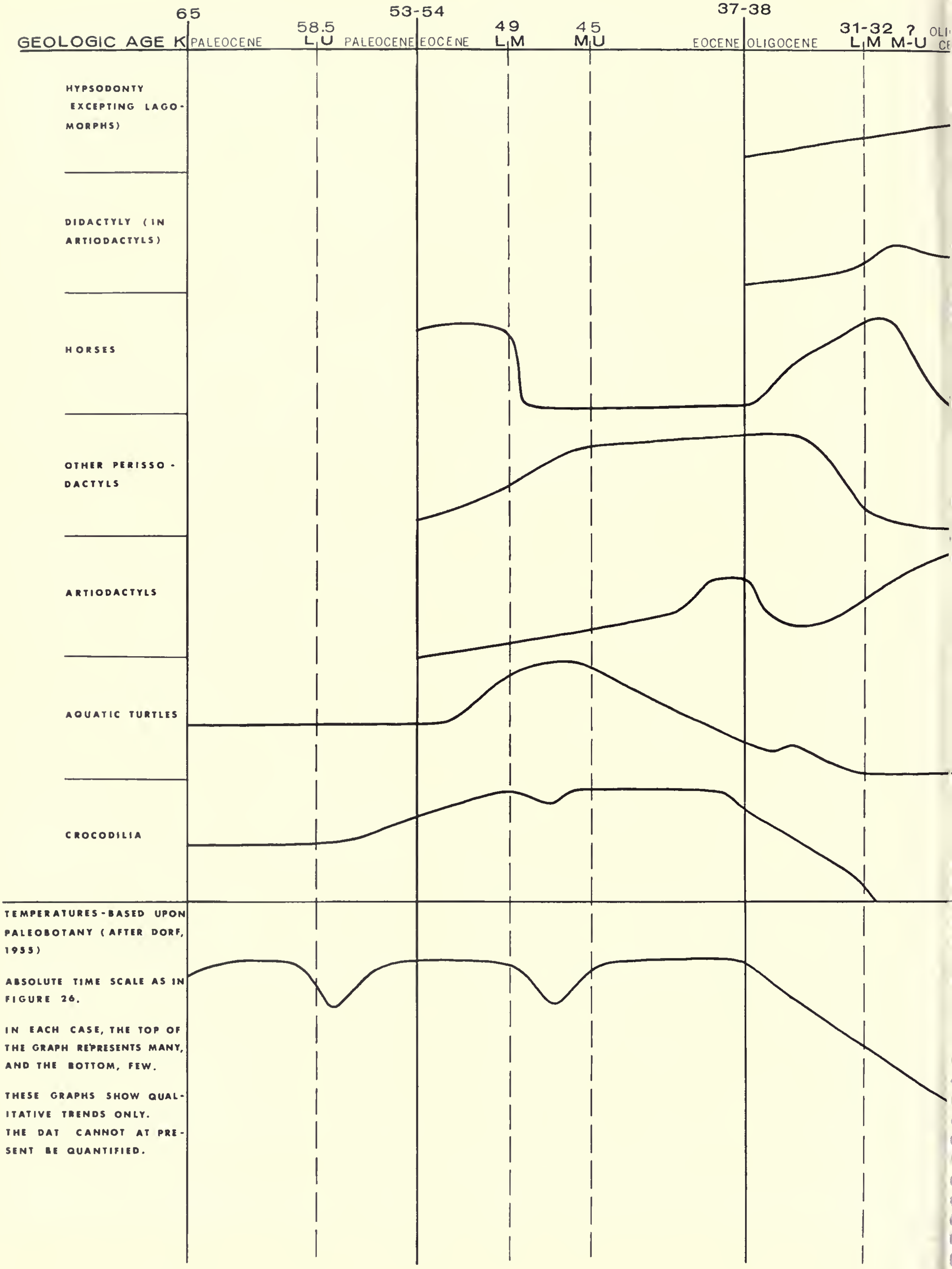
Even making a conservative measure of faunal change with the index described above, there is a great reduction in the aquatic and wet-forest elements in Peanut Peak time—from a total index of 31 in Crazy Johnson time to a total index of 16. In contrast, the index for the grasslands and dry forest elements increases only from 28 to 31. The change, therefore, lies primarily in the three habitats related to the streams and the wet forest.

The principal known changes in the physical environment from the Ahearn to Peanut Peak are (1) a reduction in mean temperature and (2) a reduction in the size of the streams and in the width of the irrigated areas adjacent to the streams. Temperature changes would affect critically the turtles and the alligator, and the reduction of streams would modify the aquatic environment considerably. In turn, the reduction of the irrigated areas would reduce the extent of the wet forest and thus affect the semi-aquatic and river-border forest animals, both in total habitat area and possibly in the number and kind of available niches.

Further, the reduction of the areal extent of the river-border forest would probably affect the exploitation of the herbivores by the savanna carnivores. Finally, the increase in the savanna fauna, although relatively small, might have altered to some extent the predation pressure and amount of competition by the savanna animals on the semi-aquatic and river-border forest animals. Inasmuch as the simple presence of the savanna fauna during Crazy Johnson time did not greatly affect the aquatic, semi-aquatic, and river-border forest faunas, the climatic changes appear to be the critical factors, and these probably called into play the biotic factors.

Olson (1952) defined a chronofauna as: ". . . a geographically restricted, natural assemblage of interacting

TERTIARY PALEOGEOGRAPHIC DAT



ABSOLUTE TIME SCALE AS IN FIGURE 26.

IN EACH CASE, THE TOP OF THE GRAPH REPRESENTS MANY, AND THE BOTTOM, FEW.

THESE GRAPHS SHOW QUALITATIVE TRENDS ONLY. THE DAT CANNOT AT PRESENT BE QUANTIFIED.

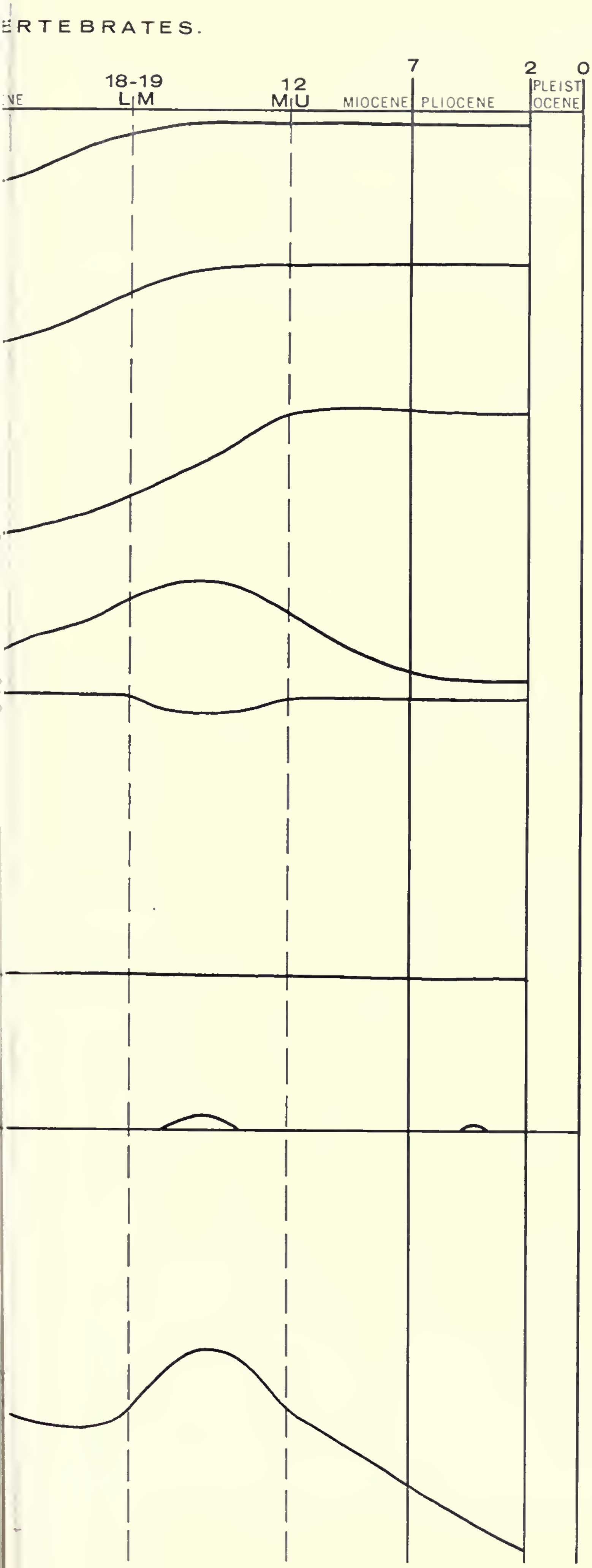


FIG. 27. Tertiary Paleogeographic Data-Vertebrate Fossils.

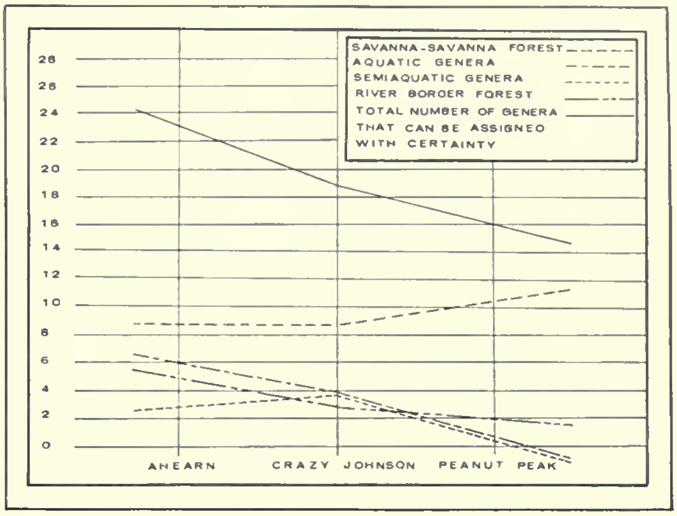


FIG. 28. Chadronian paleoccology by genera.

animal populations that has maintained its basic structure over a geologically significant period of time." The Chadronian fauna of South Dakota fails to meet the requirements of this definition because the disappearance of many genera without replacement and the appearance of some new genera in new niches demonstrate an instability of structure. If, however, the Chadron fauna is subdivided into an aquatic-wet forest component and a savanna component, these components appear to bear a clear relationship to at least two chronofaunas.

If we examine the ancestral affinities of the aquatic-wet forest genera we find three rather indistinctly separated groups. One of these groups has its closest relatives in the North American Eocene and includes *Mesohippus, Menodus, Agriochoerus,* the four-toed camel, and *Eotylopus.* The second group has close relatives in the Eocene of both Eurasia and North America. This holarctic group includes *Anosteira, Trionyx, Alligator, Trigonias, Colodon,* and *Daphoenus.* The third group comprises two genera, *Heptacodon* and *Bothriodon,* known from the Eurasian Eocene only. The ancestry of these groups then lies in the well known Eocene faunas which are almost certainly jungle chronofaunas. It seems probable, therefore, that these genera were survivors of Eocene jungle chronofaunas. As the rather limited evidence of pre-Chadron environments in South Dakota suggests a widespread jungle or wet forest, these may have been survivors in place and in particularly favorable local habitats.

The savanna displays quite a different pattern. Two origins can be distinguished, a North American and a Holoarctic or Eurasian (see Fig. 25). Some of these genera have affinities with the Eocene jungle forms but, in general, represent different families. In turn, many of these families appeared rather suddenly during the late Eocene or early Oligocene in one or the other of continental areas. Further, in the Chadron, the biotic structure of the savanna fauna was relatively stable with no generic extinctions and a continuation of nearly all of

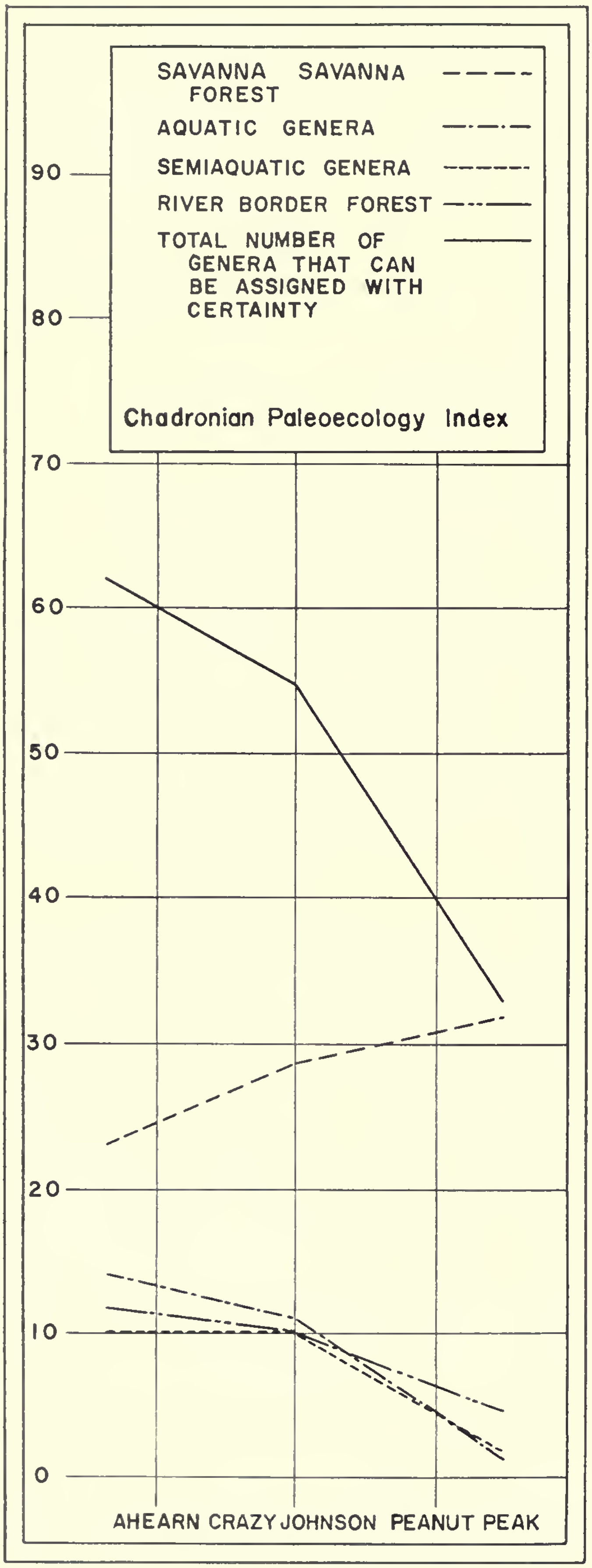


Fig. 29. Chadronian paleoecology index.

these genera into the Orellan. From this we conclude that the savanna fauna is part of an invading chronofauna derived from at least two savanna chronofaunas, one North American, the other Eurasian, which evolved during the Eocene in areas from which we have no fossil record.

The faunal changes in South Dakota may then be considered the Armageddon of these two different faunal systems. From this battle, decided by a climatic shift, developed the Orellan savanna chronofauna. This included most of the Chadronian savanna group plus a few survivors of the wet-forest chronofauna (*Mesohippus*) and some new genera which filled the newly available niches on the savanna and in the river-border forest.

Obscured in the Chadron but of great evolutionary importance were the interactions between the Eurasian savanna genera and the North American. This resulted in an Orellan fauna in which the majority of the herbivores are distinctly North American and the carnivores distinctly Eurasian, and thus suggests the greater adaptability of the carnivores.

INTERPRETATIVE SUMMARY

Review of Physical History

During late Eocene time, the streams of the Great Plains were flowing about at grade in broad, flat-bottomed valleys. The Black Hills had been eroded nearly to their present topography, and the granite core had been extensively exposed. The average annual temperature in western South Dakota was slightly above 60° F., and the average annual rainfall over 40 in. The weather system was monsoonal, with prevailing northerlies and northeasterlies during the summer bringing in abundant moisture from Hudson's Bay and the Arctic, and still air or gentle prevailing southwesterlies during the dry, cool winters. The coldest winter temperatures probably did not drop much below freezing, and summer temperatures probably did not rise much above 100° F.

Western South Dakota stood high enough to intercept the moist northerlies and received abundant rainfall. Eastward in the Interior Lowlands, however, probably only a few areas (e.g., the Ozarks) stood high enough to cause heavy precipitation, and the climatic regimen very possibly was arid or subarid.

By the beginning of Chadron time, polar cooling had established a hemispheric circulation strong enough to break up the monsoonal circulation. Prevailing westerlies and northwesterlies, with cyclonic storms and fronts gradually replaced the monsoonal weather. This shift resulted in a progressive drying of western South Dakota with a concomitant increase in rainfall over the Interior Lowlands. South Dakota changed from a place of extensive semi-tropical forests to a savanna with forest belts following the larger streams.

The increasing aridity changed the regimen of all the streams in the Northern Plains. From a typical wettropic slope system like that of southeastern China, with steep mountains of resistant rock rising above almost flat lowlands of weathered strata, the streams shifted to assume the more uniform profile normal under semi-arid conditions. This forced the deposition of lenses of alluvium from the edge of each mountain range outward some tens of miles into the Plains. The lenses were necessarily thickest very close to the foot of the ranges, feathering rapidly upstream into the mountain valleys, and thinning more gradually downstream.

The sediments included in the Ahearn member of the Chadron formation represent the first depositional episode in the development of the lens east of the Black Hills. (The relationship of deposition of the Slim Buttes Formation to this general history is not known.) The materials of the succeeding Crazy Johnson and Peanut Peak members represent the second episode.

Rainfall in western South Dakota decreased during Chadronian time, and the mean temperature probably dropped a little. By the end of Chadron time, the surface was a broad depositional plain, with the old topography buried mountainward to the base of the lower Cretaceous hogback that rimmed the Black Hills.

The confluent waters of Battle Creek and Spring Creek received French Creek as a southern tributary and flowed eastward as the "Red River." The northern Black Hills were drained by an east-flowing stream which lay north of Rapid City and north of the present Wall of the Badlands, but commingled its sediments with those of Red River once the old divide between them was buried.

Origin and Evolution of the Chadron Fauna

The fauna of the Chadron has some genera in common with the earlier Oligocene Duchesnean faunas but, in general, is much more similar to the succeeding Orellan fauna. Analysis of the phyletic relationships and of the evolving biotic structure suggests a multiple origin for this fauna. Most of the genera associated with the aquatic, semi-aquatic, and wet forest habitats are related rather closely to genera from the jungle or wet forest faunas of the late Eocene from both North America and Eurasia. The majority of the Chadronian genera, those associated with the savanna environment, are less close to well-known Eocene genera and appear to be derived from some unknown late Eocene savanna faunas. The savanna probably represents an intermixing of North American and Eurasian (or at least holarctic) elements by intermigration during the earliest Oligocene.

The oldest Chadron fauna apparently is slightly younger than the Vieja but the river-border forest portion of the Chadron fauna shows very close affiliations with the Vieja fauna. The Yoder fauna, on the other hand, would seem to be the same age as the Ahearn but its precise stratigraphy and paleoecologic relation to the Ahearn awaits additional study. The Pipestone Springs fauna is correlative with that of the Peanut Peak and is very probably Peanut Peakian. The Pipestone Springs fauna, however, has a larger proportion of forest animals and demonstrates the persistence of several species that disappeared earlier in South Dakota.

Of the Chadronian genera only a few show determinable evolutionary series; the remainder are either too poorly known or fail to show any distinct change during this time. In general, the rate of evolution appears to be relatively slow—for example, the early Orellan horse, *Mesohippus bairdi*, is barely distinguishable from the early Chadron horse, *M. hypostylus*. The late Chadronian *Parictis dakotensis* and *Daphaeonocyon dodgei* are, however, distinctly different from what appear to be their early Chadronian ancestors, *P. parvus* and *D. minor*.

Aside from the trends in these latter genera, no clear evolutionary patterns appear in the Chadron. This is very probably an artifact of our data inasmuch as we are unable to determine the adaptive significance of minor structural changes.

The fauna as a whole, however, shows rather marked development. During Ahearnian time, over half of the fauna was of aquatic, semi-aquatic, or river-border forest types. This part of the fauna was slightly reduced in variety and abundance in Crazy Johnson time, but the difference may not be significant. In Peanut Peak time, however, many of these genera disappeared and the remainder were less abundant. On the other hand, the savanna genera increased slightly in numbers and in relative abundance from Ahearnian to Peanut Peakian time.

The relation of these changes and the faunal origins discussed above suggest interaction of a surviving Eocene wet-forest chronofauna with immigrants from a savanna chronofauna. The increased aridity of Peanut Peak time gave the final decision to the savanna genera and only a few wet-forest forms survived to form part of the Orellan savanna chronofauna of the South Dakota area. We conclude that the critical factor was the climatic shift but that once initiated, competition and predation became increasingly important in the final destruction of the wet-forest chronofauna. In this respect, some forest genera apparently survived longer in the forested valleys of Montana and were represented in the late Chadronian Pipestone Springs fauna.

Comparison with chronofaunal development in the Texas Permian (Olson, 1952; Olson and Beerbower, 1953) discloses a number of significant differences and similarities. The equivalent of the Eocene wet forest chronofauna appears to be the early Permian (Wichita and Clear Fork ages) delta chronofauna. The disappearance of the Chadron wet forest chronofauna and its replacement by the savanna savanna-forest chronofauna is analogous to the disappearance of the delta chronofauna in late Clear Fork time and the appearance of the uplands chronofauna in San Angelo and Flower Pot time (early middle Permian). The extinction of the Permian delta chronofauna, however, must be attributed solely to deterioration of the physical environment to an arid, salt-pan floodplain characteristic of late Clear Fork time, rather than to biotic pressure as the upland fauna is unknown prior to late San Angelo time. The Chadronian thus is equivalent to both late Clear Fork and San Angelo times and must, therefore, reflect a somewhat more complex faunal development than occurred in the Texas Permian.

Even with these differences, the general pattern of extinction and development are much the same. In neither case is there any evidence of rapid evolution of any of the component genera. The new genera, on the contrary, appear by immigration and thus may represent slow evolution in some other area. These new genera probably evolved somewhat more rapidly than the genera in the delta or wet forest chronofaunas as they diverge rather more from their common ancestors, but many differences would appear to be in the direction rather than in the amount of evolution.

The extinction of a chronofauna appears a gradual process though groups of closely integrated genera within the chronofauna may become extinct almost simultaneously and thus produce discontinuities in the downward curve. During this period some immigrant genera appear briefly to fill new niches or to crowd indigeneous genera from changing niches. These forms however disappear also as the wet-forest or delta environment continues to change. The development of the new chronofauna likewise appears to be gradual, although documentation of this stage in the Texas Permian is poor. Again, groups of genera may appear suddenly and produce discontinuities in the upward curve. The entrance of genera into the new niches can proceed no faster however than the appearance of the niches with the changing environment and the occupancy of potential niches is restricted by the need for the genus to adapt to the peculiarities of the new environment.

CONCLUSIONS

The following conclusions seem justified by the characteristics of the Chadron and of its fauna:

1. During late Eocene time monsoonal air circulation prevailed over the Great Plains and Rockies. The mountains and higher basins received heavy rainfall, but the Interior Lowlands were probably arid or subarid. Temperatures were warm-temperate or sub-tropical, and the low temperature differential between Pole and Equator subordinated the hemispheric circulation system to local systems, in this case a monsoon.

2. The relief of the Black Hills and other ranges under this climatic regimen was very like that of the present.

3. A major decrease in temperature starting at the close of Eocene time established a stronger differential between the North Pole and the Equator and consequently a stronger hemispheric wind system with prevailing westerlies. This period of cooling appears to be a minimum in an older 10-million-year climatic cycle, coincident with the beginning of a broader downward temperature trend that culminated in the Pleistocene minimum. Periodicity of 20 million years seems to characterize the downtrend period.

4. As a result of this global climatic change, the local climate became drier and somewhat cooler. The stream regimen was altered and deposition initiated adjacent to the mountain ranges.

5. Deposition continued into late Chadron time because of continued climatic deterioration. Fluctuations in deposition during this period are probably related to minor climatic fluctuations which may be the result of the same rhythms shown in the Pleistocene by glacial advances and retreats.

6. The earliest Chadron is somewhat younger than the Vieja. The Yoder fauna is Ahearnian and the Pipestone Springs is Peanut Peakian.

7. During middle and late Eocene time, a semi-tropical rainforest chronofauna developed in the swampy woodlands of Utah, Wyoming, Colorado, and South Dakota. This is recorded in Bridger and Uinta fossils.

8. Concurrently, a savanna to arid chronofauna developed elsewhere, possibly in the Interior Lowlands. The history of this chronofauna, however, is unrecorded.

9. During Chadronian time, the forest chronofauna lingered along the stream-margins in Dakota. It underwent gradual, partial replacement by the immigrant savanna chronofauna.

10. A few of the genera of the forest chronofauna, among them *Trigonias*, *Mesohippus*, and *Pseudoprotoceras*, managed ultimately to evolve into savanna and plains form.

11. Study of the Chadron chronofauna tends to substantiate conclusions drawn earlier from the Texas Permian by Olson.

Chapter VI

PALEOGEOGRAPHY OF THE SCENIC MEMBER OF THE BRULE FORMATION

by

John Clark

INTRODUCTION

Widespread, excellent badlands exposures combine with sharply defined sedimentary facies to make the Big Badlands an almost ideal area for the study of fluvial sedimentation through time. Brule channel deposits, unlike those in the Chadron Formation, are restricted to definite courses and separated from each other by considerable distances. This makes possible the mapping and study of individual Brule streams in detail which cannot be approached in studies of their Chadron predecessors. Recognition of differences between heavy-mineral suites from the northern and the southern Black Hills has further enhanced the precision of paleogeographic studies in the area.

This chapter in part summarizes a series of preliminary studies of Oligocene sedimentation which the author and his students conducted at the South Dakota School of Mines and Technology from 1958 through 1961, financed by grants from the National Park Service, through the Badlands National Monument. The final studies reported here were completed under the auspices of Field Museum of Natural History during 1963 and 1964. The author is indebted to his colleagues at the Museum for numerous ideas and conferences. Those students who made helpful contributions (Ritter and Wolff, 1958; Seefeldt and Glerup, 1958) have fortunately published their work, and hence have already received proper credit for it.

This research has proven useful, not only in revealing details of Oligocene paleogeography, but also in elucidating certain aspects of fluvial sedimentation which have not, to the best of my knowledge, been previously recognized.

TOPOGRAPHY AND GENERAL STRATIGRAPHY

The Brule Formation characteristically erodes to badlands slopes of 30–75°, varying to barren flats and occasional vertical cliffs where the local situation produces special conditions. The Brule can be differentiated at once from the underlying Chadron by the change from convex-outward Chadron "haystack" slopes to steep, concave-outward slopes, and usually by a change from predominantly pale tan or greenish-gray color to yellowish tans. Gully texture is also very much finer on Brule slopes than on the Chadron.

The actual contact usually consists of a silicified pond limestone a few inches thick, containing *Charagonia*, snails, and ostracods. The limestone is nowhere continuous for more than a mile, and usually not for over one-half mile. Between these definite pond limestones and replacing them in the area north and east from Scenic, the contact consists of a few feet of mudstones with intercalated limy laminae which often crosscut individual mudstone strata.

The Scenic Member of the Brule everywhere directly and conformably overlies this remarkably flat limy zone. Only at Chamberlain Pass (Sec. 25, T. 3S., R. 13E., Pennington Co.) is there an appreciable relief, and there it does not exceed 10 ft. (see Fig. 30). The Scenic Member consists of alternate layers a few feet thick of buff, tan, red, or gray mudstone with laminated gray to green siltstone and occasional channel fills of greenish sandstone.

Bump (1956) described as the top of the Scenic Member a prominent dark band which separates banded Scenic sediments from the much more massive, buff-colored, Poleslide tuffaceous clays which conformably overly them. The change to more massive bedding in the Poleslide is everywhere apparent, but this change does not everywhere occur at the same horizon, and the dark marker bed extends only from Bump's standard section southwestward. The apparent dividing horizon between Scenic and Poleslide is not, therefore, exactly coeval throughout the Big Badlands. This situation resembles that of the Orella and Whitney members of the Brule in Nebraska (Schultz and Stout, 1938, p. 1921; Schultz et al., 1955, p. 4; Schultz and Stout, 1955, p. 44). The Orella-Whitney contact at their standard section, Toadstool Park, can be observed to change

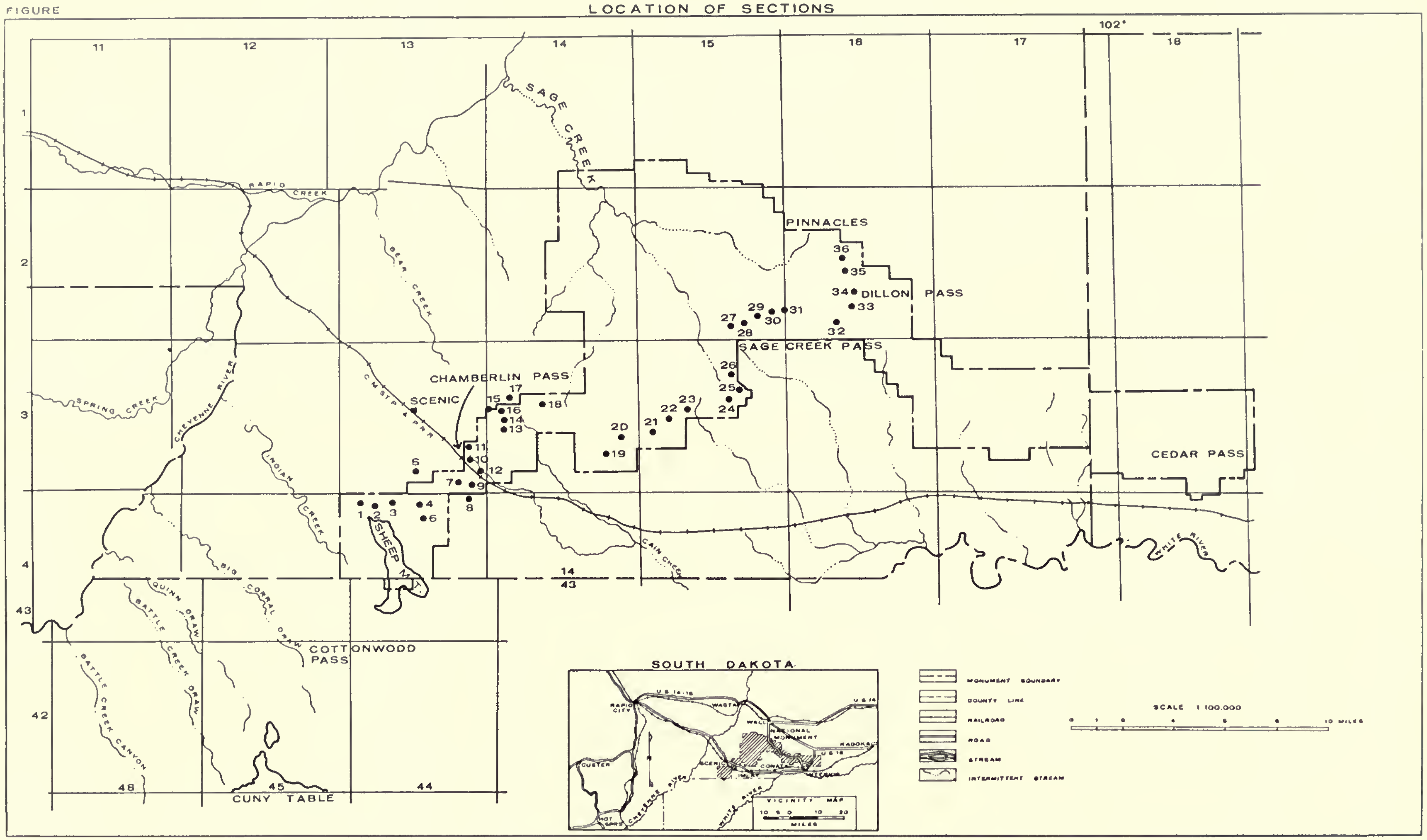


FIG. 30. Location of numbered sections and of places mentioned in Chapters VI and VII.

position stratigraphically by 5 ft. in 200 yards. Obviously the lithologic characteristics of these members reflect changes in the nature of deposition, rather than cessation and resumption.

LITHOLOGY

Detailed field observations, plus laboratory study of 111 specimens in the FMNH collection, have supplied the data for this section.

A. Type of Sediments

The Scenic Member comprises five types of sediment: 1) limestone, 2) heterogeneous mudstone, 3) laminated clay, 4) laminated siltstone and sandstone, and 5) cross-bedded sandstone.

1. Limestones. These are of two types. The first are local, inconspicuous limestones never more than 2 in. thick and 100 yards in diameter, which consist almost entirely of algal crusts and threads. The thicker ones are laminated. No fossils other than algae have been observed in them. These limestones occur interbedded with the laminated siltstones and sandstones. They are uncommon, and apparently represent ephemeral stages of rapid algal growth in small, temporary swamps.

The other type of limestone is massive to flaggy, and frequently shows some silicification. Lenses up to almost 3 ft. thick occupy areas of 200 yards to more than a mile in extent. These limestones contain *Chara*, ostracods, gastropods, and occasional fish bones. They occur rarely, and only at the base and at the top of the Lower Nodular zone, in the areas southwest of Scenic and southeast of Wall. The fauna and flora leave no doubt that these were shallow ponds of some permanence. Certain of these ponds were significant elements of Oligocene flood plain morphology, as will be discussed later.

2. Heterogeneous mudstones. Complete heterogeneity, embracing particles of all sizes from 5μ up to clay pellets 2 cm. in diameter, characterizes these rocks. They occur as layers a few inches to 40 ft. thick; the usual thickness is 3-20 ft., composed of poorly-separated increments 3 to at least 18 in. thick. Contacts with the subjacent and superjacent sediments are always sharp. A matrix of tan to gray mudstone invariably includes numerous sharp-edged chips and pebbles of darker and lighter mudstone which generally differs from the matrix in being less cemented. (see Fig. 31)

Microscopically, the mudstones consist of tiny quartz fragments mixed with devitrified glass and a few fresh shards of glass, interspersed with clay which is largely montmorillonite or mixed-layer. Calcite cement penetrates the mass, which varies from completely farctate to moderately porous, depending upon the extent of cementation. Neither thin-sections nor skiagraphs reveal any trace of arrangement of even the finest particles. Grains of very fine sand are occasionally included, especially in the vicinity of channel-fill sandstones. These consist of quartz, fresh microcline and sanidine, and biotite. The biotite flakes are usually fresh, but sometimes show a tiny cloud of hematite surrounding the frayed edges or rising from a single spot on a cleavage face, indicating incipient intrastral alteration.

The chips and pellets of mudstone differ very little from the matrix. Rarely, they show a higher percentage of calcite, indicating a higher initial porosity. Usually they yield to weathering more readily than does the groundmass, producing the rough, pitted surface characteristic of "Lower Nodular Zone concretions." Treatment of fresh-cut surfaces with water causes the chips to swell, while the groundmass remains unaffected, suggesting that the chips are more clayey than the groundmass.

Although the contact surfaces of these mudstones with other sediments are always sharp, they usually show ragged irregularities. Chips and particles of underlying laminated clays occur in profusion within the lower few inches of any mudstone stratum (Specimens G 3743, G 3745, G 3999, G 4058, G 4077).

3. Laminated clays. Layers of laminated clay, from less than an inch thick to an extreme of 2 ft. thick, form a notable proportion of the total mass in the Sage Creek-Dillon Pass area, decreasing southwestward both in thickness and in total bulk. South of Scenic they occur as laminae less than 3 in. thick, interbedded with siltstone and fine sandstone laminae; west of Sheep Mountain they have not been observed, although a few laminae probably occur there. They are present and conspicuous to the southeast of Cuny Table (see Figs. 30, 32.)

The laminae in these clays are not apparent on field inspection. A variety of laboratory staining techniques have been tried upon them, none of which has proven completely satisfactory. The best results to date have been obtained by cutting a smooth surface, soaking the specimen overnight in kerosene, and placing the smoothed surface face down on a hot metal plate. The laminations usually show up beautifully after this treatment, but the resulting stain fades almost completely within a few weeks.

Laminations vary from about 2 mm. to less than 0.5 mm. in thickness. They are exceedingly regular, showing no depositional structures. Post-depositional deformation comprises: (1) small, vertical faults with vertical displacement of 1 cm. or less; (2) small, curved, slickensided surfaces developed during compaction by overlying sediments; (3) intricate systems of more or less vertical cracks, with intrusion of heterogeneous mudstone from above or below, depending upon the local situation. (See specimen G 3743, G 3745, G 4046, and others). The crack-fills form a network with a spacing of 1 to 4 in. They vary from a fraction of an inch to more than an inch wide. The wider ones show considerable foundering of small blocks of laminated clay into the surrounding mudstone, also small hollowed-out, eroded excavations along the walls, and all stages of assimilation of clay particles into the mudstones. The structures are exact homologues of igneous roof-structures peripheral to a batholith.

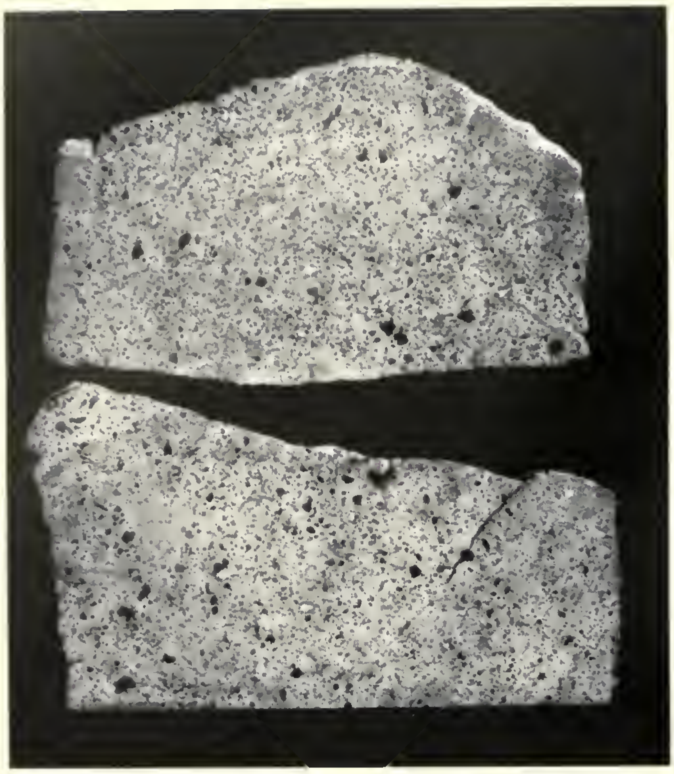


FIG. 31. Photograph of G 4077, a sample of heterogeneous mudstone, showing heterogeneity in both horizontal and vertical sections.

The laminated clay must have accumulated in shallow, temporary ponds, and cracked due to desiccation shrinkage. Absence of any curved laminae indicates that intrusion of fluid mud from below, or in some cases burial by fluid mud, occurred before dessiccation was far advanced. All of the cracks observed completely penetrate their respective laminated sequence; none have been found which affect only the lower moiety of a laminated stratum. Any one laminated sequence, therefore, accumulated during a time of continuous existence of a pond.

The laminae need not represent annual increments, nor even those of individual storms or floods. Experimentally, a lump of this laminated clay was thoroughly mixed with water, permitted to settle, then disturbed by one brisk shake: a sequence of four distinct laminae developed on the bottom. Presumably, therefore, a strong wind, or one of the larger Oligocene mammals wading, could have disturbed a shallow pond enough to have produced multiple laminae after a single influx of sediment.

The clays vary from somewhat calcareous to noncalcareous, and generally are much lower in montmorillonite than are the clay fractions of the heterogeneous mudstones. Whether the laminations reflect differences in clay-mineral composition, or texture, or cementation, is not known.

4. Laminated siltstones and sandstones. Laminae 1 to 20 cm. thick characterize these sediments. Except in the proximity of channel-fill sandstones, they show no cross-bedding. Individual layers thicken and thin, change texture, or lens out, so gradually as to be perceptible with difficulty. The layers are gray to greenish siltstones and fine-grained sandstones, characteristically well-sorted but thoroughly mixed with abundant montmorillonite. Any one layer shows no sorting or stratification whatever, but each layer has sharp contacts with the adjacent underlying and overlying ones. The clastic minerals of these sediments always resemble those of the nearest channel-fill sandstone.

Thin, algal limestones occur as lenses of restricted areal extent interbedded with these siltstones and sandstones, as mentioned above.

5. Cross-bedded sandstones. Cross-bedded sandstones occur as linear channel fills (see Figs. 33–36), which occupy areally restricted zones. Westward from Sheep Mountain, the channel fills generally have definite top and bottom contacts with the surrounding finer sediments; to the east and northeast, neither the lateral nor the top and bottom contacts are sharp. The sandstone zones show distinct lateral restriction, but extend vertically through a considerable thickness of beds with which they intergrade and interfinger. These sandstone masses, therefore, represent deposits in the beds of individual aggrading streams through a considerable period of time, rather than the fill of channels which once existed as trenches reaching from top to bottom of the present sandstone mass.

Cut-and-fill structures are absent, and foreset crossbeds nearly so. Cross-beds with dips up to 20°, usually not over 10°, strike characteristically parallel to the direction of flow (see Figs. 34, 35). In parts of every channel-fill outcrop, the sands are disposed in a series

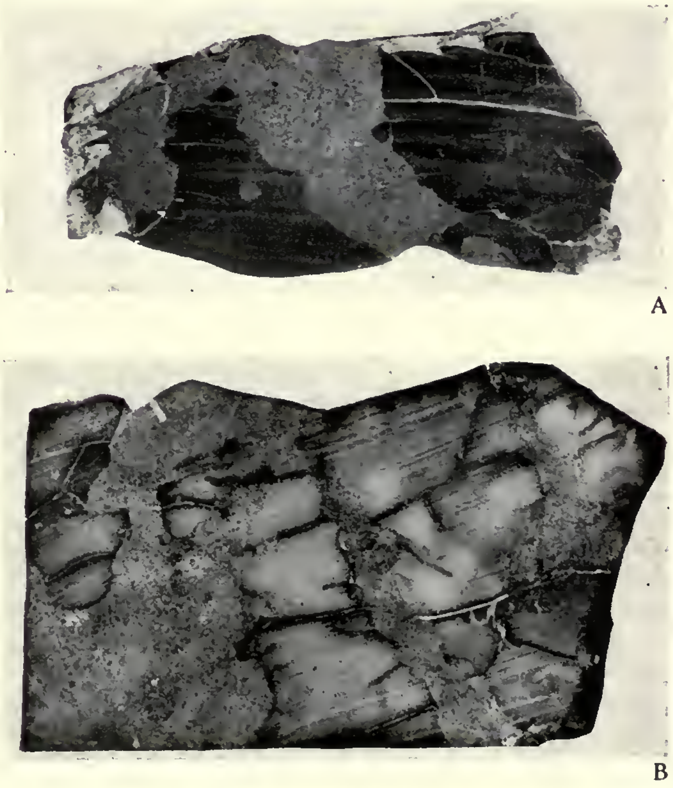


FIG. 32A and B. Photograph of G 3743, showing laminated clay with intrusive heterogeneous mudstone. Stained specimen.

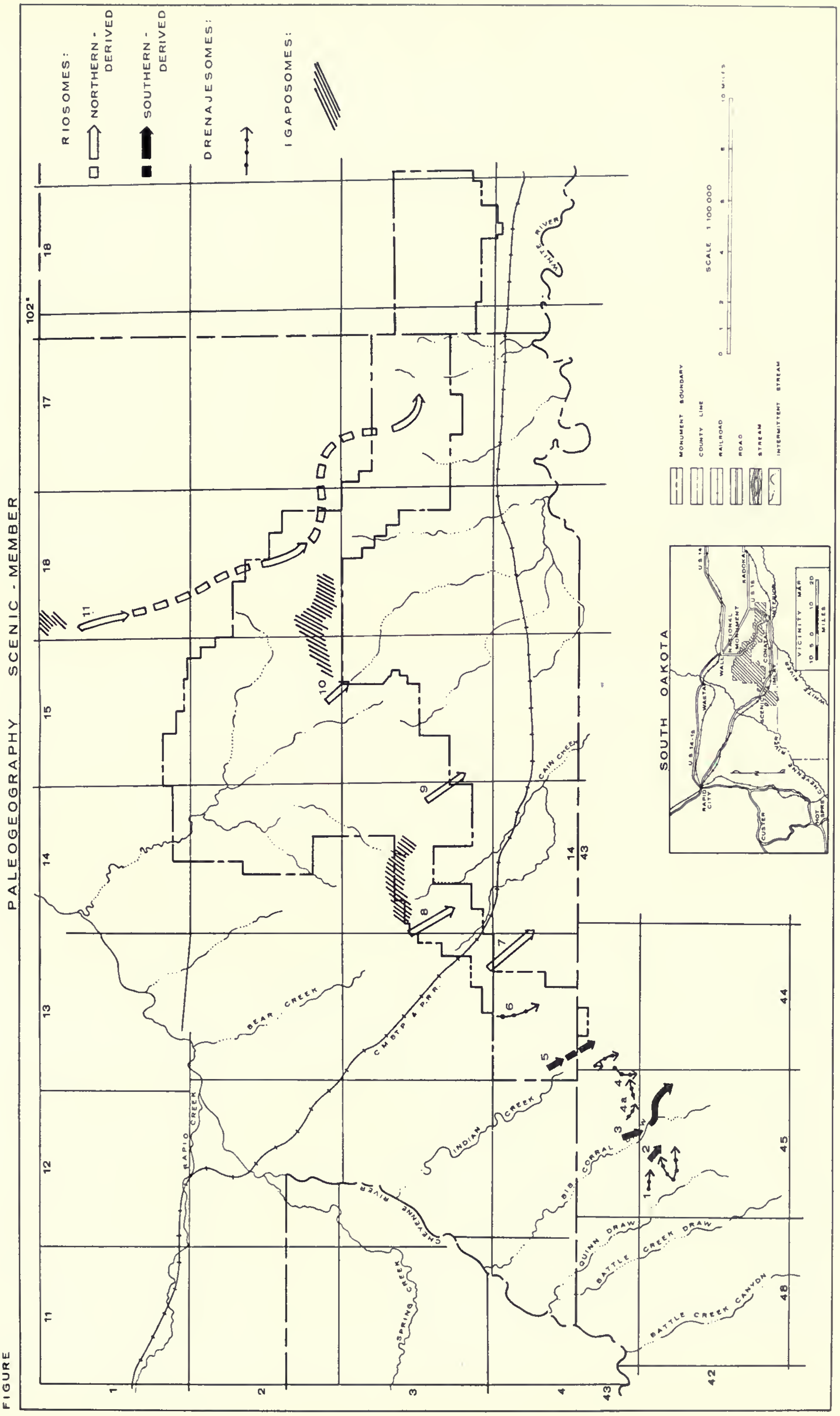


FIG. 33. Paleogeography of the Scenic Member.

FIG. 34. Riosome No. 3, near Cottonwood Pass. Looking downstream. Shows cross-bedding normal to direction of flow.

of low, rounded crests and troughs, with distances of 2–5 ft. between crests, whose axes parallel the direction of flow. The height is usually about 4 in. Any one crest can generally be traced for a few tens of feet. The sands in these sediments are usually coarse to fine grained, and somewhat more micaceous and better-sorted than the material in the completely unbedded portions of the sandstone mass. Obscure ripple marks of low height and wave lengths of 3–6 in. occasionally V downstream in the troughs, but linguoid and well-developed oscillation ripples have not been observed.

The total width of a "channel-fill" at any one horizon is 100–300 ft., and the apparent depth at any one time, estimated from the greatest vertical height of any one set of crossbeds, was not over 3–6 ft. Therefore, these longitudinal troughs and crests probably do not represent islands in a typically braided stream, (Orr, 1964, p. 1) in that they probably did not protrude above the surface. This is further borne out by the fact that individual sedimentary increments can be traced across several troughs and crests.

The troughs and crests, plus the margins of the channel-way, produce cross-bedding of which over 90% dips normal to the direction of flow. The remaining cross-beds dip predominantly downstream, with a small fraction dipping upstream. Were it not for the linear shape of the deposits and the proximity of the Black Hills as the known source of clastics, the direction of flow would be very difficult to ascertain. Shingling, or any definite orientation of pebbles, has not been observed.

Interbedded with these sands are others showing little or no sorting and no visible bedding. Cementation is usually notably less in the massive layers, and the percentage of montmorillonitic clay is notably higher. The coarsest gravels of any one outcrop usually, but not always, occur in the massive layers.

Seefeldt and Glerup (1958) studied the clastic minerals of the channel-fill which lies (Fig. 33) in Sec. 25 and 36, T. 43N., R. 45W., and Sec. 30, T. 43N., R. 44W. They found that the average mineral composition is:

Garnet	63%	Barite	2%
Black Tourmaline	26%	Limonite	1%
Orange Sphene	3%	Hematite	1%
Zircon	2%		

Occasional actinolite, chlorite, glauconite, red-brown hornblende, biotite, and muscovite grains were also noted. Individual samples vary widely from these averages, but all of the channel-fills mapped as "Southern-derived" (Fig. 33) show heavy percentages of garnet and black tourmaline, with small amounts of orange sphene and brown hornblende; none include magnetite, lemon-yellow sphene, or greenish hornblende. Samples of recent sand from French Creek near the town of Custer, and from Battle Creek near Hermosa, resemble the Oligocene sediments in their heavy-mineral assemblages.

Since these channel-fills trend generally east-southeastward from the southern Black Hills, possess granite pebbles and mineral assemblages known to occur in the southern Black Hills, and resemble recent stream sands from the same area, they are believed to represent Oligocene streams whose head-waters lay in the southern Black Hills.

The channel-fills east and northeastward of Sheep Mountain differ notably from those just described. They have much less definite boundaries and are much less thoroughly cemented than the Southern-derived sandstones. Any one outcrop includes individual laminae or cross-beds which are thoroughly indurated, interbedded with others soft enough to crumble between the fingers. The channel-fills weather into greenish-gray columnar zones several feet thick, which look at a distance like over-accentuated areas of laminated siltstone. They grade laterally into laminated siltstones, differing from them in possessing cross-bedding and much coarser sediment. Those which occur within mudstone zones are very much smaller and finer-grained than those within the siltstone zones.

Ritter and Wolff (1958, p. 189) found the following heavy-mineral assemblage in the large, northeasternmost channel-fill which they traced for 12 miles (#11, Fig. 33):

Hornblende	22%	Limonite	6%
Barite	19%*	Epidote	5%
Magnetite	23%	Garnet	4%
Sphene (lemon-yellow)	8%	Hematite	2%
Biotite	6%	Tourmaline	2%

Minor, variable amounts of chlorite, glauconite, gold, pyrite*, and zircon were also noted.

* Grains of these two minerals are subhedral to euhedral and neither would withstand long transport. Hence they were probably locally derived and have no bearing on ultimate headwaters of the Oligocene streams.

The lemon-yellow sphene is exactly like that known to occur in certain of the Tertiary intrusives of the northern Black Hills. This sphene is not known to occur elsewhere. The magnetite is believed to have come from these intrusives also, but definite evidence is lacking.

Abundant magnetite and greenish hornblende, low but consistent percentages of lemon-yellow sphene and greenish epidote, low percentages of tourmaline, and generally low percentages of garnet characterize northern Black Hills-derived sands. The three channel-fills nearest Sheep Mountain contain much higher percentages of garnet than do those farther northeast, but otherwise they are typically northern-derived. Since garnet is locally abundant at many places in the northern Black Hills Precambrian, this variation is not regarded as significant.

The largest pebbles observed in northern-derived channel-fills are less than 1 in. in diameter; the more easterly contain nothing larger than a coarse sand. This suggests that the velocity of the transporting streams decreased rapidly as they travelled farther from the Black Hills and is in agreement with observations on individual channel-fills (Seefeldt and Glerup, 1958).

The northern-derived sediments contain minerals known to occur abundantly in the northern Hills, and

FIG. 35. Riosome No. 3, near Cottonwood Pass. Looking south, normal to direction of flow which is from west to east, or right to left in the picture. Note lack of cross-bedding parallel to flow.

not known to occur in the southern Hills. Geographically, the northern-derived channel-fills lie to the north of the southern-derived ones, and are roughly aligned toward the northern Black Hills.

FIG. 36. Drenajesome No. 4, looking north, or upstream. Pick marks the site of a sandstone dike of Chadron sand intrusive into Brule. The drenajesome lies between mudstone I and III; III is overlain by well-developed laminated siltstones.

B. SEDIMENTARY LITHOTYPES.

The individual rock types described above occur associated into four sedimentary lithotopes: (1) silty mudstones; (2) laminated siltstones; (3) laminated mudstones; (4) channel-fill zones. These lithotopes grade into one another laterally, but not vertically.

1. Silty mudstones. This lithotope consists almost entirely of the heterogeneous mudstones described. Rarely, it includes discontinuous limestones. Commonly it grades laterally into sandstone along the borders of the northern-derived channel zones.

The mudstone lithotype makes up the famous Lower Nodular Zone (Wanless, 1923, p. 213, et al.) and several zones higher in the Scenic Member. It consists of massive buff, gray, bright yellow, or reddish mudstone, usually with greenish mottling. Weathered surfaces develop a crust with an intimate system of cracks, which outline polygons about an inch in average diameter. Less-indurated strata weather to "pop-corn" surfaces quite like those of the underlying Chadron.

Within 1½ miles of channel-fills occurring at the same horizon, these mudstones are irregularly indurated into nodular concretions by a calcite cement. The concretions occur usually in the buff or gray phases, rarely in the bright yellow, and never in the red. They are generally 4–12 in. thick vertically, and of slightly greater horizontal than vertical diameters. At a distance from the channel-fills, individual concretions occur thinly scattered at separate, discontinous levels within the mudstone zones, but they increase to quite regular, massive beds nearer to the sandstones. None at all occur within 100 yards of the sandstone channel-fills proper.

Individual concretions contain numerous clay-pebbles which weather out producing an irregular pitting. A heavy incrustation of limonite stains the weathered surfaces umber brown, but freshly broken faces are pale gray or tan, with either greenish or tan clay-pebbles. Concretions frequently enclose fossil bones or entire skeletons, but coprolites occur rather in the uncemented clays. Nodular concretions are widely distributed through the mudstone layers from the Sage Creek basin southwestward to Cedar Creek (west-southwest of the area covered by this report); they lie in one thin, discontinous band within the Lower Nodular Zone as far east as Dillon Past. They never occur in the red zones, and die out quickly in the pale-yellow zones 3 miles northeast of Scenic, and also southwest of the area of channel fills (Fig. 33). They occur, but are less well-developed, in the mudstone zones above the Lower Nodular.

Sinclair (1921, p. 463) proposed that the nodular calcareous concretions in the Lower Nodular zone represent a limy caliche, produced by carbonate-laden water soaking out of streams into the surrounding flood-plain deposits and evaporating at or near the surface. Wanless (1923, p. 216) concurred. The distribution of the concretions near channel-fills, and the fact that they occur in layers which are horizontal but occur in otherwise massive, unbedded sediment, could support this hypothesis, or could equally well result from the action of groundwater soaking out from the permeable channel-fills at any time after deposition.

However, the fact that they are absent within 100 yards of channel fills at the same horizon strongly supports Sinclair's hypothesis. A stream-border zone, even in a dry climate, might well be the site of fairly rapid groundwater movement and little precipitation, while the areas farther out would be evaporating water as rapidly as it infiltrated, producing a cement. Still farther from the nearest streams, influent groundwater would not penetrate in sufficient quantity to develop a continuous cement. On the other hand, groundwater soaking from sandstones into neighboring sediments at some time after deposition should have deposited its dissolved load either as a concentrated "front" zone at the outer boundary of its area of penetration, or decreasingly outward from the sandstones, depending upon the cause of the precipitation.

Distribution of the concretions, therefore, supports Sinclair's hypothesis that they are a penecontemporaneous caliche produced by influent groundwater. Since the development of caliches is normally a phenomenon of dry climates, the nodular concretions suggest deposition under conditions of aridity more severe than during the preceding Peanut Peakian (in which caliches were not developed). It is my belief that the calcite formed below rather than at the surface, but I have found no definitive evidence of this.

The general yellow-tan to gray color of the mudstone indicates a higher state of oxidation than the more greenish clays of the Chadron, which also suggests that these mudstones were deposited on essentially dry surfaces with little included organic matter to keep them reduced.

The complete heterogeneity of these sediments does not readily accord with their apparent fluvial origin and flood-plain environment of deposition. The presence of unweathered feldspars and practically unweathered biotite proves that the mudstones are not soils; the heterogeneous distribution of large chips gives structural evidence in the same direction. Careful observation reveals no trace of animal burrows or digging which might have destroyed all bedding. Even the thickest grass cover on a depositional surface would have holes and thin spots where some sorting and lamination would occur. Therefore, the heterogeneity probably is not related to phenomena at the depositional interface. Furthermore, the fairly regular increase in size and angularity of the larger clay lumps toward the nearest channel fills suggests that the heterogeneity is a phenomenon related to conditions of transportation.

Biostratonomic data furnish decisive clues to the factors necessary to produce heterogeneity.

First, deposition occurred in increments over flood-plain surfaces which were relatively dry between floods. The abundant coprolites, hackberry seeds, and partially weathered bones attest to this. Such additional details as groups of carnivore coprolites around a pre-depositionally weathered herbivore skull, a rodent partial skeleton inside a turtle shell, skeletons in tetanic death poses, and the sheer presence of abundant non-aquatic mammals over many square miles can only be explained by assuming inter-depositional sub-aerial episodes. Presence of twisted, calcareous tubes resembling tree-roots may indicate exposure long enough to develop forests.

Second, the floods deposited increments 4 to at least 18 in. thick. Thickness of an increment is best revealed by the vertical thickness of the largest skull (or other bone) to be buried by that increment. If any bone should be partially buried by one flood, the temporarily exposed portion would be much more weathered than the lower, buried part. This is never the case. Fresh bone is fresh from top to bottom, and cracked, spalled bone is equally weathered from top to bottom.

An interesting example of this is FMNH PM 9359, a skull of *Archaeotherium mortoni*, which occurred upside down, with the lower jaws missing. One upper canine had fallen from its alveolus before deposition, and lay enmatriced about 6 in. anterior to the skull, roughly on the same horizontal plane as that on which the skull rested. Fragments had broken from the back of the cranium, and lay a few inches behind and to the left of it. The skull itself was cracked in many places, but equally so from top to bottom. There can be no doubt, *a*, that the skull was weathered in air for several years before burial, *b*, that burial was sudden and complete, burying an object of more than 6 in. vertical dimension, and, *c*, that burial occurred so gently as to engulf both the skull and its surrounding fragments without moving them. This specimen is typical of many hundreds from the mudstones, and none are known which offer contrary evidence.

Third, the heterogeneous mudstones have undergone little compaction during deposition and essentially none since then. The less-cemented portions show up to 25% permeable pore space, and the thoroughly-cemented nodules show, in thin section, that cement occupies what must once have been 25–30% open pore spaces. The great majority of fossil skulls show deformation only by cracking followed by the slight warping of individual pieces of bone which usually accompanies post-mortem desiccation. Nowhere do the mudstones exhibit compaction type slickensides. By contrast, the Chadron mudstones are extensively slickensided, and fossil skulls enmatriced within them always show strong flattening. Finally, the included chips and mudlumps in the Brule mudstones show no distortion whatever, as they certainly would if significant compaction or post-depositional flowage had occurred.

Fourth, the mud which comprises the mudstones was deposited as a moderately viscous fluid rather than as material settling from suspension. The skull of *Archaeotherium*, FMNH PM 9359, demonstrates the nature of the entombing fluid very clearly. Apparently the bone was sufficiently dry at the moment of burial to abstract water from the enveloping fluid and cause it to "freeze" or gel instantly. The entire dorsal surface of the skull (which faced downward as the skull lay upside-down) is covered with markings of tiny clay ropes 0.7–3.0 mm. in diameter. twisted into tight, flat spirals 5–17 mm. in breadth, which lie appressed against the bone (Fig. 37). These can only be interpreted as turbid flow-currents of influent viscous fluid forcing its way under the skull. No possible mechanism of settling from a thin water suspension could produce such structures. Piece #3 (the matrix from the specimen has been preserved and the pieces numbered to show position) of the matrix, which comes from the right temporal fossa, shows a series of partial lamellae, shaped like concentric open cones with the apices downward, pressed into each other but still distinct enough to cleave apart, although no lineation or arrangement of grains is apparent. This structure also can only be explained as engulfment by a series of pulses of viscous, fluid mud.

In summary, the mudstones consist of completely heterogeneous material, originally highly porous, which has not been significantly compacted. They were deposited in increments 4 to 18 in. thick, and show structures indicating that they flowed as thick, viscous fluids which set instantly when they lost water by contact with dry surfaces. This is consistent with the high montmorillonite content, and is the only explanation which fits the observed evidence. The high initial porosity favored penecontemporaneous migration of influent ground-water, which deposited interstitial calcite in the form of nodules and tabular masses.

2. Laminated siltstones. This sedimentary lithotope consists of alternate laminae of coarse and fine siltstone, massive, fine-grained sandstone, and laminated mudstone (see Fig. 36). Occasionally, a lamina of heterogeneous mudstone is also included in the sequence, but

these are always less than 1 ft. thick, occur near channel-fills, and are quite discontinuous.

Individual laminae vary from less than an inch to over 10 in. in thickness; they show regular bedding rather than scour-and-fill structures, and may be traced for distances of hundreds of yards to over a mile. The coarsest siltstones grade into extremely fine-grained, massive, structureless sandstones; they usually constitute the thicker laminae. These coarser sediments are greenish in color; the finer siltstones are gray, and the mudstone laminae buff to grayish. The laminated siltstone lithotope occurs in total thicknesses of a few feet to more than 30 ft. From Scenic eastward, it characteristically thickens and coarsens to occasional channel-fill sandstones with gradational borders; southwest of Sheep Mountain the borders between siltstones and channel-fills are usually sharp.

Fig. 37. Photograph of marks of viscous flow on a skull of *Archaeotherium*, FMNH-PM 9359.

The coarser laminae develop flat, greenish concretions which are always as thick as the laminae vertically, and extend horizontally two to four times their vertical diameter. At a distance from channel-fills these concretions occur singly and are larger, and of irregular rounded shapes, but within 1 mile of a definite channel fill they form almost continuous beds. The cement is calcite. The concretions weather to a much lighter brown than do those of the mudstones, and the surfaces are always smoothly rounded, never pitted. No fossils have ever been found in these concretions or in the siltstones proper.

A curious structure of completely unknown significance usually characterizes these concretions (Fig. 38). Series of thin, vertical plates, spaced 1 to 5 mm. apart, transect them in many areas. The plates are irregularly bundled into sheaves, but they do not touch each other, and over any one area of a few tens or hundreds of yards they have a strong directional trend. The trends usually vary through the NW-SE quadrants. These plates weather out to fine, paper-like ridges which evidently represent structures penetrating the concretion. However, freshly-broken surfaces show no trace of them. They do not show up in thin-sections, except in sections over 50 μ. thick, where they appear as light lines. Concretions formed in coarser, greenish layers generally have either no plates at all or more widely spaced ones.

Returning to a more general consideration of the laminated sediments, it is apparent that these are deposits from bodies of standing or slowly moving water. The stratification, uniform for distances of hundreds of yards, the generally good-to-excellent sorting of clastics (except for clays; all of these sediments contain moderate to high percentages of uniformly dispersed montmorillonite), the relatively thin bedding, and the absence of channelling or scour-and-fill structures all indicate subaqueous deposition. The generally coarser sediment in this lithotope suggests a higher energy system than that which transported the heterogeneous mudstones. The larger amount of water needed to sheet-flood the Badlands area, as opposed to the smaller amounts needed to produce mudflows from each stream, is in accordance with this. Generally the channel-fills interbedded with mudstones are narrower and composed of finer sediment than are the same channel fill zones higher or lower in section where they interbed with the laminated siltstones.

However, the siltstone sequences show no varves, nor any development of graded bedding. Probably they do not represent lakes that persisted for as long as a year, but rather flood-lakes which drained off within a few weeks after each rainy spell. The only fossils observed are algae in a few very thin limestones, and one trail of a limbed invertebrate in a sandy siltstone. If these sediments accumulated in semi-permanent lakes, fossil fish and leaves should have been locally abundant. Also, there are nowhere any beach or beach-bar deposits on even a minute scale.

The absence of mudcracks is attributable to the high percentage of silt and sand in these sediments, which greatly reduces shrinkage and thereby inhibits cracking. However, the absence of any root-marks, burrows, or other disturbance of bedding surfaces indicates plainly that periods of exposure between floods were not long enough to allow development of a forest or even of a well-established plains flora. It may be that the reason for the absence of fossils is that periods of lake development alternated so rapidly with times of emergence that neither a lacustrine nor a terrestrial biota had time to establish itself.

3. Laminated mudstones. The lithotope consists solely of the rock type described above (p. 77) under the name "laminated clay." Occurrence is limited to the area bordering the old Sage Ridge (see Figs. 32 and 33) and to the district southeast of Cuny Table, which has not yet been thoroughly studied.

In the Sage Ridge area, laminated mudstones occur at the top of the Lower Nodular Zone, resting directly upon heterogeneous mudstones, and also intercalated with laminated siltstones at various horizons through the Scenic Member. They range in color from bright red to flesh colors and pale buff. The color distribution is geographic rather than stratigraphic: if at a particular place one laminated mudstone is bright red, then all

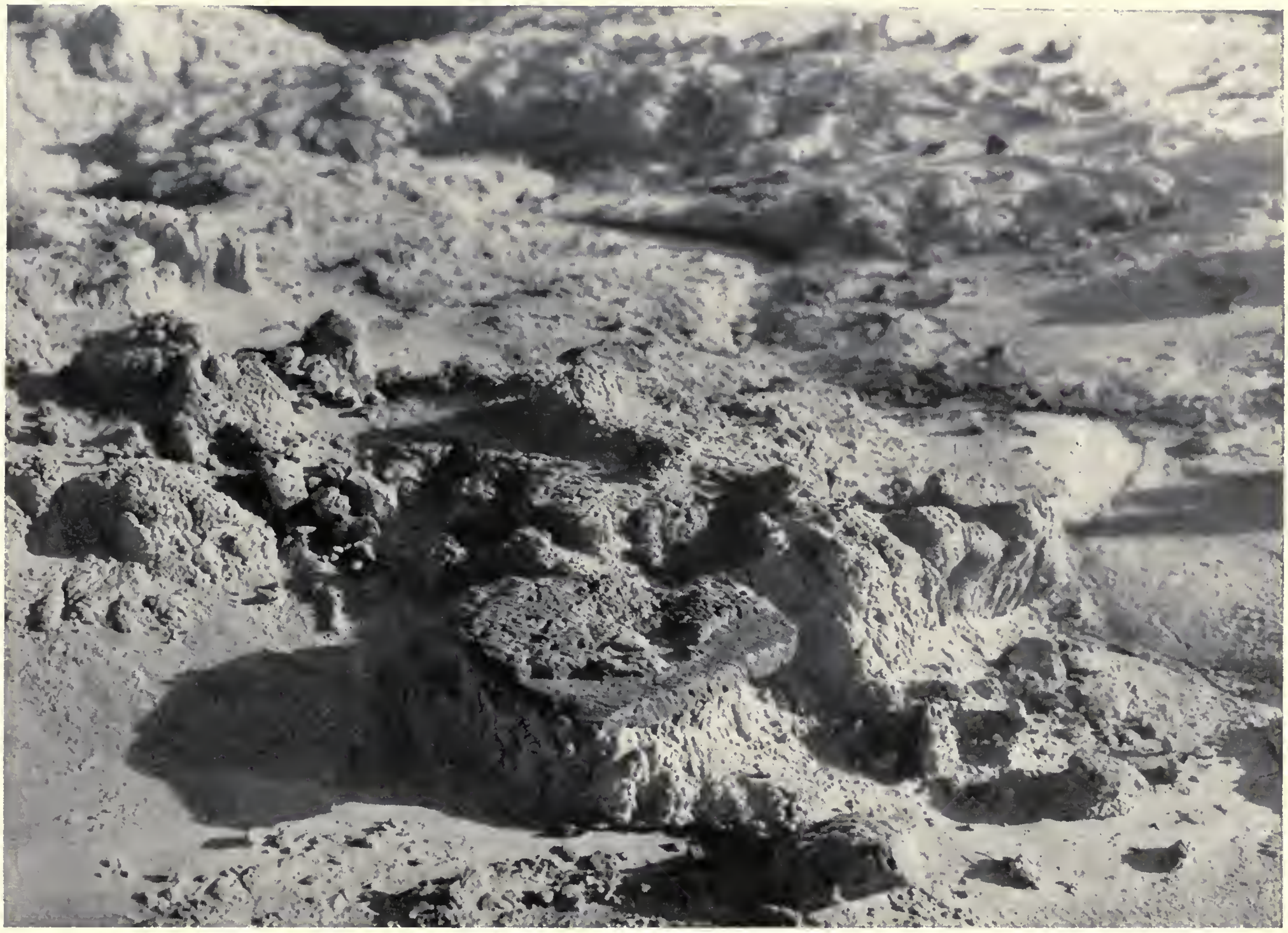


FIG. 38. Photograph of layered concretions in a silty mudstone, showing vertical plates of unknown origin.

laminated mudstones throughout the section are bright red at that place and even the heterogeneous mudstones are reddish brown. The paleogeographic significance of this lithotope is considerable; more complete discussion will be given in the following two sections, after the presentation of more evidence.

4. Channel-fill sandstones. This lithotope also includes only the rock-type of the same name. The first notable feature of these channel fills is their vertical continuity, indicating that any one Oligocene stream remained in one place through the deposition of several tens of feet of sediment both in its channel and on the surrounding plains. Meanders, cut-offs, and ox-bow lakes were nowhere present.

The second feature is the rarity of any structures which could be interpreted as braiding in the true sense (Leopold and Wolman, 1957). Actual division of a channel by a stream-built island, with reunion at the downstream end, was observed in only one doubtful case (NE ¼ of Sec. 11, T. 42N., R. 45W., Shannon Co.).

Third is the apparent rapid decrease in stream velocity, represented by the decrease in maximum grain size, with increasing distance from the Black Hills. All of the major Southern-derived streams, whose courses were 25–40 miles long from the edge of the Precambrian to their present area of outcrop, carried pebbles 2 in. or more in diameter. The shortest Northern-derived stream (outcropping on Heck Table, SE ¼ of Sec. 35, T. 3S., R. 13E., Pennington Co.), with a course from its last Precambrian contact of about 50 miles, carried feldspar and quartz pebbles not over 1 in. in diameter, with flat disks and spindles of black quartz-schist up to 1 in. maximum diameter. All of the channel deposits farther east, with necessarily longer courses, contain no grains larger than coarse sand.

Finally, the channel deposits are remarkable for the lack of evidence of any erosive action. Nowhere are there signs of ancient cutbanks, or even commonly of cut-and-fill structure within the channel itself. The streams must have operated either continuously under a depositional regimen or, more probably, under a regimen of deposition during high water and graded flow during low. Probably the excessive proportion of montmorillonite present on the depositional plains, as well as in the channel-ways at all times, caused the flood waters to resemble thick soup; at low-water stages the water was probably more normal.

STRATIGRAPHIC RELATIONS OF SEDIMENTARY LITHOTOPES

A. METHOD OF DETERMINATION.

The relationships of the sedimentary lithotopes were determined by detailed field observations, with measured sections spaced an average of one mile apart. Individual strata were followed from one butte to the next by direct visual observation; levelling by instrument was unsatisfactory because the separate beds were only a few feet thick, varied in thickness locally, and were everywhere gently warped by low structures. However, the excellent badlands outcrops plus the large number of key beds made visual tracing effective. Direction of flow within channel-fills was determined by mapping the channel-fills and observing cross-bedding within them. Source was established by heavy-mineral analysis.

B. Stratigraphy of Mudstone Zones in Detail.

Over the entire area except in the immediate neighborhood of channel-fills the Scenic member consists of alternate beds of mudstone and laminated siltstones. The contacts between these are sharp. Near channel-fills, the siltstones become sandier and some of the mudstones grade laterally into siltstones. Channel fills of Northern Black Hills derivation everywhere grade laterally into the surrounding sediments without scouring or trenching them. Those of Southern Black Hills derivation have sharper boundaries and have entrenched themselves in a few places to an absolute maximum of 6 ft.

At the standard section of the Scenic Member (south edge of Sec. 27, T. 4S., R. 13E.), a total of five mudstone strata, each overlain by a siltstone, can be recognized. One-half mile further south and east, the top of the uppermost siltstone grades into a sixth mudstone, separated from the overlying Poleslide by a dark band. Since the standard section is very near a series of channel-fills, gradation of this sort is to be expected here.

The mudstone zones were numbered I–VI, starting with the Lower Nodular Zone at the bottom as I, and effort was made to trace them as far as possible. If they should be restricted lenses related to particular channel-fills, they would be of no geologic significance. If, on the other hand, they should extend across the flood plains of several Oligocene streams, they would represent times of flooding by waters less competent than those which deposited the siltstones from large areas of the Black Hills and would carry considerable climatological significance. It might also be possible, if these layers were continuous, to establish a faunal succession within the Scenic Member.

Careful tracing revealed (see Figs. 30, 33, and 39, and Appendix) that Sheep Mountain was during Oligocene time the location of the major divide between Northern-derived sediments to the northeast and Southern-derived sediments to the southwest. The standard section of the Scenic Member lies near a Northern-derived channel zone, three miles northeast of the Oligocene divide.

Section #1, well within the Southern-derived depositional area, revealed mudstones I, III, IV, and combined V and VI clearly evident. All of these were traced directly from outcrop to outcrop between the two positions. The siltstone separating V and VI at the standard section can be observed to grade laterally southwestward into a mudstone, which explains the union of these two, southwestward. Mudstone II is probably present, but I am unable to distinguish it from other entirely local mudstone laminae within the siltstone zone which separates I and III.

It is thus apparent that, with minor changes, these mudstone zones do extend from one Oligocene drainage area to another.

Northeastward, the continuity of certain mudstone zones is even more striking.

Mudstone I, the paleontologically famous Lower Nodular Zone, has long been recognized as continuous throughout the Big Badlands (Wanless, 1922, 1923; Sinclair, 1921, 1924, et al.). The nodules gradually disappear two miles northeast of Chamberlain Pass, and the color of the mudstone changes from buff and gray to red (Sec. 15, 16, 17, 18, T. 3S., R. 14E.) (Fig. 39). A thin, discontinuous greenish layer, apparently a small swamp deposit, occurs two-thirds of the way toward the top of the zone at this place. The red color fades to more normal buff, yellowish, and gray eastward in Sections 22 and 23 (Figs. 30, 39). The red reappears in the neighborhood of Sage Creek Pass (Sec. 11, T. 3S., R. 15E.); it continues thence northward to outcrops near the town of Wall, and eastward, with few interruptions, throughout the Monument. The red zone is, therefore, definitely divided into two areas (Fig. 33, "Igaposomes").

Red color occurs in zones II, III, and in any local mudstone lenses which may be present, over exactly the same areas as those described for zone I. Where one is red, all are red. Zones V and VI, where recognizable, show little if any red color. Nodular concretions never occur in the red zones. However, in the neighborhood of the Pinnacles a thin buff lamina within the red, a few feet below the top of zone I, is marked by both nodular concretions and abundant fossils.

Zone II. This mudstone is much less continuous than is zone I. It can be traced from the northeast flank of Sheep Mountain east-northeastward for 6½ miles, within the floodplains of two Northern-derived Oligocene streams, but beyond the second stream it disappears.

As zone II disappears eastward another mudstone zone (designated IIA in the columnar sections, Fig. 39, and Appendix) lenses into the section a few feet above it. This has been traced all the way to the Pinnacles, a distance of 14 miles, and may extend farther. It is never more than 12 ft. thick, and usually less than 6. Since zones II and IIA have been observed in the same hillside (see columnar section 14 and appendix), it is evident that they are two strata of slightly different age and of less areal extent than mudstones I and III.

Zone III is fully as continuous as zone I; it varies generally from 10 to 20 ft. thick, occasionally thinning to 7 or 8 ft. This zone shows a strong tendency to develop a middle stratum different from the top and bottom. In the Sheep Mountain area the middle is either

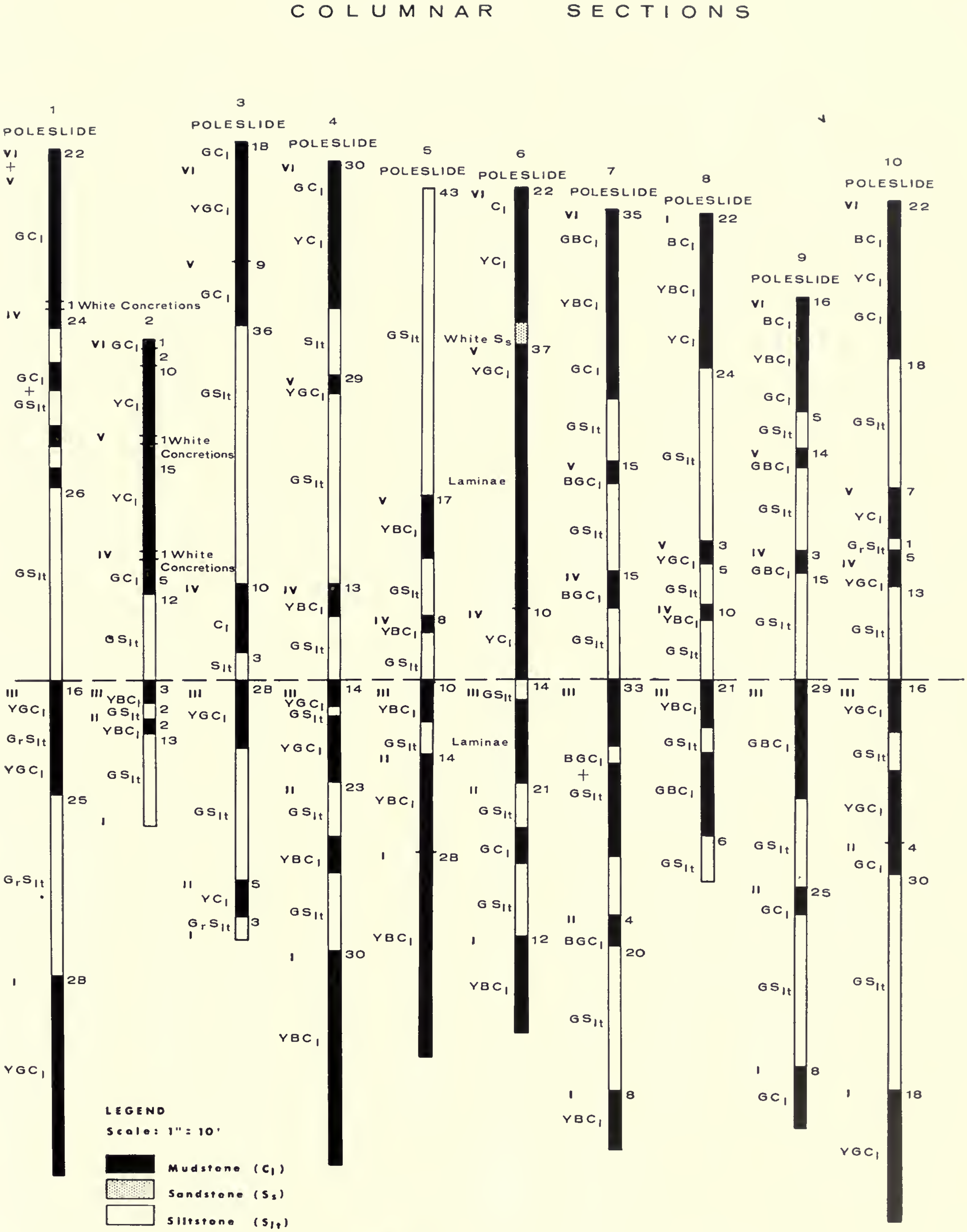


FIG. 39A.—Columnar sections, Scenic Member.

COLUMNAR SECTIONS

FIG. 39B. Columnar sections, Scenic Member.

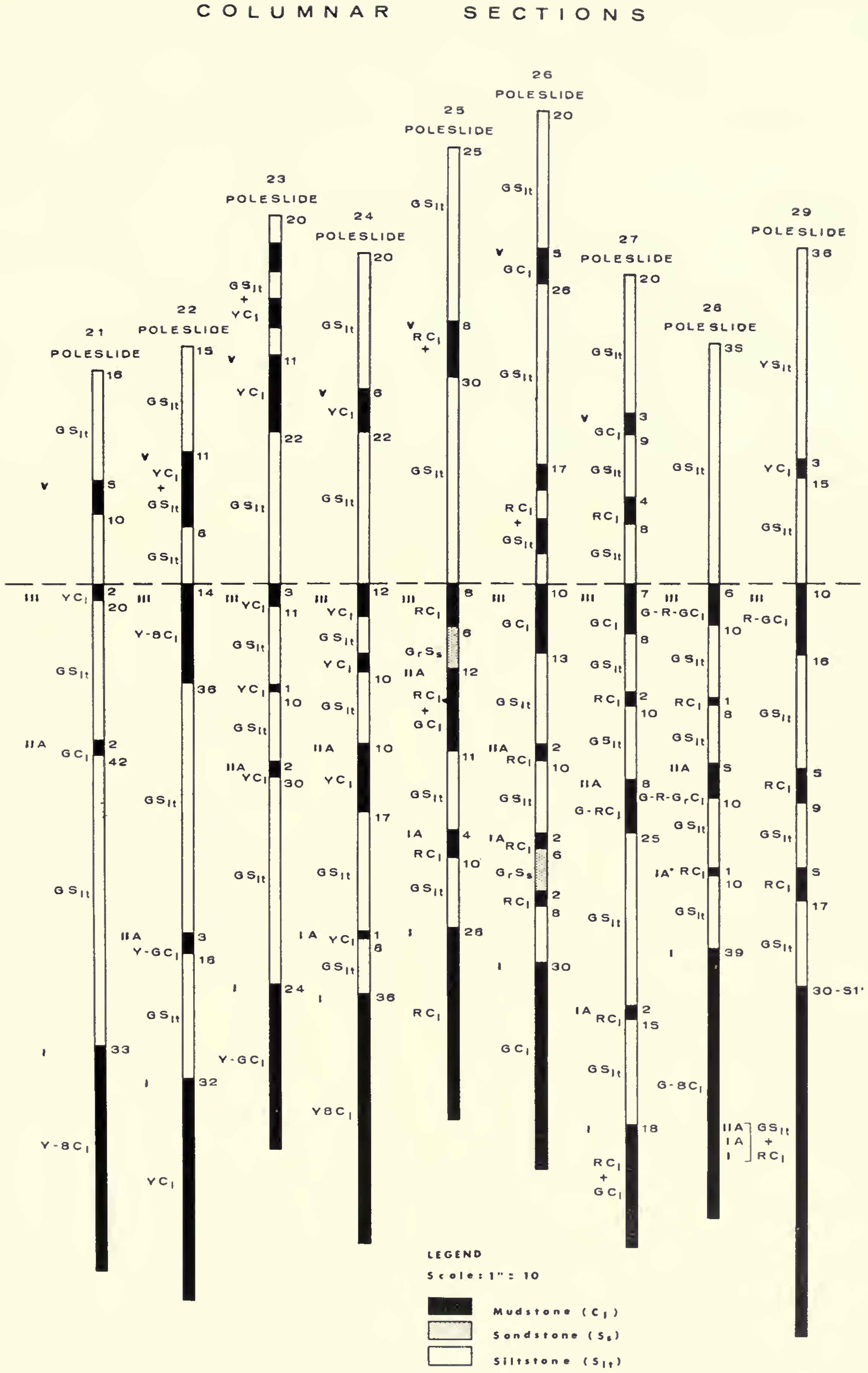


FIG. 39C. Columnar sections, Scenic Member.

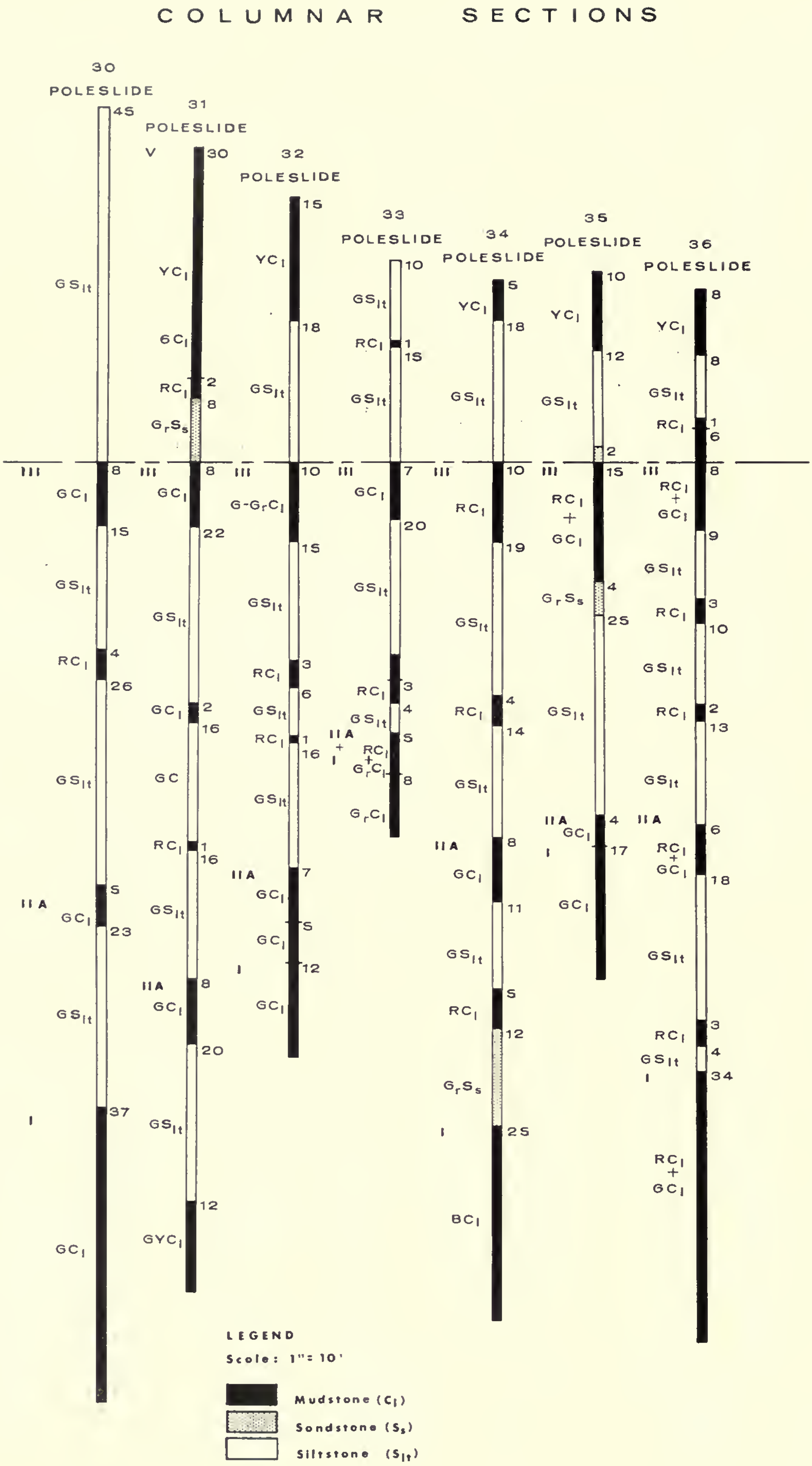


FIG. 39D. Columnar sections, Scenic Member.

FIG. 40. Photograph of Scenic Member mudstones, looking NW at the SE¼ of Sec. 28, T 2S, R 16E. This is the location of Columnar Section 33, Figure 39. Shows numbered mudstones, with red igaposomes.

white or gray, and silty; farther east it is a grayish or buff layer between more reddish ones.

Mudstone IV thins and merges with V about two miles northeast of Chamberlain Pass, a distance of about 12 miles from Sheep Mountain. Its eastern distribution almost corresponds to that of II; southwestward it extends for about eight miles.

Mudstone V is almost as continuous as I and III. It merges with VI on the west side of Sheep Mountain (Section 1, Appendix) and (with VI) merges with the Poleslide east of Sage Creek Pass, 18 miles to the east-northeast. This zone, like I and III, continues recognizably across several Oligocene stream courses (Fig. 33) and therefore cannot be genetically related to any one of them. It loses identity by the thinning out of the siltstones which separate it from the overlying VI and Poleslide, rather than by wedging out itself. East of the area where V can be recognized, the basal 20 to 30 ft. of what is apparently Poleslide contains obscure, discontinuous concretionary bands and thin siltstones, which probably represent the upper boundaries of V and VI. However, these rocks resemble Poleslide lithology, without a marker zone to separate the two members. Away from the main channel zones, apparently, conditions of deposition of the upper Scenic Member and the Poleslide Member were so similar that the resulting mudstones are indistinguishable: the apparent boundary between the two members is the top of the laminated siltstone lithotope overlying Zone III. This means that the apparent boundary between Scenic and Poleslide is somewhat older from Sage Creek Pass eastward than from the Pass southwestward.

North of Chamberlain Pass and southwest of Sage Creek Pass, V is yellowish and contains fossiliferous nodules indistinguishable from those of I, the Lower Nodular Zone. *Ischyromys*, *Eumys*, *Paleologus*, *Ictops*, *Mesohippus*, and *Merycoidodon* have been collected, also hackberry seeds, snails, and coprolites. Study reveals no differences between these and specimens from the Lower Nodular Zone.

Mudstone VI merges indistinguishably with V, west of Sheep Mountain, and with the Poleslide approximately 14 miles to the northeast. It also merges with the Poleslide northward, in Sec. 12, T. 3S., R. 13E. The dark marker band which separates Scenic from Poleslide at the standard section disappears east of Sec. 18, T. 3S., R. 14E., two miles northeast of Chamberlain Pass.

From the vicinity of Sage Creek Pass eastward, a number of bright cinnamon-red, laminated mudstone zones lens in and out of the section. These are never continuous for distances of more than a mile or two, and they differ markedly in appearance from the heterogeneous mudstones numbered I, IIa, III (IV disappeared farther west, and V and VI have here merged with the Poleslide). The latter are always more brownish or chocolate-red, and show some variability in color from bottom to top. These discontinuous lenses are thinner, bright red, and show no variation from top to bottom of an individual bed. They always consist of laminated clays, never of heterogeneous mudstone. They wedge out from both north and south against the flanks of the Sage anticline at Dillon Pass (Fig. 40).

The underlying Chadron covers the top of the Sage Anticline but thins to 9 ft. in doing so (Clark, 1937, p. 264). It is believed that these reds represent local wash of red Interior zone soil from areas immediately to the northwest which may still have been exposed during Brule time. The top of the Interior zone is a very bright red in this neighborhood. However, it must be understood that this suggestion is hypothetical, because the Scenic Member cannot anywhere be observed in contact with Interior Zone. This situation could occur north of Sage Creek basin, where the Oligocene is everywhere either covered or eroded away, but it is not known to do so.

In summary, from the Sheep Mountain area northeastward the Scenic Member comprises three mudstone zones, I, III, and V, which apparently were deposited generally over the whole area, although V merges eastward with the overlying Poleslide Member. It also includes three mudstone members, II, IV, and VI, which are local and related to not more than three adjacent channel fill zones.

To the southwest (see Figs. 30, 33, 41) the situation is somewhat different. As the cross-section diagram indicates, the siltstone sequence between mudstones I and III thins southwestward. At the Cottonwood Pass area it is represented only by major channel fills. Concomitantly, zone III thins, the nodules within it disappear, and it changes to a brownish color. It appears to be simply a brownish clay zone a few feet thick, forming the top of the Lower Nodular Zone (I), separated from more typical nodular clays of that zone by a few inches to several feet of greenish clay or by channel-fills.

Meanwhile, the Lower Nodular Zone thickens to 40 ft. at Cottonwood Pass, then gradually thins westward.

Zone IV, which is not persistent eastward, can be traced westward through most of the area of major Southern-derived channel-fills (Sec. 16 and 17, T. 42N., R. 45W., Shannon Co.). It apparently represents some situation general over the part of the area of the southern and middle Black Hills, but not the northern Hills.

The characteristic yellow-buff of zone V, with a thin, relatively dark gray zone at the top, is a good stratigraphic marker which continues southwestward somewhat beyond the main area of channel-fills.

Westward along the main flank of Cuny Table, (from Sec. 32, T. 42N., R. 45W., to Sec. 9, T. 41N., R. 46W., Shannon Co.) the entire Scenic Member thins and changes. Zone I becomes pale tan, and the nodules grow smaller, fewer, and less well-developed. In many places it is difficult to distinguish between Chadron and Brule. A mass of laminated siltstones, some slightly cross-bedded, replace zones IV and V. The entire section of the Scenic Member becomes:

	Poleslide—yellow-buff	
	Gray siltstone and gray platy sandstone	40′
Zones I and III	Yellow to brown clay	20′
	Pale tan clay with small brown concretions	30′
	Chadron	

Still farther southwest, in Sec. 31, T. 41N., R. 46 W., the sections thins more, and the sediment becomes even finer grained:

Poleslide	
Pale grayish silty clay	15′
Yellow to brown clay	10′
Chadron	

There are no channel-fills, and no laminated siltstones in the Scenic Member over the entire area south to the Slim Butte (T. 36N., R. 48W., Shannon Co.). Apparently this area received only fine sediment during times of maximum flooding from the streams to the north. Much of the fine material is montmorillonite, which may represent locally weathered ash merely rehandled by occasional flood waters.

C. Siltstones and Sandstones.

As already indicated, the channel-fill sandstones lie in definite restricted areas (see Fig. 33) extending vertically almost or entirely through the Scenic Member. Individual channel-fills usually do not have definite boundaries, but grade laterally into laminated siltstones. This makes determination of the size of the depositing streams at any one time quite difficult. In general, the sandstones are widest where they lie within siltstone zones; the sandstone zones are 100 to 500 yards wide at these horizons, with individual channel-fills a maximum of 100 yards wide by 6 ft. thick. The sandstones are notably restricted where they occur within the mudstone strata, especially within I, the Lower Nodular Zone. There they are less than 50 ft. wide, but 4 to 6 ft. thick. The diminution within zone III is almost as great, but is impossible to measure accurately. Very few channel-fills continue into V. Mudstones II and IV, on the other hand, are generally interrupted by the channel zones so that tracing them across is very difficult.

The sandstone channel-fills likewise show a decrease in maximum grain size within the mudstone strata. No sediments coarser than fine sand have been observed within the Lower Nodular (mudstone I), in the same channel-fill series which carry pebbles up to 10 mm. diameter in their siltstone-stratum levels. Briefly, the mudstone strata are associated with channel-fills of fine sand, and the siltstone strata with channel-fills of grit.

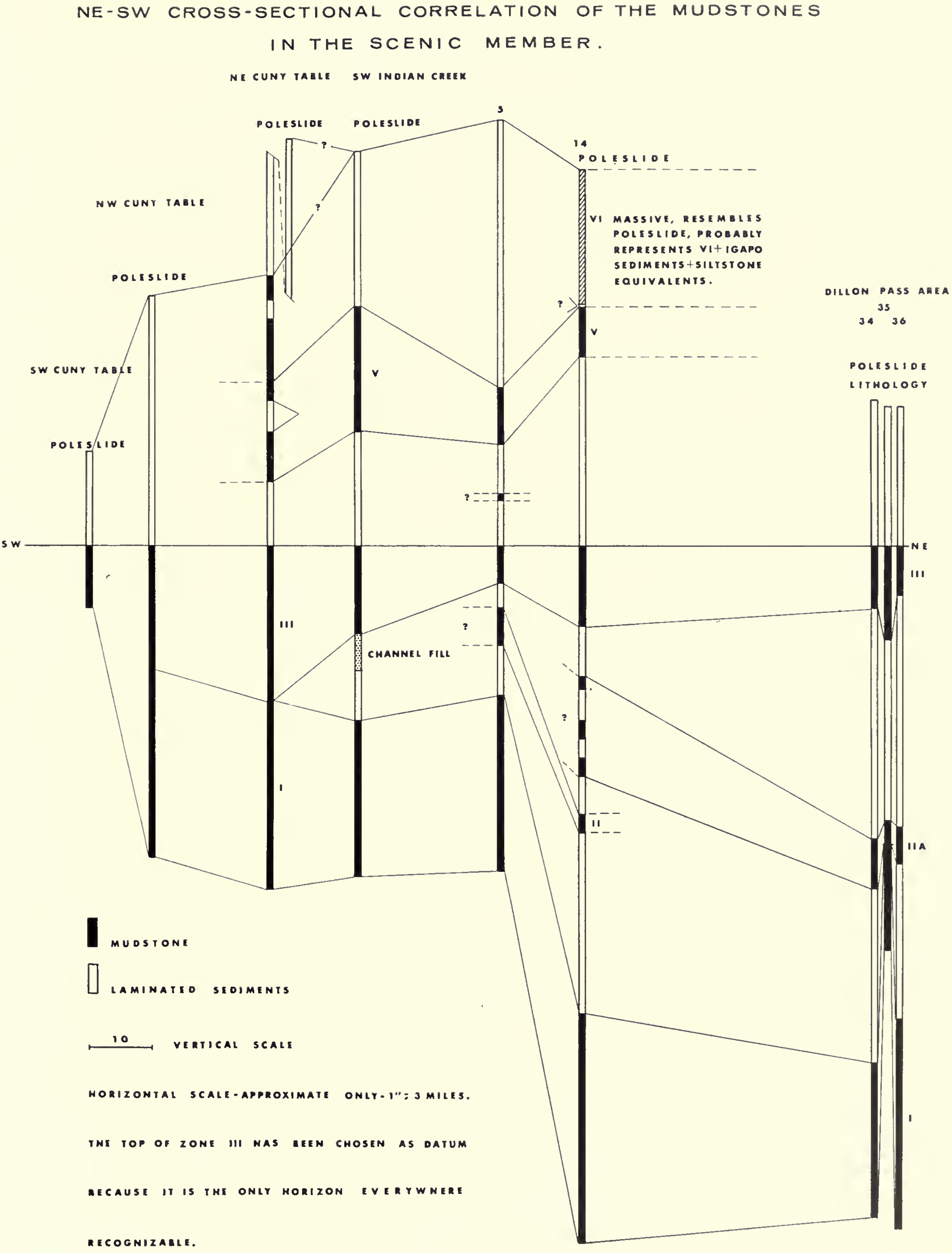
The siltstone strata, which occur intercalated between the numbered mudstones, have definite top and bottom contacts with those mudstones. They grow noticeably finer, more even-grained, less laminated, and less concretionary, away from the channel-fills. Near the channel-fills, they consist of alternate thin laminae of mudstone with thicker layers of siltstone or fine sandstone.

Two miles north of Chamberlain Pass, at a few places in Sage Creek basin, and north of the Pinnacles, the siltstones grade laterally into gray to buff mudstones. At these places, the numbered mudstones are red, and the contacts between successive layers of differently colored mudstones remain sharp.

PALEOGEOGRAPHIC INTERPRETATION OF THE SCENIC MEMBER

A. Areal Distribution of Physiographic Units.

The Oligocene strata of South Dakota and Nebraska have been recognized as flood-plain deposits for several decades. Their thickness, their wide areal extent, the fact that they transgress divides, and their close proximity to their source mountains, indicate conditions very different from those normal to flood plains. From the data presented above, interpretation of some of these special conditions is possible.



VI MASSIVE, RESEMBLES POLESLIDE, PROBABLY REPRESENTS VI+IGAPO SEDIMENTS+SILTSTONE EQUIVALENTS.

HORIZONTAL SCALE-APPROXIMATE ONLY-1"; 3 MILES.

THE TOP OF ZONE III HAS BEEN CHOSEN AS DATUM BECAUSE IT IS THE ONLY HORIZON EVERYWHERE RECOGNIZABLE.

FIG. 41. NE – SW cross-section of the Scenic Member, showing relationships of mudstone units.

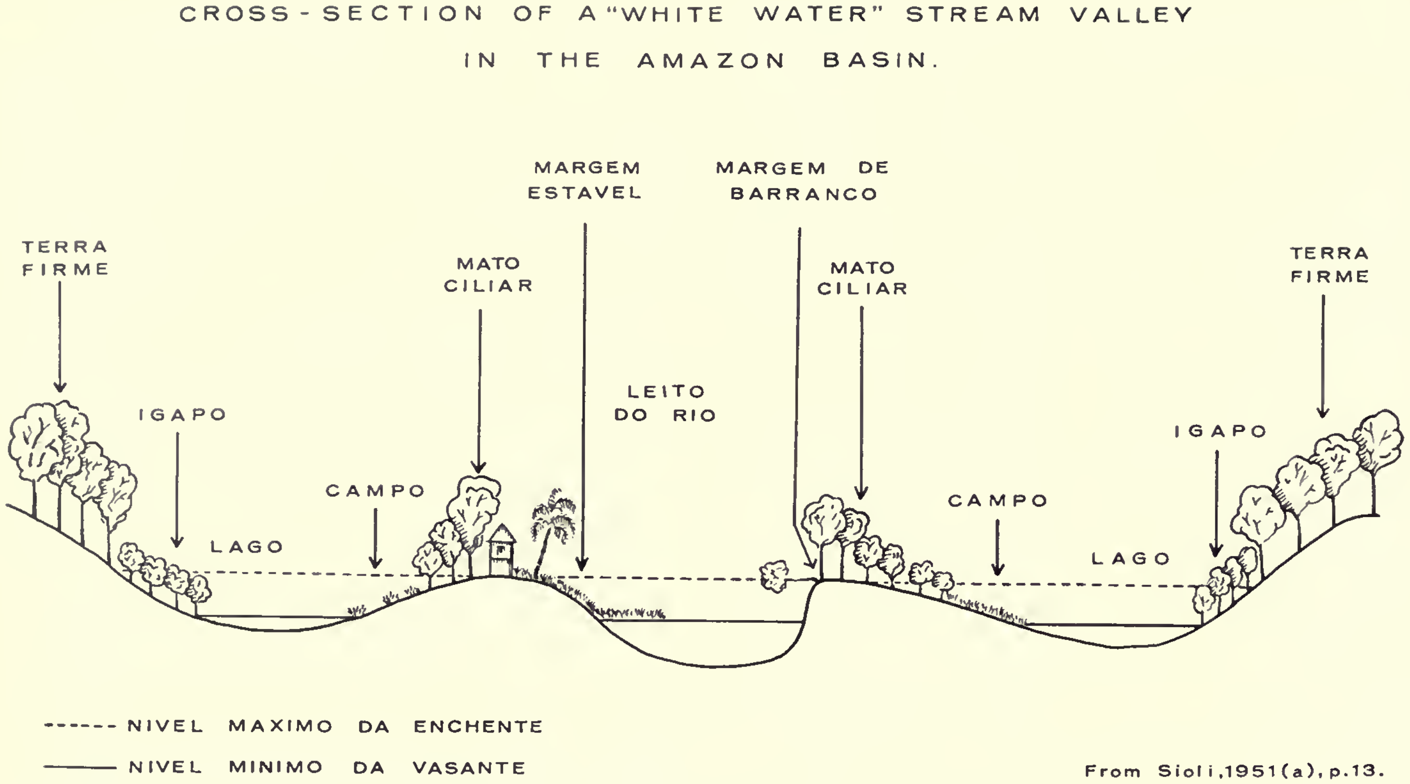


Fig. 42. Cross-sectional diagram of a stream in a depositional regimen, from Sioli.

In an effort to discover a recent situation similar enough for fruitful comparison, I turned first to the Punjab of Pakistan. Observation from the air of the major floods of 1951 revealed several roughly-parallel rivers in flood simultaneously, producing a sheet of still to gently-moving, muddy water about 40 miles wide, with swift, turbulent currents marking the courses of the main streams. The flood water was generally less than 3 ft. deep over the entire area. Complete withdrawal to the original channels occurred within two weeks; none of the flooding streams changed their courses and, except where irrigation works created artificial situations, there was no significant erosion.

Unfortunately, I was unable to make ground observations immediately after the flood. News reports spoke of several feet of mud partially burying riverbank villages, but since the villages were all constructed of adobe, much of this mud probably derived locally from crumbling walls. Judging from the appearance of vegetation several weeks later, 1 to 12 in. of sedimentation would be a better estimate.

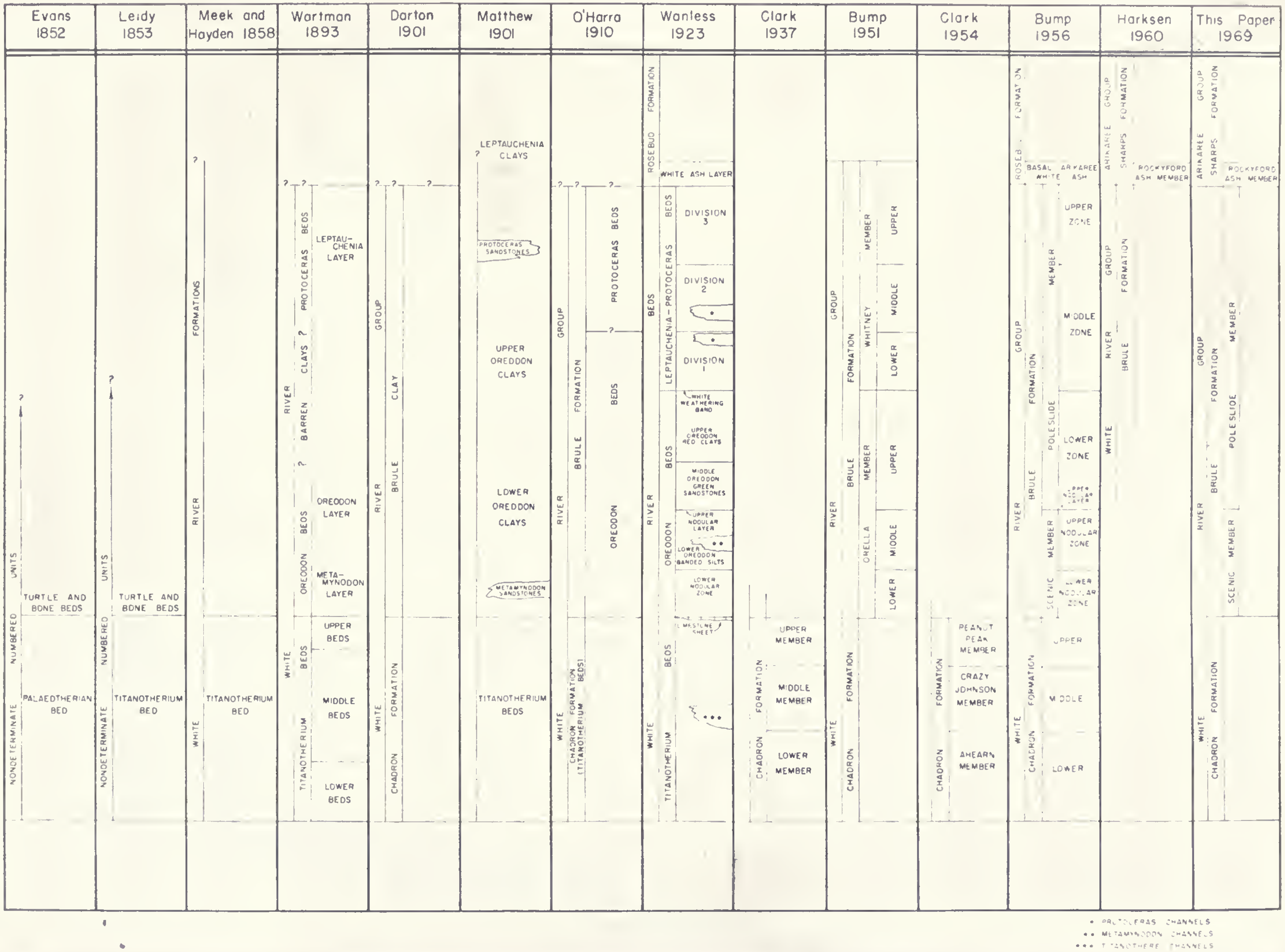
Garden and cereal crops were widely destroyed, but trees, shrubs, and taller herbaceous plants suffered only minor damage. No eye-witness reports of stranded fish came to my attention. This might have been due to stranded fish being locally considered un-newsworthy, but three possible biotic factors seem to offer more satisfactory explanations. First, the normal fish fauna of any one stream would, if it were evenly distributed by the flood, be areally diluted to about .01 to .05% of its channel concentration. Second, the floodwater lake was so shallow and so muddy that most fish would probably have attempted to remain in the turbulent, better-oxygenated water of the main stream. Third, any fish trapped and killed by the lake subsidence would certainly have decayed or been devoured to destruction within a few days, under the Punjab summer climate, and carnivore and insect population (Payne, 1965).

The findings having significant reference to Oligocene sedimentation were that parallel streams on a confluent plain could flood contemporaneously, producing a lake tens of miles wide but very shallow, which would disappear within a matter of weeks, and that the flooding streams neither meandered nor changed their courses.

Much more detailed observations on the central Amazon have been reported by Sioli (1951). His cross-section diagram of the parts of a stream system in a depositional regimen (Fig. 42) divides the area into definite physiographic provinces; as amplified in his text, several of these units seem to be represented by Scenic Member sediments. Figure 43 shows the physiographic provinces as parts of a surface, with the sediments deposited in each province continuous stratigraphically below it, as they occur within the Scenic Member.

There is first of all the through-going stream with its provenance outside the area, which functions as an avenue of entry for the bulk of both the water and the sediments that enter the entire province; Sioli refers to this as the "Rio." Since another type of stream occurs in the fluvial province, it seems wise to employ the Portuguese term in a technical sense, as defined in the preceding sentence. The body of sediments deposited by the rio within its bed through time, structurally controlled by water moving downstream, is here designated

Table I   Nomenclature chart showing the development of the stratigraphic nomenclature of the White River Badlands of South Dakota



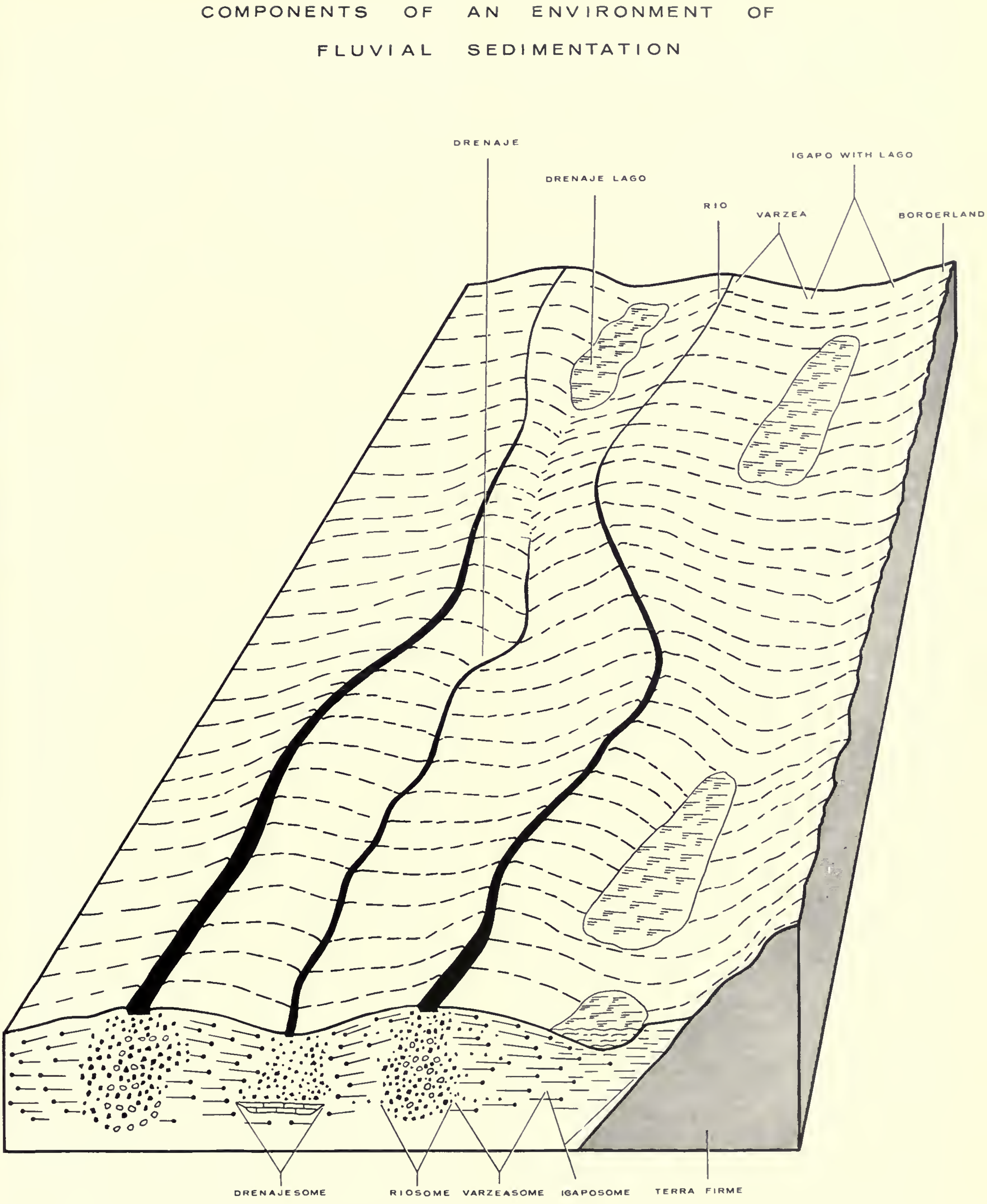


FIG. 43. Components of an environment of fluvial sedimentation.

"riosome." A riosome differs from a channel-fill physically in that it does not represent the fill of a single channel or depression which ever existed as one entity. It is rather the body of sediment deposited within one stream throughout a period during which the stream operated in a dominantly depositional regimen.

Sioli's second fluvial sub-province is named "varzea." This, Sioli makes plain, includes the relatively high ground (natural levee) along the rio banks, and the entire back slope away from the banks. This area, which is exposed except during floods, receives its sediment primarily by outward flow of flood water from the rio. The mass of sediments accumulated through time in a varzea should be referred to as a "varzeasome." They are composed primarily of allochthonous material, but may be deposited either as mudflows or by settling from suspension in slow-moving to temporarily still water. The heterogeneous mudstone and laminated siltstone lithotopes of the Scenic Member constitute a varzeasome.

Finally, Sioli recognizes valley walls, normally composed of rock different from that of the stream's provenance, which he calls "terra firme." Where the varzea back-slope meets the foot of the terra firme, a linear hollow is produced, which he terms "campo" when dry, "lago" if occupied by a lake, and "igapo" if occupied by a slow-moving stream composed primarily of run-off from the bordering terra firme. For geologic purposes, the term "campo" may be omitted, and "igapo" used to mean the shallow trough, intermittently occupied by still or moving water, which lies at the foot of the terra firme. The sediments accumulated in an igapo environment come primarily by wash from the terra firme; they should be called "igaposome." In the Scenic Member, the laminated mudstone lithotope, derived from neighboring hillocks of Cretaceous shale rather than from the Black Hills, is an igaposome.

Sioli was dealing with one very large river in a wide valley. In the Scenic Member we have at least seven rios (#2, 3, 5, 7, 8, 11, Fig. 33) on a confluent flood plain, not separated by terra firme ridges. The varzea back-slopes of any two adjacent rios must have met in a winding, relatively linear depression. Floodwaters moving down the varzea slopes would deposit much of their load on those slopes, and meet at the intervening depressions (see Fig. 43) to form first a series of ponds, then a slow-moving, temporary stream with no headwaters. These streams should be called "drenaje" (="drain"; I have used a Portugese word in order to remain consistent with Sioli's terminology), and the body of sediments deposited by such a stream through time a "drenajesome."

Fortunately, a recent, small-scale development of a drenaje system can be observed in the Badlands. In Sections 4, 9, and 16, T. 42N., R. 45W., Shannon Co., a series of gullies debouch from the north flank of Cuny Table onto flats which have not yet been incised by the present erosional activity of Big Corral Draw. During major rainy spells these gullies, heavily charged with Oligocene mud and concretions, cross the flats as a series of overloaded rio streams at relatively low gradients. Their courses are almost straight, with flat-bottomed channels 2–6 ft. wide and up to 6 in. deep, flanked by low natural levees and long varzea backslopes. The streams overflow as sheet floods, breaching their banks first along the straightest stretches. Maximum deposition takes place at the curves. Breakthrough channels, heading from the main rio course to the drenaje depressions, never develop. Such breakthroughs would inevitably produce a sharp change in direction; the resulting energy loss in a stream already heavily overloaded makes impossible the erosion necessary to cut a breakthrough channel. Sheet-overflow remains the only way in which excess water can escape from the rio channel.

The overflow water, still charged with sediment, first forms ponds and then true drenaje streams, as already described. The drenaje comprise the apparatus necessary for sedimentation in the inter-varzea hollows. The recent small-scale rios and drenaje very quickly discharge into eroding gullies of Corral Draw. Without such a downstream drainage, they would presumably continue as separate entities until they reached some change of gradient.

The channel deposits numbered 1, 4, 6, and possibly 9 and 10 are drenajesomes. They are notably finer-grained and smaller than the adjacent riosomes. Drenajesome #4a rests directly upon a pond limestone with which it is almost coextensive, for a distance of over a mile (Sec. 35 and 36, T. 43N., R. 45W., and north edge Sec. 2, T. 42N., R. 45W., Shannon Co.). Apparently it started as a "lago" (pond formed by sheet-flood waters in either a drenaje hollow or an igapo hollow), and with increased water supply became a drenaje. Drenajesome #4 illustrates the rambling, relatively unpredictable course resulting from the unrelated depositional slopes of neighboring varzeas.

The nature of channel deposits #9 and #10 is doubtful. They are composed of notably finer sediment than that in the neighboring riosomes, #7, 8, and #11, and are much less cross-bedded, which suggests that they are drenajesomes. However, they are fully as wide and large as riosomes #8 and #11, which is improbable for drenajesomes.

In summary, the Scenic Member comprises deposits laid down on a confluent flood plain, in an orderly system of physiographic subprovinces designated as rio, varzea, igapo, and drenaje. The sediments were derived from three sources: (1) The Black Hills; (2) neighboring outcrops of weathered Cretaceous marine shale; (3) airborne volcanic ash and its weathering products.

Control of the regimen of these streams was not structural, since overlap of both Chadron and Brule sediments into the Black Hills shows that no downwarp of the Badlands relative to the Black Hills occurred at this time. Depositional activity by all Brulean streams from Canada to Colorado further precludes local structural control.

Excessive deposition of volcanic ash could not have functioned as a control of the entire regimen. Streams temporarily overloaded by an ash-fall would immediately have entrenched themselves during times between falls, and no such entrenching occurred. The existence of a depositional regimen must have been determined by climatic factors; the nature of the deposition and the sedimentary structures produced were strongly influenced by the volcanic materials.

If the temperature control of climatic patterns suggested on page 72 is correct, the dry episodes of heterogeneous mudstone deposition and restricted stream flow represent cooler periods, and the times of increased precipitation indicated by the laminated siltstones represent warmer periods.

Surprising evidence in support of this hypothesis was discovered by a South Dakota School of Mines collector in 1965. He found an alligator skeleton within the laminated siltstones between the Lower Nodular (Zone I) and Zone III, in the area near riosome #3, Fig. 33. (NW¼ of SE¼, Sec. 13, T. 42N., R. 45W., Shannon Co.). This is the first alligator reported from the Brule Formation, anywhere in its area of outcrop. The completeness of the specimen rules out any possibility of its being re-worked from the Chadron. Furthermore, this is the first fossil vertebrate reported from the laminated siltstones.

The enormous amount of collecting from the underlying Lower Nodular Zone leaves little doubt that, had alligators been present during Lower Nodular time, they would have been found. It is therefore a reasonable presumption that: (1) alligators were present in South Dakota during Chadronian time but uncommon during latest Chadronian (known); (2) alligators were absent during Lower Nodular time; (3) at least one individual returned during the next succeeding warmer and more humid episode.

Since streams continued to exist throughout the time, the temporary withdrawal of alligators and their even more episodic return must be ascribed to some cause other than lack of waterways. The most logical assumption is that: (1) late Chadronian time was cool enough that only a few small alligators survived; (2) further cooling which initiated the Lower Nodular deposition caused a southward retreat of the north border of their range; (3) temporary warming, with associated increase in precipitation, permitted at least one venturesome individual to repenetrate northward as far as the Badlands.

This bit of paleontologic evidence gains credibility as it tends to reinforce conclusions already drawn from the interpretation of the sedimentary history. We have two quite independent lines of evidence (albeit one rests upon a single fossil) pointing in the same direction.

B. Developmental History of Scenic Member.

At the beginning of Scenic Member time the entire area was a depositional plain composed of Chadron fluvial sediments which were thick over the old Red River Valley (see p. 22), but very thin over the Sage Ridge and the Pine Hills. It is probable that deeply weathered Pierre shale was exposed in places along these bordering uplands, although no such places have been found.

At least six major streams (#2, 3, 5, 7, 8, 11; Fig. 33) flowed in a general southeasterly direction across this plain; two others (#9, 10; Fig. 33) may have done so, although these were possibly merely drenajes. The southwesternmost three streams had their headwaters in the Harney granite; the others arose in the metamorphics and Laramide intrusives of the northern Black Hills.

It is possible that streams #2, 3, and 5 represent, respectively, the courses of ancestral French Creek, Battle Creek, and Spring Creek, while #7, 8, and 11 were Rapid Creek, Boxelder Creek, and Elk Creek respectively. This suggestion stems from the fact that all of the major creeks flowing from the Black Hills today pass through large gaps in the Cretaceous hogbacks, most or all of which are structurally controlled. Oligocene sediments lap up to and, in some cases in the southern Hills, into these gaps, indicating plainly that the present topography along the front is essentially an exhumed Oligocene landscape. No evidence of major post-Oligocene changes in the drainage pattern of the Black Hills has been reported. Association of Oligocene streams with their possible Recent descendants is justifiable in the case of the Southern-derived streams, where riosomes can be distinguished from drenajesomes. However, due to question about the nature of channel deposits #9 and 10, the relationship of Northern-derived streams to Recent ones is not at all clear. (Pleistocene piracy of all Black Hills drainage by Cheyenne and Belle Fourche rivers has necessarily curtailed the courses of all Recent streams, outside the Black Hills).

The Oligocene streams underwent five periods of alternate restriction and expansion, followed by a sixth restriction.

During the first period (that of the Lower Nodular Zone) the individual streams were less than 100 ft. wide, generally less than 3 and everywhere less than 6 ft. deep, and were capable of carrying only fine sand and silt. In successive floods, they spread a thick layer (15–40 ft.) of ashy, slightly bentonitic mud over the whole area.

This mud was added in increments up to at least 18 in. thick, since fossil rhinoceros (*Subhyracodon*) and giant pig (*Archaeotherium*) skulls and one mass of *Hypertragulus* skeletons of that vertical depth were buried quickly enough to preserve them entirely. Modern bones, if partially buried, show damage or destruction of the exposed parts within one or two years. Bone flakes and fractured bones are common in the Lower Nodular zone, but they are broken from bottom to top, not better preserved on the bottom as they would be if partially buried. The vertical thickness of the thickest well-preserved fossil bone, therefore, is a safe measure of the thickness of the individual sedimentary increment which buried it.

Fractured bones, abundant coprolites, hackberry seeds, and occasional rodent-gnawed bones all demonstrate that there were many episodes of non-deposition. During these times an abundant fauna roamed the plains, which must have been well-vegetated to support them. Intermittent floods deposited mud in layers up to 18 in. thick, burying both the more recent dead and bones which had partially disintegrated. The flaking and splintering type of disintegration which the bones underwent before burial is typical of bone under temperate semi-arid to arid climates. So also are the pale tan and gray colors of the sediments.

When flooding did occur, water from the overloaded streams either reached the area charged with montmorillonite, or rapidly picked up a charge as it swept out of the channelways, or more probably derived its load of gelatinous material in both ways. In any case, the water became a viscous mass, loaded with sand and silt particles and chips of clay incorporated from the dry surface across which it was advancing. The mass advanced by rolling and engulfment, almost in the manner of a lava flow rather than of a more normal flood. Almost no horizontal movement of engulfed bones was accomplished: they were simply plastered to the surface on which they had lain.

In most cases, floods were not attended by much if any rain in the area of deposition. The angular chips of surface clay which the advancing flows picked up would certainly have softened to rounded masses had they been wetted before incorporation. The igapo area near Sage Ridge remained free of standing water most of the time, and only enough "Interior" red soil washed off the terra firme of Sage Ridge to stain the viscous sediments of the area slightly.

Following this period came a time of greatly increased stream activity. The rivers tripled in volume during low water; their channels widened to a low-water maximum of 150 yards; floods spread frequently over the entire varzea area from Cottonwood Pass eastward, producing continuous sheets of shallow, muddy water. These alternately filled the lower igapo zone near the Sage Ridge, or dammed back within it the runoff from torrential rains in the Badlands area to produce lakes red with fine clay from the "Interior" soils on the ridge. The igapo lakes thus received alternately varzea-derived muddy silts, and fine-grained, terra firme-derived red clays. Increased volume of water meant increased velocity within the channel-ways during floods. Stream #8, for example, increased its ability to transport clastic grains from about 1 mm diameter during the dry, Lower Nodular time to about 10 mm during this time of moisture. Maximum velocities, based upon this transporting competency, would be 1.0 f/s or 2/3 mph during the dry time, and 1.3–1.6 fs or 4–5 mph during the wet periods (Emmons, Thiel, Stauffer and Allison, 1955, p. 171).

The drenaje streams also increased in size and in velocity, since they functioned as major outlets through which the flooded areas drained. Apparently the finer varzea clays and silts packed quickly, permitting considerable coarse material to bypass and reach the drenaje channels. This is best seen at channel deposit #4, a drenaje containing ¼ inch diameter pebbles, separated by sandy silts from its neighboring rios, #3 and 5, which were carrying pebbles up to 2 in. in diameter.

From Cottonwood Pass westward, the streams underwent great expansion but apparently slopes were sufficiently steeper, due to proximity to the Hills, that there was very little or no flooding, and hence not over 3 ft. of sediment were deposited.

A second period of stream diminution, much shorter than the first, occurred in the area watered by streams 4, 5, 6, and 7; very shortly thereafter, a period of diminution occurred also over the eastern area of streams 8–11. This brief episode is now represented by mudstone zones II and IIA. Vigorous stream activity, with frequent episodes of flooding from Cottonwood Pass eastward, resumed quickly.

The third period of decrease in stream volume was as widespread as the first, but presumably not as long-lasting, since only about half as great a thickness of heterogeneous mudstones accumulated. In all respects except duration, conditions of deposition must have resembled those of Lower Nodular (Zone I) time. From Indian Creek eastward, the succession of:

Zone III mudstones

Laminated sediments and Zone II

Zone I mudstones

is easy to interpret, but westward the time of stream increase is represented only by extensive channel deposits separated areally by a 3–5 ft. layer of greenish siltstone. Upon cursory examination, zone III appears to be merely the upper part of zone I, and only by careful tracing can the pinching out of the intervening laminated zone be recognized. Probably, slopes in the western area were steep enough to prevent general flooding during the wet period.

There followed another general episode of stream revival and flooding. This time, floods spread laminated sediment over the western part of the Badlands area, as well as in the east.

The fourth period of relative decrease in stream activity was general but quite brief: only 1–3 ft. of heterogeneous mudstones accumulated before the area as far east as channel-deposit #8 began another sequence of general floods which laid down more laminated sediments.

A fifth period of restriction covered the whole area, continuous with the fourth in the east. The fifth stream revival, a very shortlived one, seems to have been local in the neighborhood of channel-deposit #7.

A sixth time of restriction laid down mudstones over the whole area, distinguishable in the west from the overlying Poleslide mudstones, but not in the east. Briefly, stream restriction and mudstone deposition were continuous in the east from Mudstone zone IV time into Poleslide time, while in the west the streams underwent one more episode of revival.

A stream can undergo increased activity due either to increased gradient or to increased volume. Increased gradient would normally cause a stream to incise, which did not occur. Furthermore, the normal overlap of Oligocene sediments on the east flank of the Black Hills militates against differential uplift of the Hills relative to the Badlands area during Oligocene time.

A series of uplifts of the Black Hills relative to the Badlands area would normally produce a series of deposits each coarse-grained at the bottom, grading upward to finer. No such gradation exists; all contacts of mudstone members with siltstones are sharp. Also the Scenic Member begins with its thickest zone of mudstone (the Lower Nodular Zone), rather than with coarse sediment, as it would if deposition were controlled by uplift of the source area. All the evidence of the sediments themselves indicates that the times of greater stream activity were times of greater stream volume. Therefore, it seems probable that the Oligocene streams underwent periods of alternately increased and decreased volume.

Since such volume changes could only reflect changes in amount of precipitation in the source area, Scenic Member time saw three dry-to-wet climatic changes over most of the Black Hills, and three more changes over parts of them.

How long did these periods of alternate aridity and rainfall last? Admitting that individual laminae several inches thick were deposited within a few days, how long did it take to build up 10 ft. of either mudstone or siltstone? How long were the lapses between floods? Does the post-Chadron, pre-Scenic interval of nondeposition represent a time as long as that represented by the Scenic Member, or longer?

To the last question we have not yet an answer, but considerable evidence has accumulated which bears upon the others.

Two lines of negative evidence indicate that the total time period represented by the Scenic Member was very short. First, none of the mudstone or siltstone strata show any indication of weathered zones or soils at their tops. Furthermore, no evidence of interstratal erosion has been observed. It is unreasonable to assume that soils could form on surfaces many times, and be completely eroded down to fresh material without either leaving relict patches of soil or cutting notable gullies in the eroded surface. Therefore, it seems reasonable that no weathered zones have been observed because no one surface was exposed long enough for significant weathering to occur.

The second line of evidence consists of several specimens of *Ischyromys typus*, *Mesohippus bairdii*, and *Merycoidodon culbertsoni* which were collected from Mudstone V, on the south flank of 71 Table, and one specimen of *Ictops dakotensis* collected from Mudstone V at the standard section, south of Scenic. (These specimens are at present in the collection of the South Dakota School of Mines and Technology). In addition, specimens of *Ischyromys*, *Eumys*, *Paleolagus*, *Mesohippus*, and *Merycoidodon* have been collected from Zone V in Sage Creek, and are now in the FMNH collection. These specimens, from the top of the Scenic Member, are specifically identical with specimens from Mudstone I, at the bottom of the Member. If no observable development occurred within six species representing five different mammalian orders, the time involved must have been geologically very short. Probably 500,000 years would be maximum, with the possibility that the entire Scenic Member was deposited within a few years.

Fortunately, biostratonomic data enable us to limit the maximum and minimum possibilities more closely.

Weigelt (1927) has reported extensive observations on degenerative processes in animal corpses. The author has also observed that exposed corpses of medium to large-sized animals undergo a regular series of degenerative processes which reduce them, through recognizable stages, to eventual complete dissolution. The processes vary in nature and in rate of action, depending upon the climate. It is proposed that the sum total of these destructive processes be called perthotaxy[1], and an assemblage of bodies in various stages of destruction be called a perthotaxis.

If an animal community inhabits an area without interruption or catastrophic death for several years, the land surface at any one time will exhibit a complete perthotaxis, that is, bodies in all stages of destruction. Burial effectively halts perthotaxy, and thereby preserves all stages of the perthotaxis.

If, on the other hand, episodes of sedimentation occur at intervals shorter than the time necessary to develop a complete perthotaxis, each sedimentary increment will entomb a partial or incomplete perthotaxis. If some such catastrophe as an epidemic should cause the sudden, contemporaneous death of numerous individuals, the result will be a dilated perthotaxis, with a disproportionate number of individuals at one stage of destruction. The dilation may be early, middle, or late, depending upon the time lapse between the catastrophe and the next depositional episode. Catastrophic death by burial, as by a volcanic ash fall or a death-dealing flood, would cause a primary dilated perthotaxis, with disproportionate numbers of whole skeletons.

Figure 44 illustrates perthotaxy on temperate steppes, such as the northern Great Plains, at present, as determined by the author's observations. Naturally, variations in exposure alter the processes somewhat. Season of death makes a considerable difference also: the body of an animal who dies in November undergoes very little alteration before the following March. However, the diagram does give an order of magnitude and a set of recognizable stages.

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[1] From περθω, to destroy, and ταξιζ, an arrangement or order.

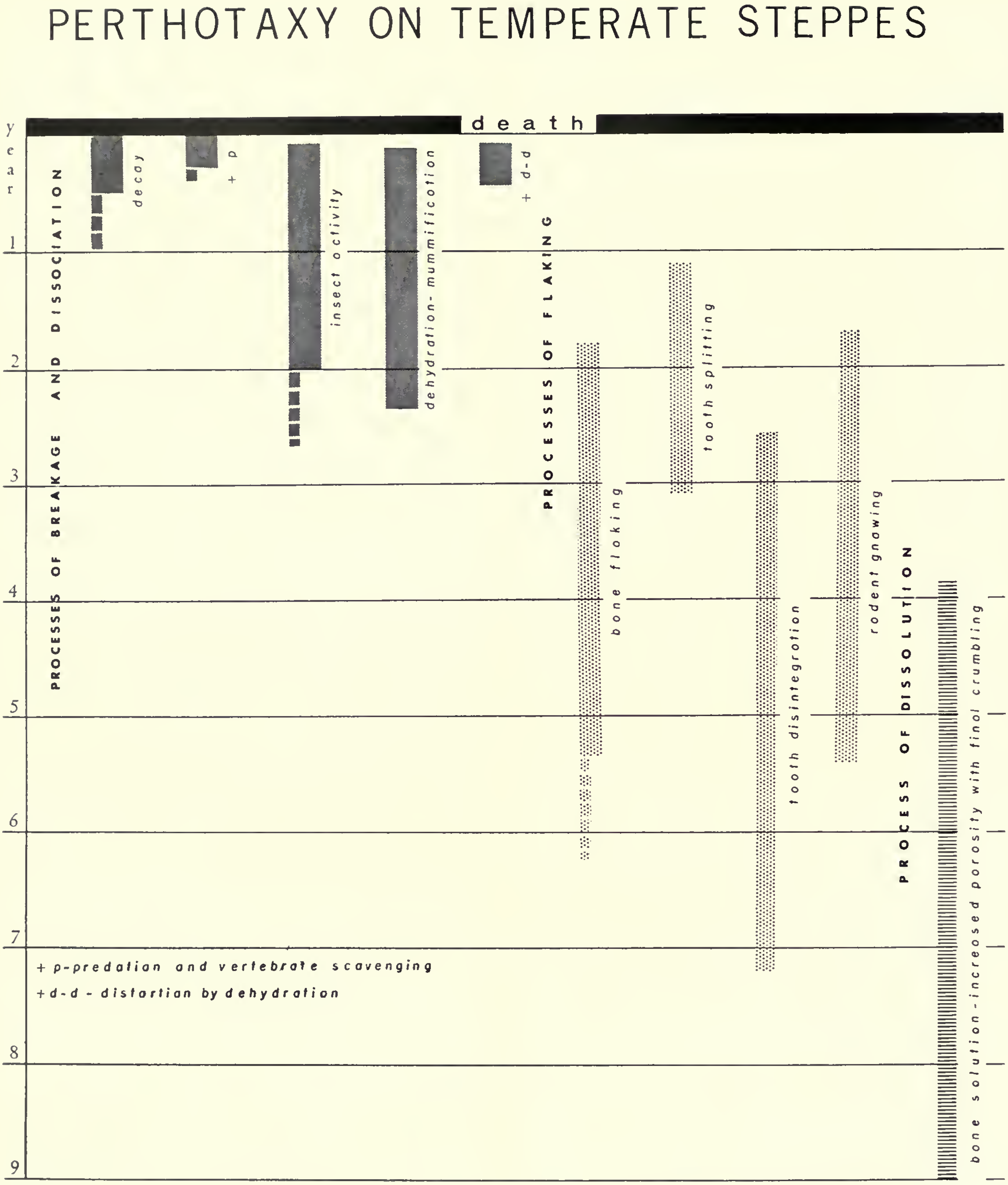

FIG. 44. Perthotaxy on temperate steppes.

In applying perthotaxic criteria to any bed or lamina, one must first determine that the fossils represent a death assemblage rather than a mechanical accumulation. Mudstone I, the Lower Nodular zone, has long been recognized as such an assemblage. The abundant, well-preserved coprolites could not have undergone significant transportation. Skeletons in various tetanic "death poses" have apparently been buried quickly, without appreciable disturbance by the entombing floods. Most significantly, those bones in which perthotaxy has progressed to an advanced stage of flaking lie surrounded by the chips which have spalled from them.

Plainly, this fossil assemblage is a true death assemblage, suitable for perthotaxic studies.

Fossils occur at several different horizons within the Lower Nodular zone. Usually any one horizon is several inches thick, and continuous for distances of a few hundred feet to over a mile. Any one vertical section contains from one to three or four of these. In the richly fossiliferous near-stream area south and southwest of the town of Scenic, the total number of these fossiliferous zones, interpolated laterally, is not over 20. The exact number cannot be determined, because local variations in thickness make precise correlation of 4–18 in. zones over distances of a half mile impossible.

All of these zones which the author has examined contain an almost complete to complete perthotaxis. Flaking is always well developed; occasionally, one finds bone which suffered enough solution to become spongy before burial. This indicates that the surfaces, and the corpses upon them, were exposed for periods of at least 7–10 years, between floods.

If, as postulated, each layer is the deposit of a single flood of not more than a few days duration, and if the period between floods was 7–10 years, then 20 relatively complete perthotaxies would represent 140–200 years at a minimum. This sets an absolute minimum but does not directly help to limit the large maximum of 500,000 years, suggested by the lack of evolutionary development during Scenic time.

Still another piece of negative evidence is suggestive here. Under the warm-temperate steppe climate postulated, recognizable soil zones would almost certainly develop within 100 years. None of these have been found. Twenty periods of exposure at 100 years each would be 2000 years as a maximum period for deposition of the Lower Nodular Zone; the minimum we have established is 200.

Allowing roughly the same conditions of deposition for the other mudstones but taking into account that they are thinner and consist of fewer beds, we can set up the following table:

Mudstone	Minimum duration (years)	Maximum duration
V	200	2000
IV	30	300
III	100	1000
II	20	200
I	200	2000
TOTAL	550	5500

The laminated siltstones probably required much less time to deposit, but we have no direct evidence on this point. Assuming generously that they represent about half of the total time of deposition, we have for

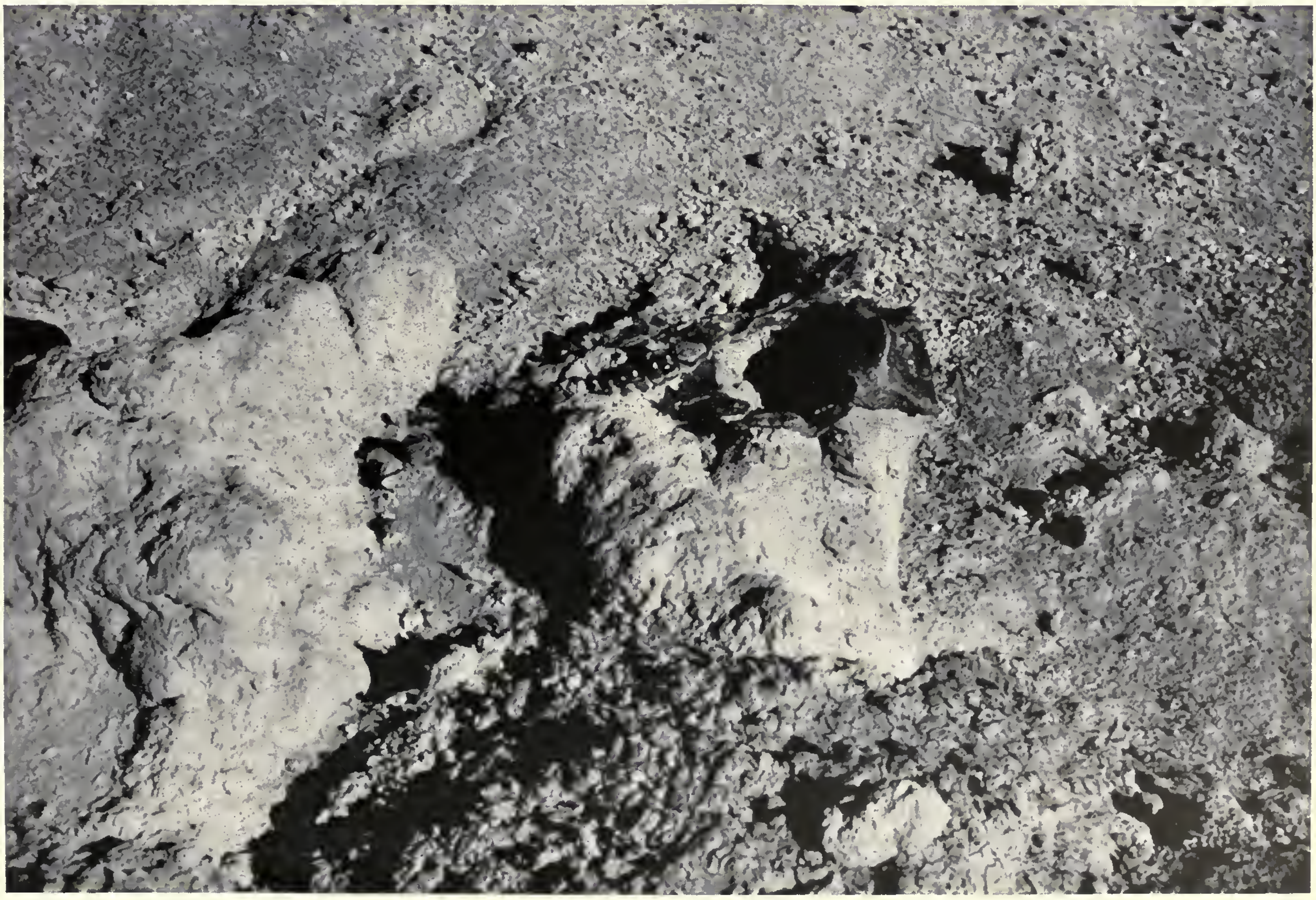

FIG. 45. Photograph of Archaeotherium skull FMNH no. PM9359, *in situ*, showing advanced perthotaxy. Note the chip of bone several inches below the skull, also the matrix-filled crack in the right zygoma.

the deposition of the entire Scenic Member a probable minimum of about 1100 years, and a probable maximum of about 11,000.

This gives a duration for the climatic alternations of a few hundreds to a few thousands of years, which would then be of the order of magnitude of the postglacial climatic fluctuations described by Dorf (1959, pp. 194–205) and others. By circular reasoning, if these climatic fluctuations are of the order described for postglacial climates, the Scenic Member probably represents more nearly 11,000 years than 1100. However, the probability is high that at least one among so many streams would shift temporarily to an erosional regimen during 11,000 years. The fact that none of them did so suggests that the time was shorter. It may be a matter of considerable interest to meteorologists that fluctuations of this order of duration are not, apparently, related to glaciation. It may also be of assistance in the interpretation of other pre-Pleistocene sediments to expect that sedimentation may have been influenced by such climatic fluctuations, and look for their effects.

The chapter on the Chadron formation demonstrates (p. 74) that a few mammalian lines show a recognizable development from bottom to top of that formation in South Dakota. It is, therefore, probable that the time required to deposit the Chadron formation was considerably longer than that represented by the Scenic Member of the Brule.

The much greater total thickness and relatively much greater proportion of mudstone in the Poleslide Member suggest that it also represents more time for deposition than does the Scenic Member. Such evidence is extremely vague and unsatisfactory; it is no more than an inconclusive suggestion.

The Poleslide consists mainly of mudstones like those of the Scenic, with siltstones absent over most of the area. Channel deposits are finer-grained and more restricted than those of the Scenic. The proportion of fresh volcanic ash increases toward the top of the Poleslide, and the amount of bentonitic ash is uniformly less than in the Scenic. Calcite comprises the usual cementing material, but a few of the sandstones have a mixed calcite-silica cement. The significance of the cements is not known. However, the Poleslide plainly represents deposition under a climate generally as arid as that which occurred only at intervals during Scenic time. Detailed paleogeographic study is needed before adequate interpretation of the Poleslide can be made.

RELATIONSHIP TO ORELLAN STRATIGRAPHY AND SEDIMENTATION IN NEBRASKA

Removal by erosion, widespread cover of grass and Pleistocene sediments, and local changes in Brule lithology combine to preclude direct visual tracing of the South Dakota members of the Brule Formation southward into Nebraska. Faunal correlation confirms the general impression that the Scenic Member is approximately correlative with the Orella Member of Nebraska. However, the very short time represented by the Scenic Member renders impossible an exact correlation based upon fossils: an identical fauna might be expected to have inhabited Nebraska at any time during the 50,000 years immediately preceding or following the particular 1100–11,000 years represented by the Scenic Member.

Examination of the literature describing Oligocene stratigraphy and paleogeography in Nebraska (Schultz et al., 1955. and their earlier papers) suggests that Orellan conditions in Nebraska were strikingly different from those in South Dakota. In 1951, Falkenbach and Schultz (1951, pp. 47–50) proposed a division of the Orella Member into faunal zones A and B. They also divided the Whitney member, producing the following correlation:

Member	Falkenback and Schultz	Wanless, 1923
Whitney	D	Leptauchenia
	———————	——Upper Oreodon
	C	Middle Oreodon
Orella	B	
	A	Lower Oreodon

Since they state clearly that these are faunal zones, one must presume a faunal succession within the Orella Member, and also within the Scenic Member in South Dakota (Wanless' original division was lithologic, not faunal). My own collections indicate no such faunal succession within the Scenic Member. Much of what Wanless included in the "Upper Oreodon Beds" in the Corral Draw area is actually part of the Poleslide Member: due to thinning of the middle part of the Scenic Member westward, and to local changes within the upper Scenic and lower Poleslide, (see cross-section, Fig. 52, and columnar sections, appendix) individual zones within the Scenic Member have been universally miscorrelated.

The definitive 1955 paper (Schultz et el., 1955) describes deep channelling associated with two major and several minor paleosol complexes. The authors' cross-sectional diagram is reproduced here for reference (Fig. 46). The authors state (loc. cit., p. 5) that they first suspected that paleosols might be present due to the very sudden appearance of oreodont skulls with larger, inflated bullae only 10 ft. stratigraphically above other skulls in which the bullae were uninflated.

The following pertinent points were apparently not considered in this context:

1. The authors had no way of estimating the actual rate of sedimentation.

2. The sudden change, if actual, might have been due to immigration.

3. There is obviously no way of estimating the extent of genetic change required to accomplish the somatic change in the bulla. Therefore, there can be no way of estimating the time involved in such a change—it might have occurred even as a mutation in one generation.

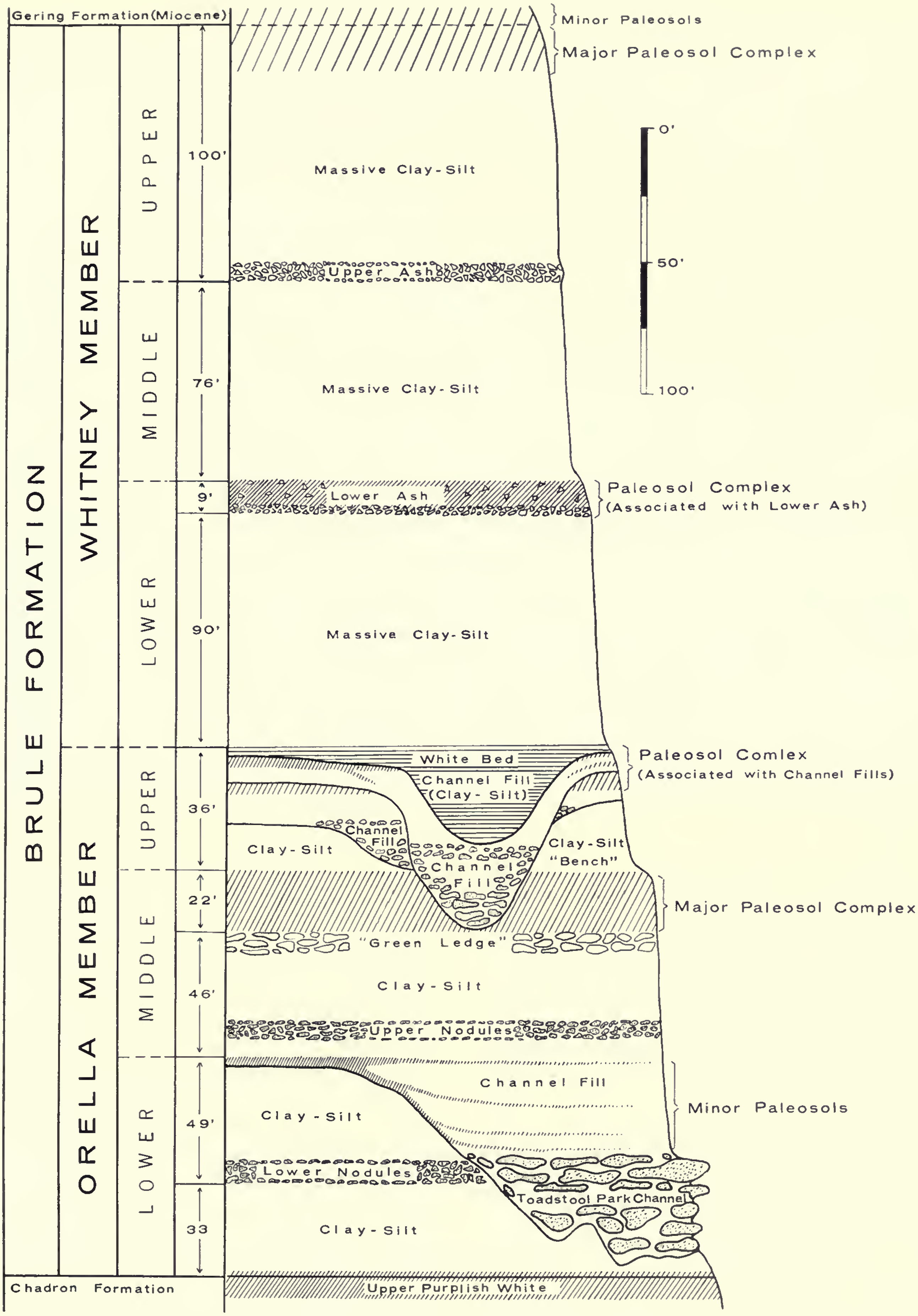

FIG. 46. Cross-section of the Toadstool Park area, copied from Schultz, Tanner, and Harvey, 1955.

The reasoning which led to the search for paleosols was based, therefore, upon a discrepancy between the time necessary to deposit 10 ft. of sediment whose rate of deposition was unknown, and the time necessary to develop an anatomical structure whose manner and rate of evolution was unknown.

The authors' description of the paleosols gives as distinctive characters the "facts" that (loc. cit., p. 10) "The Orella deposits of the Brule Formation typically are massive, with an angular to subconchoidal fracture when fresh, but these properties are usually lacking in the paleosol profiles. Many samples do not show the characteristic subconchoidal fracture at all. Some are neither massive nor angular. In several places the fracture is distinctly granular, reminding one of the soil pieces of beds of a modern soil—Certain paleosols and paleosol complexes tend to weather out as topographic benches (see figs.). Some of the benches are due to ledges of secondary lime, and others may be related to concentrations of clay representing B horizons of ancient soils.

"Not only is a paleosol complex a break in the otherwise continuously fossiliferous strata, but careful study of the faunas has shown that all of the major breaks in the faunal successions coincide with the occurrence of major paleosol complexes. In other words, the period of time represented by such a paleosol complex must be of considerable length.

"Some paleosols are associated with extensive valley fills which may be as much as fifty or sixty feet deep."

The criteria offered as diagnostic of paleosol origin are:

1. Granular fracture.
2. Presence of "ledges of lime" and layers of clay.
3. Absence of fossils.
4. Evidence of breaks in the faunal succession coinciding with the paleosols.
5. Association with deep channel cutting and filling.

The literature on Nebraska presents us with a picture of Orellan cutting and filling, with development of thick soil complexes during long periods of nondeposition, and a total duration sufficient to permit significant mammalian evolution. This is strikingly different from the situation, as interpreted in this report, existing at the same time in the Big Badlands only 120 miles to the northeast with no major Oligocene topographic barrier intervening.

I have twice studied the Toadstool Park area of Nebraska, in 1956 and again in 1964. My observations of 1956 seemed so at variance with the published interpretation that I have several times discussed them with the authors quoted, without altering their opinions. It is therefore necessary to present my own observations and interpretations at this time.

First, the "paleosols" are actually the sedimentary lithotope described in this paper as "laminated sediments." They consist of alternate laminae of fine sandstone, sandy siltstone, and laminated mudstone, a few inches thick, with normal, sharp sedimentary contacts between the laminae. No graded bedding or gradational phenomena have been observed. Some of the coarser-grained strata at Toadstool Park even exhibit some cross-bedding (see Figs. 47, 48). Naturally, some of the coarser-grained sediments are better-cemented with Ca CO$_3$ than are the finer ones, and weather out differentially as ledges. The clays are normal for the Brule—chiefly montmorillonite and mixed layer, associated with abundant quartz and some half-altered shards of volcanic glass. Microscope study reveals abundant, unweathered acid feldspar, with some muscovite and unaltered to little-altered biotite. The rock does fracture to a granular surface in the coarser grades, due to the presence of clastic grains of quartz and feldspar set in a normal calcite cement. These sediments have absolutely none of the physical, structural, or mineral characteristics of soils, in any of their laminae. Their association with channel-fills, as succeeding paragraphs will demonstrate, is not as described or diagrammed by Schultz et al., but is rather the same as that already described for the Big Badlands laminated sediments.

FIG. 47. Photograph of "the Bench," looking south from Toadstool Park. The lamination of the sediments, and their similarity to those in South Dakota (see Fig. 36) is apparent.

Thin bedding and lamination; uniformity within each lamina from top to bottom; normal sharp, sedimentary contacts between laminae; alternation of finer and coarser clastics; presence of abundant, unweathered feldspars; presence of less abundant but frequent unaltered biotite; presence within the sequence of cross-bedded members; and presence of crystalline calcite cement are characteristics any one of which would militate against a deposit being a soil or paleosol. Cumulatively, they are overwhelming, positive evidence against it. Furthermore, my rather extensive observations of Oligocene sediments have failed to reveal any paleosols of Chadronian or Orellan age anywhere in South Dakota, western Nebraska, Colorado or eastern Wyoming. The burden of proof of the existence of any such paleosols must now rest with those who describe them, and must necessarily include careful field study of the sedimentary structures, and laboratory study with a petrologic microscope.

Far from indicating slow deposition, this lithotope in Nebraska, as in South Dakota, should be interpreted

FIG. 48. Closeup view of laminated sediments including one cross-bedded sandstone, ¼ mile south of Toadstool Park. The photograph was taken just out of sight to the east (left) of the view in Figure 47.

as representing exceedingly rapid deposition by successive sheet-floods from actively-depositing streams. Presumably, successive increments were deposited in such quick succession that no one surface remained exposed long enough to develop a phanerogamous flora. For this reason, land mammals temporarily abandoned the area and hence, naturally, left no fossil record of their presence.

For evidence explaining the reported faunal differences in the heterogeneous mudstones above and below these laminated lithotopes, one must turn to the regional tectonic structure.

The Toadstool Park area is crossed by a major normal fault trending N 60° E, dipping SE 70°, with a vertical displacement of 70–75 ft. The fault brings a lower Orellan channel-fill, north of the fault, into approximate juxtaposition with a laminated siltstone lithotope (= "the Bench") south of the fault. Figures 49, 50, and 51 illustrate the fault. A small block of sandstone located in a recent gully along the fault (see Fig. 49) at one place may be either a rotated block within the fault zone or a recent slump block; in either case, it is a purely local phenomenon of no significance. The fault plane is slickensided and is mineralized with chalcedony; Figure 50 shows chalcedony casts of slickensides, also laminae of sandstone transected and slightly dragged by the fault movement. This fault was apparently overlooked by Schultz et al. (loc. cit.), and the sharp, fault-scarp terminations of the sandstone have been misinterpreted as edges of deeply-cut channel-fills (loc. cit., fig. 1.). Faulting was mentioned, but without acceptance of its stratigraphic effects, by Schultz and Stout (1961, p. 47). Actually, the base of the large riosome in the figure shows a maximum of 3 to 5 ft. of cutting, which is also maximum for Orellan riosomes of the entire area. Figure 1 in Schultz et al. (loc. cit.) represents so many correlations of lithotopes on one side of the fault with lithotopes of similar nature but different stratigraphic position on the other, that no consistent correlation between it and the interpretation in Figure 51 of this paper is possible.

However, channel cutting such as described in the paper cited does not exist in the Toadstool Park area. To the best of my knowledge, it does not exist elsewhere in the Crawford-Chadron area, but further reconnaissance is needed before I can state this positively.

Evidence has now been presented that two of the major points of difference between the Orellan paleogeography of South Dakota and the described paleogeography of Nebraska do not exist in fact: there are no paleosols in Nebraska, and no deep-cut channels, at least in any area described. Let us now consider the third: faunal evidence that the Orella Member represents a length of time sufficient to allow significant evolution of oreodonts.

The most significant advance in oreodonts reported during Orellan time (Shultz et al., 1955, pp. 4, 5; Schultz and Falkenbach, 1954, pp. 153–159, and 1956, pp. 381–390) seems to be the change from uninflated to inflated bullae. However, when one remembers that this advance is based upon stratigraphy which overlooks a 75-foot fault in a 270-foot section, and uses as marker beds zones of sheet-flood sediments interpreted as paleosols, plus zones of volcanic ash (the "purple-white" layers) which can be demonstrated to be local in South Dakota, the detailed age reference of the specimens lies open to question. Also, Schultz and Stout's reference to "the faulting (and folding) so characteristic of the Chadron and Orella" (loc. cit., 1961, p. 47) is one in which I concur—faults of significant magnitude can be found at many places. (I do not, however, concur at present in their dating of the faults.) How many of these faults were, like the one at Toadstool Park, unrecognized at the time the oreodonts were collected? One can only hold the age reference of all specimens collected in the Orella Member in question. There can be little question of these specimens' reference to the Chadron or to the Orella Member, but any reference to subzones within the Orella, or to an upper subzone of the Orella as opposed to a lower subzone of the Whitney Member, must be questioned.

The use of "purple-white layers", which are actually bentonitized volcanic ash beds, as markers is subject to serious question due to the field relations of three similar beds in South Dakota. The two already described from the Ahearn Member of the Chadron (see p. 22 of this paper), show mineralogic differences sufficient to demonstrate that they do not represent the same ash fall, although they occur stratigraphically in the upper part of the Ahearn Member, and geographically only a few miles apart. A third such "purple-white layer" occurs (NW¼ of SE¼, Sec. 13, T. 42N., R. 45W., Shannon Co.) in the Scenic Member between zones I and III, as a lens not over 50 ft. wide and about 1 ft. thick in a small depression-fill. Any such discontinuous lenses are obviously of no value as stratigraphic key beds. It is not clear whether or not the "purple-white layers" of Nebraska are discontinuous; in view of the confusion which must arise from the misinterpretation of faults as channel-fills and sheet-flood sediments as soil zones, the continuity of any one horizon in Nebraska must be determined anew by visual tracing.

As a final note on stratigraphic correlation between Nebraska and South Dakota, the cross-section (Fig. 41) clearly demonstrates the danger of "marker beds." Zone III nodules northwest of Sheep Mountain are usually referred to as Wanless "Upper Nodular Zone." Eight miles to the southwest, Zone III has come to rest upon Zone I, and Zone V becomes the "Upper Nodular Zone." In Sage Creek and upper Cain Creek, both Zones III and V contain fossiliferous nodules. At Dillon Pass, Zone V has merged indistinguishably with the Poleslide. Along the northwest side of Cuny Table (see Fig. 41) Zone V is the "Upper Nodular Zone," but a new zone, about 60 ft. up in the Poleslide, has come to resemble Zone V lithologically. Anyone studying the standard section of the Scenic Member, then measuring a section on the north flank of Cuny Table, would almost certainly make the miscorrelation indicated in Figure 52, rather than the true correlation determined by visual tracing.

The hypothesis of oreodont evolution, and consequent stratigraphic correlation, offered by Schultz and Falkenbach, has two alternatives which are equally probable.

First, the oreodont stratigraphy in Nebraska may be correct, but the "Orella Zone B" of Nebraska may be equivalent to the lower part of the Poleslide in South Dakota. Since the evidence discussed at length above indicates that the oreodont stratigraphy in Nebraska cannot be correct in detail, this hypothesis is purely academic but worthy of future consideration.

Second, in their last publication on the subject, Schultz and Falkenbach (1956, pp. 381–392) pointed out that the members of the subfamily Miniochoerinae have the bulla small and uninflated throughout Chadronian and Orellan time. Actually, it is difficult in practice to separate a Scenic Member Miniochoerine from a *Merycoidodon*. Schultz and Falkenbach have, in their monographic study, attempted a vertical classification of Oligocene forms supposedly ancestral to definitely sep-

FIG. 49. View westward along the fault at Toadstool Park. Left (south) side downthrown; the fault plane dips to the left. The sandstone in the left foreground is part of the same stratum as that near the top of the Badlands to the north of the fault. Note drag on the downthrown block. Also note the apparent continuity of the sandstone north of the fault with the much higher laminated sandy strata on the downthrown block; apparently this led to the misinterpretations in figure 46.

FIG. 50. Fault face cutting channel-fill sandstone. This is a view of the ledge from which Figure 49 was photographed. Note the cut edges of sandstone strata. The whitish material is chalcedony, on which casts of slickensides are visible.

arable Miocene groups. It is highly possible that middle Oligocene oreodonts represent an interbreeding genetic pool, exhibiting certain genetically controlled, non-adaptive characters which, during Orellan time, were interbred freely, but later became separated as divergent groups moved genetically further from each other. Briefly, an Orellan *Merycoidodon* with small bullae might well have mated with a *Miniochoerus* with large bullae, although the Whitneyan forms possessing these characters could not have interbred. This situation, coupled with misinterpretation of the stratigraphy and accidents of preservation, could easily produce such an artifact as an apparent sudden appearance of large bullae in one "phyletic line."

In summary, careful study of the Chadron-Crawford-Toadstool Park area of Nebraska demonstrates that:

1. There are no paleosols in the Chadron or in the Orella Member of the Brule.

2. The lithotopes described in this report also, with minor variations, make up the mass of Orellan sediments in northwestern Nebraska.

3. There is no evidence of significant channel-cutting or erosional episodes during Orellan time: reports of cutting have arisen through misinterpretation of a faulted sequence.

4. Due to the misinterpretations listed, the actual faunal sequence within the Orella Member has not yet been determined.

5. All available evidence in northwestern Nebraska is consonant with a paleogeographic interpretation similar to that given here for the Scenic Member in the Big Badlands.

6. Due to the extremely short time represented by the Scenic Member, no exact correlation of the Scenic Member with the Orella Member is possible at this time. Lithologic changes within the lower hundred feet of the Poleslide Member, in the southwestern part of the Big Badlands, suggest that the lower part of the Poleslide of South Dakota might be correlative with the upper part of the Orella Member of Nebraska. This is a possibility to be explored, not a suggested correlation.

7. The supposed evolution of oreodont bullae within the Orella Member could be equally well explained as: (*A*) an immigration of forms with large bullae; (*B*) a mutation, spreading within a few generations over the relatively small area involved; (*c*) an artifact due to the downward expansion of a vertical classification, coupled with a misinterpretation of the stratigraphic position of specimens.

CONCLUSIONS

1. The Scenic Member of the Brule Formation comprises five types of sediments:

Limestone
Heterogeneous mudstone

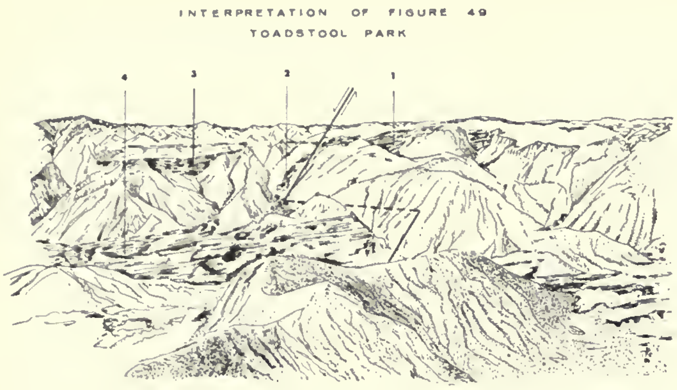

FIG. 51. Diagrammatic interpretation of Figure 49, for comparison with the interpretation of Schultz *et al.*, 1955, in Figure 46. 1, Basal Orellan channel-fill north of fault; 2, Slice or slump block along fault; 3, "The Bench," Orellan–Whitneyan contact sandstones; 4, Basal Orellan channel-fill, equivalent to no. 1, south of fault.

Laminated clay
Laminated siltstone and sandstone
Cross-bedded sandstone.

These combine to form four sedimentary lithotopes:

Silty mudstones
Laminated siltstones
Laminated mudstones
Channel-fill zones.

2. These four lithotopes grade into one another horizontally but not vertically.

3. The silty mudstone zones transgress the depositional areas of several Oligocene streams, and can be traced for distances of several miles.

4. Alternating strata of mudstone and siltstone have sharp contacts, not gradational ones. No instances of graded bedding have been observed.

5. The channel-fill sandstones are of two types, Northern Black Hills derived and Southern Black Hills derived, each with a characteristic suite of heavy minerals.

6. The silty mudstones represent times of discontinuous deposition by mud-flows from flooding streams of small volume and low energy.

7. The siltstones represent more rapid deposition by sheet-floods from the same streams at times when their volume, and therefore their energy, was much increased.

8. The fluctuations in energy of Oligocene streams in this area were the result of fluctuations in volume rather than of changes in gradient.

9. The fluctuations in volume of streams resulted from alternations of wetter and drier climate.

10. The presence of alligators in the underlying Chadron, and the presence of one alligator in the first Scenic Member wet-climate deposit, plus the absence of alligators in the intervening dry-climate deposit, suggest that the times of dry climate were also times of cool climate.

11. The fact that fossils representing five mammalian orders show no differences from bottom to top of the Scenic Member indicates that deposition of the entire member required not over 500,000 years (see p. 99).

12. Individual increments of 6–18 in. were deposited within the span of a very few days.

13. The complete absence of weathering or of soil zones at the top of any one increment shows that never did a period of more than 100 years elapse between episodes of sedimentation.

14. The presence within any one fossiliferous increment of a complete perthotaxis indicates that periods of 10 years or over usually elapsed between episodes of deposition.

15. Using the data from the last two conclusions, the total time required for deposition of the mudstones of the Scenic Member was 550–5500 years. Allowing equal time for deposition of laminated sediments, although the evidence suggests that they were deposited more rapidly, the total time represented by the Scenic Member was 1100–11,000 years.

16. The alternations of dry-cool and warm-wet climates were, on this basis, of the same general order of magnitude as Recent post-glacial warm and cool alternations.

17. The geographic distribution of lithotopes within the Scenic Member at any one time can best be explained by comparison with the distribution of sedimentary environments within the Central Amazon Basin, as described by Sioli.

18. Using Sioli's terms with additions where necessary, the following sub-environments of fluvial sedimentation can be recognized:

Rio: the channelway of a throughgoing stream.

Varzea: the area of sedimentation outward from a rio, including the natural levee and the long backslope away from the stream.

Drenaje: secondary streams which arise locally as drainageways in the more or less linear depressions between adjacent varzeas.

Terra firme: valley walls, composed of material other than that being handled by the rios.

Igapo: The approximately linear depression lying between a terra firme and the adjacent varzea, receiving sediment chiefly by local wash from the terra firme, but occasionally by sheet-wash from the rio.

The body of sediments formed in these environments through time are termed, respectively, riosome, varzeasome, drenajesome, and igaposome.

19. Deposition of the Scenic Member in the Big Badlands was controlled by three rios with sources in the Southern Black Hills, and two to four rios with sources in the Northern Black Hills.

20. Although deposition of the Scenic Member was episodic, there were no periods of erosion and all streams were continuously at grade to overloaded.

21. The lower part of the Poleslide Member generally resembles the mudstones of the underlying Scenic Member in lithology and origin. Easterly gradation of the upper mudstones of the Scenic Member into the basal Poleslide indicates either that the widespread aridity of Poleslide time started earlier in the Northern Black Hills than in the Southern, or that the eastern part of

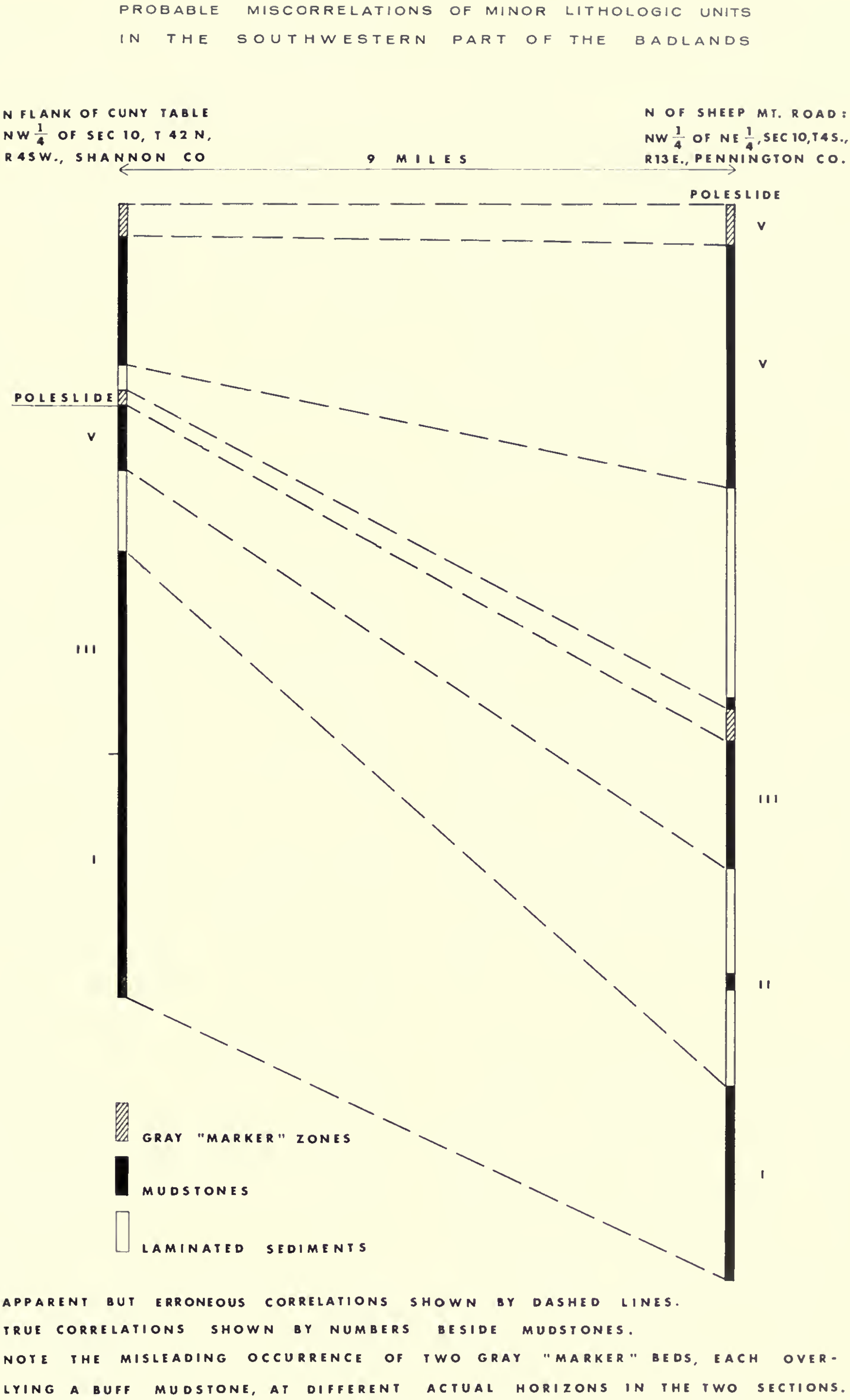

FIG. 52. Probable miscorrelations of minor lithologic units in the southwestern part of the Badlands.

the Badlands area was, by late Scenic Member time, receiving notably less rainfall than the western part, or both.

22. The flesh-colored to brilliant, discontinuous red laminated clays of the Dillon Pass and Big Foot Pass areas represent igaposomes, having as their source local rainwash from exposed hillocks of weathered Pierre shale along the Sage Ridge.

23. The dull red-brown colors of the heterogeneous mudstone zones in the same geographic areas as the igaposomes represent varzea mudstones mixed with slight amounts of locally-derived red clays.

24. The sediments in northwestern Nebraska, previously interpreted as paleosols, are actually laminated siltstone lithotopes similar to those of the Big Badlands. They represent rapid rather than slow deposition.

25. The structures in northwestern Nebraska previously interpreted as deep channel-cutting are actually due to faulting.

26. Faunal zoning of the Orella Member in northwestern Nebraska is based upon erroneous stratigraphy.

27. The evolution of oreodonts within Orellan time is not established.

28. No satisfactory correlation of subdivisions of the Orella Member in Nebraska with subdivisions of the Scenic Member in South Dakota has been achieved. In view of the brief time represented by the Scenic Member, such detailed correlation is unlikely on paleontologic grounds, although it may be achieved through paleogeography.

29. Both in South Dakota and in northwestern Nebraska, Middle Oligocene sediments indicate rapid deposition of increments several inches thick, with no periods of erosion and no long periods of non-deposition, under an alternation of warm-wet and cool-dry climates.

Chapter VII

PALEOECOLOGY OF THE LOWER NODULAR ZONE, BRULE FORMATION, IN THE BIG BADLANDS OF SOUTH DAKOTA

by

John Clark and Kenneth K. Kietzke

INTRODUCTION

Determination of Scenic-Member paleogeography in detail raises the interesting possibility of collecting vertebrate fossils from different local environments. Because the Lower Nodular Zone, the most richly fossilferous horizon, represents a time interval of not over 1100 years, during which there is no evidence of change of climate or of significant shifting of stream courses, the chance of collecting an unmixed fauna representing one local environment at any one place seems very good. A series of such collections from different local environments might be expected to demonstrate faunal differences controlled by the known environmental differences. From this information, it might be possible to determine the environmental preferences of various Oligocene genera and species.

The only two previous methods of approach available for the study of Oligocene mammalian ecology have been interpretation of osteological characters and analogy with related recent genera. The first of these is partially vitiated by the enormous adaptability of mammals: for example, a pine squirrel from northern Canada and a rock squirrel from western Texas give no osteologic evidence of the differences in their environment and way of life. Tigers from the Amur basin of Siberia are specifically identical with tigers from Bengal. Analogy with closest living relatives suffers from the fact that few if any Oligocene genera have recent relatives close enough to give any assurance of valid homology. Paleogeographic evidence may, therefore, offer a valuable, independent line of evidence regarding the habits of individual genera and species.

Collecting was directed toward these purposes in 1956, 1959, and 1962. These collections form the basis for this chapter. Collections from the same localities, made in 1964 and 1965, have more than doubled the number of specimens; however, these have not yet been fully studied. Preliminary study indicates that they will considerably modify some of the statistics presented here, but will not significantly change the basic conclusions.

Figure 54 includes graphs I–XIII, which will be referred to by graph number rather than by figure number hereafter.

ACKNOWLEDGMENTS

The authors wish first to acknowledge the kindness of the staffs of the South Dakota School of Mines and Technology Museum, and of the University of Colorado Museum, in which these collections are now housed, for permitting this study. The senior author wishes to express his appreciation of research grants by the Yellowstone-Bighorn Research Association, in 1956, and the Badlands National Monument, National Park service, in 1959, which financed the field work in those years. Finally, the senior author wishes to thank the following for their services as field assistants: 1956—R. Livingston and E. Kanesky; 1959—P. Nelson and V. Gunn; 1962—The authors enjoyed the cooperation of Dr. P. Robinson and his assistants in making the CU near-stream collection (#IX). The open-plains collection of 1962 (CU #I) was made by the authors, working with private funds.

GENERAL PHILOSOPHY OF FIELD WORK

Selection of localities for collecting was based upon the primary assumption that an area immediately adjacent to one riosome and within a short distance of others might reasonably be considered to have been forested. Conversely, an area several miles from the nearest riosome and near an igaposome would represent a least-watered spot and would have been either prairie or brush-covered, if any such cover existed anywhere. Several places answered each of these descriptions; selection between them depended upon the following practical considerations:

1. Localities should be abundantly fossiliferous, in order to yield adequate samples.

2. They should be relatively inaccessible to the numerous local amateur collectors.

3. They should have been relatively untouched by professional collectors for at least ten years.

4. They should be areas in which corresponding portions of the section are well exposed, in order to achieve the greatest possible degree of contemporaneity. Brule streams did not shift their geographic positions significantly during Lower Nodular time, nor is there any evidence of climatic fluctuations which might affect vegetational distribution during that time, so this was not practically important.

With these qualifications in mind, one near-stream locality at Cottonwood Pass, one swamp locality in Sage Creek, and three least-watered localities, one in Sage Creek and two near Dillon Pass, were selected. Collections were then made from each. Where possible, two collections were made from the same locality at different times by different field assistants to reduce psychologic and ocular collecting biases to a minimum. Fortunately, the junior author observes small specimens more readily than large ones, while the reverse is true of the senior author. The mutually cancelling effect of these biases was utilized by prospecting side-by-side over the same ground, several times.

One major determination had to be established before the collections could be used: do the fossils at these places constitute a death assemblage, or are they simply a mechanical accumulation? For the near-stream locality and the localities in Sage Creek, a definite answer can be given, based upon the following evidence:

1. Individuals in every stage of perthotaxy, from entire skeletons to separate chips, have been found.

2. Coprolites are abundant.

3. None of the bones show water abrasion.

4. Some partially disintegrated specimens have their broken chips dispersed around them uniformly in all directions.

5. The varzea sediments in both areas are heterogeneous mudstones, which can be demonstrated in both areas to have engulfed bone without transporting it appreciable distances.

6. Complete skeletons have been found in death poses. One herd of *Leptometryx* found previously in the Cottonwood Pass area, and a herd of *Hypertragulus* in the Sage Creek area, showed the individuals in both cases obviously lying in death poses.

7. *Celtis* seeds and bones of very small animals occur scattered throughout, never accumulated as they would be along a strand line, or washed against an obstacle. (*Celtis* seeds sometimes occur in sausage-shaped or egg-shaped masses, apparently representing storage by rodents in burrows or hollows).

8. Bones and skeletons of all sizes occur indiscriminately in both localities.

These lines of evidence, considered cumulatively, seem a clear indication that the Cottonwood Pass and Sage Creek fossils constitute death assemblages, essentially untransported. The evidence for the Dillon Pass localities consists only of points 2, 3, 5, 7, and 8; no complete skeletons are known to us from these areas. The evidence for a death assemblage is not conclusive here, although there is no evidence against it. The Dillon Pass localities must, therefore, be considered in relation to the known assemblage at Sage Creek, before conclusions are drawn from them.

In order to establish a uniform basis for collecting, the following principles were followed:

1. All teeth and jaws, including fragments, were collected.

2. In case two or more anatomically compatible fragments showing the same maturity and amount of dental wear were found within a foot of each other, and no other bones of that species occurred within several feet, the two were regarded as belonging to the same individual. Otherwise, each fragment found was counted as a separate specimen. This may produce a bias in the direction of increasing the total number of specimens. Probably the commoner small forms would be favored relative to larger ones.

However, the only other consistent method of counting, that of computing the least possible number of individuals, would in this case introduce a larger bias in the other direction. Where the bones are known to be essentially untransported, the only scattering of parts of one individual is accomplished by perthotaxy before burial and by recent anataxy. Perthotaxic separation involves distances of a few inches to a few feet, depending upon the size of the corpse. Direct field observation of all but the commonest small forms can, therefore, usually determine whether or not two jaws or teeth derive from the same individual. Recent transportation is practically always directly downslope and, except in tiny rills, destroys the smaller specimens within a few feet. Field observation, again, can usually determine whether or not two cospecific fragments are related. Application of the method of minimum numbers would, by comparison, ignore these relationships and such additional clues as amount of wear. It might well require excluding a senile maxilla found more than 100 yards away from several juvenile mandibular rami. Therefore, the method of minimum possible numbers, which may be properly applied to mechanical assemblages, seems more biased than the method of studying each situation, in a case like the present one.

3. Only teeth, jaws, and skulls were included in the final count.

4. Turtles were omitted from the collection, because of their bulk. No other group was omitted. Birds and lower vertebrates were collected, but excluded from the statistical computations.

PERTINENT FIELD DATA FOR INDIVIDUAL COLLECTIONS

I. Near Stream Facies.

Locality: N½ of Sec. 10 and 11, and SW¼ of Sec. 2, T. 42N., R. 45W., Shannon Co., South Dakota. Uppermost part of Corral Draw drainage, Cottonwood Pass area.

Stratigraphic data: One riosome passes through the north ½ of Sec. 11; another outcrops in the west half of Sec. 10, and a drenajesome in the northwest ¼ of Sec. 2. The great majority of specimens occur in the upper half of the stratigraphic section.

Collections: Collection VII, SDSM, 139 specimens, from the NE¼ of Sec. 11; 1959. Graph VII of this report.

Collection VIII, SDSM, 47 specimens, from the E border of the SW¼ of Sec. 2; 1959, Graph VIII.

Collection IX, CU, 115 specimens, from the entire area described; 1961 and 1962. Graph IX.

II. Open Plains Facies.

A.

Locality: North-central Sage Creek Basin, SE¼ of SE¼, Sec. 16, and NE¼ of NE¼, Sec. 21, T. 2S., R. 15E., Pennington Co., South Dakota.

Stratigraphic data: The nearest riosomes are at Sage Creek Pass, three miles south, and northeast of the Pinnacles, five miles to the east. In the field, the matrix here resembles that at Cottonwood Pass except that the color is a little brighter yellow and concretions are very much less developed. Most fossils in Sage Creek weather free of the matrix rather than remaining in concretions which weather free, as larger fossils usually do in the Cottonwood Pass area. In thin-section, the Sage Creek matrix is less calcareous and has a lower proportion of coarse silt to finer material; otherwise no differences are apparent. A few individual concretions are fully as calcareous as many at Cottonwood Pass.

The most fossiliferous zones are thin concretionary layers 3 to 10 ft. below the top of the Lower Nodular Zone. Most of the specimens come from these zones.

Collections: Collection II, SDSM, 458 specimens, from the entire area described; 1956. Graph II.

Collection I, CU, 531 specimens, from the northern two-thirds of the area; 1962. Graph I.

Collection V, CU, 141 specimens, from the southern one-third of the area. This collection was separated from I because a slightly greater development of concretionary nodules in this area was thought possibly to indicate closer proximity to some distributary channel now eroded away. For this reason it is labelled "Swampy Plains Collection." Comparison of this collection with the other Open Plains and Swampy Plains collections will show the extent to which faunal composition reflects this particular petrologic character; 1962. Graph V.

B.

Locality: Dillon Pass area, SE¼ of Sec. 28 and adjacent edge of Sec. 27, T. 2S., R. 16E., Pennington Co., South Dakota.

Stratigraphic data: The nearest channel-fill is a half mile to the northwest. However, the Lower Nodular Zone consists here mainly of pinkish to red-brown igaposome clays. Lithogically much of it is alternately finely-laminated reddish clays, presumably derived from the Sage Upland, and unsorted silty mudstone deposited as varzea-type sediments by fluvial water. The area, therefore, represents an outer fringe of varzea flood plain, more often subject to backwater flooding than to sheet floods, and usually not flooded at all. The fossils occur in the varzea-type mudstones, richest of which is one 3–6 ft. below the top of the Lower Nodular Zone.

Collections: SDSM Collection IV, 114 specimens, from the entire area described; 1956. Graph IV.

C.

Locality: Area south of Dillon Pass, between the centers of Sec. 33 and 34, T. 2S., R. 16E., 1 mile south of Dillon Pass, Pennington Co., South Dakota.

Stratigraphic data: The same as for the last, except that the nearest channel-fill is roughly 1 mile to the northeast, and varzea sediments form a smaller proportion of the total mass.

Collections: SDSM Collection III, 66 specimens, from the entire area described; 1956. Graph III.

III. Swampy Plains Facies.

Locality: North-central Sage Creek Basin, SW¼, Sec. 15, E½ of NW¼, Sec. 22, T. 2S., R. 15E., Pennington Co., South Dakota. This locality lies adjacent to the Sage Creek Open Plains locality, but due to a combination of recent topography and relatively unfossiliferous beds, no fossils were collected in a strip about 200 yards wide which separates them.

Stratigraphic data: The highly fossiliferous horizon about 3 ft. thick, near the top of the Lower Nodular Zone immediately to the west, changes color rapidly from tan to pale greenish. A prominent pond limestone 4–8 in. thick occupies the middle of this horizon. Greenish color develops in the sediments beneath, also, until more than half of the Lower Nodular section is greenish. The limestone contains at least three genera of pond snails in great abundance, as well as algal strands, ostracods, fish bones, and numerous pupa casts up to 1½ inches long. The limy mudstones marginal to and immediately above the limestone contain abundant fossil mammals. Since the greenish color is due to reduced iron, the presence of abundant vegetation plus enough water to prevent oxidation during deposition of the muds is indicated. This was an igapo swamp and pond, which endured long enough for the development of an aquatic and paludal biota. It is the only such situation known within the Lower Nodular Zone; the contrast with the varzea sheet-flood sediments which make up the laminated siltstone lithotope (p. 83, this report) is obvious. As the only representative of a true paludal environment, it might offer a most valuable clue to the preferences of some Oligocene mammals. A separate collection was made here in order to determine whether or not the fauna reflected the situation suggested by the lithology.

Collections: Collection VI, SDSM Swampy Plains Collection, 217 specimens; 1956. Graph VI.

CURATING AND IDENTIFICATION

The 1956 collections were made through funds supplied by the Yellowstone-Bighorn Research Foundation. Originally housed in the Cleveland Museum of Natural History, they were transferred to South Dakota School of Mines and Technology Museum in 1957. Here the senior author unpacked, prepared, identified, and curated them. The 1959 collections, VII and VIII, were prepared, identified, and curated at the latter museum by the senior author. Following the senior author's departure in 1961, all of these collections were studied by a graduate student. Unfortunately, he had no way of knowing the senior author's policy of counting closely-associated material as one specimen. He therefore separated all associated material, giving it separate numbers. In May, 1963, the senior author and this student checked the collection against the senior author's original records, and reassociated scattered specimens wherever possible. However, the present specimen catalogue of the South Dakota Museum differs in detail from the author's original specimen counts published here, due to this confusion.

The University of Colorado Museum collections were made by the authors jointly, with one day's cooperation by Doctor Robinson and his party. They were housed, identified, and curated in the senior author's home, then sent to the University of Colorado Museum for final storage. Identification was done without comparative material and with only limited access to publications. The specimen counts are accurate, and the identifications are generally so, but work with comparative material may reveal a few individual misidentifications. These are probably the inclusion of new forms within well-known species rather than assignment to the wrong genera.

In general, identification to species has not been attempted, only in part due to the fragmentary nature of the material. The major reason is that almost every Brule genus needs careful revision, and these collections themselves revealed the wisdom of not accepting the present specific designations. It is to be hoped that the collections reported here will function as part of the basis for thorough revisions at the specific level. Probably, such specific revisions will reveal differences between the various faunas which the present analysis at a generic level fails to show. *Merycoidodon* was separated into the easily recognizable species, *culbertsoni* and *gracilis*, which have been placed in separate subfamilies by Schultz and Falkenbach (1956).

Early in 1962, one private collector invaded the near-stream area. He showed the senior author his collection, which was later sold. It consisted of *Merycoidodon culbertsoni*, 28 specimens; *Agriochoerus*, 2 specimens; *Mesohippus*, 19 specimens. Since these were collected from the same horizon and locality as collection IX, during the same year, they have been included in this collection although they are not in the University of Colorado Museum collection. Omitting them would have produced a serious bias. The authors also found several broken limb bones of *Metamynodon*, *Hydracodon*, *Caenopus*, and possibly *Archaeotherium*, at this time, suggesting that the rarity of dental specimens belonging to large mammals may be due to activities of amateur collectors than than to any scantiness of large-animal populations in the Oligocene near-stream faunas.

VARIABLES AND BIASES AFFECTING INTERPRETATION OF THE POPULATION STATISTICS

I. Preliminary considerations.

The ideas presented in this section have been expressed, in relation to studies of various mammalian assemblages, many times. However, through their unusual habitat documentation the present collections offer an almost unique opportunity for determining the possible relationship between a collection of fossils and the mammalian population from which it was derived. We have evidence, first, that the collections represent, essentially, death assemblages which have undergone no transport; second, that these death assemblages accumulated in different local habitats within a few miles of each other geographically; third, that they are truly contemporaneous; and fourth, that no significant climatic changes occurred during the time of accumulation. The only remaining reasons for variation between collections are the actual differences between faunas of the different habitats, and the fidelity of the collections as samples of those faunas. It is, therefore, justifiable to repeat and organize ideas regarding validity of the sample which have been expressed in part many times.

We shall consider here those variables and biases which are known or presumed to affect the accuracy of our samples. Four preliminary considerations must be accepted as part of any census analysis of a fossil population:

1. No complete census of any living mammalian fauna has ever been made. We have, therefore, no norm for direct comparison with a fossil population. In view of the extreme modification of all modern faunas by human action, it is improbable that any significant census could be taken of any area, now or in the future. Every biologist is aware that such broad general situations as: a collection consisting entirely of animals larger than sheep; one containing 80 per cent carnivores; or one including no rodents, are presumed to be abnormal. Beyond vague generalities like these we simply have no information.

2. We have no way of estimating the total size of the population or universe of which the total collection is a single sample. It is impossible, therefore, to evaluate the significance of the sample.

3. A fossil collection must represent a death assemblage rather than a mechanical assemblage in order to justify statistical analysis. Any mechanical assemblage has suffered so much non-random selection as to be worthless for census purposes. To illustrate this point:

(*a*) Among the Glires, a single *Ischyromys* molar will, due to its rounded shape, travel very much farther by rolling than will a *Paleolagus* molar. This would produce a sorting by shape rather than by size.

(*b*) The enamel thickness and pattern of *Merycoidodon* teeth make them very much more resistant to breakage than *Hoplophoneus* teeth of the same general size.

(*c*) One molar of *Daphoenus*, if it survives transport, is readily identifiable to genus, but a felid molar is not, because the molars of the genera *Dinictis* and *Hoplophoneus* are practically indistinguishable. Interaction of transport breakage with a curating bias of this sort can permit serious distortion of a census.

The predictable biases inherent to transportation are profound and by no means mutually cancelling, nor is there any reason to expect that the unforseeable biases will average out the total. Those studies which have been performed from time to time upon collections from obviously-transported quarry assemblages are interesting exercises in statistics, but they bear no demonstrable relationship to ancient populations.

4. Finally, a collection of fossils is not, as Olson has recognized (1957, pp. 312–313), a direct sample of a mammalian population. Actually, the situation devolves into three successive sample-universe stages, as shown in Figure 53. Each circle comprises a sample of the one above it, and a universe of which the one below is a sample.

With these four general limitations in mind, let us consider the variables which determine, either independently or through interaction, whether or not a particular animal will become an identified specimen in a collection. Olson (1957) has discussed the application of several of these factors to size-frequency distributions; their bearing upon a faunal census is sufficiently different to warrant discussion here. The factors fall naturally into seven groups:

I Biotic
II Thanatic
III Perthotaxic
IV Taphic (related to burial)
V Anataxic (related to erosion and weathering)
VI Sullegic (Collecting)
VII Trephic (Curatorial).

These factors come into play at the stages indicated in Figure 53. However, they may interact with factors at any stage in the relationship. It is not possible to consider any one universe-sample relationship in the chain without reference to factors at other stages.

II. BIOTIC FACTORS.

These are features of the life of the individual or the species, which determine the availability of individuals for the successive stages leading ultimately to their inclusion in a collection.

A. *Total range of species.* This includes climatic, topographic, and historic controls. Historic controls are such features as the physical history which precludes hippopotami from the Amazon basin, to which they might otherwise be ecologically suited.

B. *Habitat, or ecologic niche.* In the present study habitats are presumed known, and a major purpose is to determine whether a significant correlation exists between the collections of fossils and the predictable faunas of the respective habitats.

C. *Population density within the species.*

D. *Pressure to leave the preferred habitat.* During episodes of drought, animals from dry habitats would seek swamps or streams for drinking water. They would necessarily be at a comparative disadvantage while in a habitat foreign to them, and might therefore be more subject to predation than when at home. On the other hand, flooding of drenaje swamp-forests might temporarily drive some species out to the better-drained slopes.

E. *Osteologic construction.* The simple equation, fragile bone — greater destruction, is a serious oversimplification of a factor which becomes very complex due to interaction with perthotaxic, anataxic, and curatorial factors. For example, the skull of *Paleolagus* is probably more fragile than that of any other Oligocene mammal of equivalent size. Also, *Paleolagus* mandibles tended to crack, during perthotaxy, between M_2 and M_3, or posterior to M_3, releasing those molars; not uncommonly, the entire cheek-tooth battery dropped out and scattered. Moreover, single *Paleolagus* teeth often yield to anataxis by splintering. By comparison, *Leptomeryx* and *Hypertragulus* are much more ruggedly constructed. However, due to unique generic characterization of *Paleolagus*, almost every tooth fragment is generically identifiable, while partial teeth or mandibles of *Leptomeryx* and *Hypertragulus* may not be. Therefore, although good skulls of *Paleolagus* are among the rarest of fossils, identifiable specimens are among the commonest. To what extent this reflects original abundance of rabbits, or alternatively to what extent it represents a tendency of perthotaxy to enhance the possibility of finding recognizable specimens, is not known.

F. *Body size.* Body size, and hence bone size, is another extremely complex, interacting factor. In cases where transportation is not involved and where increments of sediment were thick enough to bury completely the largest bones, the chief interaction is with thanatic, perthotaxic, anataxic, and collecting factors. Some discussion of this will be given later.

III. THANATIC FACTORS.

Thanatic factors are all those circumstances surrounding the death of an animal which influence its fossilization potential.

A. *Cause of death.* Predation, disease, physical accident, poison, starvation, and intra-specific strife comprise the overwhelming majority of causes of death. Authorities differ as to the relative importance of these causes; certainly animals differ from species of species, and within one species from time to time and from place to place, as to the relative proportions dying from these different causes.

The effects upon a population census of these various causes of death, as operating upon any one species, would be quite different. Physical accident would, in such habitats as those described, be limited to occasional mass drownings of small or burrowing forms and to falls by arboreal species. The latter would average out over a period of time. Mass drownings might produce a primary dilated perthotaxis of small animals, but no such situation has been observed. Poisoning by ingestion of a toxic plant, such as occasionally occurs to cattle who eat Death Camas, should produce a dilated perthotaxis of herbivores; it is certainly a rare situation among wild populations, if indeed it occurs at all. Epidemic disease might be expected to produce mass deaths with a high incidence of individuals of whatever age group was susceptible. This is believed to be the case with *Hypertragulus* (see below). Starvation would ordinarily be a result of protracted drought causing a shortage of both food and water in the dryer habitats. It would almost certainly result in an abnormally large number of dry-plains forms dying in swamp and river-bank forest habitats. The larger animals would migrate to water more easily than the smaller ones, so the death assemblage in the dryer habitats would be biased toward smaller animals. Intraspecific strife would be a continuum which should not affect a fossil census in any way.

Predation might produce serious biases, which can be guessed at but cannot be accurately assessed. Owls usually destroy the calvarium, but regurgitate the maxillae and mandibles unharmed. Hawks, eagles, and vultures swallow, digest, and thereby completely destroy the bones of small animals. Heavy predation by these birds should constitute a definite bias against all small, diurnal mammals in a census of bones. The rarity of avian fossils precludes any evaluation of this effect. Predation by small mustelines (rare in Brule collections) almost never damages jaws and teeth; presumably this would introduce no bias. Carnivores the size of *Daphoenus* and the felids might be expected to crush and swallow any mammals up to about 5 per cent of their own body weight, which would again produce a bias against everything smaller than *Ischyromys*. *Hesperocyon*, the commonest Brule carnivore, would be expected to destroy *Eumys* and everything smaller. Ingestion of small animals whole does certainly dissociate bones and, by immersion in gastric juices, remove all organic matter from them. Such a bone emerges from the carnivore in a fairly advanced state of perthotaxy within hours of death, which greatly reduces its chance of preservation. Predation is, therefore, certainly a factor operating selectively against small mammals and, in the case of carnivorous birds, against small diurnal mammals.

In summary, mass drownings and epidemics might produce dilated perthotaxes, starvation would probably cause invasion of moist habitats by normally dry-land forms, and predation would bias a census against the smaller forms. The other causes of death would probably not recognizably affect a census.

B. *Locus of death.* Relationship to the surface of the ground seems to be a decisive factor. We have found no evidence of any mammal burrows, or, naturally, of any mammals who died in them. Supposedly, a burrowing mammal might be expected to die in its burrow from any of the causes listed except predation by large carnivores. Burrows in a flood plain subject to flood every ten years should, therefore, include large numbers of skeletons either whole or in early stages of perthotaxy. The actual situation is exactly opposite: not only have no burrows been found, but associated skeletal material of small, probably burrowing, mammals is almost nonexistent. This could mean either that no Oligocene mammals were burrowers, which seems improbable, or that individuals living in areas subject to frequent sedimentation did not dig burrows, which seems much more probable. The senior author has observed that on Badlands flats at present, burrows are dug only in those places not subject to deposition. The effect of this factor on a population study is not known.

The other peculiar locus of death lies some distance above the ground, in trees and shrubs. Presumably, an animal dying of predation in this situation would be destroyed, and an animal dying of any other cause would probably do so in a hollow tree, where it could be buried. However, there is nothing to prevent animals who build nests among branches, as do many squirrels, from falling to the ground within a few weeks or months of death. Whether or not this occurs is debatable: the generally low percentage of primates and other demonstrably arboreal forms in most fossil assemblages would suggest that it does not. One can presume that the present collection has some bias against truly arboreal forms, although a definite assignment to arboreal or terrestrial habitat is impossible for many of the genera represented.

C. *Mortality relative to age.* In the Brule collections, as in practically all other Tertiary collections, infant and juvenile specimens are exceedingly rare. One may set up the following arbitrary, but usable, scale:

Stage	Terminated by
Infancy	Eruption of M^1_1
Juvenility	Eruption of M^2_2
Adolescence	Eruption of M^3_3

On this basis, adolescent individuals are generally uncommon (except in *Ictops*, *Mesohippus*, and *Hypertragulus*, see below); juveniles rare, and infants exceedingly rare. Since most mammalian species experience an infant-juvenile mortality of 25–75 per cent, the fossil collections very apparently do not approximate the life assemblages. Presumably, the fragile bones of young individuals are more readily destroyed by perthotaxy and anataxy than are adult bones.

This sets up a strong bias against animals having a high infant-juvenile mortality, which are usually small animals with large litters. For instance, if a species has within a given area an adult population of 1000 individuals, which produces 1000 young per year 90 per cent of whom die in infancy, then due to the differential preservation of adult bone the population effective in producing fossils is very little above 1000. A species of 1000 adult individuals in the same area, producing 500 young per year, 20 per cent of whom die in infancy, would on the other hand have a fossilization potential of 1400 + individuals.

Thanatic factors combine to produce the death assemblage, which is the sum of the fresh corpses that come to rest upon a surface previous to burial of that surface by the next episode of sedimentation. As used in this paper, the death assemblage is not the partial or complete perthotaxis observable at any one time.

IV. Perthotaxic factors.

Climate and exposure are the chief variables controlling a perthotaxic system. Climate can be presumed to have been uniform in the case at hand, and exposure would be not too different within any one habitat. Physical accident, such as being stepped upon by a large Oligocene mammal, would have destroyed specimens in a truly random fashion; probably accident would destroy only a negligible number of specimens. Body size, and especially tooth volume relative to enamel thickness, seem to have had much more important effects upon perthotaxy. Observation upon recent skeletons under semi-arid conditions demonstrates that animals of rabbit size and smaller undergo almost no dehydration-cracking of the teeth, and much less splintering of limb bones than do the larger forms. Very large bones—cow and horse sizes—exfoliate but do not splinter so readily as do the bones of animals of medium size. Large teeth, on the other hand, splinter very quickly. These aspects of perthotaxy would, therefore, produce a bias favoring preservation of the smaller forms.

Scavenging-pressure is more difficult to evaluate. Once the flesh was removed from an Oligocene mammal's bones, apparently, it was of little interest to scavengers—very few instances are known of a partial skeleton with limb bones chewed or broken off. Conversely, numerous instances have been observed of undamaged herbivore skulls accompanied by several droppings of carnivore coprolites. This suggests that the skulls were of no gustatory interest, and functioned either as objects of scorn or as markers. Plainly, some process must have very quickly and effectively removed the flesh from many corpses, rendering them uninteresting before they suffered damage from scavengers. Either decay or insects could have accomplished this. The universality of the removal suggests both, operating under a climate considerably warmer and somewhat wetter than the present; Payne (1965) outlines the process under a summer climate in Virginia. Briefly, there is no evidence that scavengers destroyed a significant number of specimens, although they probably scattered the bones of the larger species.

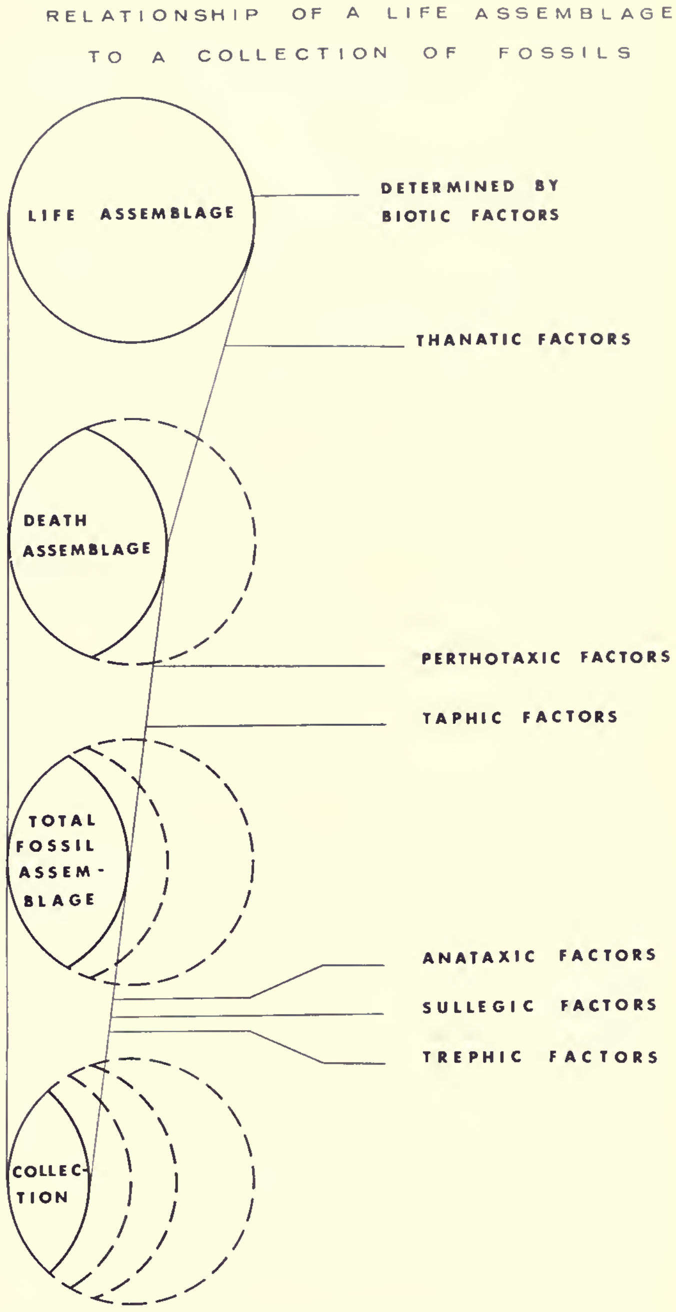

Fig. 53. The relationship of a life population to a collection of fossils. The interaction of factors has not been shown. Also, since factors would function differently for each genus in every collection, the size of the assemblages is not representative.

V. Taphic (burial) factors.

Six major factors of burial can, theoretically at least, result in a difference between the perthotaxic assemblage at any one time and the taphic or total fossil assemblage.

1. Time interval between episodes of sedimentation.
2. Thickness of sedimentary increments.
3. Velocity of depositional current in contact with bone or corpse.
4. Nature of sediment: amount of compaction, grain size, nature of clay minerals.
5. Post-depositional action of roots and burrowing animals.

6. Permeability of compacted sediment and nature of permeating solutions.

In the Lower Nodular Zone, there is no evidence that any of these functioned to destroy bone selectively, or in any way to bias the samples. The time interval was always long enough to permit development of a complete perthotaxis. Sedimentary increments were thick enough to bury completely even the largest bones. The sediments were deposited by fluids that engulfed without transporting or abrading. The sediment was a gritty siltstone, with enough montmorillonite to bind and give it adhesive strength but not enough to cause much damaging compaction. There is no evidence of bone having been damaged by Oligocene roots or burrowing animals. Such solutions as filtered through the highly permeable clastics were thoroughly charged, at various times, with lime, silica, and iron salts; they preserved the bones rather than dissolving them.

Generally speaking, therefore, the total fossil population (see Fig. 53) represents a very large proportion of the death assemblage at the several times of deposition of the sedimentary increments. It had been altered only by perthotaxic biases, not by any related to burial.

VI. ANATAXIC FACTORS.

Anataxy can be defined as the sum of the phenomena which operate to expose and to destroy a fossil. It occurs in three inter-related states: A). Weathering *in situ* of matrix and fossil. B). Exposure by erosion. C). Weathering and transportation after exposure.

A. *Weathering in situ.* Under the present climatic regime, one of the first effects of weathering is the precipitation of hematite around bone. This occurs in the near-stream sediments, but not in the Sage Creek or Dillon Pass areas. Bones of *Leptomeryx* size and larger develop a heavy aureole of hematite; smaller one develop less or none. In the Sage Creek area, weathering tends to break medium-sized bones, within the top inch of the weathered zone, but does little or no damage to jaws and teeth of *Ischyromys* size or less. Since generically identifiable fragments of the larger bones survive this weathering, little if any bias results.

B. *Exposure by erosion.* Erosion is almost always by rain-wash, rill-wash, or by gravitational sloughing of weathered material from hillsides during spring thaws. The latter may seriously damage or destroy specimens of all sizes, but particularly the larger ones. However, this type of erosion is of minor importance in the fossiliferous areas in question. Rain and rill-wash effectively separate bone particles already broken by weathering, and also separate parts broken by perthotaxy. The former case can usually be recognized, but the further separation of a pair of small jaws originally scattered by perthotaxy may result in one small animal being counted twice. For instance, a pair of *Eumys* jaws originally 3 in. apart and exposed at the same time could, if one were caught by a rill, come to rest 20 or 30 ft. apart during a single rain. This does produce a bias favoring the smaller forms, because parts of a larger animal are less easily moved and are more easily recognized as belonging to the same individual.

C. *Anataxy after exposure.* Ultimately, fossils are destroyed by weathering and transportation. A few skulls armored by the hardest nodules, in the Cottonwood Pass area, have been known to travel up to one-quarter mile with little damage. However, fossils not so protected do not usually withstand transport over 100 yards.

Medium-sized fossils not subject to transportation endure surface weathering for periods of up to tens of years in the Cottonwood Pass area. Any parts projecting from the nodules break off, and the nodules often break into angular fragments, but the bones develop an extremely durable patina of iron and manganese oxides. This does not usually occur to bones of *Leptomeryx* size and smaller, which apparently weather to destruction within years. Due to the recent activities of amateur collectors, very few identifiable, weathered specimens were collected, so our sample probably was not biased toward large forms as it might otherwise have been.

In the Sage Creek area, weathering of exposed bone is not rapid. Fragments of *Archaeotherium* bones, up to 2 in. long, exposed in 1956, were apparently destroyed by 1964; on the other hand, a piece of zygoma 6 in. long was virtually unweathered. In this area, jaws and teeth of small animals seem to be at least as resistant as large ones, and may be more so. Such bias as might occur would favor the preservation of small specimens.

VII. SULLEGIC OR COLLECTING FACTORS.

At any one time, a relatively small proportion of the total fossil population of a stratum has been exposed and is in the process of slow destruction. The collection of the most complete sample possible of this exposed group is attended by many difficulties, which may produce serious biases.

Five factors have proved to be particularly applicable to the Scenic Member collecting problem: A). Method of prospecting. B). Position of collector in visual prospecting. C). Personal bias. D). Historic re-sampling. E). Differential cementation and weathering.

A. *Method of collecting.* The traditional method of collecting consists of driving, riding, walking, creeping, or wriggling across fossiliferous terrain, observing fossils visually, and collecting them by whatever means is thought best. The senior author has personally observed cases of prospecting from car or horseback; these can obviously be ignored as serious methods of obtaining a representation of any but the largest forms. Other methods of visual collection will be discussed in paragraph B.

A second, more modern method of collection is by stealing the grit from ant hills and concentrating the tooth and bone fragments which the ants have picked up. Ant hill concentrates are very useful for giving a representation of the total small-mammal fauna, but they are subject to three biases, mechanical, psychologic, and ecologic.

Mechanically, the ant is limited to particles small enough to carry and large enough to remain on the hill through rain and wind. Any fossil species with generically identifiable jaws, teeth, or fragments thereof which fall within this range is very likely to be represented in an ant hill. The size bias is obvious and predictable.

A more serious bias, difficult to evaluate, relates to the psychology of the ants. The senior author has observed two instances of this:

On the south rim of 71 Table, in Sec. 16 and 17, T. 3S., R. 14E., Pennington Co., the ants select grit from Pleistocene gravels for their hills. They show a strong preference for garnets over quartz and feldspar grains of the same size. Do they prefer garnets because of the shape, color, texture, or specific gravity?

East of the main road in the SW¼, Sec. 29, T. 5S., R. 8E., Custer Co., the ants are selecting from materials available on the Sharon Springs Member of the Pierre Formation. Two ant hills observed are composed almost entirely of glistening, blade-shaped selenite crystals 3/4 in. long; the ants have abundant pellets of limonite and small, gray calcite concretions of suitable size, equally available. Since the limonite has a higher specific gravity than the selenite, do the ants prefer the selenite for its shape, color, luster, or surface texture? One hesitates to ascribe to them an esthetic appreciation of either glistening selenite or red garnet.

These two instances clearly document a deliberate selection upon some basis other than size and, in the second instance, other than specific gravity. All of the selenite crystals are at the upper limit of the ants' carrying capacity, and are much less easily moved than a round limonite pellet of the same weight, showing that portability is probably not the deciding factor. If shape happens to be decisive, might not the ants select *Paleolagus* teeth (which are of almost identical size and shape with the selenite) over round *Ischyromys* molars?

The psychologic bias of ants is, in the authors' opinion, plainly demonstrated. Until more is known of the basis for their preferences, all ant-hill collections should be regarded as subject to definite but unpredictable bias other than size. Such collections are therefore not fit subjects for statistical studies aimed at approximating a census of fossil communities.

The ecologic bias constitutes a third serious factor limiting the statistical usefulness of ant-hill collections. One particularly fossiliferous locality may form the homesite of 60 or 80 ant colonies, while another of equal size may support none, or at best two or three. The distribution of small vertebrate fossils within such a horizon as the Lower Nodular Zone is non-random but unpredictable, and the distribution of ant hills is certainly non-random (since it is controlled by geographically variable ecologic factors) but is equally unpredictable. We therefore have ant-hill collections of widely variant size from different localities; the collections share a qualitative psychologic bias, but differ in size-of-collection bias. We do not know whether or not the distribution of ant hills might be controlled by some factors of the local geology which themselves reflect paleogeography: the distribution of recent ant hills might actually be influenced by factors interacting as controls of fossil distribution.

Because of the psychologic and ecologic biases, plus the interaction of size, perthotaxic, anataxic, and curating biases, ant hill collections do not constitute samples suitable for population studies. The difference in method of sampling from visual prospecting makes it obviously impossible to merge the two types of collection for any quantitative analysis. The real usefulness of ant hills lies in their concentration of very small forms, which greatly increases qualitative knowledge of the total fauna.

The third sampling method consists of washing samples. The matrix itself is washed wherever: (*a*) fossils are sufficiently abundant; (*b*) fossils are dissociated enough that washing will not further damage them; (*c*) the matrix dissociates in water. Conditions (*b*) and (*c*) obtain nowhere in the Lower Nodular Zone. Placer concentrates of bone in small rill-gullies are common, however, and can be washed out. They frequently include jaws and teeth smaller than can be reliably recovered by visual collecting, and as such are qualitatively useful. The fact of Recent transportation automatically injects mechanical biases. The difference in sampling method precludes using them in combination with collections made by any other method, to form a "total population" for quantitative analysis. As previously-transported fossils, any matrix-washed collections would be unsuitable for quantitative population analysis.

B. *Methods of visual prospecting.* During the 1965 field season the authors experimented with different methods of visual prospecting in the Sage Creek dry plains locality. We first covered the fossiliferous area systematically, on hands and knees, with eyes about 2 ft. from the surface, collecting several hundred identifiable specimens, mostly *Leptomeryx* and smaller forms. We next covered the same area systematically by walking in a stooped position, with eyes 3–4 ft. from the surface. To our surprise, we found five *Merycoidodon* skulls that we had missed on the closer search, plus a scattering of smaller specimens. We then chose an area about 20 ft. by 10 ft. which we had prospected repeatedly, directly adjacent to our camp, and prospected it by crawling, with our eyes not over 12 in. from the ground. We found about 30 specimens, at least 12 of which were tiny insectivores not previously represented. We then tried the adjoining space of the same size, and found only one insectivore plus a few fragments of *Paleolagus*, small rodents, and *Leptomeryx* teeth. This experiment demonstrated to our satisfaction that an area must be prospected several times, moving in different directions, and certainly using all three ocular positions, in order to achieve an approximately complete collection. It also demonstrated a high local variability in distribution of fossils.

C. *Personal biases.* The training, persistence, psychologic fluctuations, and visual acuity of the collector constitute obvious and well-known biases. We have found that physical distractions, such as gnats, or mosquitoes, or excess sweat dripping into the field of vision, definitely reduce collecting efficiency, especially ability to see small fossils. Available time becomes a factor through reducing the possible number of times one can prospect over an area. It may also become a psychologic factor, by causing the collector to hurry and thereby to miss small fossils; the latter tendency is more prevalent in the chief of the party than in his assistants.

D. *Historic resampling.* Collection by most professional collectors of an earlier age certainly interacts with size, perthotaxy, and anataxy to produce a bias. The senior author collected over all of the districts discussed in this paper, during the decade 1932–1942, and well remembers several significant points.

Large fossils were at that time almost everywhere in evidence. During one ten-day stay in Sage Creek in 1933, our party averaged well over one skull per day of animals *Mesohippus* size and larger. Such collecting no longer exists in the Big Badlands. We are forced to the conclusion that exposure by weathering is not so fast as has been supposed. Once an area is really thoroughly collected, several decades must elapse before it will attain its original concentration of large bones.

Earlier collecting was strongly biased toward larger specimens, and especially toward more complete ones. The senior author recalls that in 1933, a party of four in Sage Creek collected less than 100 specimens of *Leptomeryx* size and smaller, in 10 days. By comparison, we two made collections I and V, totalling 672 specimens of which over 70 per cent are small, in the same area in two days in 1962.

The size bias of earlier collectors, plus a slow rate of exposure by erosion, produces a bias favoring smaller forms in any recent collections. Since this bias depends upon interaction of the ratio of small to large forms in the death assemblage, perthotaxic factors, the actual rate of erosion, and the extent of previous collection, it cannot be evaluated.

E. *Bias due to differential cementation.* Collecting effectiveness depends in a complex fashion upon cementation of the matrix. High percentages of montmorillonite with little cementation produce a "pop-corn" surface. Most small teeth and jaws are destroyed by expansion and contraction, and the remaining ones settle between lumps of matrix where they are easily overlooked.

Tight cementation, as in the near-stream nodules, tends to interact with collecting biases to favor finding large fossils. A single nodule containing a single, large skull is highly visible. Small bones either weather free, to settle among the nodules, or weather out of a large nodule a little at a time, suffering destruction in the process and never becoming easily visible.

VIII. Curatorial factors.

One can assume proper field, laboratory, and cataloging procedures in a modern institution. However, identification introduces a serious bias which the most conscientious effort cannot remove. A monospecific genus or monogeneric family can, in general, be recognized from a smaller tooth-fragment than can a species or genus having close relatives. An outstanding comparison can be drawn between *Mesohippus*, which can often be identified from less than one-tenth of a molar, and the rhinoceroses. A small *Caenopus* and a large *Hyracodon*, on the one hand, or a large *Caenopus* and a small *Subhyracodon*, on the other, can sometimes be distinguished only with difficulty on the basis of half of a molar. A larger fragment is needed to distinguish *Leptomeryx* from *Hypertragulus*, than to determine between *Merycoidodon* and *Agriochoerus*. A few rodent genera can be determined on the basis of half of a molar; several cannot be. The curatorial bias is not at all random nor is it uniformly reinforcing or mutually self-cancelling to any other bias. In practice, it becomes a very significant bias.

IX. Summary.

The life assemblage is determined by biotic factors. Thanatic factors produce a considerable bias in the death assemblage, which is a sample of the life assemblage. Perthotaxic factors considerably, and taphic factors slightly, bias the total fossil assemblage, which, in turn, is a sample of the death assemblage. Anataxic, collecting, and curatorial factors strongly bias the fossil collection, which is a sample of the total fossil assemblage. Many of these biases interact; there is good reason to suppose that they are not mutually self-cancelling. A census study of a fossil population must face, in addition to these groups of biases, the facts that we do not know the size of the life population, we have no census of a Recent mammalian population to use as a norm, a collection must be demonstrably a burial of bones *in situ* rather than a mechanical assemblage, and that the collection is not a direct sample of the life population.

ANALYSIS OF FAUNAS[1]

I. Validity of collections as samples.

The bias factors discussed above cast doubt upon the validity of our collections as representative samples, ultimately, of the Oligocene faunas of their respective areas. It is therefore necessary to consider Charts I–XIII, in order to determine whether sufficient evidence of consistency exists to justify further study. Foreknowledge of the habitats makes possible a search for consistent differences between collections from different habitats as well as consistent similarities between collections from the same habitat. Since only one collection has been made from each of the "swampy plains" habitats, and since the two have been interpreted from different geologic bases, attention must focus upon the near-stream and the open plains collections. Figure 55

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[1] Throughout this section the following abbreviations will be used in the text for brevity and clarity: SDSM—South Dakota School of Mines and Technology Museum: CU—University of Colorado Museum.

lists two characteristics shared by all collections, and six in which the two sets of collections are internally consistent but different from each other.

Paleolagus, as the ecologic homologue of *Sylvilagus*, might be expected to be both ubiquitous and ubiquitously abundant. The abundance of *Ischyromys*, however, might be actual or might be due to collecting biases, since it is one of the largest Oligocene rodents. This will be discussed later. The low, generally consistent percentage of carnivores throughout suggests that the collections probably approximate the life assemblages in this respect.

The other six characteristics listed in Figure 55, taken together, suggest that the collections are adequate to reveal broad generalities about the life assemblages of the different habitats. Chart XIII offers some support to this presumption. Of ten proportions computed, the SDSM swamp collection resembles the near-stream collections more nearly than the dry plains collections in the following five:

1. Percentage of Glires.
2. Percentage of perissodactyls.
3. Percentage of small mammals.
4. Percentage of medium-sized mammals.
5. Percentage of perissodactyls to artiodactyls.

Three more show no significant differences between collections:

1. Percentage of carnivores.
2. Percentage of artiodactyls.
3. Percentage of large mammals.

Of the remaining two, the percentage of *Merycoidodon* fluctuates irregularly, and the SDSM swamp is uniquely high in percentage of *Mesohippus*. Since the faunal assemblage of a swamp could confidently be expected to resemble that of a near-stream fauna more nearly than the fauna of a grassy plain, this strong resemblance is added evidence that our collections are significant samples.

The Colorado swampy-plains collection more nearly resembles the open plains collections than the near-stream collections. The geologic criteria for separating out the Colorado swampy-plains from the open plains environment are much less positive than are those for the SDSM swamp. Again, the faunal resemblance parallels the paleogeographic situation, reinforcing the conclusion that the collections constitute significant samples of the Oligocene life assemblages.

However, the high variance between collections should also be noted. Variations of up to 10 per cent between corresponding generic populations in Graph I (531 specimens) and II (458 specimens) increase to almost 20 per cent between collections VII (139 specimens) and IX (115 specimens). Recorded variations of more than 20 per cent for the smaller collections indicate that these are of little value except as they may justifiably be combined with others for more general information.

Using these observed variations as rough limits of significance for collections of the approximate sizes noted, we shall proceed to interpretation of the Oligocene communities of the various habitats.

II. NEAR STREAM FAUNAS. Graphs VII, VIII, IX, XII.

A. *General.* The graphs demonstrate clearly that the fauna comprises animals of varied sizes, with medium-sized species in the majority. *Mesohippus* (24%) and *Merycoidodon* (31%) make up the bulk of the fauna, as has been known for many decades. Unfortunately, the turtle *Stylemys* could not be included in the collections or the statistics; as a casual observation, there were at least as many turtles as *Mesohippus* in the field.

With a total of 296 specimens divided among 26 mammalian genera, the average number of specimens per genus is 11.4. *Mesohippus* and *Merycoidodon*, the two commonest genera, are represented by 55.4 per cent of the total number of specimens. The order of frequency among the commoner rodent-rabbit genera is: *Ischyromys, Paleolagus, Eutypomys, Megalagus, Eumys.* The rodent-rabbit population amounts to only 20 per cent of the total fauna. Small artiodactyls (*Hypertragulus* and *Leptomeryx*) constitute 4 per cent of the total. Carnivores comprise 5 per cent, with eight felids, five canids, and two hyaenodonts. Perrissodactyls account for 28 per cent of the total fauna, and are 64 per cent as abundant as artiodactyls.

B. *Individual collections.* The most striking differences between individual collections are the much higher percentage of rodent-rabbits in the CU collection —42.6 per cent as opposed to 5.7 per cent in the SDSM collection—and the absence of *Hypertragulus* and *Leptomeryx* in the CU collection. Field assistants who helped make the SDSM collections were relatively inexperienced, which might cause them to miss the smallest fossils. However, this certainly would not explain why the well-trained collectors who made the CU collection found 49 rodents and rabbits but no hypertragulids. Some extremely local phase of Oligocene geography may be reflected here, but if so no evidence of it has been detected in the sediments.

III. SAGE CREEK OPEN PLAINS FAUNAS. Graphs I, II, V, X.

A. *General.* The SDSM Open Plains Collection, Graph II, was made over the combined areas of CU Open Plains Collection, Graph I, and CU Swampy Plains Collection, Graph V. In order to maintain a uniform basis for comparison, the two CU collections are considered here, and both are included in Graph X. The distinctive characters of Collection V will be noted in Section B of this discussion.

In general, the Open Plains collections are almost four times larger than the near-stream ones. This reflects an actual greater abundance of specimens. The senior author collected 60 specimens in 30 minutes on one memorable occasion, and the total CU collection of 672 specimens represents the authors' combined efforts for two rather short working days in late September.

Even during the senior author's 1930–1934 experience in the classic near-stream area, before heavy prospecting had noticeably modified it, no comparable number of specimens was found there.

A complete perthotaxis has been observed in Sage Creek, as at Cottonwood Pass. Proportionally fewer whole skulls and skeletons, and far more separate jaws, occur at Sage Creek; the difference becomes less noticeable among the animals of medium size. Possibly this phenomenon reflects merely the large number of rodents and rabbits at Sage Creek rather than a qualitative difference in perthotaxy in two localities. Perthotaxy operates disproportionately faster on post-cranial bones of smaller animals. Conversely, tooth damage by dehydration in museum osteological collections demonstrates that teeth of small rodents lie undamaged for years in the same atmosphere which reduces teeth of sheep-sized animals to splinters.

A small-animal perthotaxis in a community of mixed sizes should, therefore, comprise a disproportionately large number of teeth and jaws, with limb bones and skeletons rare to absent. This is certainly the case in the Sage Creek Open Plains faunas.

The second notable feature is the great predominance of small animals over medium-sized and larger ones—81 per cent of the total, compared with 27 per cent in the near-stream fauna. Since both sets of collections represent complete perthotaxies, this difference is actual rather than an artifact. Perthotaxy probably did increase the number of small specimens preserved relative to large ones, within each area, but it could not have caused a significantly greater preservation of small forms in one area relative to small forms in the other.

With 1127 specimens divided between 31 mammalian genera, the average number of specimens per genus is 33.2. *Leptomeryx* and *Paleolagus*, the two commonest genera, are represented by 54.8 per cent of the total number of specimens. This compares with *Mesohippus* and *Merycoidodon*, which together comprised 55.4 per cent of the near-stream fauna.

The order of frequency among the commoner Glires genera is: *Paleolagus, Ischyromys, Eumys.*

The rodent-rabbit group makes up 37 per cent of the mammalian community, compared with 20 per cent in the near-stream population. Small artiodactyls have increased in number of genera from two to five, and in population from 4 to 40 per cent. Carnivores remain at 5 per cent, two hyaenodonts, with 40 canids, three mustelids, and eight felids. Artiodactyls dominate the population, both in number of genera and in number of individuals. They constitute 50 per cent of the total population, divided between 12 genera, contrasted with 44 per cent of the population divided between seven genera in the near-stream fauna. Small artiodactyls account for most of this; five genera include 40 per cent of the total population, compared with two genera comprising 4 per cent of the near-stream community. Perissodactyls are, conversely, greatly reduced in importance, but not in number of genera. The same four genera comprise 7 per cent of the open-plains population and 28 per cent of the near-stream population. This reflects the increase of small animals rather than any considerable change within the perissodactyls themselves; perissodactyls make up 39 per cent of the medium and large-sized animal population in the near-stream fauna, and 41 per cent of the corresponding community in the open-plains fauna.

Summarizing, the open-plains population differs from the near-stream population by the addition of tremendous numbers of small animals. *Leptomeryx* shows the greatest increase, followed by *Paleolagus, Ischyromys, Hesperocyon, Hypertragulus,* and *Eumys.* Changes of proportion within the medium-to large-sized elements of the fauna are relatively unimportant, when they are considered separately from the small animals.

B. *Individual collections.* The two open-plains collections show a somewhat higher consistency than do any two of the near-stream collections, as might be expected from the greater size of the open-plains collections. The large number of *Hypertragulus* in collection I is surprising, and the explanation is not known.

Collection V, the CU swampy-plains collection, shows several marked differences from the other two. Although the concentration of *Leptomeryx* remains as high as in the open-plains populations, *Eumys* is rare, *Paleolagus, Ischyromys,* and *Hypertragulus* have decreased, and several of the less-common small genera are absent or rare. *Mesohippus* + *Merycoidodon* have increased, relative to the total fauna. This increase is not, as the following table shows, a simple gain by default of the smaller animals:

Ratios to Large and Medium-sized Populations.

Collection	*Mesohippus*	*Merycoidodon*
XII Total Near-Stream	33%	43%
X Total Sage-Creek Open Plains	32%	41%
V CU Swampy Plains	41%	36%

Since the population of *Mesohippus* has risen markedly, while the population of *Merycoidodon* has fallen, relative to their size-group, one may presume that this constituted a most favored niche in *Mesohippus*' local range.

These population changes, involving *Mesohippus, Merycoidodon, Eumys,* and to a lesser extent *Ischyromys* and *Paleolagus,* support the hypothesis that this locality differed geographically from the adjacent collecting area immediately to the east. Collection II, SDSM open-plains collection, therefore represents a mixed fauna. Probably the collecting area of Collection V represents merely a plain with broken forest cover supported by sub-irrigation, rather than an actual swampy prairie.

IV. Dillon Pass Area Open-Plains Collections. Graphs III, IV, XI.

A. *General.* Varzea and igapo sediments meet in the locality where these collections were made. Paleogeographically, this should mean that the influence of the nearest through-going streams was minimal; local hillside wash brought as much sediment and water into the area as did the streams. Vegetational cover should, therefore, also have been minimal, and the population should be pure open-plains. Since the collections from this area did not give conclusive evidence that they represent a death assemblage (although there is no evidence against it), they have been regarded as doubtful, to be judged in terms of the more satisfactory Sage Creek collections. Their comparatively small size also limits their usefulness.

Comparison of Graph XI with Graph X shows immediately that the same population trends are present but more accentuated at Dillon Pass. Small animals make up 91 per cent rather than 81 per cent of the fauna. The commonest forms are *Leptomeryx*, *Paleolagus*, *Ischyromys*, and *Hypertragulus*, in that order. Carnivores continue between 4 and 5 per cent, with *Hesperocyon* the prevalent genus. *Mesohippus* and *Merycoidodon* are present, but in greatly reduced numbers. Between them they make up 3 per cent of the population, rather than 11 per cent as in the Sage Creek open-plains collection. Furthermore, both have been reduced relative to the total large and medium-sized population, *Mesohippus* from 33 per cent to 20 per cent, and *Merycoidodon* from 41 to 13 per cent. The general aspect of the assemblage is one of trends carried beyond those at Sage Creek. The accordance of this faunal community with the facies predictable from the paleogeography suggests that these small collections represent perthotaxic assemblages, just as the larger ones at Sage Creek do.

B. *Individual collections.* The individual collections show no peculiarities worthy of note, due partly to the high variance induced by their small size.

V. SDSM Swampy Plains Fauna. Graph VI.

A. *General.* Lithologic evidence that this was once a swamp is much stronger than the evidence indicating a swamp environment for Collection V, which actually shows merely some indication of more sub-irrigation than the adjacent areas. Collection VI might logically be expected to resemble the near-stream collections even more than does Collection V. It should differ appreciably from the open-plains collections, even though the edges of the two collecting areas are within 200 yards of each other.

The collection amply bears out this prediction. Medium-sized animals make up almost half of the population. The rodent-rabbit group is down to 10 per cent of the total, with *Ischyromys* the only genus relatively common. *Leptomeryx* has dropped to 23 per cent, while *Hypertragulus* has risen to 11 per cent. However, the increase in *Hypertragulus* may be due to a biologic accident: this collection includes a herd of at least 22 individuals, all young adults, which died and were buried within a four-foot radius. The single mass death has almost certainly unduly weighted the count of *Hypertragulus*, and also the percentages of artiodactyls and small animals.

Mesohippus apparently found its favorite environment here. It formed 30 per cent of the entire fauna, and 59 per cent of the large-to-medium sized fauna, considerably higher than in the near-stream assemblage. Conversely, *Merycoidodon* drops to 12 per cent of the total and 24 per cent of the large-to-medium-sized population.

Generally, the swampy plains community was low in rabbits and rodents (except *Ischromys*), low in *Leptomeryx* and *Merycoidodon*, and very high in *Mesohippus*. It may also have been high in *Hypertragulus*, but was not necessarily so.

B. *Individual collections.* Collection VI, SDSM, is quite different from collection V, CU. The latter is almost invariably intermediate in composition between the near-stream faunas and the open-plains faunas. Collection VI always closely resembles the near-stream fauna in those aspects in which it is intermediate. The reduction of rodents and rabbits is carried beyond that of the near-stream assemblage (however, our 1965 collection, as yet unstudied, indicates that the extreme reduction may be a collecting bias). *Merycoidodon* is most abundant in the near-stream community, less so in the CU swampy plains fauna, and least (of the well-watered areas) in the SDSM swampy plains fauna. The percentage of *Mesohippus* is directly reciprocal of this. Since the two forms are of roughly the same size, the figures probably reflect a real preference of *Mesohippus* for swamps and *Merycoidodon* for forested river-banks.

ECOLOGIC RELATIONSHIPS OF PARTICULAR GENERA

The table, Figure 56, lists the total fauna as known from our collections. Obviously, this is not the total known fauna of the Lower Nodular Zone. Our 1964–65 collections have made several additions, which will be reported as studies progress. The data on organisms other than mammals are included to assist the reader to evaluate the total ecologic setting of the mammals. We have included some, but not all, non-mammal additions of 1964–65.

I. Plants.

Known fossil plants include *Celtis* (hackberry) seeds; algal balls, incrustations, strands, and *Charagonia*; and some doubtful root casts. A few thin sections of sediments have revealed what may be spores; it is hoped that careful study by a competent palynologist may reveal much about the flora from study of spores. Meanwhile, it is apparent that our direct knowledge of the Brule flora of the area is so meager as to be meaningless.

II. Invertebrates.

Molds of *Unio* shells, frequently encrusted with algae, occur on the borders of and within the riosomes and drenajesomes. Pond snails of at least three genera occur abundantly in the limestone in the SDSM swamp locality, and less commonly in the varzea sediments near the riosomes. Ostracods are also abundant in the swamp limestone. Ovoid, smooth-surfaced masses of clay reputed to be casts of pupa cases or of larval burrows, varying in size from ¼ × ¾ in. to giants, ¾ × 1-½ inches, have been collected from all localities except those of the Dillon Pass. They are largest and most abundant in the swamp limestone.

The invertebrate fauna is almost as poorly represented as are the plants.

III. PISCES.

A few scraps of teleost bone, apparently representing two families, are under study. They have been found in the riosomes and in the swamp limestone.

IV. AMPHIBIA.

Bufonid humeri occur rarely. They also are under study.

V. REPTILIA.

Rhineura has been found in the near-stream locality, and *Peltosaurus* rarely in all localities except Dillon Pass. *Graptemys* is the only aquatic turtle included in the collection; it occurs in riosomes. *Stylemys* occurs commonly in all localities except Dillon Pass, where it is rare. It is most common, however, in the near-stream localities, and less common in both the dry plains and the swamp localities. It seems probable that *Stylemys* was capable of living in any of the local environments. but preferred forests to either swamps or open, grassy plains

VI. AVES.

The birds represented were both, apparently, shore or wading birds, and both were found along a rio margin.

VII. MAMMALIA.

A. Marsupialia.

1. *Peratherium*. This genus is exceedingly rare in South Dakota, as compared with Chadron and Brule faunas of Nebraska, Colorado, and Montana. Its presence at Florissant and relative abundance at Pipestone Springs suggests that it was at least forest-living if not truly arboreal. Relative rarity in the Big Badlands might mean either that forests were less dense or less prevalent there, or that some other element necessary to the ecology of *Peratherium* was missing in South Dakota forests. Consideration of the habits of Recent opossums leads the authors to favor the first hypothesis.

The relative abundance of *Peratherium* in Nebraska, in areas lying presently several hundred feet above the Big Badlands suggests a possible altitudinal control of vegetation, with the Big Badlands near the lower limit of forests. A similar situation is common to most semiarid regions today. There is no structural evidence that the elevation of the Badlands has changed significantly relative to Nebraska, since Oligocene time.

The alternative explanation, that of a latitudinal thermal gradient sufficient to discourage oppossums from the Big Badlands, seems most improbable. Even the present high thermal gradient is locally obscured by differences in elevation; the temperatures of northwestern Nebraska, both annual and daily, do not differ significantly from those of the Big Badlands. Oligocene world-gradients were certainly less steep than the present one. We have no reason to believe, therefore, that appreciable climatic differences existed between the two areas, other than the differences due to relative elevations.

B. Insectivora.

1. *Ictops*. The numbers collected are so small as to be insignificant, except as they indicate the probable presence of *Ictops* in all local habitats.

C. Lagomorpha.

1. *Paleolagus*. This genus is ubiquitous, but shows a strong preference for dry plains. The observed percentages in near-stream collections are almost certainly too low; our 1964–65 collections suggest that *Paleolagus* may have constituted between 5 and 10 per cent of the total assemblage. The contrast between this and 20–30 per cent for the dry plains is certainly significant. The known preference of *Sylvilagus* for brush and edge-of-forest niches may find a homologue here, but we cannot be sure.

Our collections suggest that two or more species of *Paleolagus* are involved. Analysis may reveal a closer restriction to habitat at the specific level.

2. *Megalagus*. A few specimens from each major habitat tell us only that this rabbit was present but rare in each.

D. Rodentia.

1. *Prosciurus*.

2. *Adjidaumo*.

These genera are represented by too few specimens to be significant.

3. *Eutypomys*. Although the numbers of specimens are too small to be significant, there is a suggestion that *Eutypomys* may have preferred a near-stream, forest environment. This is not evidence that they were or were not swimmers.

4. *Ischyromys*. *Ischyromys* was ubiquitous, common, and amazingly uniform in relation to the total assemblage. It varied from 7 to 16 per cent of the entire census, generally lower in the near-stream and swamp faunas, where it was the most numerous of the Glires, and higher in the plains areas, where it was far outstripped by *Paleolagus* but remained second only to the latter. Populations are large enough to suggest several ecologic hypotheses, but not to establish them.

First, since the population of *Ischyromys* varies accordantly (although not proportionally) with that of *Paleolagus*, the two were not in direct or acute competition for food. Otherwise the overwhelming preponderance of *Paleolagus* in their preferred, dry-plains habitat would have resulted in a decrease of *Ischyromys*.

Possibly *Paleolagus*, like the modern rabbits, fed mostly upon leaves of grasses and herbaceous plants, while *Ischyromys* ate chiefly seeds. The fist-sized aggregations of *Celtis* seeds which occur uncommonly in the dry-plains area might, judging from the size of the seeds and the aggregations, be hoards collected by *Ischyromys*.

Second, *Ischyromys* is commonest in the areas where trees were least common. It is therefore probable that these animals were ground-dwellers rather than predominantly arboreal in habit. Whether they dug burrows is not known; a reported occurrence of an *Ischyromys* skeleton inside a *Stylemys* shell (this we have not seen) would suggest that they found shelter on the ground, as modern chipmunks do. The cranial anatomy strongly indicates a terrestrial habitat. We regard it as probable that they lived in shallow burrows or in grass nests, but could climb trees.

5. *Eumys. Eumys* is always less common than *Ischyromys*, varying between 1 and 6 per cent of each collection, but is quite as ubiquitous and its population size roughly parallels that of *Ischyromys*. Unfortunately, the total populations are too small for statistical significance. Its apparent preference for dry plains may be an artifact and at best is only a suggestion.

E. Carnivora.

Since the total carnivore population is under 10 per cent of the total faunal assemblage for any habitat, all evidence of its composition must be regarded as inconclusive.

Hesperocyon seems to have been the most numerous, with *Dinictis* second. The variety but extreme rarity of small carnivores other than *Hesperocyon* is worthy of note; we do not understand it. The large number of *Daphoenus* relative to the cats will be surprising to anyone acquainted with the rarity of *Daphoenus* in the various large previous collections. We believe this demonstrates the fallibility of our collections at this numerical level, rather than any characteristic of the life assemblage.

Anatomical interpretations of the habits of Brule carnivores have led to a curious anomaly. *Dinictis* and *Hoplopheneus* are obviously cat-like in their adaptations and general way of life. The post-cranial anatomy of *Daphoenus* is, except for the phalanges, more cat-like than dog-like (see Scott and Jepsen, 1937, pp. 55–78). In its adaptive characters, *Hesperocyon* strongly resembles the viverrids (*ibid.*, pp. 81–105). *Hyaenodon* is generally supposed, due to the massive head, "weak" feet, and heavy teeth, to have been a scavenger.

The niche of a medium-sized, cursorial, terrestrial carnivore is apparently open, in a mammalian community most of whom would be vulnerable to attack by such a predator. Moreover, this community represents in large part an invading ecosystem (see p. 69, this report) which had a long history as a savanna chronofauna in its original home. It is certainly possible that Brule savannas and prairies may have been well-enough vegetated with brush and high grass to discourage such active runners as coyotes—pre-Columbian Illinois and western Missouri had low coyote populations—but gray wolves do not restrict themselves to short-grass plains, and dholes, dingoes, jackals, and *Chrysocyon* certainly live in vegetated places.

A brief study of *Hyaenodon* indicates that the absence of a cursorial carnivore may be more apparent than real. All three molars participate in the formation of a shearing blade which occupies up to 40 per cent of the total cheek-tooth length, as opposed to under 30 per cent in *Hyaena*. The musculoskeletal structure of the calvarium strongly resembles that of *Hoplophoneus* and differs so extremely from that of *Hyaena* as to be worthy of a separate study. The zygoma is as light proportionally as that of *Martes*. The ascending ramus is exceedingly short, as in *Hoplophoneus*, and the entire anatomy of the posterior moiety of the jaw resembles that of a cat rather than of *Hyaena*. The feet are, unlike those of *Hoplophoneus*, digitigrade. In fact, the name "*Hyaenopus*" might have been less a misnomer than "*Hyaenodon*."

The only anatomical factors weighing against a cursorial predator's role for *Hyaenodon* are the extremely large skull and relatively small feet.

The balance of the anatomical evidence suggests that *Hyaenodon* was an active predator, probably not as cursorial as the modern wolf or coyote. It might well have hunted more in the fashion of the lion, while *Hoplophoneus*, *Dinictis*, and *Daphoenus* hunted more from ambush, like leopards and jaguars.

Scavenging probably was done by any hungry individual of any species who happened upon a carcass, but no one mammalian group specialized for this activity; insects probably did the bulk of the scavenging. Abundant stock of available prey might have resulted in a very low mammalian scavenging pressure, which is in accord with the perthotaxic evidence previously discussed.

F. Perissodactyla.

1. *General.* The four genera listed in the table, plus *Subhyracodon* and *Metamynodon* which are known but not listed, all represent lines present in known Eocene wet-forest chronofaunas. The perissodactyl fauna differs qualitatively from that of Chadron time in the absence of titanotheres and in the reduction of the remaining perissodactyl population relative to the total fauna. Climatic change resulting in a general shift from forest to savanna-prairie and prairie is the most evident cause of the waning of this previously dominant order. *Colodon*, *Protapirus*, *Hyracodon*, and *Metamynodon* survived only barely into Whitneyan time, and became extinct by the end of it. *Mesohippus* and the true rhinoceroses adapted, albeit with difficulty, to their changing environment.

2. *Colodon.* No statistically significant collection of *Colodon* is known. Its presence in the open-plains collections of both Sage Creek and Dillon Pass poses a real enigma. Certainly there is abundant anatomic, taxonomic, and stratigraphic evidence suggesting that

Colodon was a forest animal. We do not know why the two individuals represented in the open-plains collections travelled in such company.

3. *Hyracodon*. *Hyracodon* seems to have been an uncommon but ubiquitous animal. It seems less common in our collections than in most of the classic collections from the Big Badlands. This may be an erroneous impression, or it may represent a bias of previous collection.

4. *Caenopus-Subhyracodon*. These two genera have been lumped and referred to as *Caenopus*, due to the difficulty of discriminating between them on the basis of fragmentary specimens. In any case, two specimens from the open plains and eight from the near-stream area can tell us only that large, wide-ranging rhinoceroses did occur as rare elements of the fauna. Since this group shares with *Mesohippus* the distinction of adapting to the changing environment, rarity during Brule time may indicate a period of near-extinction preceding their successful adaptation.

5. *Mesohippus*. *Mesohippus*' predilection for a swamp and forest habitat receives adequate documentation from the collections. The genus was, during Orellan time, meeting the change in climate by restricting its life to those relicts of the old forests which still remained. The number of individuals within the swamp and forest areas suggests that *Mesohippi* were highly successful there. The high percentage of late adolescent individuals in all collections indicates a probable even higher mortality of infants and juveniles, all trace of which is generally lost. *Mesohippus*, therefore, was almost certainly a much more important element of the faunas of its favored habitats than its numbers in collections indicate.

In contrast with their abundance in Orellan sediments, horses are one of the rarer fossils in Whitneyan rocks of Nebraska and South Dakota. Progressive cooling and drying during that time almost eliminated them from the area. Near-extinction may have been local, with abundant, evolving populations in other parts of the continent, or may have been general. In either case, the group recovered within the area during Miocene time, triumphantly adapted to their new environment.

G. Artiodactyla.

1. *General*. Artiodactyls first became dominant elements of known faunas during late Uintan time. The Uinta C fauna consists primarily of small and medium-sized artiodactyls, with lesser numbers of titanotheres, rhinoceroses, achaenodonts, and carnivores. The Uintan artiodactyls were, as far as known, all well-adapted wet-forest forms. Smaller genera filled the niches occpied in modern wet forest by rabbits, large terrestrial rodents, musk deer, and small jungle antelope. Their perissodactyl competitors were tapiroids and the exceedingly rare *Epihippus*. Rodents and rabbits apparently offered little competition. The number of genera of artiodactyls was high, reflecting a high adaptability and diversity of habitat within the wet-forest environment.

Chadron artiodactyls are diverse, and readily divisible into two groups: descendants of the Eocene jungle chronofauna on the one hand, and immigrants on the other. Several of the immigrants seem better adapted to a savanna than to a wet-forest environment. The Chadronian faunas in South Dakota show a dominance of perissodactyls by number of individuals. The numbers of genera representing the two orders are nearly equal, with a preponderance of artiodactyl genera. Exact counts have little meaning, because of the need of complete taxonomic revision of Chadronian artiodactyls.

Our collections indicate the apparently sudden eruption of the Artiodactyla into a dominance which they rarely if ever have lost. Thirteen genera compare with five of perissodactyls. Artiodactyls consistently comprise 43–55 per cent (see Table XIII) of the total mammalian census including rodents. Even in the near-stream and swampy plains habitats, favored by the relict *Mesohippus*, the total perissodactyl census is not over 70 per cent of the number of Artiodactyls. *Merycoidodon* is the most abundant single genus in the near-stream fauna, and *Leptomeryx* in the open plains; in the swampy plains fauna, *Leptomeryx* is second only to *Mesohippus*. In every case, the most abundant artiodactyl is more numerous than the most abundant rabbit or rodent.

The artiodactyl genera can be divided into two groups, the first consisting of relict genera with known late Eocene forest ancestors, the second comprising Chadronian or Orellan immigrants:

Relict genera	Oligocene immigrants
Leptochoerus	*Archaeotherium*
Stibarus	*Perchoerus*
Agriochoerus	*Bothriodon*
Hypertragulus	*Merycoidodon*
	Bathygenys
	Poebrotherium
	Leptomeryx
	Hypisodus
	Leptauchenia

Comparison of this listing with our collections is most instructive. *Leptochoerus* and *Stibarus* occur in the open plains and swampy plains faunas, but in such small numbers as to make their presence or absence insignificant. (The senior author has, in earlier years, collected both from near-stream sediments). *Agriochoerus* shows up in equal numbers, still insignificant, in the open plains and the near-stream faunas. *Hypertragulus* makes up 5–8 per cent of the open plains fauna, 11 per cent of the swampy plains assemblage, and less than 2 per cent of the near-stream fauna. The relict group are all uncommon to rare; the distribution of *Hypertragulus* suggests that it lived in marshes and high grass.

Of the immigrant group, *Merycoidodon* shows an obvious preference for a near-stream environment, and *Leptomeryx* for open plains. *Bathygenys* and *Leptauchenia* are known from one specimen each, and *Perchoerus* from three. Thirteen specimens of *Hypisodus*, all from open plains, and four of *Bothriodon*, all from near-stream, are statistically insignificant but interesting as they may suggest favored habitats in keeping with the animals' anatomy. *Archaeotherium* and *Poebrotherium,* both forms whose anatomy strongly suggests active movement over dry ground, occur in insignificant numbers in both near-stream and open-plains collections. The immigrant fauna apparently included species adaptable to all three of the habitats recognized here.

2. *Leptochoerus* and *Stibarus.* As already indicated, our collections can tell us nothing of the habits of these two forms.

3. *Archaeotherium.* The geographic distribution of *Archaeotherium* in the Lower Nodular Zone is exceedingly sporadic throughout the Big Badlands. Specimens occur in fairly large numbers at the near-stream locality, at Princeton "Entelodon Peak" locality (NW 1/4 Sec. 5, T. 4S., R. 13E., Pennington Co.), just south of the Sage Creek Dry Plains area of this report (center, Sec. 22, T. 2S., R. 15E., Pennington Co.), and 1 mile south of Dillon Pass (center, Sec. 33–34, T. 2S., R. 16E., Pennington Co.). The senior author knows of from 3 to 12 skulls collected from each of these localities, in addition to the specimens listed in the Sage Creek and Dillon Pass collections of this report. Conversely, the authors have seen only one identifiable scrap or specimen of *Archaeotherium* in the classic collecting locality of Big Hollow-Bear Creek, Sec. 3, 4, 9, and 10, T. 4S., R. 13E., and Sec. 34, T. 3S., R. 13E., Pennington Co. *Leptomeryx* occurs in fair numbers at the classic locality, and *Merycoidodon* skulls tend to be smaller on the average than those at Cottonwood Pass and Entelodon Peak. It seems probable that *Archaeotherium* inhabited some notably restricted band within the spectrum of ecologic niches available during Lower Nodular time.

4. *Perchoerus.* Occurrence of *Perchoerus* in insignificant numbers both in the near-stream and the open plains collections indicates merely that we have no adequate evidence of its habitat. In view of the size and rarity of *Perchoerus* in South Dakota, statistically adequate collections probably cannot be made.

5. *Bothriodon.* Once more, the number of specimens is statistically insignificant. However, all of the specimens came from rio borders, and we have collected others from actual riosome sands. We have never seen a scrap of any anthracothere bone in the open-plains environments. This suggests, but does not demonstrate, that the anthracotheres lived in streams and along their banks.

6. *Merycoidodon.* The evidence clearly indicates that *Merycoidodon* preferred the river-border forests to either open plains or swamps. Separation of the smaller species, *M. gracilis,* from the more abundant, larger *M. culbertsoni* reveals an even sharper preference for forests on the part of the latter. Although the numbers lie below the level of significance, there is a strong suggestion that *M. gracilis* preferred swamps and open plains.

Neither the limb structure nor the dental equipment of *M. culbertsoni* gives any particular support to the often expressed idea that it frequented plains and grassy prairies. Its relatively broad, short, tetradactyl feet, femur and humerus as long as antibrachium and tibia respectively, complete fibula, and generally heavy build certainly suggest less adaptation to cursorial plains existence than do the corresponding structures in *Mesohippus,* which is universally regarded as a "forest horse." The brachydont dentition, like that of almost all Orellan mammals, gives no indication of adaptations for grazing. The distributional evidence therefore reinforces the anatomical indications of a forest habitat for *Merycoidodon culbertsoni.*

M. gracilis shows no anatomical differences attributable to its presumably different habitus. It might be either that we are misinterpreting inadequate data, or that *M. gracilis* was not yet highly specialized for its environment.

7. *Agriochoerus. Agriochoerus* was present in small numbers both in the gallery forest and on the open plains. The numbers collected are statistically insignificant.

8. *Bathygenys.* One specimen of this rare, small form was found, surprisingly, in the open plains area. Since previous specimens all came from Chadronian deposits in Montana, from presumably forested intermontane basins, this specimen is anomalous.

9. *Leptauchenia.* One specimen of *Leptauchenia* represents a downward extension of the genus from Whitneyan sediments, in which it is abundant, to Orellan, in which it has not previously been known. Considered separately, its occurrence in open-plains sediments means only that one individual died in that area. Taken in conjunction with its universal presence in varzeasomes and absence from riosomes of Whitneyan age, the paleogeographic evidence strongly suggests that *Leptauchenia* was not so aquatic as its anatomy supposedly indicates.

10. *Poebrotherium. Probrotherium,* of all Orellan genera, might be expected to show a preference for the open plains. With nine specimens from the open plains, eight from the near-stream, and one from the swampy plains, it apparently shows no preference at all. The samples are not significant, except as they show that *Poebrotherium* occurred uncommonly but ubiquitously.

11. *Hypertragulus.* Our collections reveal that a strong habitat preference, rather than actual rarity, is responsible for *Hypertragulus*' poor representation in previous collections. The vast majority of the earlier Orellan collections were made in the near-stream areas south and southwest of Scenic, where both *Leptomeryx* and *Hypertragulus* are uncommon. *Hypertragulus* was proportionally most abundant in the swamp fauna and apparently was only slightly less important an element of the open plains community. It varied from half as abundant as *Leptomeryx* in the swamp to one-third or one-sixth as abundant in the open plains. (Total numbers of both in the near-stream environment are too small for statistical significance; our later collections confirm the relative scarcity of both in the near-stream

area, but suggest that *Leptomeryx* may have been the more numerous of the two).

Another interesting sidelight on the environment of *Hypertragulus* has been revealed by the distribution of specimens. In 1937, the senior author collected a group of over 20 skeletons of *Hypertragulus*, huddled together in rather comfortable "sleeping" poses, 18 of them with their noses east and all beautifully articulated. The group occurred near Entelodon Peak in the near-stream area. All were very young adults, with $M\frac{3}{3}$ partially erupted but unworn. The presumption was that this herd had either died of epidemic or had been overwhelmed by a windstorm as they lay with noses downwind. (The major portions of this find are in the Carnegie Museum and the University of Colorado Museum).

In 1956, the senior author discovered another group of about 20 skeletons, this time in the swamp area. The bones were partially disarticulated by perthotaxy, but burial apparently did not move them. Again, they were all very young adults. This find is in the South Dakota School of Mines Museum, and the specimens are included in our statistics.

In 1965, the junior author found a third group of *Hypertragulus* skeletons, this time largely disarticulated by perthotaxy. The bones covered an area about 2½ by 8 ft. in extent, and were disposed through 18 in. of vertical thickness, in a convex front. One rodent jaw was found with them, but no other fossils. This find has not yet been prepared, but we are sure of more than ten individuals, all very young adults. We interpret this find as representing a herd assemblage in advanced perthotaxy, picked up by the rolling front of a mudflow and transported not over a very few feet. Longer transport would have scattered the already separate bones, and mixed them with those of other forms.

We have represented here three herd assemblages, all young adults at time of death, in three different stages of perthotaxy at time of burial. Obviously, the mechanics of their burial were unrelated to the cause of their death. Obviously also, they were not killed by predation or by physical accident, since the individuals in the first group were in perfect condition. Drought or famine are improbable, because the animals were of the age group most resistant to such deprivations. We are therefore left with the probability that *Hypertragulus* was subject to fatal epidemics which struck particularly at late adolescents. Whatever the disease was, its victims characteristically died peacefully, without convulsions, and probably quite rapidly. Had the illness been of long duration, less seriously sick individuals should have wandered and the tight herd would have broken up. The animals in groups 1 and 2 (and presumably also in 3) probably died within hours of the time when they were still well enough to walk to their final resting place and lie down there.

The swamp habitat suggested for *Hypertragulus* conforms with the anatomical evidence of the relatively short, tetradactyl feet, and retention of a vestigial tibia.

12. *Leptomeryx*. *Leptomeryx*, like *Hypertragulus*, shows definite evidence of its preferred habitat. From a minor element in the near-stream fauna, it increases to 23 per cent of the swamp community, and over 30 per cent of the open plains assemblage. It is as numerous as the next two commonest genera, *Paleolagus* and *Ischyromys*, combined. *Hypertragulus*, which is half as common as *Leptomeryx* in the swamp habitat, is less than one-fifth as common in the open plains. The generally long limbs and feet, didactyl pes, and loss of the fibular shaft give anatomical confirmation of the paleogeographic evidence that *Leptomeryx* was an active runner on dry ground.

The abundance of *Leptomeryx* spotlights the apparent absence of an efficient cursorial carnivore. If, as seems probable, this genus evolved as part of a developing savanna chronofauna during middle and late Eocene time, and invaded the general area as part of that chronofauna during Chadronian time, one would expect that an adequate cursorial carnivore would have evolved and immigrated with it. Such evidently was not the case. It would have been a difficult prey for *Hesperocyon*, so we must presume that it fell only to the short rushes of *Hyaenodon* and the ambushes of *Daphoenus* and the feloids.

13. *Hypisodus*. Here again we have a small artiodactyl which, although in this case rare, shows a predilection for open plains. Again, the didactyly and long, slender limbs indicate cursorial abilities. In *Hypisodus* the plains habitat is indicated even by the teeth which, as the name indicates, are distinctly long-crowned. To the best of our knowledge, this is the oldest herbivore genus with long-crowned molars.

SUMMARY

The paleogeography established in the previous chapter offers us a record of several adjacent life habitats, coexistent through a brief time (the 200–2000 years necessary to deposit the Lower Nodular Zone), without a significant climatic change. Three easily recognizable habitats, a near-stream zone presumably occupied by gallery forests; an open-plains area, far from any stream, which might have borne plains, prairie, or savanna vegetation; and a swamp area within the plain, were chosen for ecologic study.

Fossils occurring in all three situations were buried by engulfment *in situ*; they were not transported. They therefore represent buried perthotaxies, modified only by later bias factors.

Considering the total mammal population of the three local habitats as the universe to be studied, differences between this universe and the collection as an ultimate sample are produced by seven groups of factors:

Biotic
Thanatic
Perthotaxic
Taphic

Anataxic
Sullegic
Trephic

These operate differentially upon individual species or genera within a fauna. They function both separately and as inter-related variables. Biotic and thanatic factors combine to produce the death assembly, the total number of corpses arriving upon a surface before the next episode of sedimentation. This is a sample of the life assemblage. Perthotaxic and taphic factors reduce the death assemblage to the total fossil assemblage, a sample which in turn is reduced by the last three groups of factors to the collection. A collection is thus a sample of a sample of a sample of the life assemblage or community.

We have no way of evaluating the various biasing factors. We also have no complete census of any recent mammalian community to use as a norm. Therefore, it is necessary to determine by inspection whether or not the collections show enough consistency to indicate that they are adequate samples. Collections of over 300 specimens, from the same habitat, vary from each other by up to 10 per cent. Between collections of 100 to 300 specimens, the variance is about 20 per cent. Collections of under 100 specimens are of little value.

The near-stream gallery forests were inhabited by a community of rich generic variety, primarily of medium-sized mammals. *Merycoidodon* was the commonest; together, *Merycoidodon* and *Mesohippus* comprised 50 per cent of the total mammalian population. Small artiodactyls were present, but relatively unimportant.

Small animals dominated the open-plains habitat. *Leptomeryx* and *Paleolagus* together made up over half of the community, with *Ischyromys* third in importance. *Mesohippus* dropped to 6 per cent and *Merycoidodon* to 5 per cent.

The swamp community is not well known, but *Mesohippus* (30%), *Leptomeryx* (23%), and *Hypertragulus* (11%) were the dominant forms.

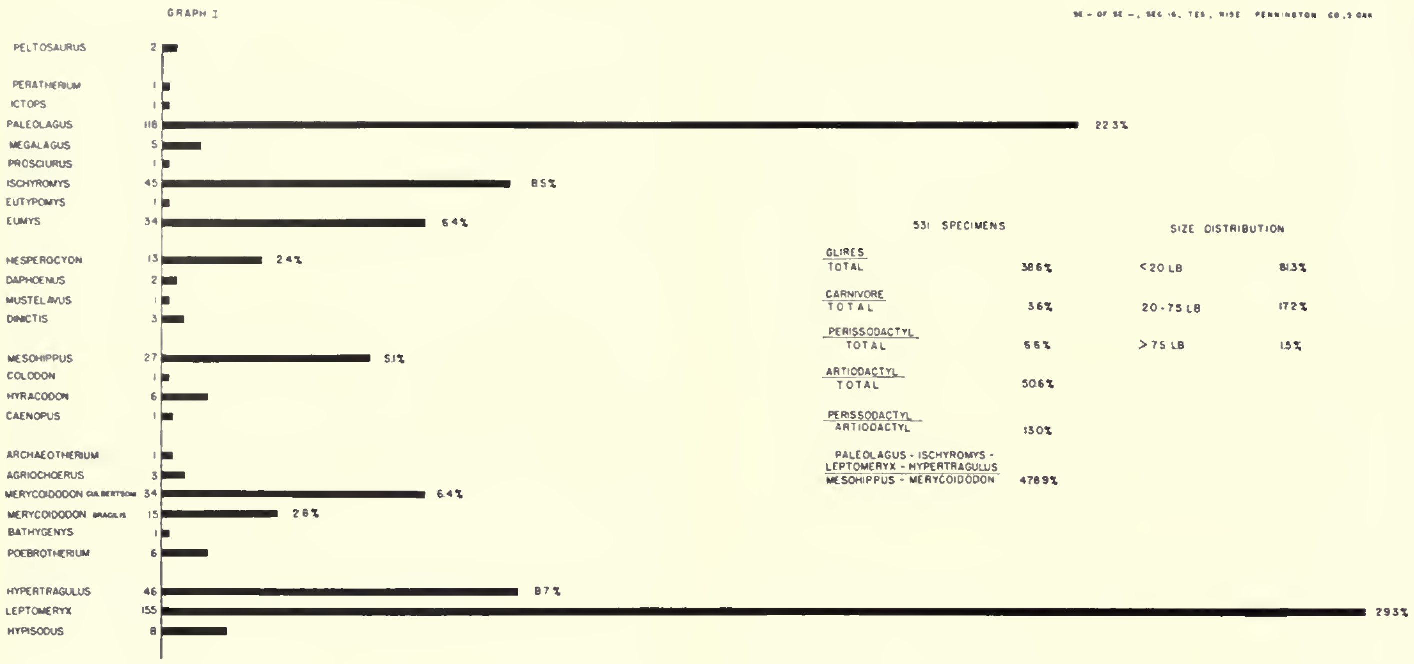
The habits of certain individual genera are considerably illuminated by the collections. *Paleolagus* and *Leptomeryx* were ubiquitous but much preferred the open plains. *Hypertragulus* was ubiquitous but preferred swamps; it ran in herds, and young adults were subject to virulent epidemics. *Ischyromys* was highly ubiquitous, and probably seeds formed the chief item of its diet. *Hypisodus* was a plains dweller. *Mesohippus* preferred swamps, although it also freely inhabited the gallery forests and to a lesser extent the plains. *Merycoidodon* strongly preferred forests; it constituted a minor element of the communities in other habitats.

Of the carnivores, *Hesperocyon* was most numerous. *Hyaenodon* was an active predator; it probably filled the niche of an entirely terrestrial, cursorial predator, although it was not very well adapted for running. The carnivore population formed 4–8 per cent of the total community in every habitat.

In general, the invading plains-savanna fauna which first appeared during Chadronian time had established dominance by Orellan time. Perissodactyls were decreasing in variety and in importance. *Mesohippus* maintained itself by clinging to the dwindling relicts of the old wet-forest environment. The artiodactyl-rodent-rabbit dominance so evident in mammalian communities ever since Orellan time was clearly recorded for the first time in the Big Badlands, although it had probably developed earlier as a savanna ecosystem in what is now the North Central States.

Ubiquitous occurrences of anatomically well-adapted plains forms in the gallery forests, and forest forms in the plains, may be due to: (1) biases in the samples; (2) incorrect or overspecific interpretations of habits from anatomy; (3) the fact that the gallery forests probably grew on firm ground and may have been quite open, at the same time that the plains may have been dotted with small thickets and woods.

COLORADO MUSEUM OPEN PLAINS FAUNA - SAGE CREEK



SDSM - OPEN PLAINS FAUNA - CENTRAL SAGE CREEK

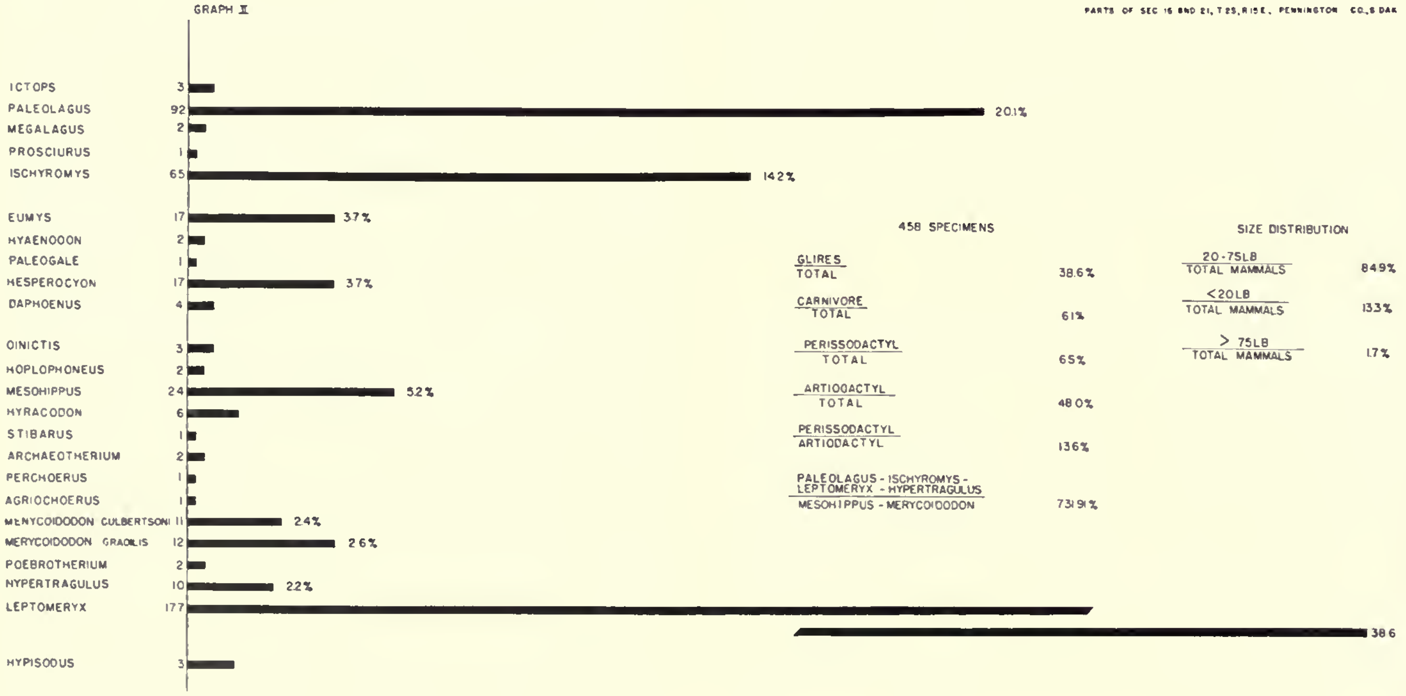
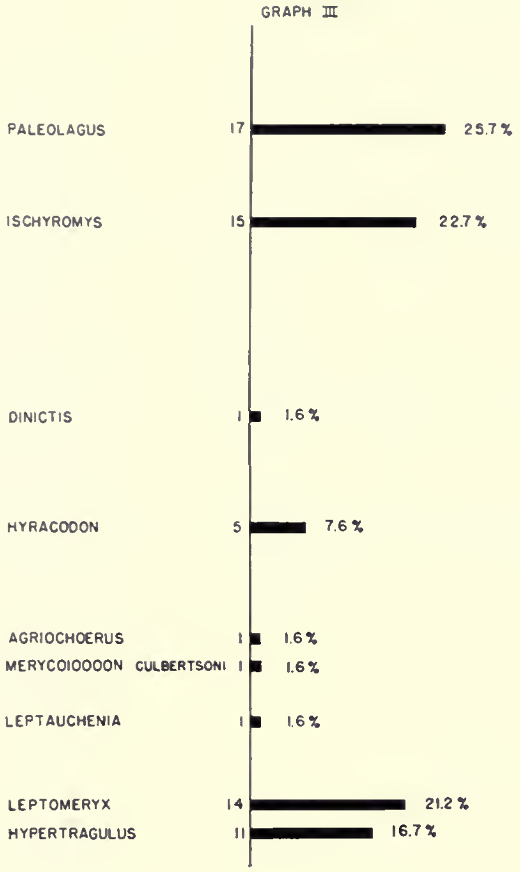


Fig. 54. Graphs I–XIII, population statistics.

SDSM-OPEN PLAINS FAUNA

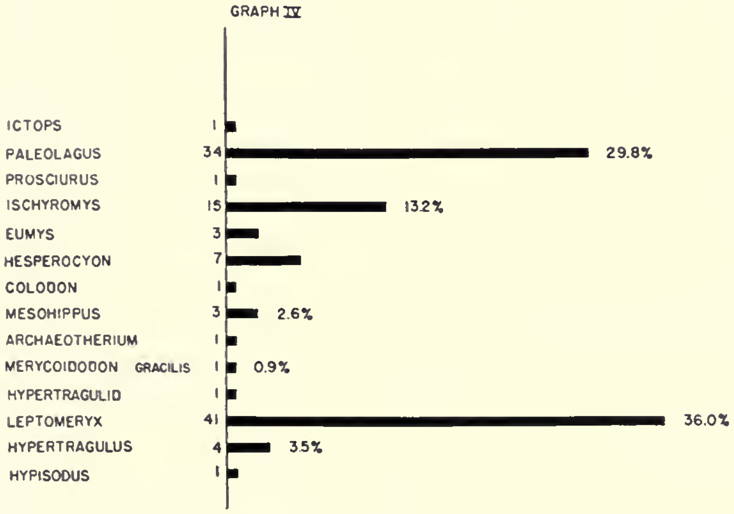
1 MILE S OF DILLON PASS JCT. CENTER, SEC 33-34, T3S, R16E



66 SPECIMENS		SIZE DISTRIBUTION	
GLIRES / TOTAL	48.5 %	< 20LB / TOTAL	86.6 %
CARNIVORE / TOTAL	1.6 %	20-75LB / TOTAL	4.5 %
PERISSODACTYL / TOTAL	7.6 %	>75LB / TOTAL	7.6 %
ARTIODACTYL / TOTAL	42.4 %		
PERISSODACTYL / ARTIODACTYL	17.9 %		
PALEOLAGUS-ISCHYROMYS LEPTOMERYX-HYPERTRAGULUS / MESOHIPPUS-MERYCOIDODON	5700.0 %		

SDSM-OPEN PLAINS FAUNA

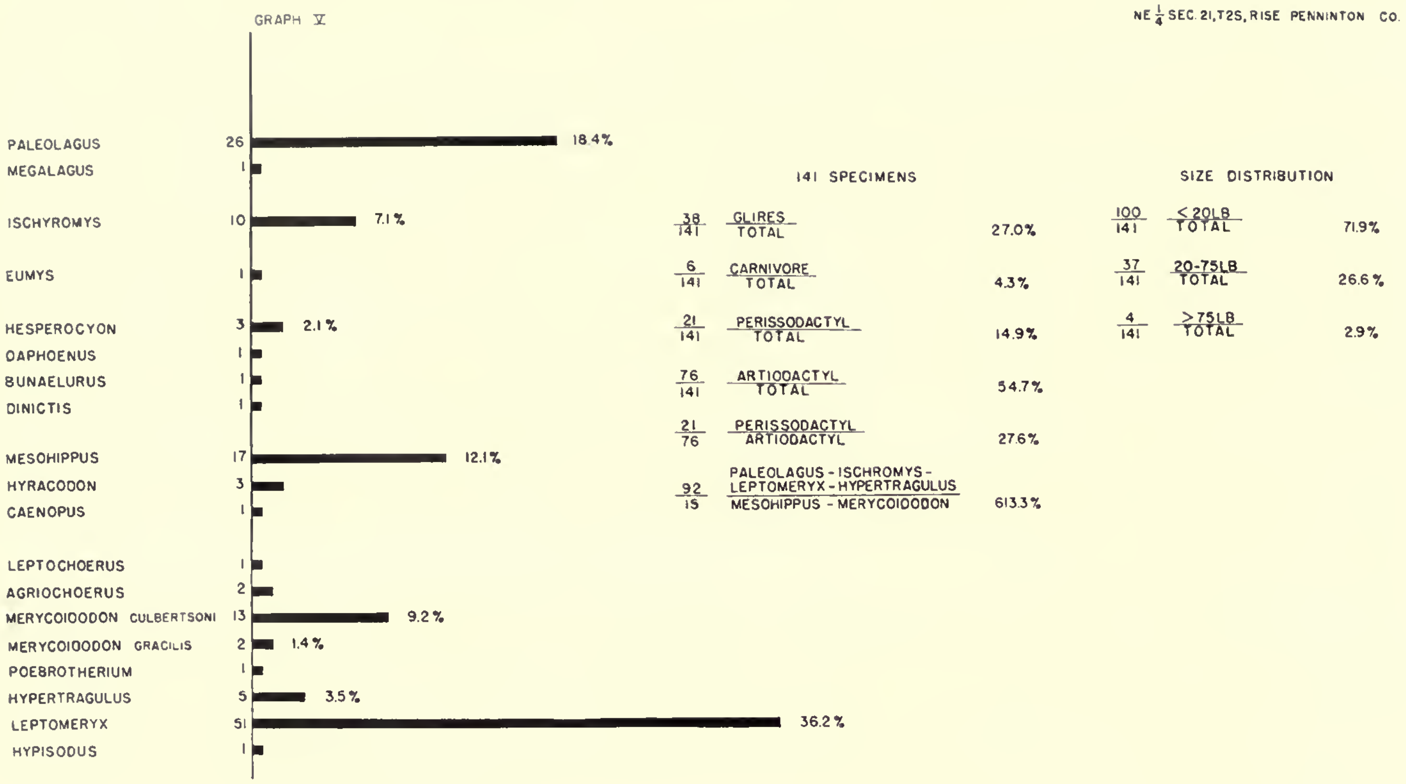
SE $\frac{1}{4}$ SEC 28 AND ADJACENT EDGE SEC27, T2S, R16E, PENNINGTON CO., S.DAK.



114 SPECIMENS		SIZE DISTRIBUTION	
GLIRES / TOTAL	46.5 %	≤20LB / TOTAL	94.7 %
CARNIVORE / TOTAL	6.1 %	20-75LB / TOTAL	4.4 %
PERISSODACTYL / ARTIODACTYL	3.5 %	> 75LB / TOTAL	0.8 %
ARTIODACTYL / TOTAL	43.0 %		
PERISSODACTYL / TOTAL	0.8 %		
PALEOLAGUS-ISCHYROMYS-LEPTOMERYX-HYPERTRAGULUS / MESOHIPPUS-MERYCOIDODON	235.0 %		

FIG. 54 (*continued*). Graphs I–XIII, population statistics.

COLORADO MUSEUM: SWAMPY PLAINS FAUNA



SDSM SWAMPY PLAINS

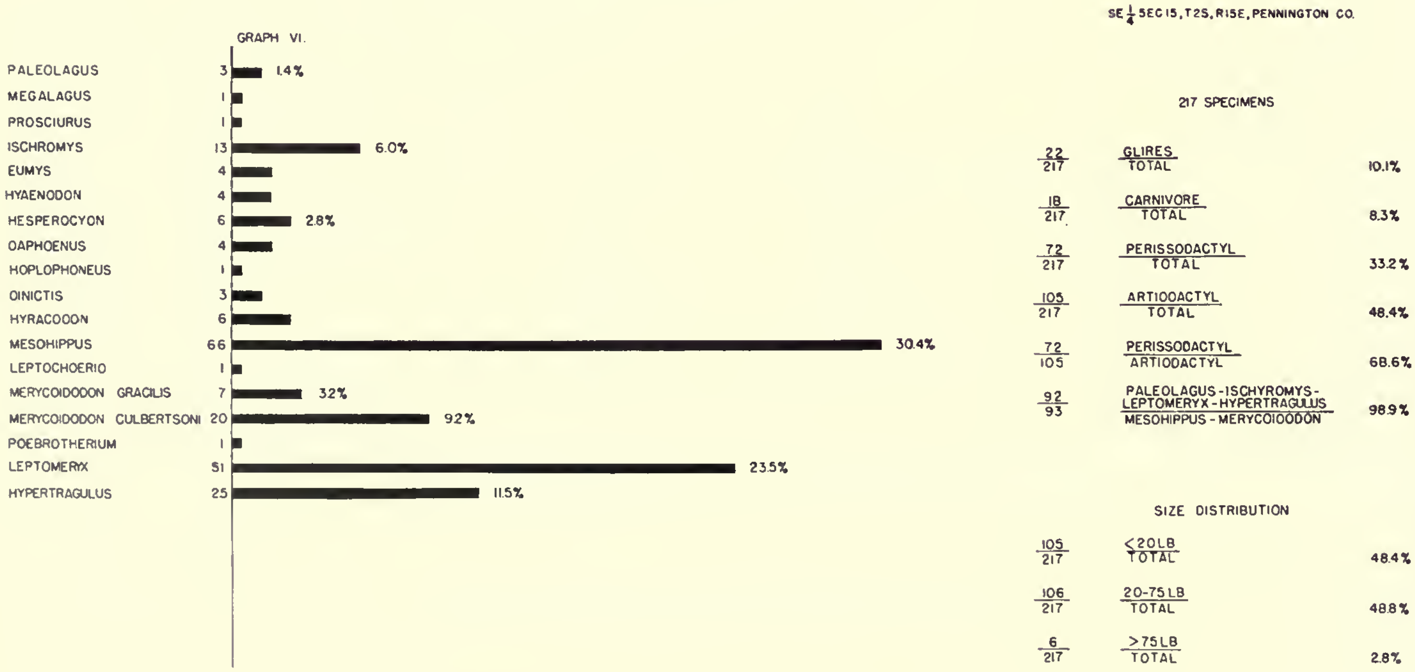
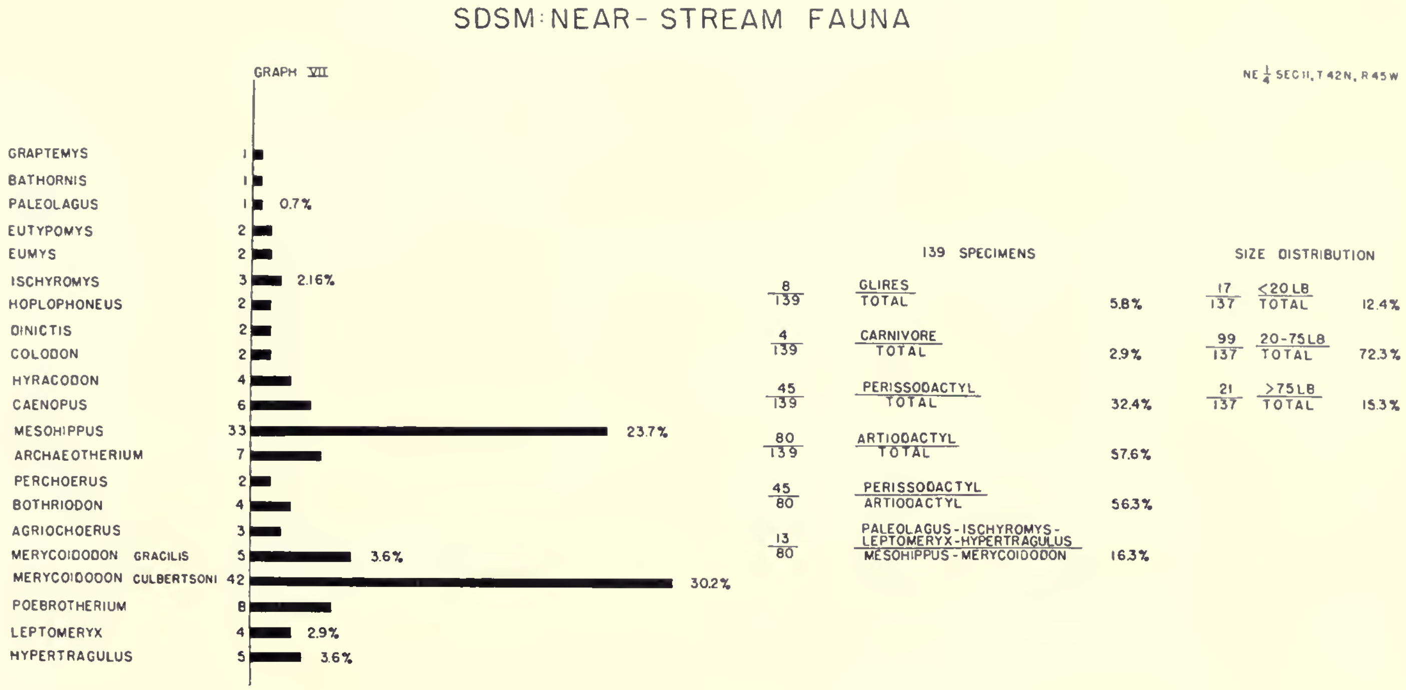


FIG. 54 *(continued)*. Graphs I–XIII, population statistics.



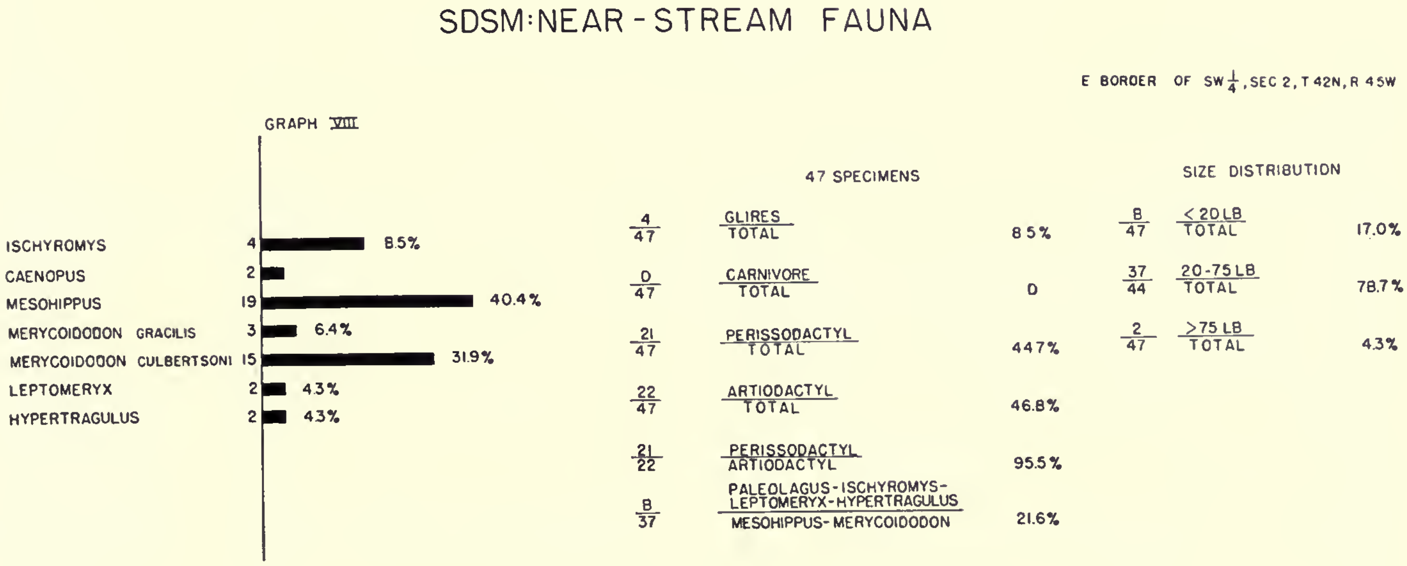
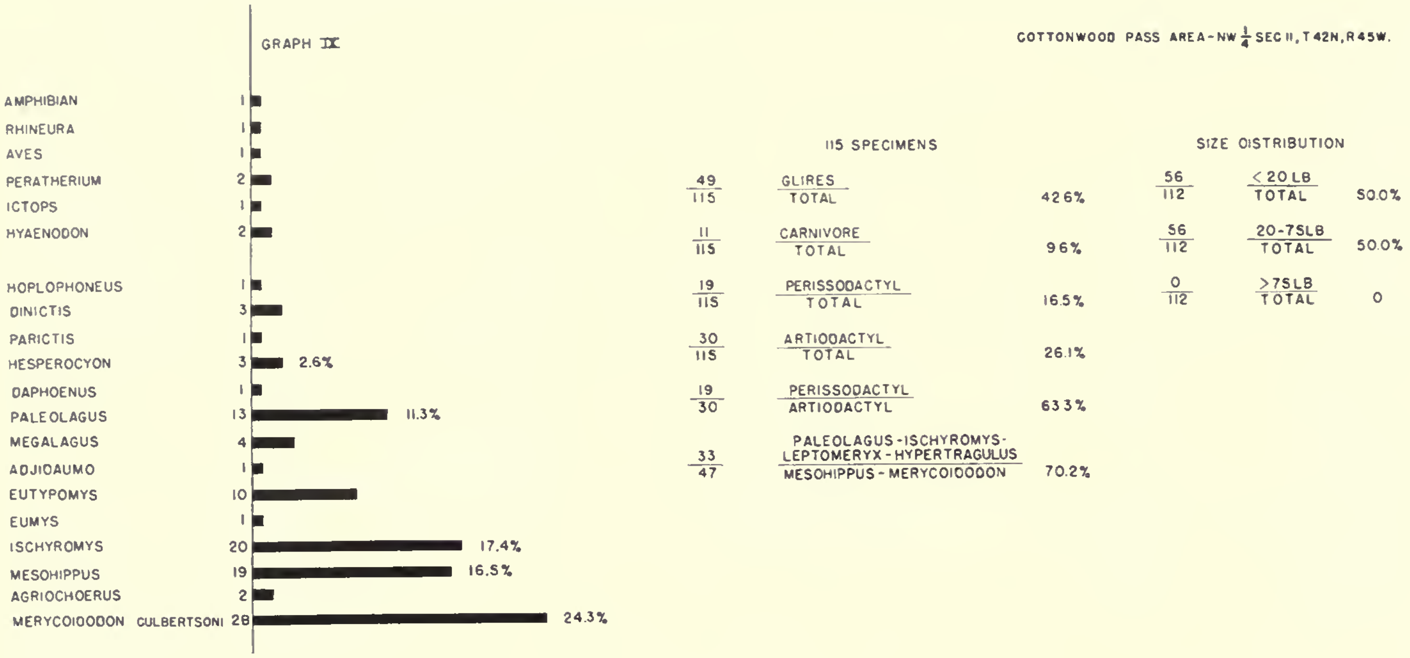


FIG. 54 (*continued*). Graphs I–XIII, population statistics.

COLORADO MUSEUM NEAR-STREAM FAUNA



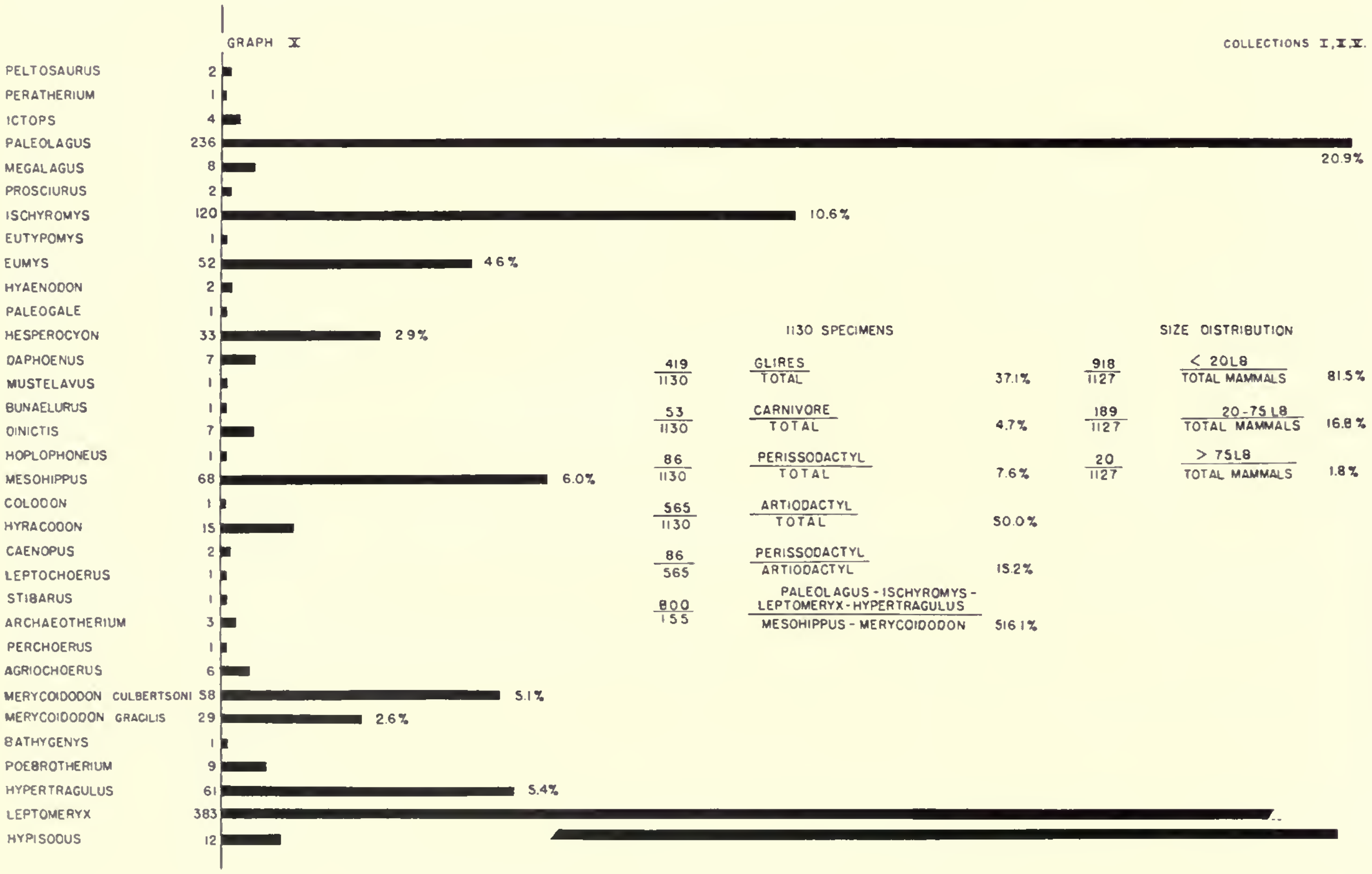
115 SPECIMENS

49/115	GLIRES/TOTAL	42.6%
11/115	CARNIVORE/TOTAL	9.6%
19/115	PERISSODACTYL/TOTAL	16.5%
30/115	ARTIODACTYL/TOTAL	26.1%
19/30	PERISSODACTYL/ARTIODACTYL	63.3%
33/47	PALEOLAGUS-ISCHYROMYS-LEPTOMERYX-HYPERTRAGULUS/MESOHIPPUS-MERYCOIDODON	70.2%

SIZE DISTRIBUTION

56/112	< 20 LB/TOTAL	50.0%
56/112	20-75 LB/TOTAL	50.0%
0/112	> 75 LB/TOTAL	0

TOTAL FAUNA, OPEN PLAINS, SAGE CREEK



1130 SPECIMENS

419/1130	GLIRES/TOTAL	37.1%
53/1130	CARNIVORE/TOTAL	4.7%
86/1130	PERISSODACTYL/TOTAL	7.6%
565/1130	ARTIODACTYL/TOTAL	50.0%
86/565	PERISSODACTYL/ARTIODACTYL	15.2%
800/155	PALEOLAGUS-ISCHYROMYS-LEPTOMERYX-HYPERTRAGULUS/MESOHIPPUS-MERYCOIDODON	516.1%

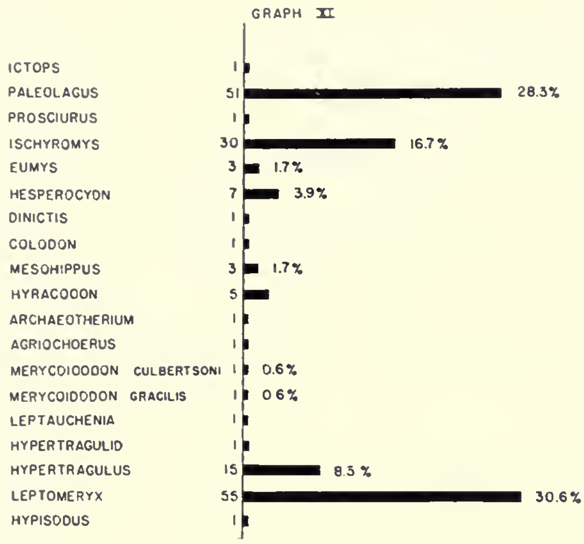
SIZE DISTRIBUTION

918/1127	< 20 LB/TOTAL MAMMALS	81.5%
189/1127	20-75 LB/TOTAL MAMMALS	16.8%
20/1127	> 75 LB/TOTAL MAMMALS	1.8%

FIG. 54 (*continued*). Graphs I-XIII, population statistics.

TOTAL FAUNA - OPEN PLAINS - DILLON PASS AREA

COLLECTIONS III, IV.



180 SPECIMENS

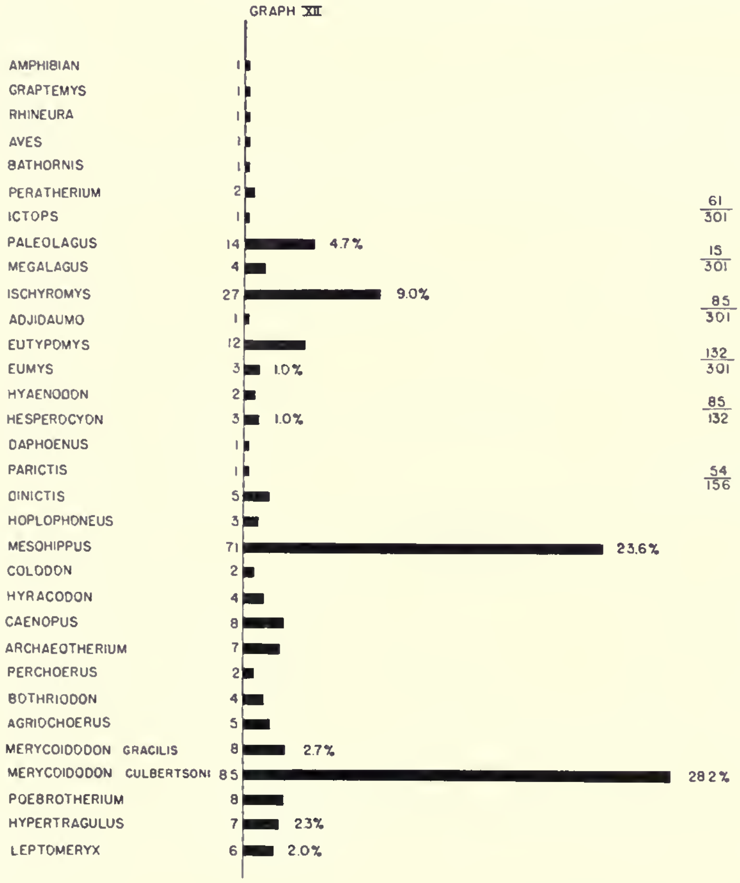
$\frac{85}{180}$	GLIRES / TOTAL	47.2%
$\frac{8}{180}$	CARNIVORE / TOTAL	4.4%
$\frac{9}{180}$	PERISSODACTYL / TOTAL	5.0%
$\frac{78}{180}$	ARTIODACTYL / TOTAL	43.3%
$\frac{9}{78}$	PERISSODACTYL / ARTIODACTYL	11.5%
$\frac{151}{5}$	PALEOLAGUS - ISCHYROMYS LEPTOMERYX - HYPERTRAGULUS / MESOHIPPUS - MERYCOIDODON	3020.0%

SIZE DISTRIBUTION

$\frac{165}{180}$	<20 LB / TOTAL	91.7%
$\frac{9}{180}$	20-75 LB / TOTAL	5.0%
$\frac{6}{180}$	>75 LB / TOTAL	3.3%

TOTAL FAUNA-NEAR-STREAM FACIES

COLLECTIONS VII, VIII, IX.



301 SPECIMENS

$\frac{61}{301}$	GLIRES / TOTAL	20.3%
$\frac{15}{301}$	CARNIVORE / TOTAL	5.0%
$\frac{85}{301}$	PERISSODACTYL / TOTAL	28.2%
$\frac{132}{301}$	ARTIODACTYL / TOTAL	43.9%
$\frac{85}{132}$	PERISSODACTYL / ARTIODACTYL	64.4%
$\frac{54}{156}$	PALEOLAGUS - ISCHYROMYS - LEPTOMERYX - HYPERTRAGULUS / MESOHIPPUS - MERYCOIDODON	34.6%

SIZE DISTRIBUTIONS

$\frac{81}{296}$	<20 LB / TOTAL	27.4%
$\frac{192}{296}$	20-75 LB / TOTAL	64.9%
$\frac{23}{296}$	>75 LB / TOTAL	7.8%
$\frac{296}{26}$	TOTAL MAMMALS / MAMMALIAN GENERA	11.4%

FIG. 54 (*continued*). Graphs I–XIII, population statistics.

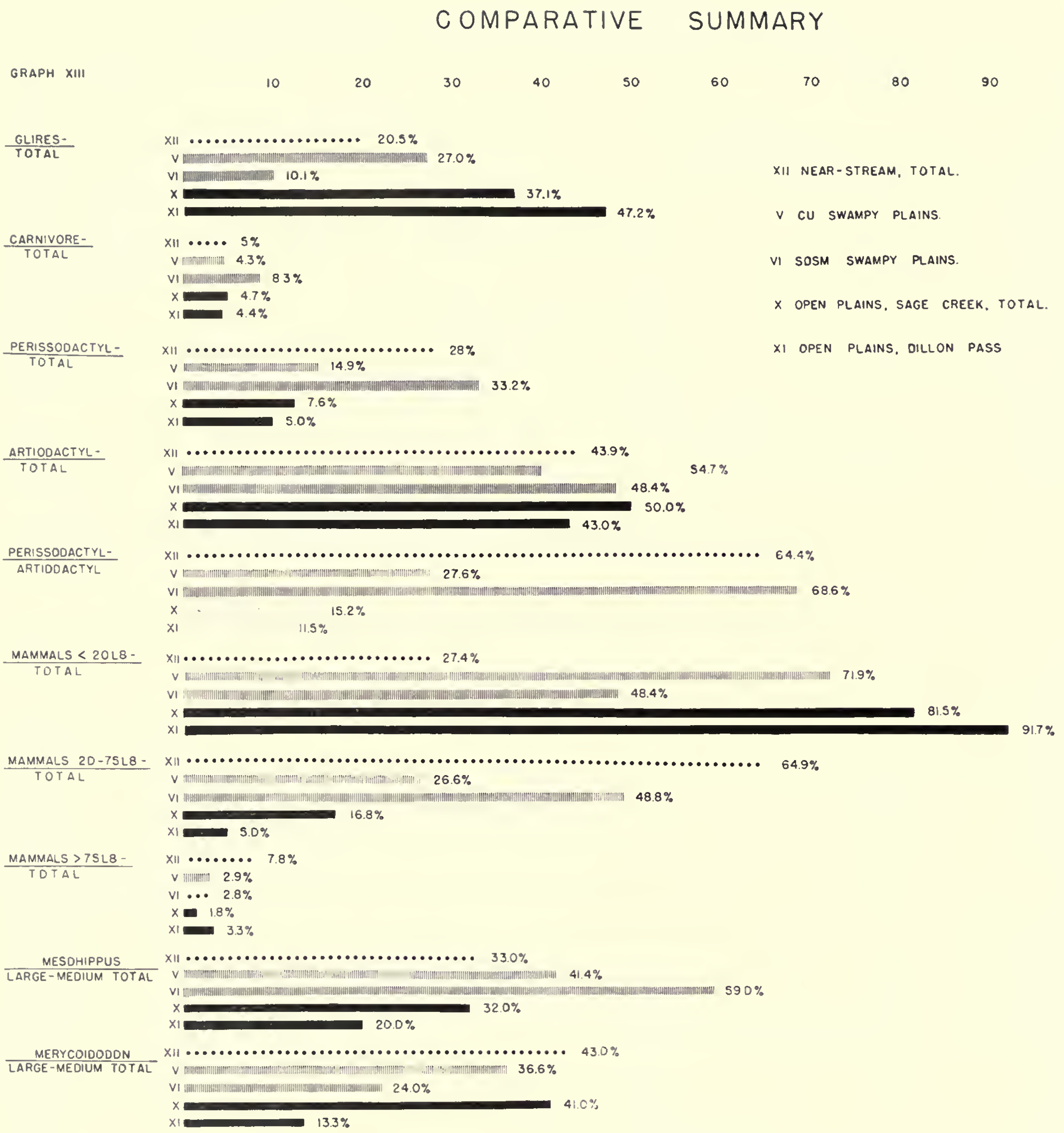


FIG. 54 (*continued*). Graphs I–XIII, population statistics.

FIG. 55. Internal consistency of Open Plains and Near Stream collections. Note that the first two items show general consistency; all others are consistent within each facies, but differ between facies.

	OPEN PLAINS (COLL. I, II, III, IV, V, X, XI)	NEAR-STREAM (COLL. VII, VIII, IX, XII)
Universally consistent	1. *Paleolagus* and *Ischyromys* form the majority of Glires.	1. *Paleolagus* and *Ischyromys* form the majority of Glires.
	2. Carnivores under 10% of total.	2. Carnivores under 10% of total.
Consistent within groups: differ between groups	1. *Mesohippus+Merycoidodon culbertsoni* under 20% of total.	1. *Mesohippus+Merycoidodon culbertsoni*=40%–70% of total
	2. Medium-sized animals under 30% of total.	2. Medium-sized animals 50%–80% of total.
	3. *Hesperocyon* over 50% of total carnivores (except in Coll. I which has only 1 carnivore specimen).	3. *Hesperocyon* less than 30% of total carnivores.
	4. Perissodactyls less than 20% as numerous as artiodactyls.	4. Perissodactyls over 50% as numerous as artiodactyls.
	5. *Mesohippus+Merycoidodon*=less than 50% of *Ischyromys+Paleolagus+Leptomeryx+Hypertragulus.*	5. *Mesohippus+Merycoidodon*=more than 100% of *Ischyromys+Paleolagus+Leptomeryx+Hypertragulus.*
	6. *Leptomeryx* approximately=*Paleolagus+Ichyromys.*	6. *Leptomeryx* much less numerous than *Paleolagus+Ischyromys.*

FIG. 56. Total fauna represented in the collections used in Chapter VII. Some non-mammal additions from 1964–65 collections have been listed.

I. Plants
    Charagonia
    Unidentified algal strands and sheets
    Celtis

II.* Invertebrates
    Pond Snails—3 genera not yet identified
    Unio

III.* Fishes
    Amia, not *Amia calva*
    ?Ictalurid

IV.* Amphibia
    Bufonid humeri

V. Reptiles
    A. Testudinata
        1. *Stylemys*
        2. *Graptemys*
    B. Lacertilia
        1. *Rhineura*
        2. *Peltosaurus*

VI. Mammals
    A. Marsupialia
        1. *Peratherium*
    B. Insectivora
        1. *Ictops*
    C. Lagomorpha
        1. *Paleolagus*
        2. *Megalagus*
    D. Rodentia
        1. *Ischyromys*
        2. *Adjidaumo*
        3. *Eutypomys*
        4. *Eumys*
        5. *Prosciurus*
    E. Carnivora
        1. *Hyaenodon*
        2. *Hesperocyon*
        3. *Daphoenus*
        4. *Parictis*
        5. *Mustelavus*
        6. *Bunaelurus*
        7. *Dinictis*
        8. *Hoplophoenus*
    F. Perissodactyla
        1. *Mesohippus*
        2. *Colodon*
        3. *Hyracodon*
        4. *Caenopus*
    G. Artiodactyla
        1. *Leptochoerus*
        2. *Stibarus*
        3. *Archaeotherium*
        4. *Perchoerus*
        5. *Bothriodon*
        6. *Agriochoerus*
        7. *Merycoidodon*
        8. *Bathygenys*
        9. *Leptauchenia*
        10. *Peobrotherium*
        11. *Hypertragulus*
        12. *Leptomeryx*
        13. *Hypisodus*

* These groups represented in 1964–65 collections, not in the collections used in this paper.

Chapter VIII

INTERPRETATIVE SUMMARY

This chapter presents in as coherent a fashion as possible the physical and biotic history established in the detailed discussions which precede it. The intention is to synthesize, in order to clarify the main threads of a story which might otherwise be lost in the morass of detailed evidence. Where alternative interpretations are possible, the one most favored is used; the alternatives have already been indicated in the preceding chapters.

Laramide orogeny elevated the Black Hills, creating consequent slopes generally eastward in the area of the Big Badlands. This simple pattern was modified by movement along a series of parallel basement faults trending ESE-WNW, which produced an asymmetrical trough with its deeper portion south. A high ridge of Cretaceous shale hills formed its southern rim, and a lower ridge the northern.

The system of basement faults extended northwestward through the Mesozoics and Paleozoics which formed the east flank of the Black Hills uplift. A series of streams developed along the fault zones, cutting watergaps wherever they intersected the encircling hogbacks. Some of these streams lay to the north of the trough, but all from Rapid Creek southward through Fall River entered it. Their coalescent waters first cut a relatively flat surface on the Pierre Shale of the trough bottom, then cut a flat-bottomed valley 5 miles wide and about 70 ft. deep, extending down the middle of it.

The valley deepened slowly westward, and shallowed from the longitude of Scenic eastward.

Meanwhile, Paleocene and Eocene erosion, under warm-temperate humid climate, carved the Black Hills almost to their present topography. The Precambrian intrusives of the southern Hills lay widely exposed, as did also the Precambrian metamorphics and Laramide intrusives of the northern Hills. The bounding scarps of the Badlands trough were concomitantly reduced to linear zones of low hillocks, which weathered to lateritic soils tens of feet deep.

This long-continued geomorphic equilibrium came to a sudden stop with the deposition of mature, quartz-chert gravels by every stream, accompanying the development of shallow lakes or swamps along their courses, at distances of 30–60 miles from the Black Hills. The streams rapidly shifted from gravel to sand transportation, and brought in quantities of highly arkosic sand. Alteration of the feldspar grains to kaolin, both before and after deposition, indicates that the climate was still warm and humid. Deposition occurred as discontinuous lenses scattered over a very wide area. The Slim Buttes formation comprises the deposits of this initial Duchesnean depositional episode.

Non-deposition, during which the sediments cracked and fissured to depths of several feet, ensued. Some actual removal of Slim Buttes sediments probably occurred also.

The next, or Ahearnian, depositional episode opened with the central valley well developed, a deep lateritic soil blanketing the trough lateral to it, and deep soil on the boundary hillocks of the trough. Abundant lenses of Slim Buttes sediments lay scattered within the trough and for many miles to the north of it.

Ahearnian streams within the valley, coalesced to form the Red River, brought in a flood of fresh arkosic grit and sand. Slim Buttes materials became incorporated with the new sediments to produce the basal conglomerate of the Chadron Formation: a coarse, siliceous gravel with arkosic sands and grit. In some places, the Slim Buttes material was so little rehandled as to retain its white color; over most of the valley-bottom, however, the arkose predominated. Red clays from older Black Hills sediments alternated with greenish, montmorillonitic muds to produce a banded, mottled sequence above the basal sands. The Red River apparently underwent frequent changes of regimen, producing cut-and-fill structures and downstream-oriented crossbedding.

Gradually the streams lost both volume and energy. Wider areas of the Red River valley became flood plain, and the streams carried smaller pebbles. Deposition became progressively slower, and ceased entirely when the old valley was filled approximately to its brim. The later flood-plain sediments were more tan than greenish, indicating more oxidation during deposition. Some areas near stream channels developed pale orange colors, as alternate wetting and drying altered a modicum of the iron content to hematite.

A third depositional pulsation started with coarse, arkosic clastics and continued to deposit gradually finer materials at a lessening rate. Greenish to grayish clays very rich in montmorillonite spread out over the old valley and across the entire trough. The streams maintained their approximate geographic positions as deposition proceeded. Once again, the finer sediments (which now constitute the Peanut Peak member) near the top of the sequence and near the stream courses were oxidized and incipiently lateritized.

The Chadron Formation thus represents two episodes of fluvial sedimentation, each starting with widespread deposition of coarse clastics by streams of high volume and energy, and progressing generally toward slower deposition of finer material, with a high percentage of altered volcanic ash. The sediments indicate a lessening of vegetation, and periodic drying, toward the end of each episode.

Annual temperatures of about 60–63° F in South Dakota and 55–60° F in southwestern Montana apparently characterized pre-Chadronian climates. Oxidation of sediments, chemistry of bone preservation, direction of ash drift from volcanic centers, and nature of the fauna all indicate a late Eocene climatic regimen of warm-humid monsoonal character. Winters were mild, with clear skies and little or no frost. Summers were warm, with prevailing northerlies bringing in moist Arctic air, which precipitated heavy rains as it rose to higher elevations. The Central States, below 1000 ft. elevation, were probably dry savannas to semi-deserts.

Studies of Duchesnean climates must await more evidence. The kaolinization of feldspars as far north as the Slim Buttes certainly indicates more warmth and humidity than at present, and probably more than during the succeeding Chadron time.

Chadronian time was definitely cooler than the preceding Eocene. Lateritization decreased relative to its previous level; bone preservation changed; feldspar grains were carried by streams and deposited in relatively fresh condition. The prevailing westerlies began to establish themselves as dominant over the old monsoonal circulation, bringing showers of ash from the Yellowstone Park centers. However, the cooling did not progress very far. Small alligators still lived in the swampy streams, and the influx of volcanic ash weathered almost completely to bentonite. Two periods of sedimentation started each with water and presumably vegetation abundant enough to keep the iron in the sediments reduced, and ended much drier but probably not much cooler. Evolution of several phyletic lines within successive faunas shows that these depositional episodes lasted at least as long as any one Pleistocene glacial-interglacial cycle.

The fauna of South Dakota at the beginning of Chadron time consisted primarily of a relict warm-temperate forest chronofauna with known Late Eocene ancestors. To this were added a few immigrant savannah forms. Throughout Chadron time, the balance shifted toward the immigrants. Extinction of titanotheres at the close of Chadron time meant the end of what had been one of the dominant super-families for several million years.

Faunal evidence supports the petrologic indications that Chadronian time witnessed a cooling and drying, with savanna-savanna forest conditions replacing the older wet forest.

Since there is no evidence of structural movement of basins relative to mountains, or of the entire area relative to sea level, and since Chadronian deposition began at only slightly different times in every east-flowing stream from Montana to Colorado, climatic control of the depositional regimen is probable. The change in both chemical and physical erosion incident to a general cooling resulted in a change from warm-humid types of stream gradients to semiarid types. This necessitated deposition close to the source mountains, in order to establish the smooth, fairly steep gradients characteristic of graded stream valleys under semiarid climate. As the cooling progressed in a series of pulsations, so also did deposition. Volcanic ash weathered concomitantly with its fall, and influenced the manner of deposition but did not control the system.

By the end of Chadronian time, the area outside the Black Hills had been built to an almost featureless plain, with a few hillocks of Pierre shale still protruding along the old Sage Ridge. Streams from the southern Black Hills were carrying gravel out as far east as the western part of Indian Creek basin, then losing power quite rapidly. Marshes and shallow, marshy lakes spread over much of the interstream plains and eastward from Indian Creek. This equilibrium maintained itself for a considerable time.

During the Chadron-Brule interval, the streams from the Black Hills established individual courses within the trough, and at least one from north of the trough had transgressed the old, partly buried Sage Ridge divide.

Brule deposition, unlike that of the Chadron, was initiated during a time of low stream volume and velocity. (It may have been, and probably was, higher than during the interval preceding). The change in regimen from almost perfect equilibrium to active deposition may have been caused by a climatic shift toward greater coolness and aridity, or by a change in rainfall distribution, but most probably both occurred.

Infrequent but widespread floods resulting from rains in the Black Hills caused sheets of thickly fluid mud to cover the plains. Laden with gelatinous montmorillonite, the material overpassed the banks of the shallow channelways, thickening as it travelled both by dehydrating and by picking up chips of dried mud from the surface. It literally plastered to the surface the skeletons and bones that lay there, congealing upon them as the dry bones absorbed water from the stiffening mass.

Each flood deposited from a few inches to two feet of sediment. Periods of a few years to less than 100 years elapsed between major floods, during which the grasses and smaller herbaceous vegetation re-established themselves. Trees and larger shrubs probably were not killed. The fauna very quickly re-established itself: larger mammals and climbers were merely inconvenienced, and smaller forms moved in from Sage Ridge, the Pine Hills, the Black Hills, and any unflooded areas on the plain. By the next time of flooding, the area had re-established its biota and its perthotaxic assemblage.

The region developed a truly depositional geomorphic pattern, with rios, probably forested varzea slopes, drenaje streams without headwaters, and probably savanna-prairie igapos between the outermost streams and the Cretaceous ridges. Even during interflood periods, none of the streams accomplished any erosion.

The climate, apparently, was considerably drier than that of late Chadron time. Apparently it was also somewhat cooler: alligators had disappeared from the streams, and titanotheres from their borders. The floodplain clays were extensively oxidized to limonitic colors, with only a faint mottling of greenish, reduced zones; rotting vegetation must have been less abundant and drying more profound. For the first time, groundwater became influent from the streams to the plains. It was apparently very limy, as opposed to the more acid water which probably flowed down the same streams during Chadron time. The climate was sufficiently arid to produce perthotaxy typical of semiarid districts, which suggests annual precipitation of under 30 in. However, winter temperatures probably were very much less severe than present ones, with only occasional frosts.

A sudden change toward warmth and greatly increased rainfall altered the nature of the floods without causing a shift in fluvial regimen. Individual streams tripled in size. Their confluent floodwaters spread over the area as widespread, shallow, temporary lakes which drained away, probably within a few days or weeks after each flood. The quantity of water and clastics so far diluted the available montmorillonite that the floods acted as normal, muddy water rather than as the thicker, more viscous fluids of the previous arid times. At least one alligator worked its way back into the area, demonstrating that precipitation increased concomitantly with increased warmth. Lakes borne of floods alternated so rapidly with exposed flats that neither a lacustrine nor a terrestrial biota had time to establish itself. Westward from Cottonwood Pass, the streams increased like those to the east, but slightly steeper gradients due to proximity of the Black Hills prevented widespread flooding.

A brief period of diminution of streams in the central part of the area was followed by a similar decrease in streams watering the eastern part. Vigorous action with widespread flooding resumed very quickly.

A third time of aridity with intermittent deposition by sheet mudflows produced sediments like those of the first. It was just as intense and widespread, but presumably not as long-lasting as the first.

Suddenly-renewed, vigorous flooding once more spread temporary lakes across the entire area. Vigorous action by the repleted streams brought in abundant clastics which, mixed with the omnipresent montmorillonite, settled to form wide-spread layers of muddy sand.

A brief return to aridity at the headwaters of the streams watering the central part of the area produced a fourth quite thin, local mudstone layer. Quick resumption of warmer, more humid climate over the whole area built up more laminated sediments, which covered the local mudstone and elsewhere formed a sequence with the sediments of the preceding humid episode.

A fifth cooler, arid period became general over the entire area. It lasted as long as the first one. Except for a brief, local return to moist conditions along one stream, it continued into Poleslide Member time.

These alternate episodes of warmer, more humid and cooler, drier climate comprised a time span of between 1100 and 11,000 years. Individual warm and cool times were, therefore, of the same order of magnitude as the post-Pleistocene warm and cool periods. Chadronian deposition, by contrast, had been controlled by climatic rhythms as long as Pleistocene interglacial episodes.

The mammalian fauna which occupied the area during the more arid times found at least three well-differentiated habitats. There were relatively well-drained, open gallery forests on the varzea slopes within a mile or less of the rios, savanna prairies in the igapo and near-drenaje areas, and occasional well-vegetated swamps or ponds in both igapo and drenaje bottoms.

Each of these habitats was occupied by a characteristic mammalian community.

Mesohippus and *Merycoidodon* together formed 55 per cent of the mammalian population of the forests. A richly varied assemblage made up the remainder. *Paleolagus* and *Leptomeryx* entered the forests, but definitely did not prefer them. Relict genera from the old Eocene warm-forest chronofauna, especially perissodactyls, were significant elements of the community.

The open plains, on the other hand, constituted the preferred habitat of a dominantly small-animal fauna, of which *Paleolagus* and *Leptomeryx* were far the most numerous. The great majority of the more successful genera in this habitat were members of the dry-plains fauna which had first invaded during Chadronian time.

The swamp fauna somewhat resembled that of the gallery forests, save that here *Mesohippus* found its most successful retreat, while *Merycoidodon* was less important. Herds of *Hypertragulus* also found shelter in the swamps.

During the times of repeated flooding, lacustrine conditions alternated with fluvial so rapidly that neither an aquatic nor a terrestrial biota was able to establish itself.

Chapter IX

CONCLUSIONS

Most of the conclusions listed here have already been listed in their respective chapters. They are repeated, with such additions as the preceding text justifies, for the sake of continuity and the reader's convenience.

1. Laramide movement produced an asymmetrical trough extending east-southeastward from the Black Hills. The deepest portion and highest bounding scarp lay to the south.

2. Streams departed from the east flank of the Black Hills through structurally-controlled gaps, flowing thence east-southeastward in roughly parallel courses. Several occupied the trough, while others lay to the north of it.

3. A dominantly erosional regimen with a warm-humid climate persisted through Paleocene and Eocene times. The bounding scarps of the trough were worn down to low ridges; deep, lateritic soil developed on the ridges, and shallower soils on the floor of the trough.

4. During Duchesnean time, streams of high velocity brought coarse, maturely weathered gravel out 60–100 miles from the Black Hills.

5. Immediately following channel-bed deposition of the gravel, large quantities of partially-weathered arkosic sand, mixed with clay, filled the channels and numerous temporary lake basins.

6. Kaolinization affected the feldspar grains of the sands both before and after deposition, indicating a very warm temperate to subtropical climate in the area of deposition during Duchesnean time.

7. Sufficient time elapsed after deposition of the Duchesnean Slim Buttes Formation to permit weathering of feldspar grains, cementation followed by cracking of the rock lenses, and erosional removal at many places.

8. During late Eocene and Duchesnean time, monsoonal air circulation prevailed over the great Plains and the Rockies. The mountains and higher basins received heavy summer rainfall, but the Interior Lowlands were probably arid or subarid. Temperatures were warm-temperate or sub-tropical; the low temperature differential between the Pole and the Equator subordinated the hemispheric circulation system to local systems, in this case a monsoon.

9. The Black Hills and other ranges were eroded under this regimen until their cores were exposed. Their relief by the end of Eocene time very closely approximated that of the present.

10. A major decrease in temperature starting at the close of Eocene time established a stronger differential between the North Pole and the Equator, and consequently a stronger hemispheric circulation system with prevailing westerlies. This period of cooling appears to represent a minimum in a 10-million-year climatic cycle coincident with the beginning of a broader downward temperature trend that culminated in the Pleistocene minimum.

11. As a result of this global climatic change the local climate became drier and somewhat cooler. The stream regimen was altered and deposition initiated adjacent to the mountain ranges.

12. Deposition continued into late Chadron times because of continued climatic deterioration. Fluctuations in deposition during this period are probably related to minor climatic fluctuations which may be the results of the same cycles shown during Pleistocene time as glacial and inter-glacial stages.

13. The earliest Chadron is somewhat younger than the Vieja. The Yoder fauna is Ahearnian, and the Pipestone Springs is Peanut Peakian.

14. During middle and late Eocene time, a semitropical rainforest chronofauna developed in the swampy woodlands of Utah, Wyoming, Colorado, and South Dakota. This is recorded in fossils of the Bridger and Uinta Formations.

15. Concurrently, a savannah to arid chronofauna developed elsewhere, possibly in the Interior Lowlands. The history of this chronofauna is unrecorded.

16. During Chadronian time, the forest chronofauna lingered along the stream margins in Dakota. It underwent gradual, partial replacement by the immigrant savanna chronofauna.

17. A few of the genera of the forest chronofauna, among them *Trigonias*, *Mesohippus*, and *Pseudoprotoceras*, managed ultimately to evolve into savanna and plains forms.

18. Study of the Chadron chronofauna tends to substantiate conclusions drawn earlier from the Texas Permian by Olson.

19. The Scenic Member of the Brule Formation comprises five types of sediments:

   1. Limestone
   2. Heterogeneous mudstone
   3. Laminated clay

4. Laminated siltstone and sandstone
5. Cross-bedded sandstone.

These combine to form four sedimentary lithotopes:

1. Silty mudstones
2. Laminated siltstones
3. Laminated mudstones
4. Channel-fill zones.

20. These four lithotopes grade into one another horizontally but not vertically.

21. The silty mudstone zones transgress the depositional areas of several Oligocene streams, and can be traced for distances of several miles.

22. Alternating strata of mudstone and siltstone have sharp contacts, not gradational ones. No instances of graded bedding have been observed.

23. The channel-fill sandstones are of two types, Northern Black Hills derived and Southern Black Hills derived, each with a characteristic suite of heavy minerals.

24. The mudstones represent times of discontinuous deposition by mudflows from flooding streams of small volume and low energy.

25. The siltstones represent more rapid deposition by sheet-floods from the same streams at times when their volume, and therefore their energy, was much increased.

26. The fluctuations in energy of Oligocene streams in this area were the result of fluctuations in volume rather than of changes in gradient.

27. The fluctuations in volume of streams resulted from alternations of wetter and drier climate.

28. The presence of alligators in the underlying Chadron, and the presence of one alligator in the first Scenic-Member wet-climate deposit, plus the absence of alligators in the intervening dry-climate deposit, suggest that the times of dry climate were also times of cool climate.

29. The fact that fossils representing five mammalian orders show no differences from bottom to top of the Scenic Member indicates that deposition of the entire Member required not over 500,000 years.

30. Individual increments of Scenic Member sediment, amounting to 6–18 in., were deposited within the span of a very few days.

31. The complete absence of weathering or of soil zones at the top of any one increment shows that never did a period of more than 100 years elapse between episodes of sedimentation.

32. The presence within any one fossiliferous increment of a complete perthotaxis indicates that periods of 10 years or over usually elapsed between episodes of deposition.

33. Using the data from the last two conclusions, the total time required for deposition of the mudstones of the Scenic Member was 550–5500 years. Allowing equal time for deposition of laminated sediments, although the evidence suggests that they were deposited more rapidly, the total time represented by the Scenic Member was 1100–11,000 years.

34. The alternations of dry-cool and warm-wet climates were, on this basis, of the same general order of magnitude as post-glacial warm and cool alternations.

35. The geographic distribution of lithotopes within the Scenic Member at any one time can best be explained by comparison with the distribution of sedimentary environments within the Central Amazon Basin, as described by Sioli (1951).

36. Using Sioli's terms with additions where necessary, the following sub-environments of fluvial sedimentation can be recognized:

Rio: the channelway of a throughgoing stream.

Varzea: the area of sedimentation outward from a rio, including the natural levee and the long backslope away from the stream.

Drenaje: secondary streams which arise locally as drainageways in the more or less linear depressions between adjacent varzeas.

Terra firme: valley walls, composed of material older than that being deposited by the rios.

Igapo: The approximately linear depression lying between a terra firme and the adjacent varzea, receiving sediment chiefly by local wash from the terra firme, but occasionally by sheet-wash from the rio.

The body of sediments formed in these environments through time are termed, respectively, riosome, varzeasome, drenajesome, and igaposome.

37. Deposition of the Scenic Member in the Big Badlands was controlled by three rios with sources in the Southern Black Hills, and two to four rios with sources in the Northern Black Hills.

38. Although deposition of the Scenic Member was episodic, there were no periods of erosion and all streams were continuously at grade to overloaded.

39. The lower part of the Poleslide Member generally resembles the mudstones of the underlying Scenic Member in lithology and origin. Easterly gradation of the upper mudstones of the Scenic Member into the basal Poleslide indicates either that the widespread aridity of Poleslide time started earlier in the Northern Black Hills than in the Southern, or that the eastern part of the Badlands area was, by late Scenic Member time, receiving notably less rainfall than the western part, or both.

40. The flesh-colored to brilliant, discontinuous, red, laminated clays of the Dillon Pass and Big Foot Pass areas represent igaposomes, having as their source local rainwash from exposed hillocks of weathered Pierre shale along the Sage Ridge.

41. The dull red-brown colors of the heterogeneous mudstone zones in the same geographic areas as the

igaposomes represent varzea mudstones mixed with slight amounts of locally-derived red clays.

42. The sediments in northwestern Nebraska, previously interpreted as paleosols, are actually laminated siltstone lithotopes similar to those of the Big Badlands. They represent rapid rather than slow deposition.

43. The structures in northwestern Nebraska previously interpreted as deep channel-cutting are actually due to faulting.

44. Faunal zoning of the Orella Member in northwestern Nebraska is based upon erroneous stratigraphy.

45. The evolution of oreodonts within Orellan time is not established.

46. No satisfactory correlation of subdivisions of the Orella Member in Nebraska with subdivisions of the Scenic Member in South Dakota has been achieved. In view of the brief time represented by the Scenic Member, such detailed correlation is unlikely on paleontologic grounds, although it may be achieved through paleogeography.

47. Both in South Dakota and in northwestern Nebraska, Middle Oligocene sediments indicate rapid deposition of increments several inches thick, with no periods of erosion and no long periods of non-deposition, under an alternation of warm-wet and cool-dry climates.

48. Three ecologic zones can be recognized in Lower Nodular Zone paleogeography: 1) A near-stream zone, probably occupied by gallery forests; 2) an open-plains area, which might have borne plains, prairie, or savanna vegetation; 3) a swamp area within the open plains.

49. Fossil assemblages within all three were buried by engulfment; they represent buried perthotaxies rather than transported assemblages.

50. Differences between the life assemblage as a universe, and our collections as a sample, are caused by at least 29 factors which can be considered in seven groups.

51. These factors affected various genera both independently and by interaction.

52. Due to the number, complexity, and interaction of these factors, only a perthotaxic assemblage can approximate an adequate sample of a life population. The various mechanical assemblages of fossils bear no more than an occasional coincidental relationship which does not justify even the most rudimentary statistical analysis.

53. The collections at hand show a 10 per cent observed variance between collections of 300 or more specimens; 20 per cent variance for collections of 100–300 specimens, and much wider variance for smaller collections.

54. The Orellan near-stream gallery forest fauna was dominated by *Mesohippus* and *Merycoidodon,* with a large number of other genera represented by relatively small numbers of individuals.

55. The open-plains fauna comprised mostly small animals, with *Leptomeryx* and *Paleolagus* making up more than half of the total.

56. The swamp fauna resembled the forest fauna more nearly than that of the open plains.

57. *Mesohippus* was much the most numerous medium- to large-sized mammal in the swamp; apparently the genus was attempting to meet the changing climate by clinging to the relict patches of swampy forest.

58. In general, the invading plains-savannah fauna which first appeared during Chadronian time had established dominance by Orellan time.

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APPENDICES

Appendix I

COLUMNAR SECTIONS

Key:

1. All measurements given in feet, to the nearest foot.
2. Roman numbers refer to mudstones as numbered in text.
3. Abbreviations:

G	Gray
Y	Yellow
R	Red
Gr	Green
B	Buff

Occasional combined letters indicate either a color intermediate between two of these, or a color which grades from one to the other irregularly. Color symbols placed thus $\left.\begin{matrix}R\\G\end{matrix}\right\}$ indicate a vertical color gradation.

Cl	Mudstone or laminated clay
Slt	Laminated siltstone
Ss	Sandstone, either laminated or cross-bedded

SECTION 1

SW¼ of NW¼, Sec. 5, T.4S, R.13E.

	Poleslide—Massive mudstone	
Zone VI	—	
V	G Cl	22
	White concretions	1
IV	G Cl G Slt G Cl ? G Slt G Cl	24
	G Slt	26
III	YG Cl Gr Slt YG Cl	10 2 4
	Banded Gr Slt—Y Cl	25
I	YG Cl	28
	Chadron	TOTAL 142

SECTION 2

Center, SE¼, Sec. 5, T.4S., R.13E.

This section is mostly mudstones, which have replaced the siltstones by lateral gradation. It lies near the position of the divide between Northern- and Southern-derived sediments, which may account for thin section and preponderance of fine-grained sediment.

	Poleslide—Massive Cl	
	White zone	1
Zone VI	Cl, dark gray	2
	Y Cl	10
	White concretionary zone	1
V	Y Cl with thin concretionary bands	15
	White concretionary zone	1
	Grades to dark at top	
IV	G Cl	5
	G Slt	12
III	YB Cl	3
	G Slt	2
II	YB Cl (discontinuous)	2
	G Slt with many concretions	13
I	G Cl bottom not exposed	
	TOTAL	67

SECTION 3

SW¼ of NE¼, Sec. 4, T.4S., R.13E.

This section lies just west of a N–S trending channel zone of Northern-derived sediments; within this channel area, zone II disappears, and zones III and IV merge to one thick mudstone, separating again on the other side. The channel zone extends upward in section from just above mudstone I to the base of mudstone IV. A few very small, discontinuous channel fills lie higher. A 10-inch zone of blue-gray siltstone, very prominent and containing numerous biotite flakes, develops near the top of mudstone IV. Mudstone II appears on both sides of the channel area, and is at one place traceable across.

	Poleslide	
Zone VI	Dark G Cl YG Cl, locally white White zone	3 14 1
V	G Cl	9
	G Slt, laminated, some Gr Ss	36
IV	Y Cl	10
	G Slt	3
III	YG Cl	9
	G Slt	19
II	Y Cl	5
	Gr Slt & Ss	3
I	YG Cl bottom not exposed	
	TOTAL	112

SECTION 4

SE¼ of NW¼, Sec. 3, T.4S., R.13E.

A prominent white zone here separates zone VI from the gray siltstones below. Northward at the standard section of the Scenic Member (Section 5, this appendix), zone VI grades laterally into banded siltstones. A dark gray zone immediately overlying separates the Scenic from the overlying Poleslide at both localities.

	Poleslide		
Zone VI	G Cl		3
	Y Cl		15
	White concretionary zone		2
	G Slt		10
V	YG Cl		3
	G Slt		26
IV	YB Cl		4
	G Slt		9
III	YG Cl	3	14
	G Slt	1	
	YG Cl	10	
	G Slt		8
II	YB Cl		3
	G Slt		12
I	YB Cl bottom not exposed		30
		Total	109

SECTION 5

SE¼ of SW¼, Sec. 27, T.3S., R.13E.

This is the standard section of the Scenic Member (Bump, 1956). Through a printer's error, this section was erroneously placed in Sec. 23, but Bump personally showed the locality to the author and mentioned the error. Likewise, the standard section of the Poleslide is in Sec. 33, not 23, of T.43N., R.44W.

	Poleslide	
	G Slt, laminae of Cl at top	43
Zone V	YB Cl	9
	G Slt	8
IV	YB Cl	1
	G-B Slt	7
III	YB Cl	6
	G Slt	4
II	YB Cl	6
	G-Gr Slt & Ss micaceous	8
I	YB Cl	28
	Chadron	
	Total	120

SECTION 6

SW¼ of SE¼, Sec. 3, T.4S., R.13E.

In this section, zone IV is indistinguishable from the upper part of III, but the two are separated by a siltstone stratum to the north, east, and south.

	Poleslide—Laminated siltstone	
Zone VI	Dark Cl	4
	Y Cl with nodules	15
	White Ss-Slt	3
V	YG Cl, dark	4
	White Ss-Slt	3
	G Slt with some Cl laminae	30
IV	Y Cl	10
	G to white Slt, concretionary	2
III	YG Cl (some Slt laminae)	12
	G Slt	8
II	G Cl	2
	G Slt and Gr Ss	11
I	YB Cl, nodular	12
	Base not exposed	
	Total	116

SECTION 7

SE¼ of SE¼, Sec. 35, T.3S., R.13E.

This section lies on the NE borders of a zone of channel fills, trending SE. The best-developed sandstones lie on the southwest flank of Heck Table and on the east side of the butte in the SW¼ of the SE¼, Sec. 35. Maximum diameter of pebbles is 10–12 mm. Stratigraphically, the greatest development is above mudstone III in both thickness and areal extent. The sandstones interfinger with and replace the mudstones in this zone. Zones IV and V alter completely to siltstones in the SE¼ of Sec. 35. They are recognizable and directly traceable in this columnar section and in Sections 8 and 9.

	Poleslide	
Zone VI	B & dark Cl	3
	YB Cl	17
	G Cl	6
	G Slt	9
V	YB Cl	2
	G Slt & Cl	13
IV	BG Cl	5
	G Slt	10
III	BG Cl	10
	G Slt	2
	BG Cl	13
	G Slt	8
II	BG Cl	4
I	G Slt, some discontinuous laminae	20
	YB Cl, nodular	8
	Bottom not exposed	
	Total	130

SECTION 8

NW¼ of NW¼, Sec. 1, T.4S., R.13E.

	Poleslide	
Zone VI	Dark Cl	4
	YB Cl, some concretions	15
	Light Y Cl	3
	G Slt	24
V	YG Cl	3
	G Slt, pale	5

IV	YB Cl	2
	G Slt	8
III	YB Cl	8
	Pale G Slt	3
	GB and YB Cl	10
	G Slt	6
	Bottom not exposed	
	Total	91

SECTION 9

NE¼ of SW¼, Sec. 36, T.3S., R.13E.

Northeastward, the siltstone between III and IV thins markedly, then thickens again and IV merges upward with V. Mudstone III divides into two, with a light sandstone in the middle.

	Poleslide	
Zone VI	Dark Cl	3
	YB Cl	10
	Gray Cl	3
	G Slt	5
V	GB Cl	3
	G Slt	11
IV	GB Cl	3
	G Slt and Cl	15
III	GB Cl, 1 white Slt in middle	16
	G Slt	13
II	G Cl	3
	G Slt	22
I	G Cl	8
	Base not exposed	
	Total	115

SECTION 10

NW¼ of SE¼, Sec. 25, T.3S., R.13E.

	Poleslide	
Zone VI	Dark Cl Y Cl G Cl	22
	G Slt with laminae of Y Cl	18
V	Y Cl	7
	Gr Ss-Slt	1
IV	YG Cl	5
	G Slt	13
III	YG Cl	6
	G-white Slt	5
	YG Cl	5
	G Slt	6
II	G Cl, some Gr Ss	4
	G Slt	30
I	YG Cl	18
	Total	140

SECTION 11

S edge of Sec. 24, T.3S., R.13W.

	Poleslide	
Zone VI	G Cl Y Cl G Cl	15
	G Slt	11
V	G Cl	8
	Gr Ss and Slt	3
IV	G Cl	10
III	Gr Ss, coarse	3
	YG Cl	6
	G Slt	11
	Y Cl	6
	G Slt	8
II	G Cl	2
	G Slt	24
I	BG Cl	10
	Base not exposed	
	Total	117

SECTION 12

NW¼ of NW¼, Sec. 30, T.3S., R.14E.

	Poleslide	
Zone VI	G Cl	5
	Y Cl	15
V	Gr Slt	16
	Y Cl	7
	G Slt	13
	Gr Ss	0–5
III	Y Cl Gr Slt and fine Ss	13
	Y Cl	1
	G Slt	24
II	YG Cl	5
	G Slt	17
I	Y Cl G Slt G Cl	32
	Chadron	
	Total	152

Note.—The Slt in Zone I is a channel-fill lens, quite restricted.

SECTION 13

Center, Sec. 19, T.3S., R.14E.

	Poleslide	
Zone VI	G Slt Y Cl	16
	G Slt	10
V	Y Cl	8
	G Slt	24
	Gr Ss	5
III	YB Cl	18

	G Slt	11
II	R Cl	6
	G Slt	21
I	Y Cl	18
	Chadron	
	Total	137

SECTION 14

NE¼, Sec. 19, T.3S., R.14E.

Mudstone I thickens downward from the last section; the base of the Scenic Member has a noticeable relief from this section southward to Chamberlain Pass. The nodules of I disappear and the zone becomes reddish brown, immediately northeast of this section. Zone V develops a nodular zone here with fossiliferous concretions like those of Zone I farther south. Zones V and VI become more massive and buff colored, like the overlying Poleslide, separated from it only by a thin, discontinuous, greenish zone with limy laminae.

	Poleslide	
Zone VI	Y Cl	22
V	Y Cl and very fine Ss	8
	G Slt	30
III	RB Cl	13
	G Slt	8
IIA	R Cl G Slt R Cl G Slt R Cl	2 5 3 3 3
	G Slt	6
II	R-Y Cl	3
	G Slt, with some fine green Ss	29
I	YB Cl	37
	Chadron	
	Total	172

SECTION 15

NW¼ of SE¼, Sec. 18, T.3S., R.14E.

Note.—The base of Mudstone I is here not sharply separated from the Chadron; there are no limy zones at the contact, and almost no concretions. The unusual thickness here may indicate that part of the Chadron has been included through error; the next section shows only 25 feet of I. Also, Mudstone I here includes a greenish siltstone channel-fill 3 feet thick, within its upper portion.

	Poleslide	
Zone VI	Y Cl	22
V	Gr Ss, fine G Slt Y Cl	15
III	RB Cl	8
	G Slt and Gr Ss, fine	17
IIA	RY Cl	7
	G Slt and Gr Ss laminae	15
II	R-G Cl	3
	G Slt	26
I	R Cl	35
	Chadron	
	Total	148

SECTION 16

SE¼ of Sec. 18, T.3S., R.14E.

This section was taken up the SE side of the same ridge of which section 15 represents the SW side.

	Poleslide	
Zone VI	G Cl, dark 3 Y Cl 10 G Cl 5	18
	G Slt	9
V	G Cl	10
	G Slt	16
III	YG Cl	11
	G-Gr Slt	12
IIA	G Cl	4
	G Gr Slt	33
I	YG Cl	25
	Chadron	
	Total	138

SECTION 17

NW¼ of Sec. 17, T.3S., R.14E.

Between this and Section 16, a greenish zone which apparently forms the top of the Scenic Member, but actually lies in the lower third of Zone VI, disappears and VI merges with the Poleslide. Occasionally, a few concretions several feet up in Poleslide lithology may mark the top of VI, but this is not demonstrable.

	Poleslide (Y Cl, bottom is part of VI)	
Zone VI	Gr Cl	3
	G and Gr Slt	7
V	YG Cl	8
	G and Gr Slt	16
III	YG Cl	16
	G Slt	10
IIA	YB Cl	5
	G Slt	25
I	YG Cl, one Gr Ss lens	35
	Chadron	
	Total	125

SECTION 18

SE¼ of SE¼, Sec. 17, R.14E., T.3S.

The buff to yellow mudstones have changed to salmon and brownish reds between Section 7 and this Section.

	Poleslide	
	G Slt	5
Zone V	G Y } Cl	8

	G Slt	14
III	B-R G	10
	G-Gr Slt, several discontinuous laminae of B-Cl	24
IIA	Y Cl	6
	G to pale Gr Slt	18
I	Y-R Cl, greenish zone, not laminated, at 20′ above base	28
	Chadron	
	Total	113

SECTION 19

SE¼ of NE¼, Sec. 26, T.3S., R.14E.

	Poleslide	
Zone VI	G Cl Y Cl Gr Ss-Slt	1 12 18
V	G-Y Cl	5
	Gr Ss and Slt	28
III	Y-G Cl	10
	G Slt	10
IIA	G-Y Cl	3
	G-Gr Slt 4 G Cl, discontinuous 4 Gr Slt 28	36
I	B Slt, pale, very few nodules	25
	Chadron	
	Total	117

Note: (1) This is a near-channel-zone section, with much coarse sediment and the mudstones notably tan to buff rather than red, like those both east and west of here.

(2) In this area, channel fills appear intermittently throughout both Scenic and Poleslide; determining the contact is difficult.

SECTION 20

Center of Sec. 24, T.3S., R.14E.

Poleslide

(Basal 9 feet, below a gray mudstone, may be Scenic VI)

	G-Gr Slt	25
Zone V	G-Y Cl	5
	G Slt	26
III	Y Cl	8
	Gr-G Slt and Ss, 3 thin, discontinuous Y Cl laminae	38
I	Y Cl, with a Gr Ss at about 20′ from base	37
	Chadron	
	Total	139

Note: One of the Y Cl laminae between I and III may represent IIA, but this cannot be demonstrated.

SECTION 21

NE¼ of Sec. 19, T.3S., R.15E.

	Poleslide	
	G Slt	16
Zone V	Y Cl	5
	G Slt	10
III	Y Cl (thickens NE to 4′)	2
	G Slt	20 (estimated)
II A		
	G Cl	2
IIA		
	G Slt	42
I	Y-B Cl	33
	Chadron	
	Total	130

SECTION 22

SW¼ of SE¼, Sec. 17, T.3S., R.15E.

	Poleslide	
	G Slt	15
Zone V	Y Cl 6 G Slt 3 Y Cl 2	11
	G Slt	8
III	Y-B Cl	14
	G Slt, one Cl lamina at 22′ from base	36
IIA	Y-G Cl	3
	G Slt	18
I	Y Cl, a few concretions in upper part	32
	Chadron	
	Total	137

SECTION 23

SW¼ of Sec. 16, T.3S., R.15E.

	Poleslide	
	G Slt Y Cl G Slt Y Cl G Slt	20 (estimated)
Zone V	Y Cl	11
	G Slt	22
III	Y Cl	3
	G Slt	11
	Y Cl (discontinuous)	1
	G Slt	10
IIA	Y Cl	2
	G Slt	30
I	Y-G Cl, no concretions	24
	Chadron	
	Total	134

SECTION 24

NE¼ of Sec. 15, T.3S., R.15E.

	Poleslide		
	G Slt	20	(estimated)
Zone V	Y Cl	6	
	G Slt	22	
III	Y Cl 5 G Slt 5 Y Cl 2	12	
	G Slt	10	
IIA	Y Cl	10	
	G Slt	17	
IA	Y Cl, turns red to east, pinches out N	1	
	G Slt	8	
I	YB Cl, no concretions, lower half highly bentonitic	36	
	Chadron		
	Total	142	

Note: IA is a red igapo clay of some areal extent. It wedges in and out, apparently representing a short time of heavy local rainfall without extensive flooding from the nearest rios.

SECTION 25

NW¼ of SW¼, Sec. 11, T.3S., R.15E.

	Poleslide	
	G Slt	25
Zone V	R G } Cl	8
	G Slt, discontinuous, bright R lens at 5′ above base	30
III	R Cl	6
	Gr Ss and Slt	6
IIA	R G } Cl	12
	G Slt	11
IA	R Cl	4
	G Slt	10
I	R Cl	28
	Chadron	
	Total	140

SECTION 26

NE¼ of Sec. 10, T.3S., R.15E.

	Poleslide		
	G Slt	20	(estimated)
Zone V	G Cl	5	
	G Slt	26	
	R Cl, G at base G Slt R Cl G Slt	4 4 5 4	
III	G Cl	10	
	G Slt	13	
	R Cl	2	
	G Slt	10	
IIA	R Cl	2	
	Gr Ss and Slt	6	
IA	R Cl	2	
	G Slt	8	
I	G Cl	30	
	Chadron		
	Total	121	

SECTION 27

SW¼ of NE¼, Sec. 34, T.2S., R.15E.

	Poleslide—Contact irregular		
	G Slt	20	(estimated)
Zone V	G Cl	3	
	G Slt	9	
	R Cl, bright, banded, in discontinuous lenses	4	
	G Slt	8	
III	G Cl	7	
	G Slt	8	
	R Cl thins northward to 0.5 foot	2	
	G Slt	10	
IIA	G-R Cl	8	
	G Slt	25	
IA	R Cl	2	
	G Slt	15	
I	R G } Cl, base not exposed	18	
	Total	139	

SECTION 28

NW¼ of SE¼, Sec. 35, T.2S., R.15E.

	Poleslide—Contact irregular	
	G Slt	35
III	G-R-Gr Cl, mottled	6
	G Slt	10
	R Cl, bright	1
	G Slt	8
IIA	G-R-Gr Cl, mottled	5
	G Slt	10
IA	R Cl, bright	1
	G Slt	10
I	G-B Slt, with base green	39

Chadron

Total 125

Notes: (1) Mudstone V merges with the Poleslide from here northeastward. The numbered zones are bentonitic and dull-colored, not bright red like the small zones.

(2) A quite persistent zone of siltstone occurs 30–40 feet up in the Poleslide in this area; careful tracing indicates that the base of this is definitely higher stratigraphically than the top of the Scenic member at the standard section.

(3) All thicknesses above Zone IA in this section are slightly inaccurate, due to extreme steepness of the cliff this section was measured on.

SECTION 29

NW¼ of NW¼, Sec. 36, T.2S., R.15E.

	Poleslide—Contact gradational	
Zone V	G Slt Y Cl at base	30 (estimated)
	Y Cl	3
	G Slt	15
III	R-G Cl	10
	G Slt	16
	R Cl bright	5
	G Slt	9
	R Cl bright	5
	G Slt	17
IIA	R Cl	51
	Gr Cl G Slt R Cl G R Cl	
I	G Cl, concretions R-G Cl, bentonitic	
	Chadron	

Total 161 (140′ ¼ mile N of here, due to pinching out of laminae between I and IIA)

SECTION 30

NW¼ of NE¼, Sec. 36, T.2S., R.15E.

Note: In this area there are many discontinuous lenses of bright red mudstone, usually under 2 feet thick, especially near the top of Mudstone I.

	Poleslide	
	G Slt; upper 20′ mostly G Cl, possibly Zone V	45
Zone III	G Cl, pink near top	8
	G Slt	15
	R Cl	4
	G Slt	26
IIA	G Cl, R at top	5
	G Slt	23
I	G Cl, reddish near top	37

Chadron

Total 163

SECTION 31

NE¼ of NE¼, Sec. 36, T.2S., T.15E.

	Poleslide	
Zone V	Y Cl G Cl	30 (estimated)
	R Cl	2
	Gr Ss and G Slt	8
III	G Cl, R at top	8
	G Slt	22
	R Cl	2
	G Slt	15
	R Cl	1
	G Slt	16
IIA	G Gl, R at top	8
	G Slt	20
	G-Y Cl, R at top	12
	Bottom not exposed	

Total 144

SECTION 32

SW¼ of NW¼, Sec. 33, T.2S., R.16E.

	Poleslide Grading Into	
	Y Cl and Y-G Slt	15
III	G Slt G-Gr Cl, R at top	18 10
	G Slt	15
	R Cl, banded	3
	G Slt	6
	R Cl, bright	1
	G Slt and Cl	16
IIA	G Cl, R at top	7
	G Cl and Slt	5
I	G Cl, R at top	12
	Bottom not exposed	

Total 108

SECTION 33

SW¼ of SE¼, Sec. 28, T.2S., R.16E.

200 yards west of Dillon Pass Tourist Camp

Note. Northeastward, Zone IIA retains its identity but comes to rest directly upon Zone I. This feature occurs apparently along an E-W zone only 200–300 yards wide; the two are separated again to the north of this zone (Section 34).

	Poleslide—Contact gradational	
	Y Cl	
	G Slt	10
	R Cl	1

	G Slt	15	
Zone III	G Cl, R at top	7	
	G Slt	20	
	R Cl	3	
	G Slt	4	
IIA	R Cl Gr Cl	5	
I	G-R Cl	8	
	Bottom not exposed		
	Total	73	

SECTION 34

NE¼ of SE¼, Sec. 26, T.2S., R.16E.

200 yards SW of Dillon Pass Road Junction

	Poleslide		
	Y Cl	5	(estimated)
	G Slt	18	(estimated)
III	R Cl, white zone in middle	10	
	G Slt	19	
	R Cl	4	
	G Slt	14	
IIA	G Cl, R at top	8	
	G Slt	11	
	R Cl, banded	5	
	Gr Ss and G Cl, banded	12	
I	R Cl Brown Cl	25	
	Chadron		
	Total	128	

SECTION 35

SE¼ of NE¼, Sec. 20, T.2S., R.11E.

This section is east of U. S. 16A, in White River drainage, just southeast of the White River–Bad River divide.

Mudstone Zone IIA here rests directly upon Zone I, by wedging out of the intervening sediments. Mudstone Zone III is a triple bed throughout this area. At the position of this section, it consists of a blue-gray concretionary mudstone with red layers above and below.

	Poleslide		
	Y Cl with concretions	10	(estimated)
	G Slt	12	(estimated)
	Gr Ss	2	
III	R Cl G Cl R Cl	15	
	Gr Ss	4	
	G Slt with 3 pale red laminae	25	
IIA	G Cl, dark	4	
I	G Cl	17	
	Chadron		
	Total	79	

SECTION 36

NE¼ of NE¼, Sec. 20, T.2S., R.16E.

This section is immediately east of U. S. 16A, on the north or Bad River side of the White River–Bad River divide.

All unnumbered red zones are bright, discontinuous lenses.

	Poleslide	
	Y Cl, concretionary	8
	G Slt	8
	R Cl	1
	G Slt	5
III	R Cl G Cl R Cl	8
	G Slt	9
	R Cl	3
	G Slt	10
	R Cl	2
	G Slt	13
IIA	R Cl G Cl	6
	G Slt	18
	G Slt	4
I	R Cl G Cl	34
	Chadron	
	Total	132

Appendix II

ABBREVIATIONS USED IN REFERENCE TO SPECIMEN NUMBERS

AMNH	American Museum of Natural History
CM	Carnegie Museum
CU	University of Colorado Museum
FMNH	Field Museum of Natural History

The following letters designate specimens in the various Field Museum collections:

G	Sedimentary Petrology
PM	Fossil Mammals
PE	Fossil Invertebrates
PF	Fossil Fishes
PP	Paleobotany

PM	Princeton University Museum.
SDSM	South Dakota School of Mines and Technology Museum.

WORDS INTRODUCED OR REDEFINED IN THIS PAPER

1. **Anataxic factors.** The weathering and erosional factors which act to destroy a fossil during the degradation of the rocks in which it occurs.
2. **Biotic factors.** Those factors which determine whether or not a population of any particular species will inhabit an area.
3. **Death assemblage.** The sum total of corpses which arrive upon a surface between the deposition of two successive increments of sediment, or between the inception of one period of incrementation and its termination.
4. **Drenaje.** A drainage-way without headwaters, developed in the trough between two actively depositing streams; also, the stream which occupies this drainage-way.
5. **Drenajesome.** The body of sediments deposited within a drenaje through an episode of sedimentation unmarked by significant erosion.
6. **Igapo.** The trough which lies between a valley wall (terra firme) and the outward-sloping depositional surface of the stream which occupies the valley.
7. **Igaposome.** The body of sediment deposited within an igapo during one depositional episode.
8. **Life assemblage.** The total number of individuals within a specified area during a specified time; the term may be limited to any group, e.g., mammals, or cervids, or plants.
9. **Perthotaxis.** A death assemblage with the animal corpses in various stages of destruction by the set of processes normally operative under the environment concerned.
10. **Perthotaxic factors.** The factors which act to destroy animals' corpses within any particular environment.
11. **Perthotaxy.** The more or less orderly destruction of animals' corpses by the combined action of natural processes.
12. **Rio.** A throughgoing stream with its provenance outside the area concerned.
13. **Riosome.** The body of sediment deposited within the channel-way of a rio during one primarily depositional episode (=period of incrementation).
14. **Sullegic factors.** Those factors influencing the collecting of fossils which determine whether or not any particular fossil at the surface will find its way into a collection.
15. **Taphic factors.** Factors determining whether or not an animal's bones will be buried.
16. **Terra firme.** The valley walls bounding a valley-way in which sedimentation is taking place. Normally composed of material other than that carried by the rivers.
17. **Thanatic factors.** The factors surrounding an animal's death which determine whether or not its body will arrive upon the surface as a member of the death assemblage.
18. **Total fossil assemblage.** The sum total of fossil specimens entombed within any particular sedimentary unit, in an area under question.
19. **Trephic factors.** The factors incident to curating and identifying a fossil specimen which determine whether or not a fossil in a collection becomes available for use.
20. **Varzea.** The depositional surface, including the natural levee and the long backslope, developed upon each side of a depositing stream by outward sheet flow over its banks.
21. **Varzeasome.** The body of sediment deposited upon a varzea through one depositional episode.

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