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# ART. XXI THE STRATIGRAPHY AND PALEONTOLOGY OF THE CHADRON FORMATION IN THE BIG BADLANDS OF SOUTH DAKOTA

By John Clark

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# ART. XXI. THE STRATIGRAPHY AND PALEONTOLOGY OF THE CHADRON FORMATION IN THE BIG BADLANDS OF SOUTH DAKOTA*

By John Clark

(Text Figures 1-12; Tables I-IV)

(Plates XXI-XXVI)

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Issued December 31, 1937

## INTRODUCTION

The fluviatile origin of the Chadron formation in South Dakota has been thoroughly established by Hatcher, Fraas, Sinclair, Wanless, Darton, and others.

Osborn,[1] basing his conclusions primarily upon Hatcher's field work, has accepted Hatcher's division of the Chadron into three faunal zones, designated as A, B, and C. These faunal zones are not related to any lithologic division of the formation. Collectors have found the local variations in lithology so extreme that no widespread order of succession could be discovered, and have, therefore, relied upon measurements upward from the base of the Chadron to determine the relative ages of specimens.

It is the purpose of this study to determine the actual order of superposition within the Chadron of the Big Badlands, and the relationship of the fossils to the stratigraphic succession. From this information, a coherent interpretation of local Chadron history may be drawn, and a standard faunal section for comparison with lower Oligocene faunas from other areas may be proposed.

Since the fluviatile origin of the Chadron sediments was first generally accepted, the deposits have been variously regarded as subærial deltas, confluent alluvial fans, and flood plain sediments. Fan deposition implies extensive reworking, erosion of earlier deposits and

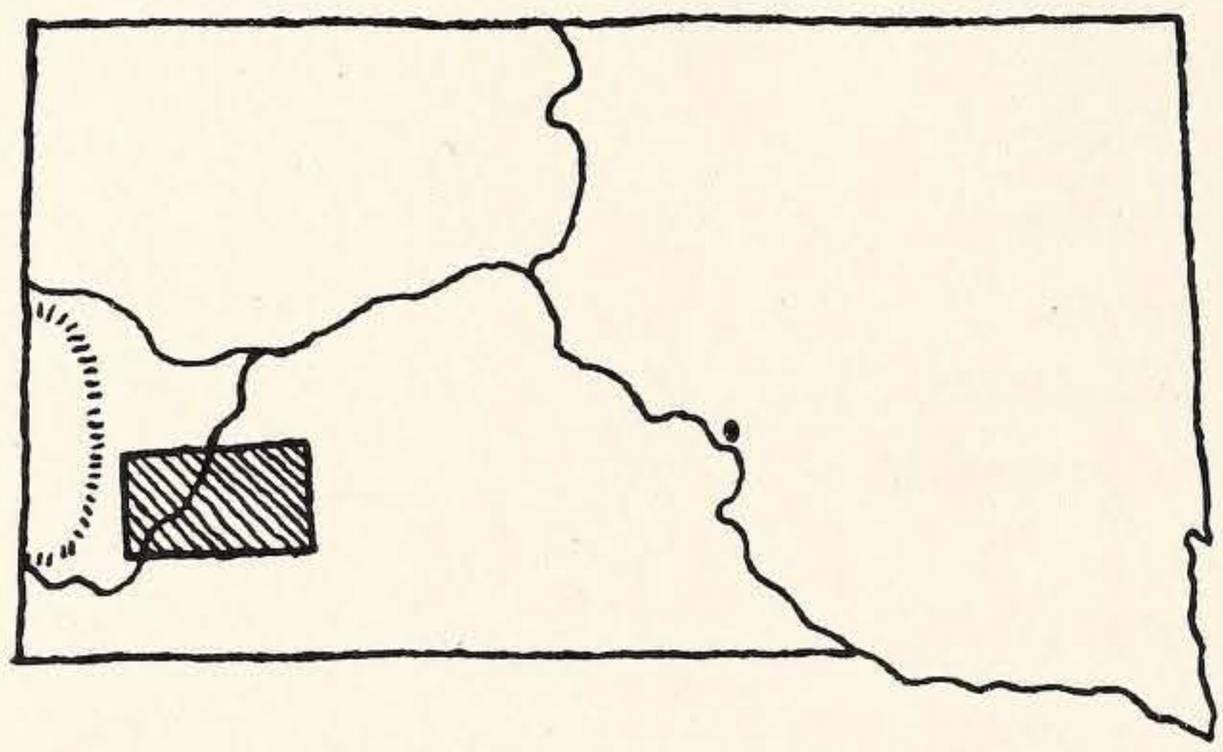


FIG. 1. Base map of South Dakota.

redeposition downstream, and a general order of succession in which the older sediments lie near their source and the younger ones farther

[1]Osborn, H. F., Titanotheres of Ancient Wyoming, Dakota, and Nebraska. U. S. Geol. Surv., Monograph 55, 1929.

downstream. Flood plain deposits, on the other hand, might be expected to be more regular, with a normal, vertical order of superposition of widespread members.

It is essential, therefore, to learn the method of deposition of the formation in order to discover the true order of superposition. The evidence bearing upon this problem will be presented in the sections on Stratigraphy and Lithology.

The area studied is shown in the maps, figures 2 and 3. It lies in Pennington, Washington, Jackson, and Custer Counties, South Dakota, and follows the outcrop of the Chadron from the town of Interior on the east to Fairburn on the west.

## STRATIGRAPHY

In 1893, Hatcher[2] divided the "Titanotherium beds" of South Dakota into A, B, and C levels, on the basis of the evolution of Titanotheres represented by the skulls which he found. His stratigraphic table is reproduced here (table I) for reference. Osborn in 1929 expanded Hatcher's brief faunal characterization of the three levels into a highly detailed description of the evolution of five separate phyla of Oligocene Titanotheres.[3]

Obviously this subdivision is stated so clearly, and the levels are so adequately characterized faunally, that a student may expect to go into the field and find a series of beds 180 feet thick (maximum, *vide* Hatcher; Osborn allows a range of 150-200 feet, *loc. cit.*, p. 443), having small Titanotheres in the lower fifty feet, medium-sized ones with medium-sized horns in the next hundred feet, and large, long-horned forms in the uppermost thirty feet. The datum plane employed[4] is the Pierre-Chadron contact. Hatcher,[5] Darton,[6] and Osborn,[7] have all stated that the subdivision is based solely on the fauna, and that lithology (and by implication, paleogeography) is of no assistance in determining the levels.

[2]Hatcher, J. B., The Titanotherium Beds; Amer. Nat., vol. XXVII, 1893, pp. 204-221.

[3]Osborn, H. F., *loc. cit.*, pp. 114-115, 443-581.

[4]Osborn, H. F., *loc. cit.*, p. 113, 117, *et al.*

[5]Hatcher, J. B., *loc. cit.*, p. 207.

[6]Osborn, H. F., *loc. cit.*, p. 115. Darton, quoted by Osborn.

[7]Osborn, H. F., *loc. cit.*, pp. 113, 116.

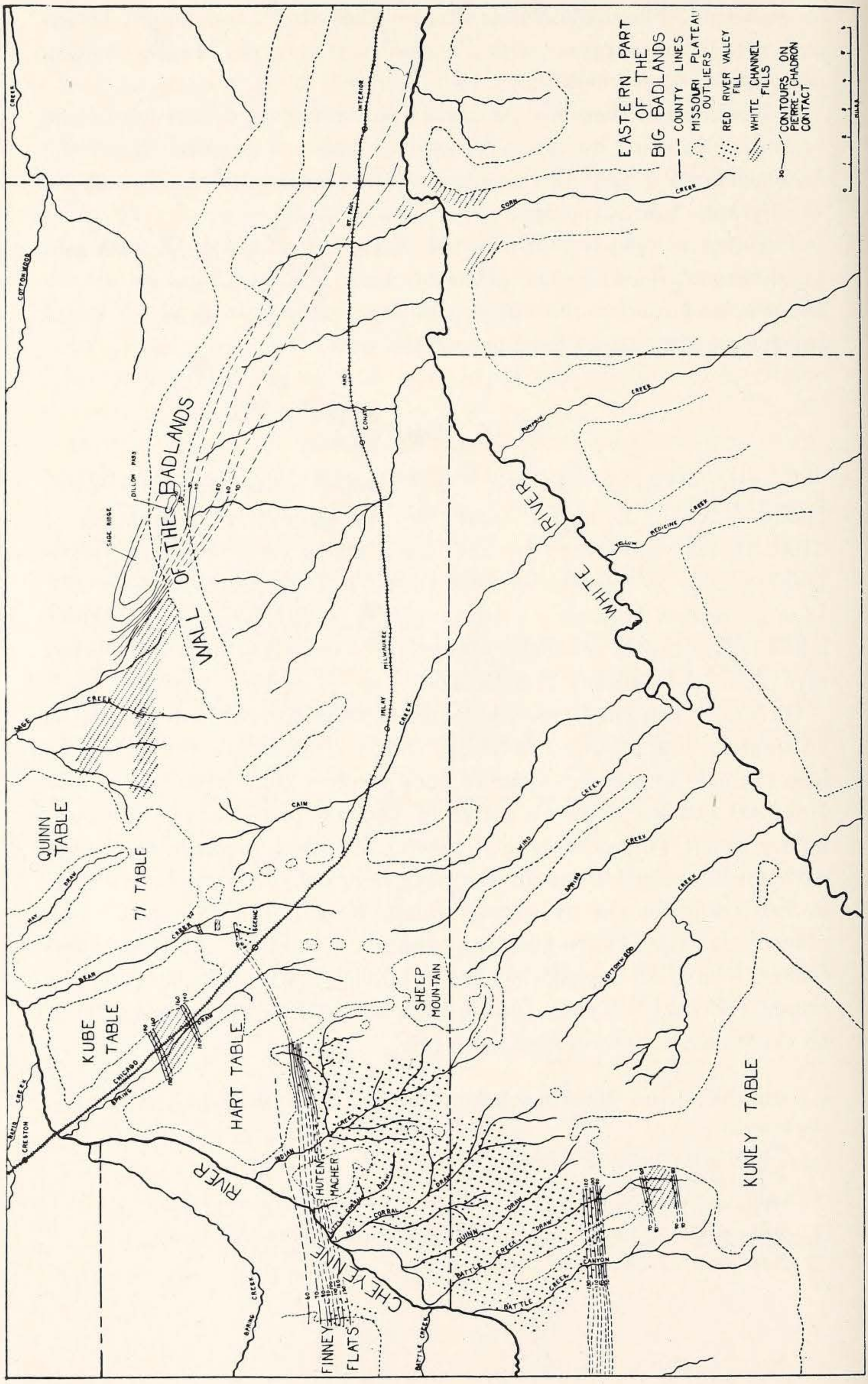



FIG. 2. Eastern Part of the Big Badlands.

As such a system of faunal horizons might be of great significance in determining the time relationships of depositional phenomena, it seems wise to re-examine the evidence for the subdivision, both in the literature and, directly, in the field. To this end I have prepared table II, giving a list of all the specimens whose measured position above the Pierre shale is quoted by Osborn, together with the stratigraphic positions to which he assigns them. Table III lists the 11 skulls which I have observed in the field, gives their actual positions above the Pierre shale, and the theoretical positions assigned to those species.

Certain features of table II are worthy of note. *Brontotherium ramosum* and *Megacerops copei*, both C forms, were collected respectively twelve and fifteen feet higher than *Allops marshi*, an A form. One might wonder if this indicates that the B zone is only fifteen feet thick in places. Also, accepting Hatcher's figures of A = 50 feet, B = 100 feet, C = 30 feet, none of the specimens listed would occur higher than the middle of the B zone. Yet it is apparent that C forms are present, so we must ask, do all three members thin locally, or is one or another absent, and further, what is the basis for assuming either of these alternatives?

Among those specimens which I have observed, the discrepancies from theoretical levels are even more striking. *Allops serotinus*, which should occur in the Chadron from about 150 feet to 180 feet above the Pierre ($B_3$-C), is here found fifteen feet above the Pierre, fifty-four feet below the Brulè, and therefore certainly within the A zone. If *Allops serotinus* is characteristic of the upper fifth of a 180 foot section, how can it occur in the lower fifth of a 70 foot section? Also, how does *Brontotherium platyceras*, typically $C_3$, come to rest at exactly the same level as *Brontops brachycephalus*, A? Most noticeable of all, how did *Brontotherium platyceras*, "the climax of the evolution of the long-horned titanotheres" ever come to be buried twenty-two feet above the Pierre shale, overlain by fifty feet of clays and widespread limestone bands?

From a study of these two tables, it appears that the only way to recognize a stratigraphic horizon in the Chadron is to find a Titanothere skull, identify it, and then say that the sediments in close proximity to it are in the A, B, or C zone, regardless of the thickness of the section and of how high in the section the skull occurred. This procedure is unsatisfactory because the phylogenetic lines are based upon a stratigraphic succession which, in turn, can be determined only by

reference to the same phylogenetic lines. Use of an evolutionary sequence as the basis for the stratigraphic subdivision upon which it depends for the time sequence of forms is, in the absence of supporting evidence, open to serious question.

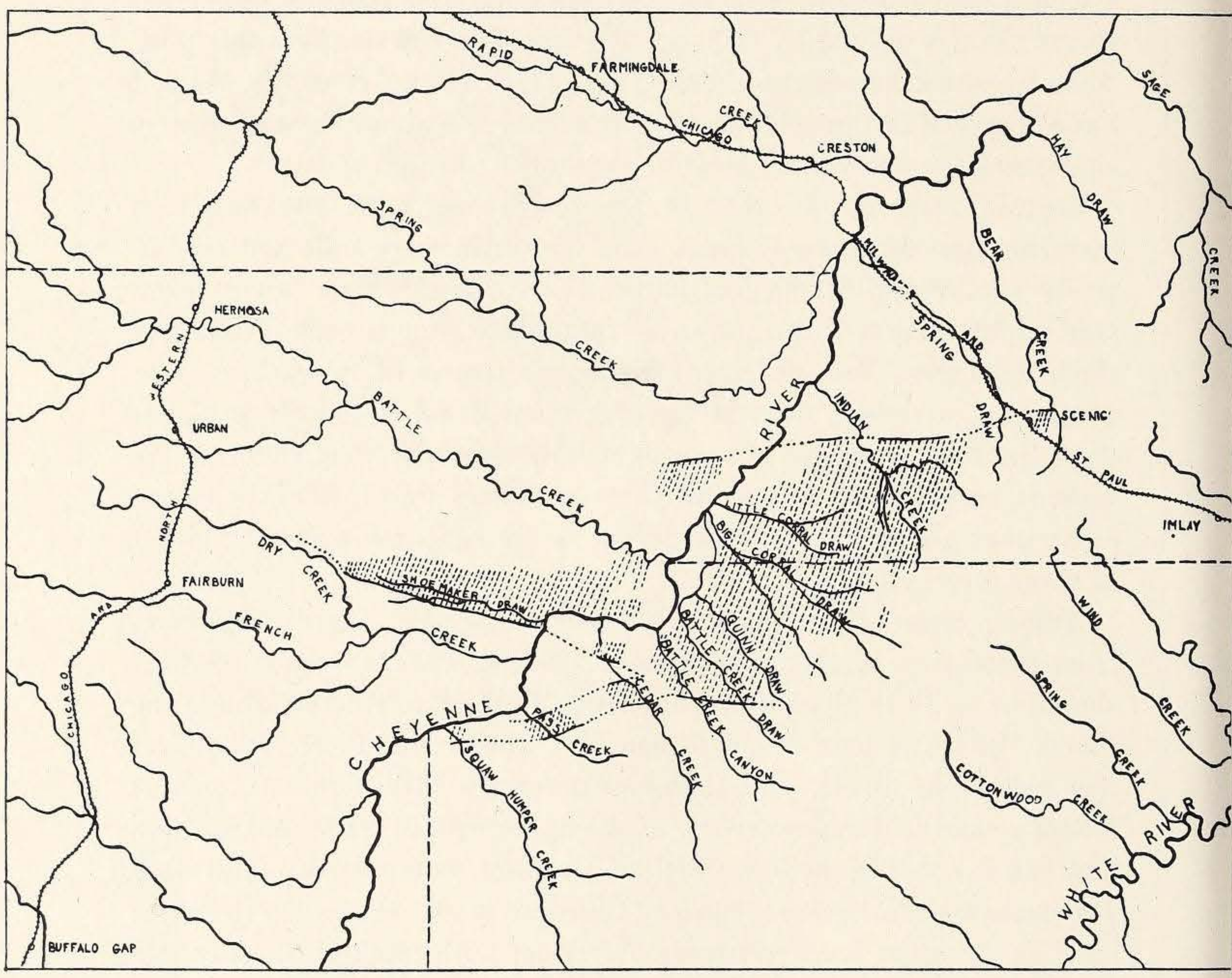



FIGURE 3
WESTERN PART OF THE BIG BADLANDS

--- COUNTY LINES
RED RIVER VALLEY FILL
VALLEY WALL (OBSERVED)
VALLEY WALL (INFERRED)

0 10
SCALE OF MILES

In view of the possibility of errors arising from application of the foregoing method, it seems best to study the Chadron without reference

to the subdivision into A, B, and C levels, leaving the relationship of those levels to the depositional phenomena to be discovered in the course of the study.

*Stratigraphic setting of the Chadron:* The general stratigraphy of the Big Badlands, as described by Wanless,[8] is summarized in the following stratigraphic column:

| | | |
|---|---|---|
| Rosebud | 50′ + (top eroded) | |
| Brulè | Leptauchenia beds | 162′ |
| | Oreodon beds | 215′ |
| Chadron | 12′-165′ | |
| Pierre | "Interior" phase | 0-70′ |
| | Unweathered Pierre, base not exposed | |

The Tertiary group has a regional dip of 1°-2° SE, and the edges of the tilted strata are bevelled by the Missouri Plateau[9] erosion surface. Outliers forming hills on the plateau surface, deep incision of the present rivers and their tributaries, and occasional local structures cause the formations to outcrop in highly irregular patches.

The Chadron is easily distinguishable from the Brulè by its weathering, as Wanless has mentioned—the Chadron weathering to hills convex outward, and the more firmly cemented Brulè clays weathering to serrate spurs and ridges concave outward. Occasionally in the exposures west of Quinn Draw, there is a gradational zone five or ten feet thick rather than a sharp contact between the Chadron and the Brulè; and in the scattered, unfossiliferous outcrops near the Black Hills it is frequently impossible to distinguish between the two, but these cases are exceptions to a widely applicable rule.

*Detailed description of the Chadron:* The Chadron of the Big Badlands is divisible into an eastern facies, which extends from Bear Creek drainage basin (="Scenic Basin") to the town of Interior, and a western facies, which reaches from Scenic Basin southwestward to Fairburn. (See map, figure 2. Using the Chadron-Brulè contact as datum plane, negative contours were drawn on the Pierre-Chadron contact on ten foot intervals, and hence show the thickness of the Chadron throughout the area. Thus the thirty foot contour line connects those places where the Chadron is thirty feet thick, etc.)

[8]Wanless, H. R., Stratigraphy of the White River Beds of South Dakota; Proc. Am. Phil. Soc., vol. LXII, no. 4, 1923.

[9]Fenneman, N., The Physiography of Western United States; McGraw-Hill Book Co., 1931, p. 61.

The eastern facies is made up of three sharply defined members: (1) restricted basal channel fills (see map, also fig. 3); (2) a widespread series of massive clays with intermittent limestone bands; (3) lenses of evenly bedded fine sand, silt, and limestone.

The basal channel fills are chalky white, sandy, and cross-bedded. A basal gravel, composed almost entirely of quartz, quartzite, and patinated chert pebbles, rests in irregular, dark festoons across the faces of the outcrops. No fossils have been found in these channel fills.

Over most of the eastern area, the formation consists of a series of massive, silty clays, 12′-70′ thick, colored various pastel shades of green, lavender, pink, and blue-gray. Freshwater limestones, ranging from concretionary bands to massive limestones 2′ thick and 400 yards in diameter, occur so frequently that any vertical section will include two or three of them. Fossils are extremely rare and fragmentary; a few scraps of Titanothere, *Oreodon*, *Mesohippus*, and *Hyænodon* have been found at various places.

Laminated lenses showing a notable absence of cross-bedding constitute the third lithologic member of the eastern facies. (See map, figure 4, for distribution.) Individual laminæ are one inch to two feet thick, composed of fine green sand, greenish to gray-white silt, and limestone. The bases of the lenses are always well above the base of the Chadron, and wherever they occur, the tops of the lenses form the top of the Chadron; individual beds of the lenses interleave with the surrounding massive clays, indicating that deposition of the lenses and of the upper part of the clay series proceeded contemporaneously.

Omitting, for the present, discussion of the somewhat anomalous section in Spring Draw between Hart and Kube Tables, the next area to be described is the great Badlands region of Indian Creek-Corral Draw and westward, Hatcher's favorite collecting ground and his standard section for the subdivision into A, B, and C levels.

In contrast with the definite lithologic division of the east, the western facies is characterized, at first sight, by extreme heterogeneity. Gravels, sands, clays, and limestones anastomose, intersect, grade into one another, wedge in and pinch out, and contain local belts of concretions. It seems hopeless to seek any recognizable order on which to base stratigraphic conclusions, but study of a large number of exposures reveals a stratigraphic succession which, once it is recognized, is general and easily applied.

The lower member is the great lens of red and green sands and clays

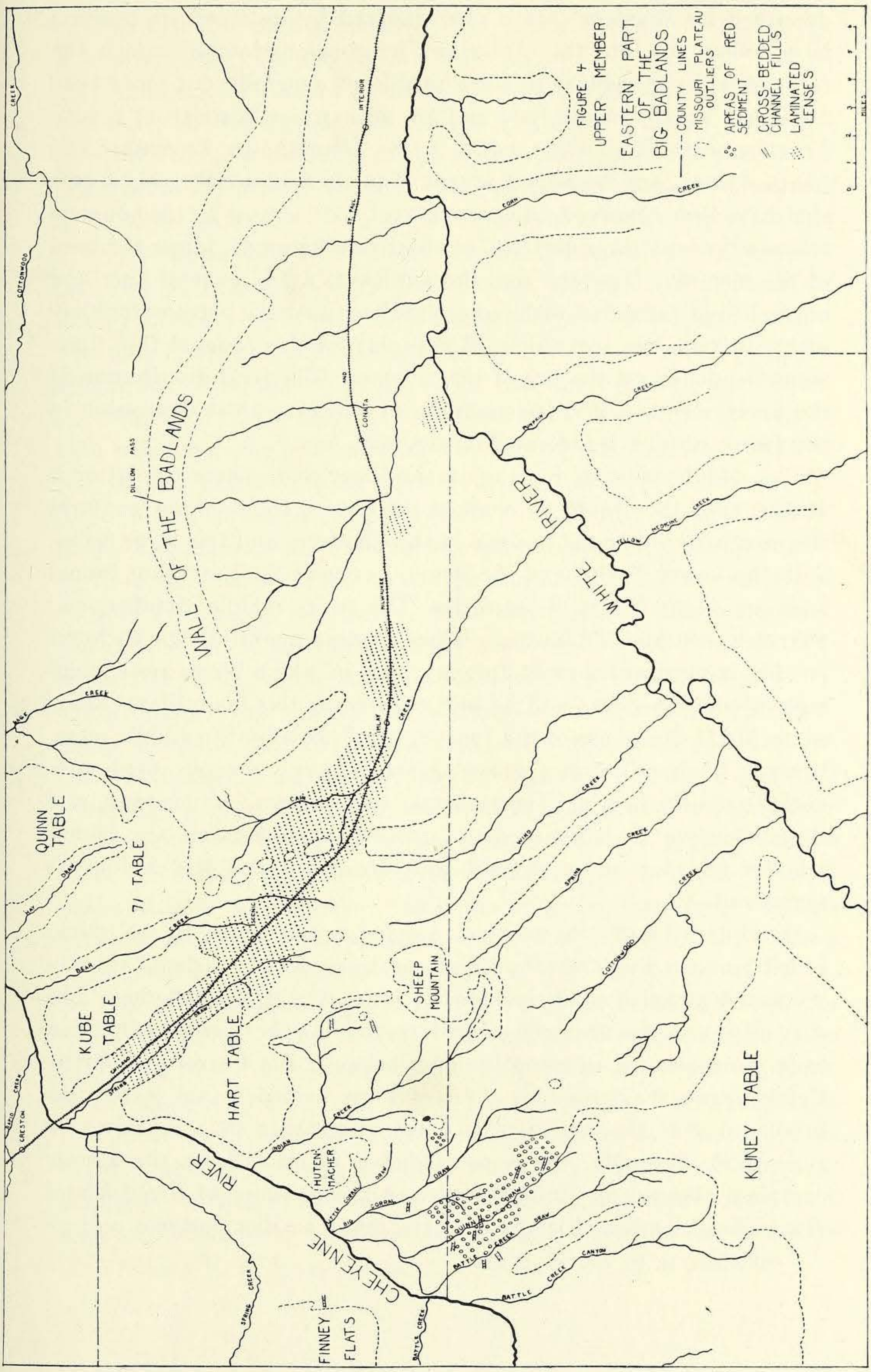


FIGURE 4
UPPER MEMBER
EASTERN PART OF THE BIG BADLANDS
COUNTY LINES
MISSOURI PLATEAU OUTLIERS
AREAS OF RED SEDIMENT
CROSS-BEDDED CHANNEL FILLS
LAMINATED LENSES
MILES
WALL OF THE BADLANDS
DILLON PASS
QUINN TABLE
71 TABLE
KUBE TABLE
HART TABLE
SHEEP MOUNTAIN
KUNEY TABLE
HUTENMACHER
FINNEY FLATS
WHITE RIVER
CHEYENNE RIVER
CORN CREEK
PUMPKIN CREEK
YELLOW MEDICINE CREEK
COTTONWOOD CREEK
WIND CREEK
SPRING CREEK
BATTLE CREEK
BATTLE CREEK CANYON
QUINN CORRAL DRAW
BIG CORRAL DRAW
LITTLE CORRAL DRAW
NOLAN CREEK
CHICAGO & NORTHWESTERN
CHICAGO & MILWAUKEE
ST. PAUL AND PACIFIC
INTERIOR
CONATA
MILLAY
SCENIC
CAIN CREEK
BEAR CREEK
HAY DRAW
SPRING CREEK
RAPID CREEK
CRESTON
SPRING CREEK
MILWAUKEE CREEK
COTTONWOOD CREEK
INGE CREEK

FIGURE 4.

described by Wanless.[10] It is characterized by its color, its position in a hollow cut into the "Interior," by conglomerates in which the ratio of feldspar pebbles to silica pebbles is generally not more than 20% and usually much less, and by an extreme scarcity of fossils. Fragments of Titanothere bone, a few *Mesohippus*, *Trigonias*, and *Oreodon* teeth, and occasional scraps of turtle shell are the only fossils that have been observed. A coarse gravel, with almost all the boulders composed of quartz, quartzite, or chert (see figure 5), forms the base of the member. Near the top, the sediments are in general finer and not so heavily streaked with red as are those near the bottom; in many places a layer, ten feet thick, of buff clay with occasional thin limestone bands, forms the top of the member. The areal distribution of the lower member, and its confinement within a great depression in the Pierre surface, is indicated on the map, figs. 2, 3.

The middle member rests upon the lower and, where the latter is absent, upon the "Interior" phase of the Pierre. Its basal ten feet form the most striking faunal horizon in the Chadron, and this layer ranks, with the Lower Nodular of the Brulè, as one of the important faunal horizons of the White River series. The entire middle member, 40′-50′ thick, contains Titanothere bones in some quantity, but its lower portion is marked by great "graveyards" in which bones are exceedingly abundant. More will be said concerning this faunal level later; plate XXII shows one of the "graveyards." Briefly, the middle member may be described as a 40′-50′ series of clays and sands, predominantly greenish, bearing Titanotheres, rhinoceroses, *Mesohippus*, and *Archæotherium* as characteristic fossils. Conglomerates are highly arkosic; feldspar ratios of 30%-50% are common. Red sediments are absent.

Overlying the middle member, a massive clay series 20′-30′ thick, bearing many discontinuous limestone lenses and occasional sharply restricted greenish sandstone lenses, forms the upper member. The silty clays are generally buff-colored, resembling the overlying Oreodon beds. However, in an extensive area between Big Corral and Battle Creek draws they are red; there is some evidence (see section on lithology) that the red color is diagenetic rather than inherited or syngenetic. Faunally, the upper member is marked by the almost complete absence of Titanotheres, and the presence of *Oreodon* and *Hyracodon*. Sandstone lenses are very much smaller and less numer-

[10]Wanless, H. R., *loc. cit.*, p. 200.

ous than in the middle member. The Chadron-Brulè contact is almost everywhere marked by limestone bands.[11]

It must not be supposed from this brief description that the contact between two members is always well defined. The contact between the lower and middle members is usually easy to detect by the cessation of red sediments and by the "graveyard" immediately above it. In some places, however, where "graveyards" are not present and where the upper part of the lower member is a massive clay, the contact may be a limestone between two clays, and can be found only by tracing carefully from the nearest place where a "graveyard" occurs. The middle-upper contact is usually recognizable at once by a great diminution of sandstone in the series (see figure 8) and by the disappearance of Titanothere bones. Here again, a local clay facies in both members, or a local sandstone facies of both, may cause trouble and require careful tracing of individual stratigraphic horizons for positive determination of the contact, Also, in places, the Chadron-Brulè contact is a gradational zone of intercalated clays and limestones up to ten feet thick, which makes the establishment of one particular plane as a "contact" impossible. All of these difficulties are very local, and can be solved by a brief period of detailed work. None of them essentially affect the fundamental features of the stratigraphy.

Fortunately, the eastern and western facies interfinger in Scenic Basin, in such a way that correlations between them are possible. The north border of the depression which holds the lower member (western) is exposed a mile and a half east and northeast of Scenic. Here a limestone, which locally forms the contact between typical western lower and middle members, can be traced northeastward to where it comes to lie on the "Interior," while the overlying fossiliferous middle member grades into the massive, barren clay series of the eastern facies (see Bear Creek cross sections, plate XXV). Two white basal channel fills, typically eastern, underly the limestone a half-mile north of where the western lower member "pinches out," and hence are to be correlated with it rather than with the middle or upper western members. Widespread erosion in Scenic Basin precludes determination of the upper member's relationships. However, in the head of Cain Creek drainage, one and a half miles to the southeast, an eastern laminated lens directly overlies the most easterly expression of the western fossiliferous, cross-bedded middle member. Also, bones of

[11]Wanless, H. R., *loc. cit.*, p. 209.

*Oreodon*, *Mesohippus*, and *Hyracodon* have been collected from the laminated lenses and Titanothere remains have not, and as has been mentioned before, the laminated lenses form the top of the Chadron wherever they occur.

Therefore, on the basis of lithology and superposition, the following correlation is proposed:

| WESTERN | | EASTERN |
|---|---|---|
| Upper Member | Laminated lenses | Massive |
| Middle Member | | Clays |
| Lower Member | | White Channel Fills |

## LITHOLOGY

*Pierre Shale*: The Pierre shale is a massive, dark gray marine shale, very soft, and high in soluble salts, organic matter, and iron.

"*Interior Formation*": To Wanless'[12] excellent summary of opinions and evidence regarding Ward's "Interior Formation," I wish to add certain details bearing upon Chadron paleogeography.

Any theories regarding the "Interior" must take into account the great hollow, seventy to eighty feet deep and eight miles wide from north to south (see figure 2), in which the lower member of the Chadron rests. Wanless assumed that this hollow was a valley, cut by a stream which had previously wandered on a peneplained surface (the "Interior peneplain"), and which later filled its valley. Discovery of the south rim of the hollow, of its east-west elongation, and of the tributary exposed in Cedar Creek, establishes his assumption beyond reasonable doubt. East of the area where the hollow is mapped, it is carried beneath the surface by the regional dip, and to the west the outcrops become scattered and inadequate, or it could undoubtedly be traced farther in both directions.

The present study has added but one significant feature to the evidence given by Wanless in his demonstration that the "Interior" is a weathered zone of the Pierre, and not a separate formation correlative with the Fox Hills as Ward[13] believed. In the region around the town of Interior and the Sage anticline, where the "Interior" zone is 50-70 feet thick, the section is as follows:

[12]Wanless, H. R., *loc. cit.*, p. 194.

[13]Ward, F., (1) Geology of a Portion of the Badlands; S. Dak. Geol. and Nat. Hist. Surv., Bull. 11, 1921.
(2) Position of the Interior Formation; Amer. Jour. Sci., 5th ser., vol. 11, 1926.

Chadron

"Interior" 50-70′ { Red 0-3′; Yellow-brown; Purple; Gray } Sometimes one absent and the other very thick.

Pierre (unweathered)

At many places underlying the Lower Member of the Chadron, there are sections of "Interior" a few inches to several feet thick. These abbreviated sections show the following color series:

Chadron

"Interior" 15′ { Green—a few inches; Brown; Purple; Gray }

Pierre (unweathered)

Except for the uppermost zones, the two sections are similar. Such a condition would be almost impossible under the assumption that the color is primary in a formation deposited upon the Pierre, but accords very nicely with the theory that the color is due to weathering of the Pierre, with a deep weathering profile developed on the old upland and a shallow profile, checked by deposition, in the old valley.

The chemical analyses which Wanless gives, in addition to two presented here, show clearly the weathering features which Wanless pointed out, *i. e.*, increase in proportion of alumina, iron, and potassium, and decrease in lime and magnesia. It is obvious that a fairly selected, large sample of "Interior," including some of the numerous limonitic veins, would show a much higher iron content than do these hand-picked clay samples.

| | Sample 1. | Sample 2. |
|---|---|---|
| $SiO_2$ | 60.72 | 62.99 |
| $Al_2O_3$ | 18.94 | 17.51 |
| $Fe_2O_3$ | 3.97 | 4.55 |
| FeO | 0.26 | 0.29 |
| CaO | 0.75 | 0.77 |
| MgO | 1.25 | 1.19 |
| $H_2O-110°$ | 3.66 | 5.34 |
| $H_2O+110°$ | 6.78 | 5.53 |
| Total | 96.33 | 98.17 |

A. H. Phillips, analyst.

A cursory examination of the voluminous literature upon laterites and the growing literature on soils shows that the changes mentioned above are characteristic of weathering which produces laterites. In the typical laterites of India and Cuba, however, those changes are so much more extensive that it seems best to call the "Interior" a weathered zone rather than a laterite, recognizing at the same time that processes similar to lateritization have formed the "Interior."

The general climatic factors favorable for lateritization and formation of red earths are semitropical to tropical temperatures and sub-humid to humid climates.[14] Recognizing this, Wanless[15] suggested that the deep weathering took place during and after peneplanation of the area, and that cutting of the great valley (which will be referred to hereafter as Red River Valley, in reference to the color of the Chadron Lower Member sediments which fill it) occurred later. Davis[16] speaks definitely in favor of the theory of peneplains being sites of origin of laterite. Other authors,[17] however, either state that lateritization occurs in the zone of intermittent saturation or describe processes which take place only in that zone.

Therefore, it seems justifiable to advance an hypothesis alternative to that of Dr. Wanless. It is not improbable that development of the large, mature Red River Valley proceeded contemporaneously with deep chemical weathering of the neighboring uplands. Under these conditions, the uplands would be in the zone of intermittent saturation, rather than below the water-table, where they would probably lie if they represent a peneplain formed by Red River and intrenched by it after weathering. The white basal Chadron lenses would repre-

[14](1) Robinson, G. W., Soils, Their Origin and Classification; Thomas Murby & Co., London, 1932, pp. 270-283, 300, 305.

(2) Leith and Mead, Metamorphic Geology; Henry Holt & Co., New York, 1915, pp. 25-44.

(3) Ramann, E., The Evolution and Classification of Soils (Translated by Whittles, C. L.); W. Heffer & Sons, Ltd., Cambridge, 1928, p. 109, table opposite p. 118.

[15]Wanless, H. R., *loc. cit.*, p. 202.

[16]Davis, W. M., Geol. Mag., vol. LVII, p. 429, 1920.

[17](1) Campbell, J. M., Laterite, Its Origin, Structure, and Minerals; Mining Magazine, vol. XVII, no. 3, p. 121, Sept., 1917.

(2) Twenhofel, W. H., Treatise on Sedimentation, 2nd edition, 1932, pp. 440-442.

(3) Leith and Mead, *loc. cit.;* (4) Ramann, *loc. cit.;* (5) Robinson, *loc. cit.*

sent former tributary or meander channels left hanging as Red River lowered its valley. The age of these white lenses will be more fully discussed later.

The thin, bright red zone at the top of the thicker sections of "Interior" may very well represent an upland surface soil, more highly oxidized and leached than the underlying brown, purple, and gray clays. Certainly there is no evidence against this idea, although it is equally true that I have no conclusive evidence in its favor.

The greenish zone at the Pierre-Chadron contact bears important paleoclimatological implications. Disseminated through the greenish clay are numerous tiny cubes of pyrite; in places the basal Chadron gravel is firmly cemented into a conglomerate band a few inches thick, with a pyrite matrix. This pyrite could, of course, have been formed either by the action of Red River waters upon the ferruginous Pierre or by later ground waters following the gravel as an aquafer.

On the southwest slope of Hart Table, and again in upper Battle Creek Draw, beneath pond limestones of late lower and early middle Chadron age, which locally form the basal Chadron, the greenish reduced zone of "Interior" is from eight to twelve feet thick. As these impure, massive, unjointed limestones and clays are almost impervious, this seems satisfactory evidence that the greenish pyritiferous zones were formed by Chadron waters, and not by later ground water. Red River had cut to the granite core of the Black Hills by the beginning of Chadron time, and hence was flowing over all the Black Hills from the Pre-Cambrian to the Pierre. It is probable, therefore, that its waters bore a strong chemical resemblance to the present Belle Fourche river, an analysis of which, on a sample taken at Nisland, has been made by Clarke.[18] As might be expected in river waters which have crossed Cretaceous shales, the amount of dissolved sulphates is very large. A river high in sulphates would, especially if it were slightly acid, dissolve considerable iron from a ferruginous shale. As Thiel[19] has shown, presence of natural organic matter is effective in reducing ferrous sulphate to sulphides. Hence abundant organic matter in the early Chadron waters would combine with organic matter in the Pierre shale to precipitate pyrite or marcasite.

[18]Clarke, F. W., The Composition of the River and Lake Waters of the United States; U. S. Geol. Surv., Prof. Paper 135, 1924, pp. 95, 96.

[19]Thiel, G. A., Experiments Bearing on the Biochemical Reduction of Sulphate Waters; Econ. Geol., vol. XXV, no. 3, 1930, p. 242.

It would also acidify the waters, aiding in the original solution of the iron. The pyrite, forming within the clay and sands at the bottom, would be protected from solution in the acid waters above it. Why pyrite formed rather than marcasite is at present unknown. Also, it is unknown why there is no greenish zone beneath the white lenses.

This interpretation of the "Interior" as indicative of warm, subhumid to humid climate with abundant vegetation differs sharply from Russell's[20] interpretation of the pre-Chadron surface to the north and east as a "fossil desert." It is almost impossible that there could be a desert within thirty or forty miles of a warm, humid area having abundant vegetation, in the absence of a mountain barrier between. Russell's evidence consists of a red, deeply weathered zone in the "pre-White River" rocks, and of wind-facetted pebbles. Deep chemical weathering is not characteristic of deserts, and red color occurs in deserts chiefly where it is transmitted from red bedrock (*e.g.*, desert areas on the Chugwater in various parts of the western United States). In his discussion of the pre-Chadron water table of the Big Badlands, Russell has apparently been unaware of the very important paleogeographic conditions indicated above. Russell's first point seems to favor Wanless' interpretation of humidity, leaving only the presence of wind-facetted pebbles in favor of the desert hypothesis. Therefore, the theory of a humid pre-Chadron climate appears more satisfactory than the desert hypothesis. Wind-facetted pebbles have not been observed in the Chadron of the Big Badlands.

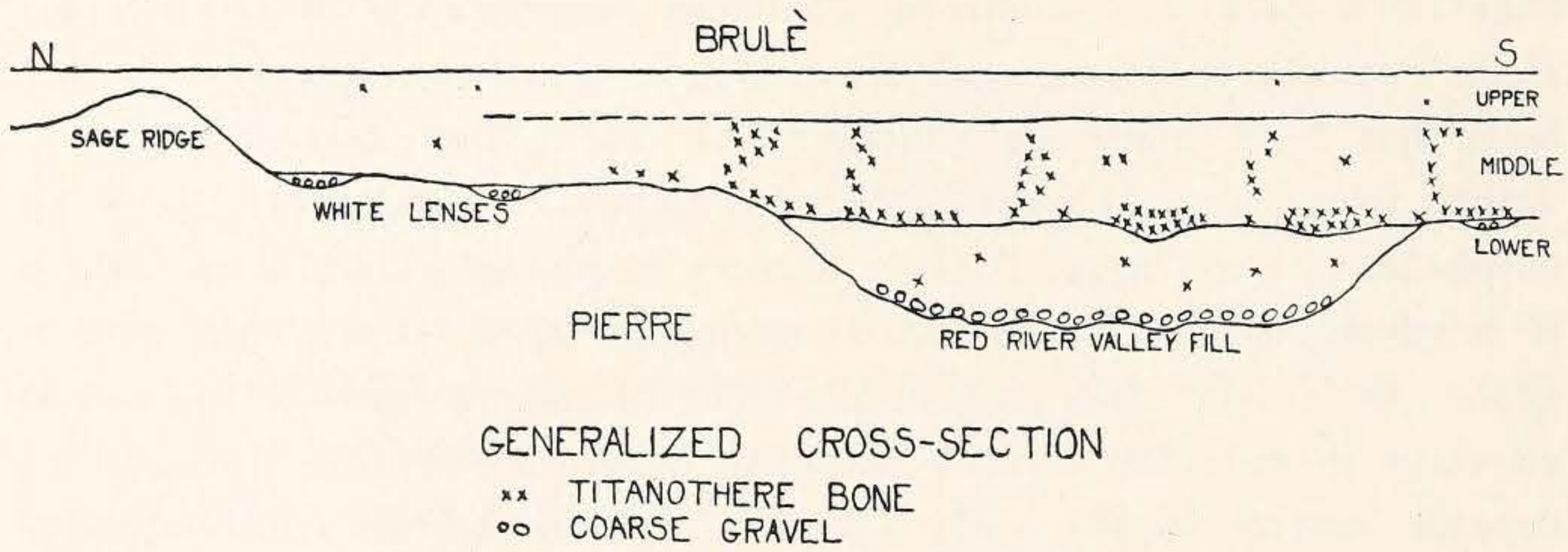



FIG. 5. Generalized cross-section, showing relative abundance of Titanothere remains in the different members of the Chadron.

[20]Russell, W. L., A Fossil Desert in South Dakota; Amer. Jour. Sci., 5th series, vol. 15, no. 86, 1928.

*Lower Chadron:* The outstanding lithologic features of the Lower Chadron have already been mentioned, *i.e.*, (1) presence of red sediments; (2) basal conglomerates and other conglomerates low in feldspars; (3) general gradation from coarse sediment at the base to fine at the top; and (4) restricted white channel fills with basal conglomerates but lacking red sediment.

Apparently the red silts and clays were red when they were deposited. Fragments of red clay are enclosed in greenish clays, little bands of red clay are interbedded with green sands and silts, and many other lithologic details point to the deposition of the beds with their present colors rather than to diagenetic color changes. There are two possible sources of red sediment; the Spearfish and Opeche formations, whose outcrop encircles the Black Hills, and the highly ferruginous "Interior" zone. Wanless believed that the "Interior" was the probable source of red sediment, pointing out that red sedimentation had ceased by the end of lower Chadron time, when the Red River Valley was completely filled. There are two phenomena somewhat opposed to this view; (1) absence of red in the white channel fills, which should have been abundantly supplied if the red were washed from local "Interior" top-soil; and (2) greater concentration of red sediment in the western part of the Red River Valley fill than in the east, possibly indicating an approach to the source of supply. This last is a notable feature; from Big Corral Draw westward, the red clay becomes more and more concentrated in the lower part of the Lower Member, until in Shoemaker Draw, it is limited to a single massive bed overlying the basal conglomerate. However, it seems that there is no conclusive evidence in either direction, and the matter must remain unsettled. Lithologic study of the sediment itself might be of assistance, but the technique of studying clay minerals is so specialized that it lies beyond the scope of the present research problem.

Age relationships of the white channel fills to the Red River Valley fill are not entirely clear. As stated above, both are older than the Middle Member of the Chadron. Both have basal conglomerates composed of pebbles up to five inches in diameter, 90-100% quartz, quartzite, and chert, the latter coated with a brown patina. Characteristically, the white channel fills have pure, noncalcareous white clay, both in pellets and mixed with the sand and gravel. Only very rarely can a faint pinkish or greenish streak a few inches long be found in them. The Red River fill, on the other hand, is dominantly red and

green, and I have observed white sediment at but one place, a restricted basal lens in Little Corral Draw drainage basin.

To state that a main stream with its headwaters in the central Black Hills would carry red sediment and no white, while its tributaries, also with their headwaters in the central Black Hills, carried white and no red, would require unwarranted physiographic assumptions. Therefore, the white lenses are probably either older or younger than the red. If they are younger, then one must assume that after the filling of most of Red River Valley with red sediments, the source of red was cut off and white was transported. In that event, the rejuvenation necessary to make the tributaries carry coarse gravel and white sediment should be represented by high, coarse gravels and white sediments in the Red River fill. Instead, there is in the Red River fill a notable gradation toward fine sediments at the top, while the upper ten feet are usually composed of buff silty clay and thin limestone. If, on the other hand, the white channel fills are tributary or old meander channels cut and filled before Red River cut its valley to its final depth, and before a source of red sediment was available, most of the theoretical difficulties are obviated. The Spring Draw section, which is the only one in which red sediments are associated with a white channel, has the red overlying the white. This may be a meander abandoned later than the others, and hence cut so low that some of the red fill washed over the older white.

Most of the coarser sediments in the lower Chadron are very poorly sorted, and are green in color due to a matrix of greenish-gray clay. The heavy minerals of White River sands have been discussed by Wanless.[21] The lower Chadron sands are characterized by low percentages of garnets, black tourmalines, staurolite, and chlorite, with subordinate quantities of biotite and very rarely with zircon.

There are two sharply defined groups of quartz grains in the coarser grades; (1) angular fragments with fresh, hackly fractures, and (2) highly rounded, somewhat frosted spherules. In the finer grades the two groups intergrade by a series of less and less rounded, but usually frosted, grains.

As Hatcher indicated,[22] the sandstones are cemented by calcium

[21]Wanless, H. R., Lithology of the White River Sediments; Proc. Am. Phil. Soc., vol. LXI, no. 3, 1922, p. 192.

[22]Hatcher, J. B., The Titanotherium Beds; Amer. Nat., vol. XXVII, 1893, p. 207.

carbonate, by clay, or are loosely held together by compaction alone. Near the base of the Red River fill, there is a horizon a few inches thick and several miles in diameter, in which the cementing calcite is well crystallized. The crystals weather into spherules (see plate XXI) usually a millimeter or two but up to a centimeter in diameter. Crystals six to eight centimeters long and three centimeters in diameter occur at this level in Shoemaker Draw. This detail is of no known stratigraphic significance; I mention it simply to place on record another horizon and locality for sand calcite crystals, in this case very imperfect ones.

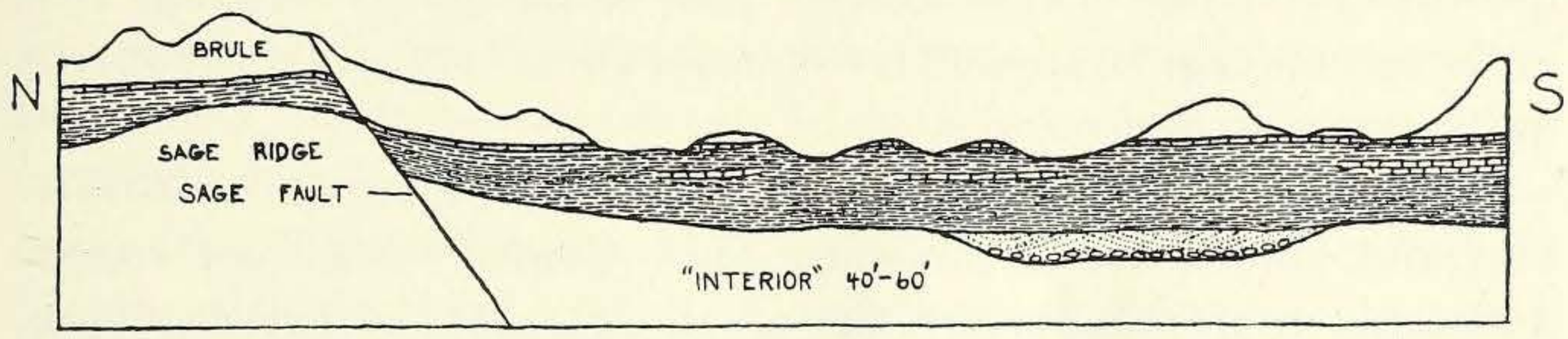



FIG. 6. Sage Creek: Cross-section about four miles long, extending NE-SW in Sage Creek drainage basin. Shows basal white channel fill, Sage Anticline, Sage Fault, and thinning of the Chadron over Sage Ridge.

The Red River Valley fill exhibits marked changes as one proceeds westward from Corral Draw toward the Black Hills.

Concomitantly with the concentration of red clay and silt near the bottom of the Member, the percentage of feldspar in the coarse greenish sands increases. In figure 8, it is plain that the Lower Member samples taken in Big Corral Draw and Indian Creek have less than 10% feldspar grains in any one grade size. Number 4, from Quinn Draw, has a percentage up to 28% in the coarser grades. Those samples taken farther west have much higher feldspar percentages, in fact as high as the samples from the Middle Member.

Samples 5 and 9 were taken in Dry Creek, at the westernmost outcrop where the Lower-Middle contact can be recognized, about fourteen miles from the flanks of the Black Hills. Their very similar constitution would indicate a similarity in quantities of quartz and feldspar supplied during Lower and Middle Chadron times. It also suggests that the climate during Lower Chadron time favored rapid weathering, causing marked diminution in amount of feldspar in thirty miles of transportation (to the present Corral Draw-Indian Creek area), while during Middle Chadron time there was little weathering of feldspars in the same distance.

The quantity of fossil "bone" within the Lower Member is roughly proportional to the amount of feldspar in the sands, grading from almost a total absence of fossils in Indian Creek to a fair amount of scrap in upper Shoemaker Draw. This would seem to indicate that the fluvial and ground waters became increasingly powerful weathering agents as they advanced; there is strong evidence that the "bone" has not, in most cases, been transported very far, and hence the explanation given for the decrease in feldspars cannot be applied here.

The coarse basal conglomerate shows no increase in feldspars or in quantity of "bone" in the western part of its area of outcrop. It is uniformly unfossiliferous and is composed almost exclusively of quartz, quartzite, and chert pebbles.

The white channel fills are uniformly nonfeldspathic, unfossiliferous, and low in heavy minerals. Their lithology does not change noticeably near the Black Hills; a sample taken on French Creek, fifteen miles from the Hills (see figure 8, no. 8), is actually slightly lower in feldspar than one from near Interior, forty-five miles farther east.

*Middle Chadron:* Absence of red sediment and a high percentage of feldspar pebbles in the conglomerates form distinctive lithologic characteristics of the Middle Member of the Chadron.

The reason for the cessation of deposition of red sediment cannot be known until the source of the red is known. Wanless suggested that the cessation of red at the top of the Red River Valley fill indicates a local source cut off by burial of the valley walls. However, there was above the valley wall an upland topography (see discussion below, and map, figure 2) of sixty feet, which could have given rise to appreciable amounts of red if the red were locally derived. Therefore, although the stronger evidence is certainly in favor of Wanless' suggested interpretation, it seems best to retain an alternative hypothesis of a source of red near the Hills, cut off just previous to deposition of the Middle Chadron.

The graph (figure 8) shows the contrasting feldspar ratios in the Middle and the Lower Members. Possible reasons for these differences have already been discussed. It should be added that most of the Middle Member sands have a composition more nearly like that of sample no. 9 than that of sample no. 10.

The quartz grains show the same division into two types in the

coarser sands and gradation in the finer grades, as do the quartz grains in the Lower Member.

Black tourmalines, pink garnets, staurolite, and chlorite make up the bulk of the heavy minerals in the Middle Member, as they do in the Lower Member. Subordinate quantities of blue and brown tourmalines, biotite, muscovite, and (rarely) zircon occur. Heavy minerals form a larger proportion of the whole than they do in the Lower Member; they reach 8% to 10% of the total sample in some grain counts from the upper part of the Middle Member.

In the field, the Middle Member is characterized by extreme heterogeneity. Pond limestones, bands of algal balls, massive clays, micaceous sandstones, calcareous sandstones, green, clayey sandstones, and conglomerates pink with feldspars, mingle with each other in great complexity. The numerous channel fills and the prevailing green color of the sediments, together with the fauna, indicate a moist climate with decaying vegetation sufficiently abundant to keep the iron in the sediments reduced. Although hackberry seeds are the only identifiable plant fossils which I have found, a humus zone one to two feet thick and several hundred yards in areal extent near the head of Battle Creek Draw indicates that there was abundant vegetation and locally very slow sedimentation at the beginning of Middle Chadron time.

All observed details of lithology and stratigraphy indicate that the Middle Member was deposited by the same stream which cut and later filled Red River Valley, deprived of its red sediment and flowing under different climatic conditions, but otherwise essentially unchanged.

*Upper Chadron:* Extensive reduction in the number and size of channel sandstones is everywhere apparent in passing from Middle to Upper Chadron (see figure 7). This may be interpreted as showing a reduced volume of water traversing the area, and hence an increased aridity in the Black Hills. Wanless[24] has demonstrated that the local climate underwent increased aridity at the end of Chadron time, using as his evidence the increase in percentage of calcite cement in the basal Brulè clays. The decrease in amount of water present in the area during Upper Chadron time is also suggested by the faunal change toward a plains facies (see below), culminating with the typical plains fauna of the Lower Nodular horizon of the Brulè.

[24]Wanless, H. R., Stratigraphy of the White River Beds of South Dakota, *loc. cit.*, p. 205.

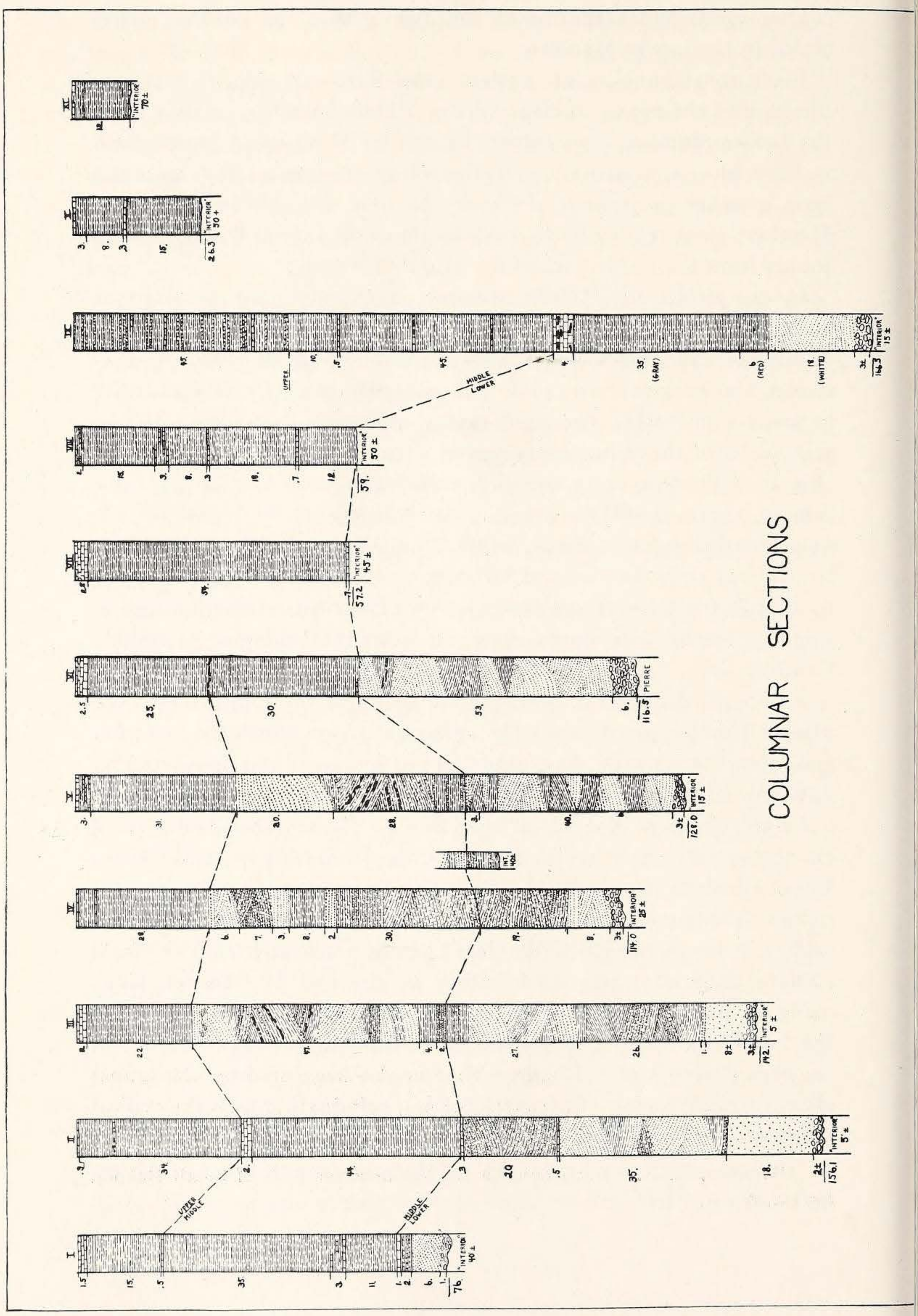

COLUMNAR SECTIONS
UPPER
MIDDLE
LOWER
PIERRE
(GRAY)
(RED)
(WHITE)
"INTERIOR"

FIGURE 7.

Over the large area shaded in the map, figure 4, the Upper Chadron clays are orange-red instead of their usual buff or green. This red color transcends local lithologic boundaries, extends in places up into the lower Brulè and down into the Middle Chadron, and is completely surrounded by sediments of different color, with no apparent avenue of entry. Therefore, the red color is in this case possibly diagenetic.

The greenish-gray, cross-bedded Upper Chadron channel sands mapped in figure 4 were evidently deposited by Red River. Feldspars make up 30% to 50% of the grains; the familiar Red River assemblage of heavy minerals is present, in quantities up to 15% of the total in some samples; in a few places, Middle Member sands can be traced directly upward into Upper Member sands.

The banded Upper Chadron lenses, extending the length of Spring Draw and thence eastward, are strikingly different from the Red River Upper Chadron. Their horizontal lamination and generally fine grade suggest deposition in sluggish waters. Two samples, one from a quarter mile south of Scenic and one from near Interior, are

FIGURE 7.

I. Upper Battle Creek Draw. Shows a basal white channel fill incised in the "Interior" upland south of Red River Valley.

II. West branch of Big Corral Draw. Shows the Red River Valley fill, with basal conglomerate and gradation to finer sediments at the top of the fill. Local clay facies of Middle Member.

III. West side of Quinn Draw. Local sandstone facies of Middle Member.

IV. East scarp of Finney Flats. The main section shows the Red River Valley fill near the north wall of the valley; the inset, taken 200 yards north of the main section, shows the north valley wall of "Interior," and the Red River fill pinching out against it.

V. North flank of "Cedar Butte," in Indian Creek drainage basin.

VI. One mile south of Hart Table, east branch of Indian Creek.

VII. Southwest slope of Hart Table. Shows the wall of Red River Valley, with the Lower Member absent, and a series of clays making up the Middle and Upper Members, indistinguishable here.

VIII. Southwest slope of 71 Table. Typical eastern facies of Middle and Upper Member clays.

IX. Spring Draw, between Hart and Kube Tables. Shows the anomalous thickness of the Chadron, the white basal channel fill overlain by a red clay, and the 45 foot series of laminated Upper Chadron sediments of the eastern facies.

X. Dillon Pass, $\frac{1}{8}$ mile south of the Sage Anticline.

XI. Dillon Pass, 400 yards north of the crest of the Sage Anticline.

very similar lithologically (see figure 8, nos. 12 and 13), helping to confirm the correlation made on stratigraphic and faunal grounds. Both are much higher in a peculiar, greenish-white microcline than are any of the Red River sands in their flesh-colored and yellowish-green microcline. Both are relatively high in staurolite, biotite, and zircon, with subordinate tourmaline (mostly brown) and garnet. Both include tiny, white, noncalcareous pellets, which contain slender, almost acicular zircons, fresh sanidine, angular flakes of biotite, and sharply euhedral cleavage flakes of biotite. This assemblage suggests that the pellets are water-transported grains of a pre-existing volcanic ash. Certainly they are entirely different from anything which has been observed in the Red River sediments.

On the basis of these lithologic data, and also of the geographic distribution of the horizontally laminated lenses, it seems justifiable to postulate that they are deposits brought in from the northwest, from a different part of the Black Hills than that area which supplied Red River.

The Chadron-Brulè contact has been so thoroughly discussed by Sinclair[25] and by Wanless[26] that little need be added here. I have nowhere seen satisfactory evidence of the "moderate erosion between the close of Titanotherium deposition and the algal limestone and Oreodon beds" which Wanless mentions. The changes in level which he cites, fifteen to twenty feet in a quarter of a mile, seem to me rather the normal irregularity of deposition to be expected on a flood plain. Plate XXIII shows the present alluvial "plain" at the mouth of Quinn Draw, with a slope of five feet in one hundred, developed on fine silt and clay.

The Chadron-Brulè contact is not recognizable along the valley walls of Spring Draw. Between definite Titanothere beds and equally definite Oreodon beds (but with the Lower Nodular zone either absent or not developed) is a zone of forty-five feet of horizontally banded sediments. The lower part of this zone is certainly within the Chadron. However, the great thickness of the lens and the absence of the Lower Nodular make it seem probable that at this place sedimentation was almost continuous from Upper Chadron into Lower Brulè time. In

[25]Sinclair, W. J., The Turtle-Oreodon Red Layer; Proc. Am. Phil. Soc., vol. LX, 1921.

[26]Wanless, H. R., *loc. cit.*, p. 208.

drawing the map, figure 2, the top of the lens was used as the top of the Chadron; this is the most plausible explanation of the anomalous thickness of Chadron recorded at that place. It must, of course, be admitted that everywhere else the lenses of banded sediments stop at the top of the Chadron; this, however, does not absolutely eliminate the possibility of continous deposition at one place.

With the exception of Spring Draw between Hart and Kube Tables, the Chadron-Brulè contact is a depositional plain of such almost perfect flatness that the contours of figure 2, if read as negative contours, show the topography of the surface on which the Chadron was deposited. The significant features of topography will be discussed in the interpretative summary which follows.

*General:* In concluding the section on lithology, certain general statements may be useful. The source of the fine silts and clays is not surely known. Certainly the Upper Chadron clays could not be locally derived, because they cover the Sage Ridge (see figure 2, and text below), which is the highest local pre-Chadron elevation known. Abundant iron and clay could have been derived either from weathering of the Black Hills igneous rocks, or erosion of the encircling Paleozoic-Mesozoics, or erosion of local hills of Pierre shale. The chemical condition of the iron would be controlled by depositional factors, irrespective of source. Therefore, Hatcher's original statement,[27] "The clays of the Titanotherium beds were probably derived from two sources, viz., from the Cretaceous clays and shales, and from the kaolinization of granitic feldspars," covers the situation adequately.

Lack of sorting or lamination is a striking feature, both of the finer massive clays and of the sands. If a sample, either clay or sand, is thoroughly dissociated in water and allowed to settle, the sediment shows an excellent gradation of coarse to fine, a series of which would produce laminations. The best explanation at present for the absence of lamination in the silty clays is that they were deposited by highly overloaded sheet-floods under atmospheric conditions favoring evaporation. The resulting rapid deposition of the entire load would mask any incipient lamination. Poor sorting in the channel fills is, of course, very common in fluviatile deposits.

The reasons for the varying degrees of cementation in adjacent sandstone lenses are not known. It is obvious that those sands and gravels with a large admixture of clay would not favor the circulation

[27]Hatcher, J. B., The Titanotherium Beds; Amer. Nat., vol. 27, 1893, p. 207.

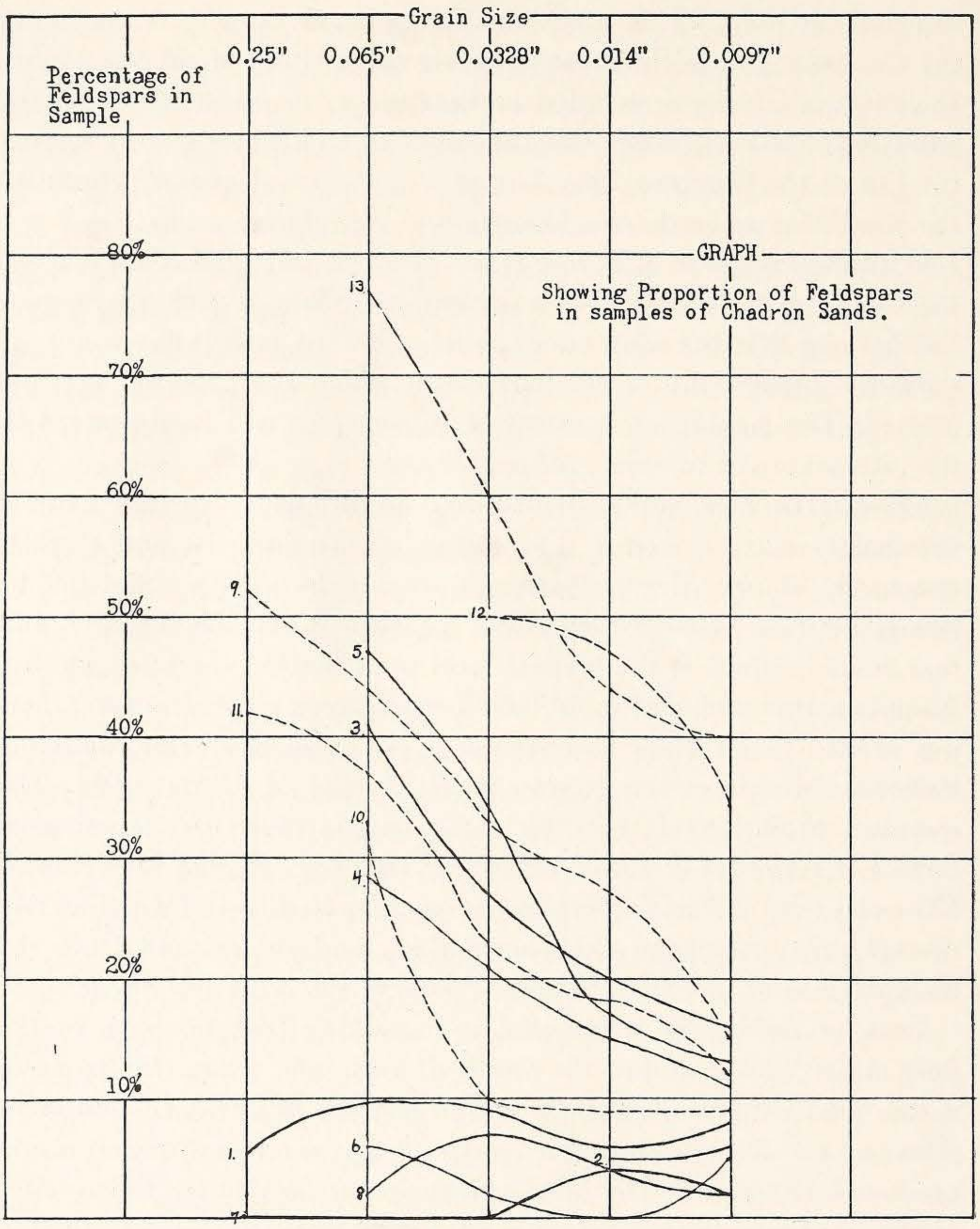



FIGURE 8.

| Sample Number | | Locality |
|---|---|---|
| | 1 | Basal Red River fill, Big Corral Draw. |
| | 2 | Basal Red River fill, northeast Indian Creek. |
| | 3 | Sand crystals, lower Red River fill, Shoemaker Draw. |
| LOWER | 4 | Sand crystals, lower Red River fill, Quinn Draw. |
| MEMBER | 5 | Red River fill, Dry Creek. |
| | 6 | Basal white lens, 4 miles southwest of Interior. |
| | 7 | Basal white lens, southeast Sage Creek. |
| | 8 | Basal white lens, French Creek. |
| MIDDLE | 9 | Middle Member, lower Dry Creek. |
| MEMBER | 10 | Base of Middle Member, upper Indian Creek. |
| UPPER | 11 | Base of Upper Member, Quinn Draw. |
| MEMBER | 12 | Laminated lens, Upper Member, ¼ mile southeast of Scenic. |
| | 13 | Laminated lens, Upper Member, 4 miles southeast of Interior. |

of solutions as would the cleaner lenses, and it is in general true that the cleaner sands are more often cemented than are the clayey ones. However, one of the cleanest sands in the Chadron, the lowest in the Big Corral Draw section (see figure 7), is so completely uncemented that it can be dug out with the fingers, and several very poorly sorted sands are well cemented. The cement is calcite in all cases observed except at the very bottom of the basal conglomerate in Quinn Draw, where it is pyrite, as mentioned above.

The presence of occasional, well-rounded grains of glauconite in sands from the Lower and Middle Members is perhaps to be expected with the Deadwood formation[28] only thirty miles away. Inasmuch as the glauconite is the only Paleozoic material whose parent formation has been identified, it is worth mentioning.

Considerable manganese is present locally in the Upper Chadron. The marrow cavities of many bones from the "microfauna locality" (see below) are filled with rhodochrosite; and small, black nodules of pyrolusite, up to a half inch in diameter, are disseminated through the base of an Upper Chadron clay in Big Corral Draw. The marrow cavities were filled diagenetically. Whether the pyrolusite nodules formed during deposition of the clays or afterward, and what might be their stratigraphic significance, is not known.

In conclusion, it may be said that the weight of evidence which has been observed in the Big Badlands favors flood plain deposition rather than alluvial fan deposition as the method of accumulation of the Chadron.

The fact that there is a vertical succession of members, which can be demonstrated over the entire area from Dry Creek eastward to Scenic Basin, is difficultly compatible with fan deposition. Furthermore, were it not for the present regional dip and topography causing burial of the Chadron southeastward from Scenic, the three members of the western facies could probably be traced several miles farther to the southeast.

The relationship of the lithologic phases of the Chadron to the pre-Chadron topography is easily explainable if the Chadron is assumed to be built of flood plain deposits, as in the interpretative summary of this paper. No satisfactory explanation of the Chadron lithologic phases is evident if the sediments are assumed to be fan deposits.

[28]Darton, N. H., and Paige, S.; Geological Atlas of the United States, Central Black Hills Folio, Folio No. 219, U. S. Geol. Surv., 1925, pp. 5, 6.

Finally, the Lower Nodular zone of the Brulè, which overlies the Chadron, extends over the entire area, rests upon a surface which has almost no relief, and lies with entire conformity upon the Upper Member of the Chadron. The top of the Chadron is, therefore, probably a depositional plain, which extends an observed distance of seventy miles east-west and twenty miles north-south. Such a surface could be formed as a flood plain of a single river or of confluent rivers. A plain formed by confluent fans might be expected to truncate those portions of the fans near the source of sediment, and to show widespread irregularities producing a relief of several feet or tens of feet.

Therefore, until opposing evidence is found, the Chadron of the Big Badlands may be assumed to be a series of flood plain deposits which is known to exhibit a recognizable vertical succession of members. This interpretation has been used throughout the present paper.

## STRUCTURE

The 1°-2° regional southeast dip has already been mentioned. Several local structures, *e.g.*, low domes, and normal faults with a few feet of throw, occur. Most prominent of these are a very low dome, with a normal fault on the south side, in the northeast part of Scenic Basin, and a small anticline, trending N 70° W, exposed in the badlands which form the south side of Dry Creek drainage basin.

The only structure worthy of detailed consideration is the faulted anticline which first becomes apparent in Sage Creek drainage basin and extends S 70° E from there, roughly coinciding with the Wall of the Badlands, at least as far east as the town of Interior.

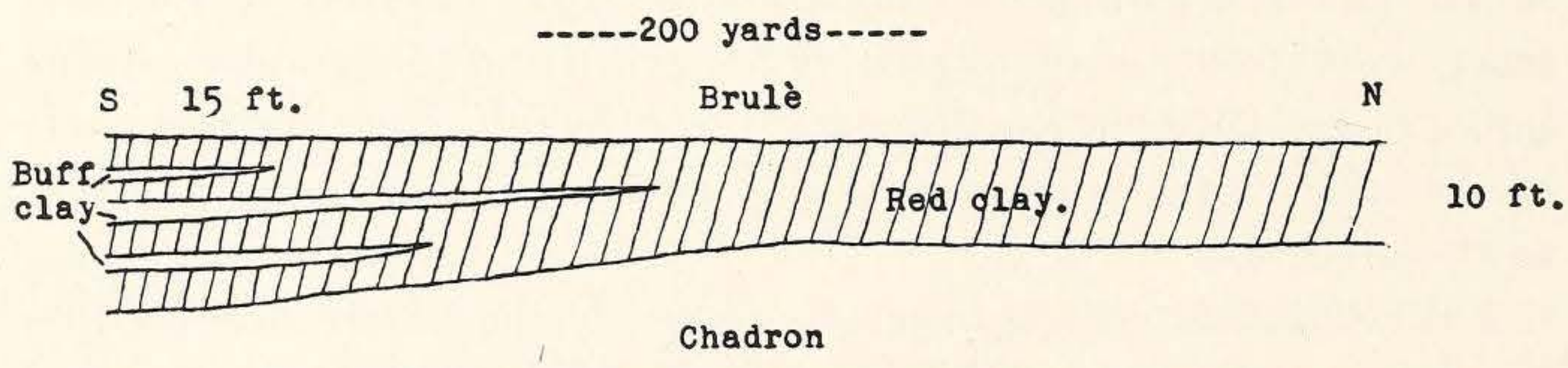



FIG. 9. Sketch of the intercalation of red and buff clay in the basal Brulé, mentioned by Ward as an angular unconformity.

The anticline is highly asymmetrical: dips on the north side are 3° to 8°, usually nearer 3°, while on the south side either the dips are 10° to 14° or the south limb is down-faulted. Where faulting occurs, as

at Dillon Pass (see plate XXII, lower fig., also map, figure 2), the fault is normal, dipping $50^0$ to $55^0$ SW, downthrown SW about thirty to sixty-five feet, usually nearer sixty-five feet. The faulting and folding affect the Leptauchenia beds, and probably the lower Rosebud also, although this has not been positively demonstrated. Frequently, minor normal faults with throws of from ten to fifteen feet form miniature horsts and graben paralleling and close to the main fault line.

The contour map (figure 2) shows that the thinnest sections of the Chadron lie immediately north of the crest of the anticline (which will be referred to as the Sage anticline, and the fault as the Sage fault, taking as the type locality the southeast portion of the Sage Creek drainage basin) while the white basal channels run toward the anticline and then turn rather than cross it. As the Chadron-Brulè contact surface in this area is a good depositional plain, the contours reveal the existence of a pre-Chadron ridge paralleling and lying about a hundred yards north of the Sage fault.

The region, then, is a post-Oligocene uplift at present topographically high, which forms the White River-Bad River and White River-Cheyenne River divides. During the Chadron it was also a ridge, which will be called "Sage Ridge" for convenience, apparently forming a divide, and not buried until almost the end of the Chadron. The similarity between these conditions and those described by Fath[29] and by Powers[30] suggests that the Sage Anticline is a structural line along which movement has taken place at least twice, pre-Oligocene and post-Oligocene, and hence very possibly reflects a structural line in the basement rocks of the area. Such a structural line might be related either to the NW-SE trends of the northern Black Hills or to the WNW-ESE anticlinal axis described by Thom[31] in eastern South Dakota.

The evidence for the "dome" near Conata, described by Ward,[32] may

[29]Fath, A. E., Origin of the Faults, Anticlines, and Buried Granite Ridge of the Northern Part of the Midcontinental Oil and Gas Field; U. S. Geol. Survey, Prof. Paper 128-C.

[30]Powers, S., Reflected Buried Hills in the Oil Fields of Persia, Egypt, and Mexico; Bull. Am. Assoc. Petrol. Geol., vol. 10, no. 2, 1926.

[31]Thom, W. T., Jr., Oil Possibilities in South Dakota; Bull. Am. Assoc. Petrol. Geol., vol. 6, no. 6, 1922, p. 551.

[32]Ward, F., The Possibilities of Oil in Eastern Pennington County; S. Dak. Geol. and Nat. Hist. Surv., circ. 8, 1921.

be more naturally attributed to physiographic than to structural causes. He admitted that no dip readings were possible, and used the rather circular outcrop of "Interior" and Pierre surrounded by Chadron as evidence of a dome. The area of outcropping "Interior" is not circular in the field, but follows White River for some distance up and down stream; the circularity is a generality of reconnaissance mapping. As the "Interior" is a weathered phase of the Pierre, local variations in depth of weathering might allow exposure of a few feet of Pierre with "Interior" on both sides. It is obvious that a river describing a great quarter circle in a northwest quadrant, with a high ridge lying to the north, must of necessity expose an inlier of older rocks if the regional dip is southeast. Therefore, as this inlier is perfectly explainable on physiographic grounds, and as there is no evidence of a structure, it is my belief that there is no dome there.

A careful study of the outcrop figured by Ward[33] as evidence of an angular unconformity between the Chadron and the Brulè reveals the condition shown in the sketch, figure 9—an interfingering of sediments within the basal red clay of the Brulè, with buff clay coming probably from the southwest and red clay from the north and northwest. There is no sign of an angular unconformity between the bottom of the red clay and the Chadron, nor is there an angular unconformity at the Chadron-Brulè contact anywhere in the area discussed in this paper.

## PALEONTOLOGY

### LOWER CHADRON

The fauna is very restricted, due at least in part to the fact that the member is almost unfossiliferous. The formal list is as follows:

#### REPTILIA

##### Order Chelonia

1. Family Emydidæ Gen. et sp.?—scraps of Emyd shell
2. Family Testudinidæ Gen. et sp.?—scraps, probably *Testudo*

[33]Ward, F., The Geology of a Portion of the Badlands; S. Dak. Geol. and Nat. Hist. Surv., Bull. 11, 1922, pp. 23, 24, plate XIIIB.

MAMMALIA

Order Perissodactyla

3. Family Equidæ

**Mesohippus celer** Marsh

Portion of a right maxilla, with $P^{3-4}$, $M^1$, Princeton Museum no. 13829; agrees with type[34] in general size.

4. Family Brontotheriidæ

Gen. et sp.?—fragments recorded from various localities.

5. Superfamily Rhinocerotoidæ

Family Rhinocerotidæ?—three tooth fragments, probably *Trigonias*.

6. Family Hyracodontidæ

**Hyracodon** *cf.* **arcidens** Cope

Fragment of maxilla, with $P^{3-4}$, $M^{1-3}$, Princeton Museum no. 14062. Collected near the top of the Lower Member, east side of Quinn Draw, one mile south of the Indian Reservation fence.

This specimen is the only *Hyracodon* observed in the Lower or Middle Members. In general, the genus *Hyracodon* may be considered typical of the Upper Member; this specimen is of value in proving the earlier existence of the genus. In dental characters it stands about midway between *H. arcidens* and *H. nebraskensis*; the specific reference is, therefore, questionable.

Order Artiodactyla

7. Family Agriochœridæ

*Oreodon*? sp? Two palates, weathered beyond generic recognition, observed in Shoemaker Draw.

These two palates, together with the premolar listed from the Middle Member, constitute the known Agriochœrid fauna below the Upper Member, in which Oreodonts are relatively numerous.

[34]Osborn, H. F., Equidæ of the Oligocene, Miocene, and Pliocene of N. America, Iconographic Type Revision; Mem. Amer. Mus. Nat. Hist., (n.s.) II, p. 37, 1918.

## MIDDLE CHADRON

## REPTILIA

### Family Testudinidæ

**Testudo brontops** Marsh

Fragmentary plastron in a green channel sand, Indian Creek drainage basin. Comparative in size and all observable characters with Marsh's type of *T. brontops*[35] which Hatcher collected from the Titanothere beds of Indian Creek.

### Family Emydidæ

**Trachemys antiqua** sp. nov. Figure 10

*Type:* Plastron, right bridge, right posterior border of carapace. Princeton Museum no. 13839.

*Horizon:* Middle Chadron, channel sand.

*Locality:* Two miles southeast of "Cedar Butte," Indian Creek drainage basin, Pennington County, South Dakota.

*Specific Characters:* Size and general anatomy of plastron like that of *Trachemys hilli* (Cope).[36] Differs from *T. hilli* in having the entoplastron markedly hexagonal, with the border back of the epihyoplastral sutures composed of two lateral edges directed almost antero-posteriorly, and a very slightly curved posterior edge. Notch in the edge of the plastron at the femoral-anal sulcus is less prominent that in *T. hilli.* Median sulcus and suture vary notably from the midline, rather than following it closely as in *T. hilli.* The shell is sculptured with rather fine, vermiculate furrows.

The other characters of the specimen are evident from the table of measurements and the drawing, fig. 10 The small extra scute at the postero-median corner of the left abdominal is very apparently an individual variation.

It is probable that future careful studies upon Tertiary Emydidæ will show that this species is not *Trachemys* at all. Relatively few Oligocene and Miocene Emyds are known, and the tendency has been to place them in Pleistocene and recent genera if at all possible.

[35]Hay, O. P., Fossil Turtles of North America; Carn. Inst. of Wash., 1908, p. 398.

[36]Hay, O. P., *op. cit.*, p. 348.

Until a thorough revision is made this seems the conservative course, and as the present specimen cannot be separated generically from

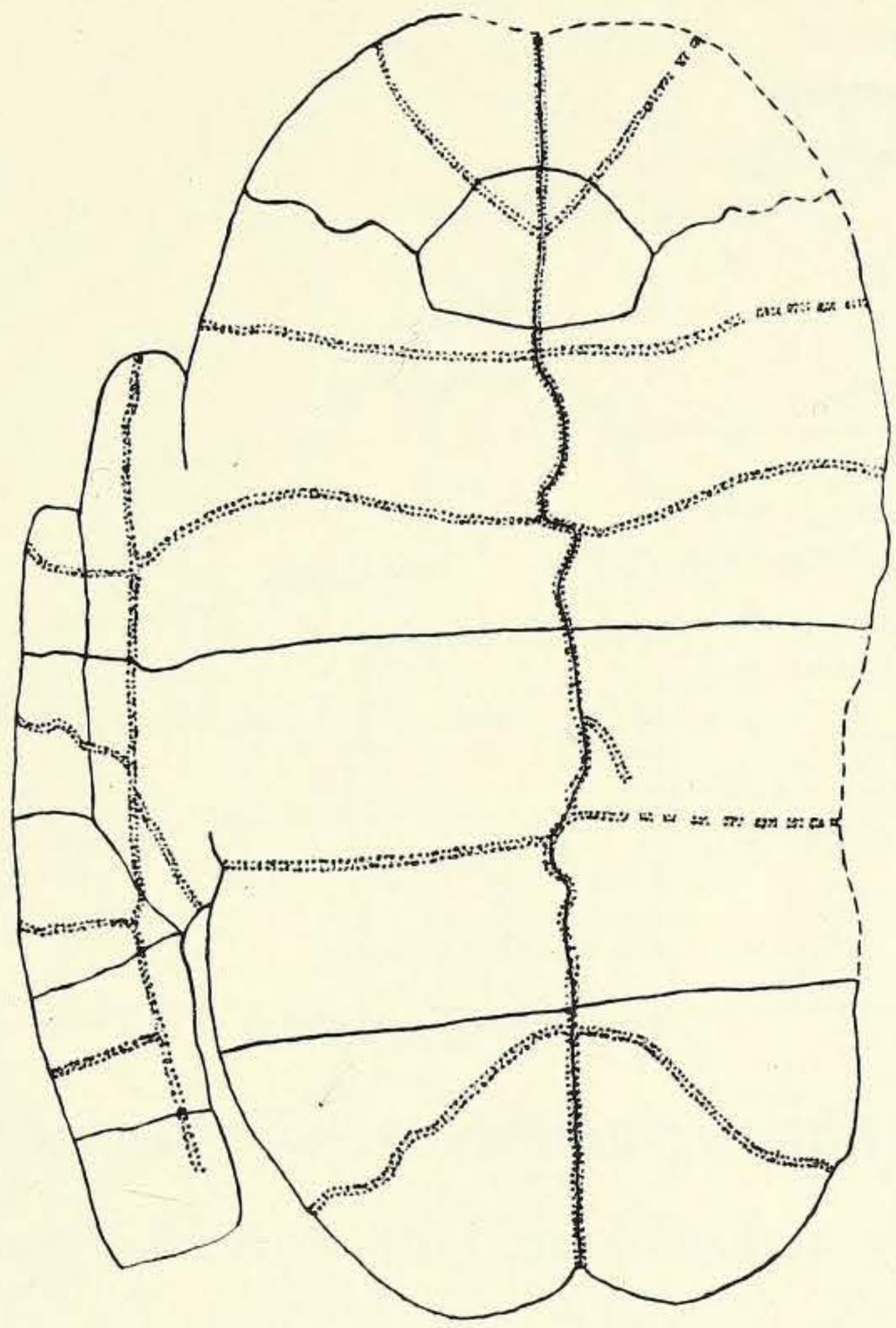


FIG. 10. *Trachemys antiqua* sp. nov. Plastron.

Amer. Mus. Nat. Hist. no. 2425, the type of *Pseudemys hilli* Cope, which Hay has referred to *Trachemys*, the species *antiqua* is referred to *Trachemys* also.

## Measurements of *Trachemys antiqua*

Plastron: (note: "length" is always antero-posterior; "width" is transverse.)

| | mm. |
|---|---|
| Length along midline | 190 |
| Length of anterior lobe | 64 |
| Length of bridge | 62 |
| Length of posterior lobe | 64 |
| Width at axillary notches | 108 |
| Width at inguinal notches | 96 |
| Length of: epiplastron | 36 |
| entoplastron at midline | 26 |
| hyoplastron " " | 44 |
| hypoplastron " " | 58 |
| xiphyplastron " " | 42 |

| | | mm. |
|---|---|---|
| Width of: | epiplastron | 43 |
| | entoplastron | 35 |
| | hyoplastron | 70 |
| | hypoplastron | 70 |
| | xiphyplastron | 52 |
| Length of: | gular scutes at midline | 32 |
| | humeral " " " | 19 |
| | pectoral " " " | 22 |
| | abdominal " " " | 47 |
| | femoral " " " | 30 |
| | anal " " " | 38 |
| Width of: | gular scutes | 25 |
| | humeral " | 48 |
| | pectoral " | 62 |
| | abdominal " | 66 |
| | femoral " | 54 |
| | anal " | 40 |

Family Emydidæ

**Graptemys** (?) **cordifera** sp. nov. Figures 11-12

*Type:* Carapace and plastron, both somewhat restored, Princeton Museum no. 13838.

*Horizon:* Middle Chadron, channel sand.

*Locality:* West side of Quinn Draw five miles from the mouth of Quinn Draw, Washington County, South Dakota.

*Specific characters:* Somewhat smaller than *Graptemys* (?) *inornata* (Loomis),[37] entoplastron heart-shaped rather than roughly quadrangular, neural 7 more compressed antero-posteriorly than neural 8. Otherwise very similar to *Graptemys inornata.*

The specimen at hand is so crushed, and judging from Hay's remarks the type of *G. inornata* is also, that several other apparent distinctions worthy of mention are not included as specific because they may be due to post-mortem injury. The gular-humeral sulci meet the midline at a considerably smaller angle in *G. cordifera* than in *G. inornata.* The lateral borders of the anterior lobe of the plastron almost parallel the midline in *G. inornata,* while they diverge from it in *G. cordifera.* Both species show traces of a rounded, obsolete dorsal keel on the midline of the carapace. The pygal of *G. cordifera*

[37]Hay, O. P., *op. cit.*, p. 358.

is rounded up into a half-cone shaped eminence pointing backward; this may be a sexual or an individual character. The lateral borders of

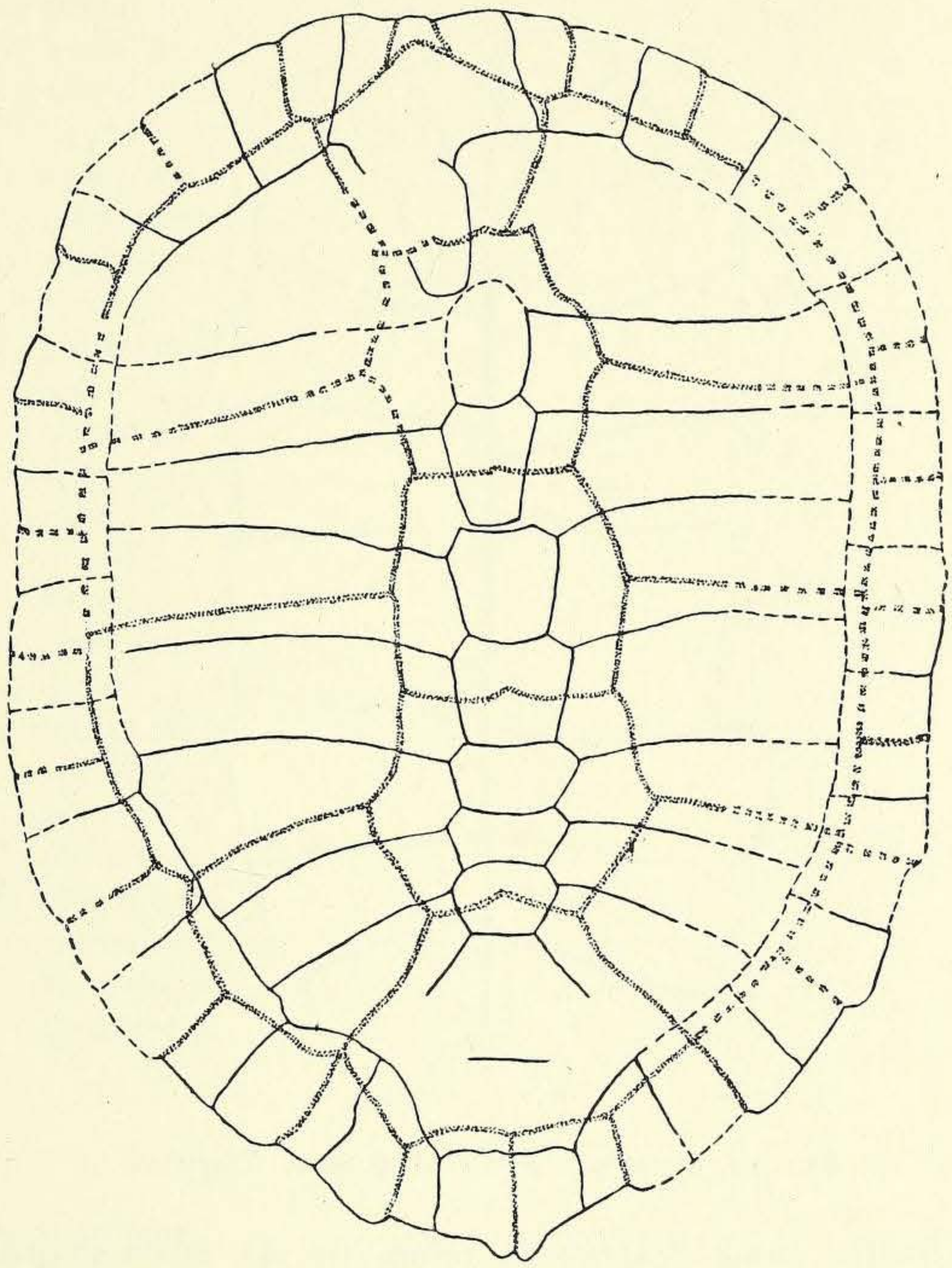


FIG. 11. *Graptemys cordifera* sp. nov. Carapace.

the first vertebral scute are concave outward in *G. inornata* and convex outward in *G. cordifera*, but here again the difference may conceivably be due to crushing. The lateral sulcus of the first vertebral scute meets the costo-marginal sulcus on the nuchal bone in *G. inornata* and on the first peripherals in *G. cordifera*; the taxonomic value of such a character is doubtful.

The generic reference in this case is as questionable as that of *Trachemys antiqua*. Hay's only reasons for referring *inornata* to *Graptemys* are the "low rounded dorsal carina and. . . . elongated first suprapygal." In the absence of any better characters he was

forced to use those, but he himself expressed doubt as to the truth of the results.

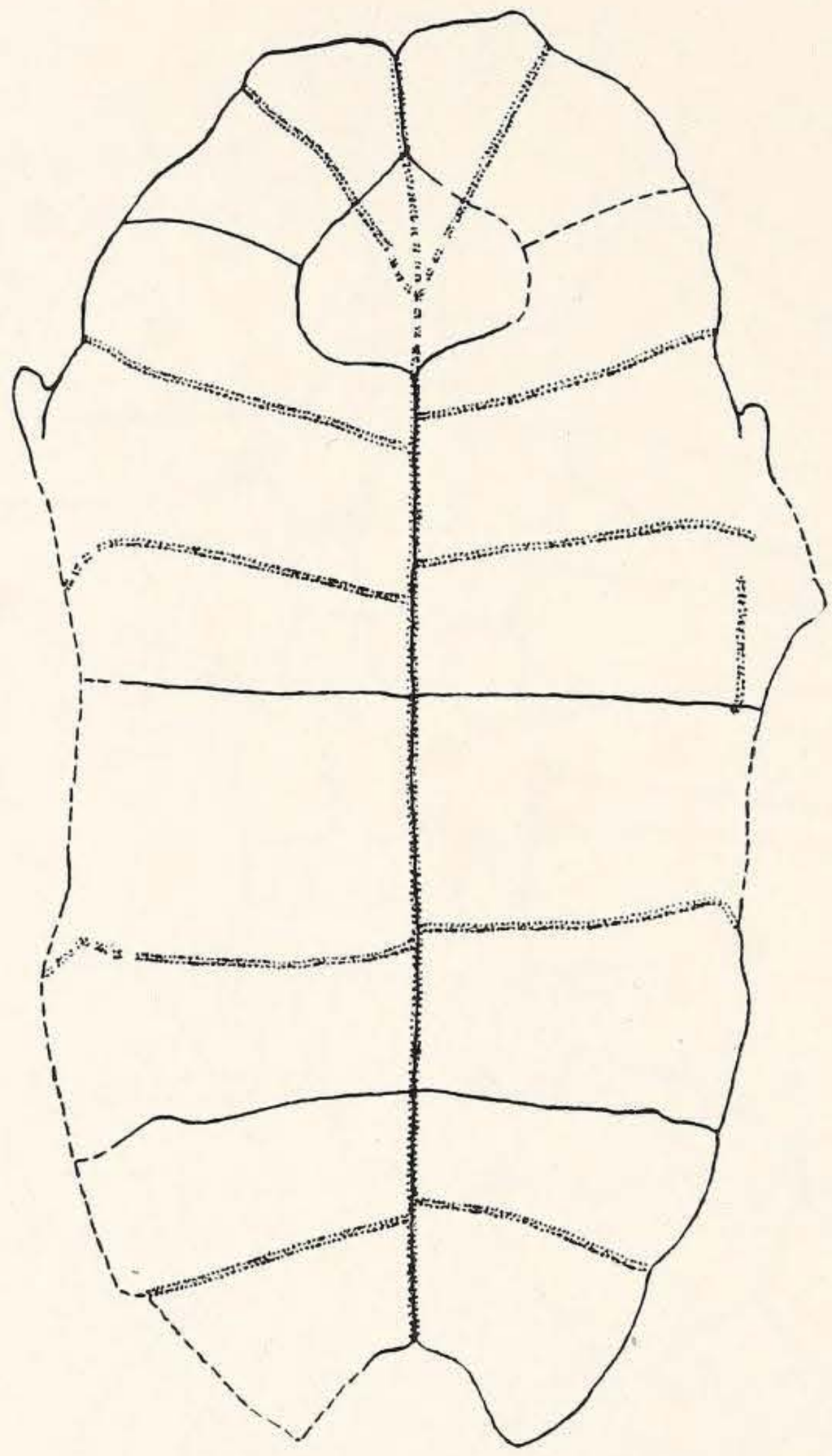


FIG. 12. *Graptemys cordifera* sp. nov. Plastron.

The specific name "*cordifera*" refers to the heart-shaped entoplastron.

## Measurements of *Graptemys cordifera*

NOTE: Crushing and weathering have distorted or destroyed many of the parts whose measurements are usually given. Only those measurements which can be made with reasonable accuracy are given here. "Length" is always anteroposterior; "width" is always transverse.

### CARAPACE

| | mm. |
|---|---|
| Length along midline | 267 |
| Length of: nuchal bone | 40 |

| | | mm. |
|---|---|---|
| | neural 3 | 25 |
| | neural 4 | 22 |
| | neural 5 | 21 |
| | neural 6 | 15 |
| | neural 7 | 10 |
| | neural 8 | 15 |
| | suprapygal 1 | 27 |
| | suprapygal 2 | 27 |
| | pygal | 23 |
| Width of: | nuchal bone | 50 |
| | neural 3 | 20 |
| | neural 4 | 22 |
| | neural 5 | 24 |
| | neural 6 | 26 |
| | neural 7 | 26 |
| | neural 8 | 21 |
| | suprapygal 1 | 33 |
| | pygal | 31 |
| Length of: | nuchal scute | 9 |
| | vertebral 3 | 46 |
| | vertebral 4 | 43 |
| | vertebral 5 | 56 |
| Width of: | nuchal scute | 8 |
| | vertebral 3 | 47 |
| | vertebral 4 | 59 |
| | vertebral 5 | 73 |

## PLASTRON

| | | mm. |
|---|---|---|
| Length along midline | | 212 |
| Length of anterior lobe | | 65 |
| Length of bridge | | 85 |
| Length of posterior lobe | | 87 |
| Width at axillary notches | | 116 |
| Width at inguinal notches | | 111 |
| Length of: | epiplastron | 36 |
| | entoplastron | 34 |
| | hyoplastron | 50 |
| | hypoplastron | 66 |
| | xiphyplastron | 56 |
| Width of: | epiplastron | 43 |
| | entoplastron | 38 |
| | hyoplastron | 59 |
| | hypoplastron | 55 |
| | xiphyplastron | 52 |

| | | mm. |
|---|---|---|
| Length of: | gular scutes at midline | 40 |
| | humeral " " " | 24 |
| | pectoral " " " | 25 |
| | abdominal " " " | 54 |
| | femoral " " " | 44 |
| | anal " " " | 22 |
| Width of: | gular scutes | 25 |
| | humeral " | 53 |
| | pectoral " | 61 |
| | femoral " | 57 |
| | anal " | 41 |

## Order Crocodilia

## Family Crocodilidæ

### **Alligator prenasalis** (Loomis)

Princeton Mus. no. 13799; an almost perfect skeleton, with the dermal armor in place, was collected from the great faunal horizon at the base of the Middle Chadron by the 1933 Expedition. Locality was the east scarp of "Finney flats," between Spring Creek and Battle Creek, one mile north of Cheyenne River. This is the only prominent Chadron badlands locality near Folsom post office, so it is probable that Loomis' type is from the same badlands pocket. The skeleton agrees closely in all essentials with those described by Mook,[38] differing only in such details as might be expected to show individual variation.

Two features of the individual's physiology deserve mention. The right humerus shows a great callus patch more than twice the diameter of the bone, slightly distal to the middle of the shaft. As the shaft is bent about fifteen degrees at the callus area, it is certain that the animal suffered a fracture which subsequently healed. While trimming the block containing the skeleton in the field, collectors uncovered several pebbles ¼ inch to ½ inch in diameter, interspersed among the gastralia in a restricted area along the midline. They picked out and saved a few of these, separately; the others are still associated with the skeleton, which has been mounted in relief. The association, together with the fact that the greenish sandy lens in

[38]Mook, C. C., A study of the osteology of Alligator prenasalis (Loomis); Bull. Mus. Comp. Zool., vol. LXX, no. 2, 1932.

which the specimen was entombed was uniformly fine-grained and contained no pebbles at all, suggests that the pebbles are "stomach stones" swallowed by the animal to aid in its digestive processes.

MAMMALIA

Family Felidæ

Subfamily Machærodontinæ

**Hoplophoneus o'harrai** Jepsen

South Dakota School of Mines Museum no. 2417. The type of *H. o'harrai* is recorded[39] as coming from 46 feet below the Chadron-Brulè contact, Big Corral Draw. Such a measurement would place it well within the Middle Chadron, no matter where in Big Corral Draw the specimen was found, so the type is referred to the Middle Chadron without doubt. For an evolutionary discussion of the White River Hoplophonids and Eusmilids, the reader is referred to Jepsen's recent paper.[40] The referred specimen, Princeton Mus. no. 13593, comes from the Upper Chadron (see below).

Order Perissodactyla

Family Equidæ

Subfamily Anchitheriinæ

**Mesohippus portentus** Douglass

Princeton Mus. no. 13828, an upper cheek tooth dentition lacking right $P^4$ and left $P^{3-4}$, and Princeton Mus. no. 13827, a group of associated upper molars and premolars.

Osborn[41] has listed twelve Chadron species of *Mesohippus*, many of them based on trifling differences exhibited by single molar teeth as types. The multiplicity of species combined with the inadequacy of

[39]Jepsen, G. L., The Oldest Known Cat, Hoplophoneus oharrai; The Black Hills Engineer, vol. XIV, no. 2, 1926, p. 91.

[40]Jepsen, G. L., American Eusmiloid Sabre-tooth Cats of the Oligocene Epoch; Proc. Am. Phil. Soc., vol. LXXII, no. 5, 1933.

[41]Osborn, H. F., Equidæ of the Oligocene, Miocene, and Pliocene of North America, Iconographic Type Revision: Mem. Amer. Mus. Nat. Hist., new series, vol. II, part I, 1918, pp. 36-44.

types makes identification of any specimen difficult. The two specimens at hand (no. 13827 may represent more than one individual) agree better in size and anatomical details with *M. portentus* than with any others listed, so they are referred to that species. Both of them lack the "small conule in the posterior valley of the tooth" which is present in the type.

## Family Brontotheriidæ

It is not within the scope of this paper to discuss the taxonomy of the Titanotheres. Table 3 gives a list of the specimens whose exact locality in the field I have observed. None of these specimens agrees exactly with the types of the species to which they have been referred; inasmuch as no two Titanothere skulls are exactly alike, the reference has been made in each case to the species which the specimen most nearly resembles.

Table 3 illustrates definitely the impossibility of using the Pierre-Chadron contact as a datum-plane for stratigraphic measurements, and also the impracticability of the A-B-C "levels" of Hatcher and Osborn. All of the specimens except no. 8 and no. 10 came from the bottom few feet of the Middle Chadron; no. 8 was half-way up in the Middle Member, and no. 10 at the top of it. The species assemblage at this one level is, with the notable exception of no. 7, distinctly typical of the upper B or the C zone. The distribution of Titanothere bones within the Chadron of the Big Badlands (see figs.) is very striking. As indicated before, there are only occasional fragments in the Lower Member; great piles of bones associated with the channel phases of the Middle Member, especially in its lower ten feet; only exceedingly rare scraps in the Upper Member clays, and none yet observed in the associated sandstone lenses.

The "graveyards" have certain uniform characteristics. Bones are always dissociated and tumbled about and skulls are on their sides or even up-ended. I have seen but three cases where bones were articulated. Titanothere bones are always associated with those of *Mesohippus*, rhinoceros (*Trigonias*?), and *Archæotherium*, about in the proportion 1000:10:10:1. Other forms, even turtles, are not common. Any one "graveyard" is generally not over two feet thick and fifty yards in diameter, although it may cover an area up to $\frac{1}{8}$ mile in diameter. "Graveyards" do not occur in the thoroughly cemented,

resistant sandstones, but rather in the clayey sands. They may occur in almost any type of sediment. The great one at the head of Battle Creek Draw extends from a silty clay into a pond-limestone and a humus zone. Isolated bones, even occasional skulls, may be found in the resistant sandstone ledges, but true "graveyards" have not been discovered. The bones may be encrusted with algal balls, but they are never enclosed in any other form of concretion. The "graveyards" are notably concentrated in the slight basal Middle channels cut in upper Lower Member clays, which are more prominent in the western part of the Big Corral Draw area than in the east.

The "graveyards," then, are concentrations of bones, most of which have undergone some transportation by streams previous to deposition; the fact that only a few bones are battered and stream-worn shows that the distance travelled was usually in the magnitude of yards and hundreds of yards rather than of miles. Concentration probably occurred wherever back-waters or obstructions in the channels slowed the transporting waters.

The extreme scarcity of Titanotheres, and indeed of all fossils, in the widespread clays of the Middle Chadron is peculiar. It is difficult to believe that the entire fauna lived along the swamps and stream-banks, and never ventured on the low alluvial plain which those steams traversed. The occurrence of some fossils shows that chemical conditions favorable for replacement existed. Therefore, the most probable explanation is that the plains away from the streams were well-populated, but that sedimentation there was sufficiently intermittent to allow the bones to distintegrate before burial.

In conclusion, it can be demonstrated that many, if not all, of the forms referred to the A, B, and C life zones occur at this one stratigraphic horizon. Therefore, any evolutionary lines or family trees of Chadron Titanotheres must be regarded as founded upon no stratigraphic evidence. It is, of course, possible that the Titanotheres developed along the lines sketched by Hatcher and Osborn, previous to Middle Chadron time, and that by the beginning of the Middle Chadron all forms, primitive and advanced, were living together. This is logically a possibility, but as there is not a trace of evidence for it, it seems a most radical and dangerous assumption. In either case, use of the suggested evolutionary stages of Titanotheres as stratigraphic horizon-markers is impossible.

I do not regard the demonstration of the inapplicability of Hatcher's and Osborn's subdivision and evolutionary conclusions as a reflection upon Hatcher's ability at field stratigraphy or Osborn's powers of anatomical generalization. A brief review of the history of the subdivision shows that its use and extension result from a most unfortunate combination of unavoidable circumstances.

Hatcher first proposed the subdivision in 1893.[42] At that time he still believed in the lacustrine origin of the White River group and not until nine years later did he indicate a complete acceptance of the fluviatile origin.[43] Obviously, a lacustrine origin argues a continuity of levels parallel to the bottom, quite different from the implications derivable from a fluviatile theory. Thus he was led to use the Pierre-Chadron contact as his datum plane, and so his great collections, on which the later work was based, were made with reference to that contact. Measurements upward from an erosional unconformity having a 130 foot relief into a formation with a usual maximum thickness of 140 feet and an extreme of 160, will, as in Table 3, place specimens stratigraphically contemporaneous in quite different horizons. The necessity of producing specimens, the need for reconnaissance geology, the limitations of physiographic concepts of his day, physical difficulties immeasurably greater than those at present, and very poor health, combined to rob Hatcher of the freedom and possibility of detailed study which most students now enjoy. It is, therefore, no cause for wonder that later work should expose oversights in his conclusions regarding stratigraphic details.

Hatcher himself felt extremely doubtful about the stratigraphic position of many of his specimens.[44] Before his doubts could mature, he died, a brief two years after the publication of his paper in favor of a fluviatile origin of the White River beds.

His death left Osborn with a great group of Titanothere skulls, all labelled in accordance with the A, B, C subdivision, and with no good evidence for doubting that subdivision. Osborn's subsequent determinations of evolutionary trends, able and painstaking though they

[42]Hatcher, J. B., The Titanotherium Beds; The American Naturalist, vol. 27, 1893, p. 204.

[43]Hatcher, J. B., Origin of the Oligocene and Miocene Deposits of the Great Plains; Proc. Amer. Philos. Soc., vol. XLI, p. 113, 1902.

[44]Osborn, H. F., Titanotheres: U. S. Geol. Surv. Monograph 55, p. 114, 115, 117. See notes on specimens listed in tables.

were, could be no more accurate than the determinations of field relationships of the specimens upon which they were based. In the absence of the field check, which Hatcher would probably have supplied could he have lived, Osborn was forced into the unknowing perpetuation and expansion of the original error in stratigraphy.

Family Rhinocerotidæ

Subfamily Diceratheriinæ

**Trigonias osborni** Lucas

A complete skull, Princeton Mus. no. 14050, from twenty feet above the base of the Middle Member, west side of Quinn Draw, 1½ miles south of the Indian Reservation boundary fence. Also a fair skull with a good palate, Princeton Mus. no. 13793, from the base of the Middle Member, ½ mile east of the "Cedar Butte" in Indian Creek drainage basin.

The dentition in these skulls agrees closely in size and cusp arrangement with the figures of other specimens referred to this species. As Wood, Gregory and Cook, and Matthew have shown,[45] there is good reason to expect considerable individual variation within the species of the Rhinocerotidæ; since the present specimens show only the most trifling variations from others referred to *T. osborni*, they are here referred to that species.

As nearly as could be determined by a field examination of specimens too fragmentary to merit collection, this is the genus characteristically associated with the Titanotheres. It has not yet been observed in the Upper Member of the Chadron.

[45](a) Wood, H. E., Some Early Tertiary Rhinoceroses and Hyracodonts; Bull. of Amer. Paleont., vol. 13, no. 50, 1927.

(b) Gregory, W. K. and Cook, H. J., New Material for the Study of Evolution; A series of Primitive Fossil Rhinoceros Skulls (Trigonias) from the Lower Oligocene of Colorado; Proc. Colo. Mus. Nat. Hist., vol. 8, no. 1, 1928.

(c) Matthew, W. D., Critical Observations on the Phylogeny of the Rhinoceroses; U. of Calif. Publ., Bull. Dept. Geol. Sci., vol. 20, no. 1, 1931.

(d) Wood, H. E., Lower Oligocene Rhinoceroses of the Genus Trigonias; Jour. Mammalogy, vol. 12, 1931, p. 414.

Order Artiodactyla

Family Leptochœridæ

*Stibarus* sp? Lower jaw with $P_{3,4}$, $M_{1-3}$, Princeton Mus. no. 13782. Larger and more robust than *S. montanus*, it is probable that this specimen represents a species as yet undescribed. However, as there seems to be some confusion in the taxonomy of the Leptochœridæ which would be increased rather than abated by description of another species based upon a fragmentary type, it will probably be advantageous to await revision of the family before erecting a new species.

*Stibarus* sp? or *Leptochœrus* sp? Fragment of a lower jaw, with $P_4$, $M_1$, Princeton Mus. no. 13598. Middle Member, northeast branch of Indian Creek. About the size of *S. montanus*, but with the principal cusp of $P_4$ much higher and more acute than in *S. montanus*.

Family Elotheriidæ

**Archæotherium *cf.* crassum**

Pair of lower jaws, with most of the teeth, Princeton Mus. no. 13623, from a channel sandstone near the base of the Middle Member, in the upper part of Indian Creek drainage basin. This is a typical *A. crassum* except that the canines are very large, which may very well be a sexual character.

**Archæotherium scotti**

Pair of lower jaws, lacking most of the teeth, Princeton Mus. no. 13621. Middle Titanothere beds, channel sandstone, ¾ mile south of Taylor's old ranch house (see map, Wanless, *loc. cit.*, p. 192), Indian Creek drainage, Pennington County, South Dakota. These jaws compare very closely with those of the type.[46] The original index card of the type, in Hatcher's handwriting, gives the horizon as "Upper Titanotherium Beds, White River Miocene," and states that the specimen was "purchased of H. F. Wells." It is, of course, perfectly possible that *A. scotti* might occur both in the Middle Member and the Upper Member as I have delineated them. However, in

[46]Sinclair, W. J., Entelodonts from the Big Badlands of South Dakota in the Geological Museum of Princeton University: Proc. Amer. Philos. Soc., vol. LX, 1921, p. 467.

view of the fact that no entelodonts have been observed in the Upper Member, while many fragments have been found in the Middle, and also that much of what I term the "Middle Member" might have been "upper Titanothere beds" to one of Hatcher's collectors, the type cannot be regarded as a definite record of *Archæotherium* from the Upper Member of the present subdivision. Certainly the referred specimen, no. 13621, and all other entelodont remains observed, was in the Middle Member.

### Family Agriochœridæ

One broken lower premolar, about the size of a large *Merycoidodon* (*Oreodon*) *culbertsonii*. In a channel sand, Middle Member, Indian Creek drainage. This generically indeterminable specimen was not collected. It is the only record of Oreodonts in the Middle Member.

### Family Hypertragulidæ

*Leptomeryx*? sp?; a few fragments, probably *Leptomeryx*, in channel sands near the base of the Middle Member. Not specifically identifiable.

## UPPER CHADRON

Sixteen of the thirty forms listed from this member are from one locality; fourteen of them, or all except *Leptomeryx* and *Pseudocynodictis*, have not been collected from other localities in the Upper Member. The extremely fossiliferous locality was found by Professor G. L. Jepsen. It was an area a few feet across in a massive buff clay, eleven feet below the Chadron-Brulè contact, in a northerly draining pocket which lies about 600 yards NNE of the most northwesterly outcrop of Protoceras channel no. 5 on Wanless' sketch map,[47] separated from that outcrop by one valley and one low ridge; head of the west fork of the east branch, Big Corral Draw, thirteen miles SSW of Scenic, South Dakota. In the following descriptions, the locality will be referred to simply as "microfauna locality."

## REPTILIA

### Family Anguidæ

*Peltosaurus*? sp? Fragment of reptilian maxillary, probably *Peltosaurus* or *Glyptosaurus*. Microfauna locality.

[47]Wanless, H. R., *loc. cit.*, p. 223, fig. 7.

### Family Testudinidæ

Several fragments of *Testudo* and some questionable *Stylemys* at various localities. As *Stylemys* is particularly abundant in the Lower Nodular immediately above, and has been reported from the Chadron of Saskatchewan,[48] its occurrence in the Upper Chadron in South Dakota is almost to be expected.

## AVES

Two scapulæ and three ulnæ, apparently of passerine birds about the size of large sparrows. Microfauna locality. This record of Oligocene passerines is interesting, but the material is so inadequate that it is of no significance.

## MAMMALIA

### Family Didelphidæ

*Peratherium* sp? Fragmentary left mandible with $M_4$ in place. The generic reference is unquestionable, but the specimen is too fragmentary for specific identification. It is almost twice as large as the type of *P. titanelix* Matthew,[49] and is, therefore, probably not referable to that species.

### Superfamily Tenrecoidea

### Family Apternodontidæ

**Apternodus altitalonidus** Clark Plate XXVI, figs. 3-4*

*Apternodus altitalonidus* Clark (Ms.) in Scott and Jepsen; Trans. Am. Philos. Soc., *n. s.*, vol. XXVIII; p. 12; 1936.

*Type:* Fragment of left mandible, with $P_4$, $M_{1-2-3}$ in place, Princeton Mus. no. 13774.

*Locality:* Microfauna locality.

[48]Lambe, L. M., Vertebrata of the Oligocene of the Cypress Hills, Saskatchewan; Contrib, to Canad. Paleont., vol. III, part 4, 1908, pp. 9, 18.

[49]Matthew, W. D., Fauna of the Titanotherium Beds at Pipestone Springs, Montana; Bull. Amer. Mus. Nat. Hist., vol. 19, no. 6, 1903, p. 202.

*Preliminary descriptions of this and a number of following species were published by Scott and Jepsen (Scott, W. B., and Jepsen, G. L. The Mammalian Fauna of the White River Oligocene—Part I, Trans. Am. Philos. Soc., n. ser., vol. XXVIII, part I, April, 1936); the full descriptions are published here for the sake of completeness.

*Horizon:* Upper Member, Chadron formation, lower Oligocene.

*Specific characters:* Extremely minute, about half as large as *Apternodus mediaevus* and less than half as large as *A. gregoryi* and *A. brevirostris.* Talonid of $M_3$ very strongly developed, almost equalling the trigonid in antero-posterior length. Posterior cusp of $M_3$ talonid (=hypoconulid?) very high, point falling in line with points of protoconids on $P_4$, $M_{1-2-3}$, rather than with points of paraconids of those teeth as it does in the other *Apternodi.* Although this tiny jaw differs from the mandibles of the three described species of Apternodus[50] more than they do from each other, it is plainly congeneric with them. Unfortunately the material is so scanty that it cannot be determined whether small size and large $M_3$ talonid are primitive characters or specializations. Therefore, any "family tree," or any conclusions regarding relative ages of the Upper Member of South Dakota and the Chadron of Pipestone Springs based on such a family tree, are out of the question.

The taxonomic scheme which is employed above is that used by Hay,[51] which differs from that of Schlaikjer. The relative significance of the similarities between *Apternodus* and *Solenodon* as listed by Schlaikjer[52] and the differences between the two, *e. g.*, in development of the auditory plate, and in development of the lower incisors, is largely a matter of personal opinion. In the absence of any upper Tertiary forms as connecting links, it seems to me best for the present to keep the two genera in separate families, as did Matthew and Gregory in 1910[53] and Hay in 1928.

Measurements of *Apternodus altitalonidus*

| | mm. |
|---|---|
| Length of molar series | 3.9 |
| Depth of mandible | 1.1 |
| Approximate height, alveolar border to tips of protoconids | 1.0 |

[50](a) Matthew, W. D., *loc. cit.*, p. 202.

(b) Schlaikjer, E. M., A Detailed Study of the Structure and Relationships of a New Zalambdodont Insectivore from the Middle Oligocene; Bull. Mus. Comp. Zool., Harvard, vol. LXXVI, no. 1, 1933.

(c) Schlaikjer, E. M., A New Fossil Zalambdodont Insectivore; Amer. Mus. Novit., no. 698, 1934.

[51]Hay, O. P., Second Bibliography and Catalogue of the Fossil Vertebrates of North America; Carnegie Inst. of Wash. Publ. no. 390, p. 426, 1928.

[52]Schlaikjer, E. M., 1933, *loc. cit.*, p. 17.

[53]Osborn, H. F., The Age of Mammals; MacMillan & Co., 1910, p. 519. Footnote "The present arrangement (of the Insectivora) is by Matthew and Gregory."

Family Solenodontidæ

**Clinopternodus*** gen. nov.

*Clinodon* (gen nov.) Clark (Ms.), *in* Scott and Jepsen, Trans. Am. Philos. Soc., *n.s.*, XXVIII, 1936, p. 22. Type, *Clinodon gracilis* Clark, sp. nov.

Preoccupied by *Clinodon*, Regan, 1920, Annals and Magazine of Natural History, ninth series, Vol. V, p. 45.

In a footnote (page 45) in his paper, "The classification of the fishes of the family Cichlidæ—I. The Tanganyika Genera," Ann. and Mag. Nat. Hist., 1920, ser. 9, vol. V, pp. 33-53, C. Tate Regan described "*Clinodon*, gen nov. (type *Hemitilapia bayoni*, Bouleng.); structure of *Haplochromis*, dentition of *Hemitilapia*."

Since this previous usage of "*Clinodon*" makes necessary a new name for the present genus, Professor W. B. Scott has, in correspondence, suggested the above emendation.

Type of genus: *Clinodon gracilis* Clark.

**Clinopternodus gracilis** (Clark) Plate XXVI, figs. 5-6

*Clinodon gracilis* Clark (Ms.) in Scott and Jepsen, Trans. Am. Philos. Soc., *n. s.*, vol. XXVIII; p. 13; pl. II; 1936.

*Type:* Anterior portion of left mandibular ramus, bearing C, $P_{3,4}$, $M_1$. Princeton Mus. no. 13835.

*Locality:* Microfauna locality.

*Horizon:* Upper Member, Chadron formation, lower Oligocene.

*Generic and specific characters:* Dental formula $\frac{?}{I?\text{-}C\text{-}Po\text{-}2\text{-}3\text{-}4\text{-}M1\text{-}?}$ Teeth strongly procumbent, closely set, no diastemata except possibly between $P_{2-3}$. Canine small, laniary. $P_2$ probably single-rooted. $P_3$ anterior cusp pointed, conical, ovoid in cross section with long axis antero-posterior; small, sharp postero-external cusp touching principal cusp of $P_4$ and lateral to anterior cusp of $P_4$. $P_4$ tri-cuspidate: (1) small anterior cusp which is median with respect to $P_4$ but internal with respect to $P_3$; (2) large principal cusp, very broad transversely and highly compressed antero-posteriorly, curving mesially as it rises from the alveolar border to the triturating surface; (3) a short, sharp posterior cusp like an upward extending wing from the lower posterior surface of the principal cusp. $M_1$ with high, antero-posteriorly com-

*From κλίνω, to incline, πτερ, wing, and δούς, tooth.

pressed trigonid and much lower talonid. Protoconid highest, notably higher than metaconid; paraconid small, little higher than talonid, very slightly internal to a position directly anterior to metaconid. Talonid about one-half as high as trigonid; hypoconid highest, entoconid and weakly developed hypoconulid about equal. $M_1$ curved mesially like $P_4$. Mental foramen below posterior part of $P_3$.

In its cuspidation, *Clinopternodus* strongly resembles *Micropternodus* Matthew.[54] It differs from *Micropternodus* chiefly in having the teeth strongly procumbent and incurved rather than vertical to slightly recumbent, and in having the cheek teeth crowded and compressed rather than well spaced. Also, it is about one-third larger than the type and only reported specimen of *Micropternodus*. As the specimen was broken between the $P_2$ alveolus and $P_3$, the presence or absence of a tiny posterior root of $P_2$, such as Schlaikjer[55] has described on the type of *Micropternodus*, cannot be determined. There does not seem to be room for an alveolus between the one present and $P_3$, but this is not conclusive.

Measurements of *Clinopternodus gracilis*

| | mm. |
|---|---|
| Length of $\overline{P}$ series | 5.0 |
| Height of $\overline{C}$ alveolar border to tip | 1.9 |
| Height of $P_3$, alveolar border to tip of principal cusp | 2.0 |
| Height of $P_4$, alveolar border to tip of principal cusp | 3.0 |
| Height of $M_1$, alveolar border to tip of principal cusp | 3.6 |
| Length of $P_3$, antero-posteriorly | 1.8 |
| Length of $P_4$, antero-posteriorly | 2.0 |
| Length of $M_1$, antero-posteriorly | 2.5 |

## Superfamily Erinaceoidæ

## Family Leptictidæ

### **Ictops dakotensis** Leidy

A series of six partial maxillæ and five mandibular rami, none associated, from the Microfauna locality. One mandibular ramus is numbered Princeton Mus. no. 13605; the other specimens are no. 13773. Most of the specimens agree quite closely with the typical Brulè

[54]Matthew, W. D., *loc. cit.*, p. 204.

[55]Schlaikjer, E. M., *loc. cit.*, 1933, p. 20.

*I. dakotensis.* There is a noticeable size range among the maxillæ, and a diverse spacing of premolars in the mandibles. The variations and inconstancies among these contemporaneous and almost certainly co-specific individuals illustrate Matthew's contention that when syntaxial "quarry" suites are collected, a species will be found to contain variants sufficiently different to be classified as separate species or even genera were they known from isolated specimens. If the species of *Ictops* described by Douglass and Matthew[56] are valid, then the presence in the Upper Member of *I. dakotensis* rather than of those species would indicate that the Upper Member is somewhat younger than the Chadron of Montana.

## Family Leptictidæ

### **Metacodon*** **magnus** Clark. Plate XXVI, figs. 1-2

*Metscodon magnus* Clark (Ms.) in Scott and Jepsen, Trans. Am. Philos. Soc., *n. s.*, vol. XXVIII; p. 22; pl. II, figs. 5, 5a; 1936.

*Type:* Partial lower jaw with $P_4$, $M_{1, 2, 3}$. Princeton Mus. no. 13835a.

*Locality:* Microfauna locality.

*Horizon:* Upper Member, Chadron formation, Lower Oligocene.

*Generic and specific characters:* In general character much like *Leptacodon* Matthew and Granger.[57] One-third to one-fourth larger than the species of *Leptacodon.* Angle of jaw almost completely absent, condyle almost in line with lower border of ramus. $P_4$ submolariform; metaconid directly lingual to protoconid rather than postero-lingual to it as in *L. packi.* Molars similar to those of *Leptacodon;* protoconid is higher than metaconid which is higher than paraconid.

[56](a) Douglass, E., Fossil Mammalia of the White River Beds of Montana; Amer. Philos. Soc., vol. XX, no. 5, 1901, p. 245.

(b) Douglass, E., The Tertiary of Montana; Mem. Carn. Mus., vol. II, pp. 203-223, 1905.

(c) Matthew, W. D., Fauna of the Titanotherium Beds of Montana; Bull. Amer. Mus. Nat. Hist., vol. XIX, 1903, p. 204.

[57](a) Matthew, W. D., and Granger, W., New Genera of Paleocene Mammals; Amer. Mus. Novit., no. 13, 1-7, 1921.

(b) Jepsen, G. L., Stratigraphy and Paleontology of the Paleocene of Northeastern Park County, Wyoming; Proc. Amer. Philos. Soc., vol. LXIX, no. 7, 1930, p. 510.

*From μετά, late; ἀκή, sharp; and δοντ, tooth.

Hypoconulid of $M_3$ set well posterior to hypoconid and entoconid, as in *L. tener* rather than *L. packi.*

Future discoveries may show that this genus is synonymous with *Leptacodon.* The characters listed above admittedly are not very satisfactory. The specimen is placed in a new genus because the extreme reduction of the angle and lowering of the condyle until it falls in line with the tooth row may be reflections of skull differences more striking than would be indicated by the conservative Leptictid lower molars. It seems undesirable to extend the range of an Insectivore genus from the Paleocene to the Oligocene on the basis of imperfect lower jaws, so the Oligocene specimen is placed in a separate genus. All the evidence on the type would indicate that *Metacodon*, if it is a valid genus, is derived directly from *Leptacodon.*

Measurements of *Metacodon magnus*

| | mm. |
|---|---|
| Depth of mandible below $M_2$ | 2.9 |
| Length of $\overline{M}$ series | 6.0 |
| Height of: $P_4$, alveolar border to tip of principal cusp | 2.2 |
| $M_1$, alveolar border to tip of protoconid | 2.2 |
| $M_2$, alveolar border to tip of protoconid | 2.2 |
| $M_3$, alveolar border to tip of protoconid | 1.9 |
| Length (antero-posteriorly) of: $P_4$ | 2.0 |
| $M_1$ | 2.1 |
| $M_2$ | 2.0 |
| $M_3$ | 1.7 |

Family Apatemyidæ

*Sinclairella* Jepsen; see Jepsen's paper[58] for a complete discussion of this form.

Family Hyænodontidæ

**Hyænodon cruentus** Leidy

A lower jaw, Princeton Mus. no. 12745. The label gives the horizon as "upper ⅓ of the Titanotherium Beds," 1922 collection. A visit to

[58]Jepsen, G. L., A Revision of the American Apatemyidæ and the Description of a New Genus, *Sinclairella*, from the White River Oligocene of South Dakota; Proc. Amer. Philos. Soc., vol. LXXIV, no. 4, 1934.

the exact locality, accompanying Professor Sinclair, demonstrated that the specimen is from the Upper Member. The jaw is a typical *H. cruentus*, and needs no special description.

*Hyænodon cruentus* (?); a skull, Princeton Mus. no. 12970. Intermediate in size between *H. cruentus* and *H. crucians*, nearer *H. cruentus*. Resembles the individual from the Duchesne River in size.[59] The posterior portion of the basicranium, between the glenoid fossæ and the occipital condyles, is notably longer in proportion to the palatal length than is the corresponding region in typical adult *H. cruentus* and *H. crucians*. Study of a series of skulls shows that a long basicranium is a common juvenile character in *H. cruentus*. Although no. 12970 seems to be full-grown, it is very young adult, and this coupled with its small size, suggests that the long basicranium is merely an adolescent feature held over, rather than a valid specific character. The specimen is, therefore, referred with question to *H. cruentus*.

## Family Canidæ

### Subfamily Cynodictinæ

### **Pseudocynodictis gregarius** (Cope)

Two specimens: (1) right lower jaw with $P_4$, $M_{1, 2, 3}$, from the Microfauna locality, Princeton Mus. no. 12620; (2) right lower jaw with C, $P_4$, $M_{1, 2, 3}$, associated with *Hoplophoneus o'harrai* Princeton Mus. no. 13593. These jaws compare very closely with several typical *P. gregarius* jaws in the Princeton Museum Brulè Collection. They do not compare with Matthew's description (he gives no figure)[60] of *P. paterculus*.

### Subfamily Cynodontinæ

### **Parictis dakotensis** Clark. Plate XXIV

*Parictis dakotensis* Clark (Ms.) in Scott and Jepsen, Trans. Am. Philos. Soc., *n. s.*, vol. XXVIII; p. 106; pl. XIV, figs. 1, 1a; 1936.

*Type:* Right mandible with $P_{2, 3, 4}$, $M_{1, 2}$, and alveoli for C, $P_1$, $M_3$. Specimen in South Dakota School of Mines Museum.

[59]Peterson, O. A., New Species from the Uinta Oligocene; Ann. Carn. Mus., vol. XXI, no. 2, 1932, p. 64.

[60]Matthew, W. D., Fauna of the Titanotherium Beds of Pipestone Springs, Montana; Bull. Amer. Mus. Nat. Hist., vol. XIX, 1903, p. 209.

*Horizon:* Probably Upper Member, Chadron Formation, lower Oligocene. Position given (in personal communication) is "somewhere between the type of *Hoplophoneus o'harrai* and the Chadron-Brulè contact." As the type of *H. o'harrai* is from 46 feet below the contact, and the Upper Member is there 25-30 feet thick, *Parictis dakotensis* is from the Upper Member or the upper part of the Middle Member.

*Locality:* Big Corral Draw, Washington County, South Dakota.

*Specific characters:* Tooth-row somewhat longer than that of *Parictis primævus:*[61] $P_3$ larger than $P_2$ and much expanded posteriorly, while in *P. primævus* $P_3$ is slightly shorter than $P_2$ and not expanded posteriorly. Jaw very much deeper and more robust, actually and proportionally, than that of *P. primævus.*

Measurements of *Parictis dakotensis*

| | mm. |
|---|---|
| Depth of mandible below $M_1$ | 11. |
| Depth of mandible below $P_2$ | 9.5 |
| Length of $\overline{P}$ series | 21.5 |
| Height of: $P_2$, alveolar border to tip of principal cusp | 4. |
| $P_3$, alveolar border to tip of principal cusp | 4. |
| $P_4$, alveolar border to tip of principal cusp | 5. |
| $M_1$, alveolar border to tip of protoconid | 6. |
| $M_2$, alveolar border to tip of protoconid | 1.5 |
| Length (antero-posteriorly) of: $P_2$ | 5.5 |
| $P_3$ | 6. |
| $P_4$ | 7.5 |
| $M_1$ | 9. |
| $M_2$ | 5. |
| Length of $\overline{M}$ series | 17. |

The information borne by the present specimen far transcends the mere addition of knowledge of a few more characters to the very imperfectly known genus *Parictis.* Comparison of Plate XXIII with Wortman and Matthew's type figure of *Phlaocyon*[62] shows at once

[61](a) Scott, W. B., On a New Musteline from the John Day Miocene; Amer. Naturalist, vol. XXVII, p. 658.

(b) Hall, E. R., Description of a New Mustelid from the Later Tertiary of Oregon, with Assignment of *Parictis primævus* to the Canidæ; Jour. Mammal., vol. 12, no. 2, 1931, p. 156.

[62]Wortman, J. L., and Matthew, W. D., Ancestry of Certain Members of the Canidæ, the Viverridæ, and Procyonidæ; Bull. Amer. Mus. Nat. Hist., vol. XII, no. VI, 1899, p. 135.

## TABLE SHOWING COMPARISON BETWEEN *PARICTIS* AND *PHLAOCYON*

| | *Parictis dakotensis*, type | *Phlaocyon leucosteus*, type |
|---|---|---|
| $P_1$ | alveolus about equals alveolus in *Phlaocyon*. | Small, subconical, small heel. |
| $P_2$ | Long, subquadrangular (marked) anterior and posterior cingulum. | Slightly shorter anterior-posteriorly, rounded in front; cingulum smaller, especially in front. |
| $P_3$ | Subquadrangular, antero-internal and postero-external angles sharply expanded. | Tooth not nearly so large as in *Parictis*, corresponding angles not strongly expanded. |
| $P_4$ | Long antero-posteriorly; almost quadrangular; complete cingulum, very prominent antero- and postero- internally. | About ¾ as long as in *Parictis;* tooth much narrower anteriorly than posteriorly; cingulum developed weakly if at all on sides of tooth. |
| $\overline{P}$ | series. Longer by half of $P_4$. All teeth tend to be subquadrangular with postero-external angle expanded. | Reduced, all teeth tend to be subquadrangular with antero-external corner retracted. |
| $M_1$ | Little larger than $P_4$. Very slight indication of fossa in posterior rim of heel. | Much larger and more robust than $P_4$. Well developed fossa in posterior rim of heel. Tooth somewhat broader, very little longer, than $M_1$ of *Parictis*. |
| $M_2$ | Small, cusp pattern partly masked by wear. | Much larger, subquadrangular, cusp pattern partly masked by wear. |
| $M_3$ | Alveolus about ½ the size of alveolus in *Phlaocyon*. | |
| $\overline{M}$ | series. Not as long as $\overline{P}$ series by length of $P_1$ and ¼ of $P_2$. | Fully as long as $\overline{P}$ series. Longer than *Parictis* $\overline{M}$ series by length of $M_3$, and much stouter. |

Jaws: *Parictis* not quite so high or so heavy as *Phlaocyon*. Position of mental foramina the same in the two.

Tooth row, $P_1$-$M_3$, equal length in the two.

that the two forms are closely related. The table following this discussion gives all the differences observed in a careful comparison of the types. Briefly, the table shows that *Parictis dakotensis* is a rather generalized form, with molars and premolars about equally developed. *Phlaocyon*, with almost exactly the same cuspidation, has the premolars reduced and the molars enlarged. The only differences in cuspidation are trivial differences of relative development in $M_2$, development of fossæ in the posterior rim of the heel of $M_1$, and stronger cingulum in *Parictis*. Therefore, *Parictis dakotensis* or some yet unknown and very closely allied species may be regarded as the Chadron ancestor of *Phlaocyon*, and hence (*vide* Wortman and Matthew) of all the Procyonidæ. The small and imperfectly known *Parictis primævus* cannot be regarded as ancestral to *Phlaocyon* because it is from the John Day, and hence nearly contemporaneous with the latter genus.

Wortman and Matthew[63] suggested *Cynodictis* as a possible ancestor of *Phlaocyon;* Teilhard in 1915[64] believed that *Pachycynodon* was possibly the ancestral form. *Parictis dakotensis* resembles the Princeton Museum specimens of *Cynodon* and Teilhard's figures of *Cynodon* and *Pachycynodon* in the general tooth cuspidation, in the tendency toward sub-quadrangular premolars, and in the tendency toward a prominent cingulum on the premolars. There are slight differences in the pattern of $M_2$, the teeth of *Parictis* are broader, heavier, and more blunt than in most of the species of the European genera, and the jaw is more massive in *Parictis*. *Cynodictis* has sharp, high, blade-like premolars, $M_1$ much larger than $P_4$, and is in general of a lighter, more delicate build than is *Parictis*. Such evidence as the lower jaws can offer, then, indicates a relationship between *Parictis* and *Cynodon-Pachycynodon*, rather than between *Parictis* and *Cynodictis*.

As *Parictis* and its European relatives are approximately contemporary, it would be unjustifiable to derive either form from the other; all that can be said is that both are probably descended from a common ancestral stock not far removed from them in time. Teilhard's complicated family trees[65] show polyphyletic origins, put different

[63]Wortman, J. L., and Matthew, W. D., *loc. cit.*

[64]Teilhard de Chardin, Pierre, Les Carnassiers des Phosphorites du Quercy; Annales de Paleontologie, 9, 1914-15, p. 41.

[65]Teilhard de Chardin, Pierre, *loc. cit.*

species of one genus into different major groups, and in general are not in accord with American ideas about the method of evolution, so I regard the ancestry of *Parictis*, *Cynodon*, and *Pachycynodon* as a matter still unsettled. It is not even demonstrated satisfactorily that those genera are of European ancestry; the recorded occurrence of *Cynodon* (*Pachycynodon*) in Asia[66] and possibly in North America[67] throws the question of the place of origin open. However, the abundance of *Cynodon* and related forms in the Phosphorite and their apparent scarcity elsewhere suggests a European place of origin.

### Subfamily Simocyoninæ

#### **Daphœnus dodgei** Scott

A pair of broken lower jaws with C, $P_{3,\ 4}$, $M_1$; associated skeletal fragments, Princeton Mus. no. 13601. Upper Member, Chadron formation, in a gray clay, about 25 feet below the Chadron-Brulè contact, east slope of Hutenmacher Table. This specimen compares very closely with the lower jaws of the type. It is very slightly larger than the type, and $P_4$ is more robust. $P_3$ on the left is much more robust than is $P_3$ in the type, but its counterpart on the right is the same as the type $P_3$, clear indication of the amount of individual variation which must be expected.

*D. vetus* has not yet been found in the Chadron, nor *D. dodgei* in the Brulè. The fragment on which Lambe[68] based his identification of *D. felinus* in the Cypress Hills Chadron is a maxillary bit with $P^4$ in place; no specific comparison is possible as the upper dentition of *D. dodgei* is unknown. Also, Russell has referred the Cypress Hills fragment to a new species, *D. canadensis*. For the present, therefore, *D. dodgei* may be considered characteristic of the Upper Member of the Chadron, and *D. vetus* (=*felinus*) characteristic of the Brulè.

[66]Matthew, W. D., and Granger, W., New Carnivora from Mongolia; Amer. Mus. Nov., no. 104, p. 8, 1924.

[67]Cook, H. J., Faunal Lists of the Tertiary Mammals of Sioux County, Nebraska; Nebr. Geol. Surv., VII, 1914, p. 34.

[68](a) Lambe, L. M., Vertebrata of the Oligocene of the Cypress Hills, Saskatchewan; Contrib. to Canad. Paleont., vol. III, part IV, 1908, p. 62.

(b) Russell, L. S., Revision of the Lower Oligocene Vertebrate Fauna of the Cypress Hills, Saskatchewan; Trans. Roy. Canad. Inst., vol. XX, part I, 1934, p. 56.

Family Mustelidæ

Subfamily Mustelinæ

**Mustelavus priscus** Clark. Plate XXIV

*Mustelavus priscus* Clark (Ms.) in Scott and Jepsen, Trans. Am. Philos. Soc., *n. s.*, vol. XXVIII; p. 107; pl. XIV, figs. 2, 2a; 1936.

*Type:* A skull, somewhat crushed, with lower jaws in occlusion (separated during preparation); Princeton Mus. no. 13775.

*Referred material:* Partial lower jaw with $P_4$, $M_{1,2}$, Princeton Mus. no. 13776. Fragment of maxillary with $P^{3,4}$, $M^1$, Princeton Mus. no. 13777.

*Locality:* Microfauna locality (both type and referred material).

*Horizon:* Upper Member, Chadron formation, lower Oligocene.

*Generic and specific characters:* Skull long and slender. Very faint parietal crests, close to midline. Basicranium long, palate rather broad relative to entire skull. Bullæ moderately inflated. Dentition $\frac{3-1-4-2}{?-1-4-2}$ $I^1$ smallest, $I^3$ largest, all very slender. $\underline{C}$ slender, slightly curved, pointing anteriorly. $P^1$ single-rooted. $P^2$ double-rooted. $P^3$ simple, sub-conical, strongly compressed laterally with a well defined posterior basal cusplet. $P^4$ rather small, protocone very little higher than that of $P^3$, tritocone not extended very far inward. $M^1$ rather high-cusped, parastyle prominent, set external to paracone. $M^2$ alveolus small. Mandible long, delicate, laterally compressed. Condyle in line with tooth row and internal end directed antero-ventrally. $\overline{C}$ short, sharp, conical. $P_1$ small, single-rooted, cusp directed anteriorly and heel vertically. $P_2$ simple, two-rooted, with anterior and posterior cingula and rather long heel. $P_3$ like $P_2$, but slightly larger. $P_4$ slightly larger than $P_3$, with small but distinct deuterocone. $M_1$ trigonid distinctly higher than $P_4$, protoconid over-topping the equal paraconid and metaconid, and set slightly anterior to the metaconid; talonid low, slightly basined. $M_2$ small, sharply cusped, having an anterior and a posterior basin separated by a low elevation connecting the protoconid and metaconid.

Comparison of the type's lower jaws with those specimens of *Plesictis* in the Princeton Museum and with Teilhard's description and figures[69] shows no good basis for a generic separation. In fact, the

[69]Teilhard de Chardin, P., *loc. cit.*

Measurements of *Mustelavus priscus*

| SKULL | mm. |
|---|---|
| Length along midline, ventral | 62. |
| Length of palate | 32. |
| Length of basicranium | 30. |
| Length of auditory bullæ, antero-posteriorly | 13. |
| Width between canines | 6.5 |
| Width between $M^1$ parastyles | 23. |
| Length of $I^3$ | 3. |
| Length of $\underline{C}$ | 7. |
| Length of $\underline{P}$ series | 18. |
| Length (antero-posteriorly) of: $P^3$ | 4. |
| $P^4$ | 6. |
| $M^1$ | 3.1 |
| Height of $P^3$, alveolar border to tip of principal cusp | 3. |
| Height of $P^4$, alveolar border to tip of principal cusp | 4. |
| Greatest width of $M_1$ | 6. |

| MANDIBLE | |
|---|---|
| Length of mandible, $\overline{C}$ alveolus to condyle | 42. |
| Length of tooth row, $\overline{C}$ alveolus through $M_2$ | 26. |
| Height of ascending ramus, angle of jaw to tip of coronoid process | 16.5 |
| Height of mandible below $M_1$ trigonid | 5.5 |
| Length of $\overline{P}$ series | 15. |
| Length (antero-posteriorly) of: $P_1$ | 2. |
| $P_2$ | 3.5 |
| $P_3$ | 3.5 |
| $P_4$ | 4. |
| Height of: $P_1$ | 2. |
| $P_2$ | 3. |
| $P_3$ | 3.1 |
| $P_4$ | 4. |
| $M_1$, protoconid | 4. |
| $M_2$, protoconid | 2. |

resemblance to *Plesictis pygmæus* is so close that it is almost impossible to find ground for a specific distinction in the lower jaws.

Comparison of the skull with Filhol's figures of *Plesictis*[70] reveals

[70]Filhol, H., Etude des mammiferes Fossiles de Saint-Gerand le Puy (Allier). Annales de Societe Geologique de Paris, XXI, 1879, plates 20, 21, 22, 27.

one sharp difference—retention of $M^2$ in *Mustelavus* and its absence in *Plesictis*. Also, the parietal crests of *Plesictis* are more strongly developed than are those of *Mustelavus*. Otherwise the two are extremely similar in dentition, in skull configuration, and in basicranial anatomy.

In keeping with its stratigraphic position, *Mustelavus* exhibits many primitive and generalized characters. Retention of $M^2$, parastyle of $M^1$ relatively small, internal basin of $M^1$ not extending anterior to protocone, metaconid of $M_1$ as large as paraconid, $M_2$ long antero-posteriorly and sub-rectangular, are all characters which may be regarded as primitive within the subfamily Mustelinæ. The recent genera have all lost $M^2$, have the parastyle of $M^1$ large, the internal basin of $M^1$ encircling the protocone, the metaconid of $M_1$ very small or absent, and $M_2$ sub-rectangular to round although with essentially the same cuspidation as $M_2$ of *Mustelavus*. The same dental specializations are present in *Gulo* as in the Mustelinæ.

The dentition of *Oligobunis* is, except for its much greater size and massiveness, extremely similar to that of *Mustelavus*. Reduction of the metaconid of $M_1$ to a small tubercle on the inner side of the protoconid is the only real advance toward a specialized cuspidation.

*Mustelavus* is, therefore, representative of the ancestral stock from which *Oligobunis*, the recent Mustelinæ, and the recent Guloninæ were derived. *Plesictis*, lacking $M^2$, is much less satisfactory as the ancestral stock, inasmuch as $M^2$ is present in the American Miocene Mustelinæ (*Oligobunis*, *Paroligobunis*, *Brachypsalis*). *Bunœlurus*, with the protocone of $M^1$ a simple, transverse blade lacking any encircling basin, the metaconid of $M_1$ absent, the heel of $M_1$ trenchant rather than basined, and $M_2$ trenchant rather than basined, is markedly different from the other American Mustelinæ, and cannot be regarded as ancestral to them.

## Family Felidæ

### Subfamily Machærodontinæ

#### **Deinictis** *cf.* **fortis** Adams

A group of skeletal fragments and left $\overline{c}$, $P_4$, $M_1$, Princeton Mus. no. 13638. The teeth closely resemble those of referred specimens (the type has no lower teeth preserved) in Princeton Museum. The

type is labelled "Upper Titanothere beds, Corral Draw"; the present specimen is merely a definite record of *D. fortis* from the Upper Member in the present system of stratigraphic subdivision.

**Hoplophoneus o'harrai** Jepsen

Skeleton with skull and lower jaw, Princeton Mus. no. 13593. Upper Member, 28 feet below the Chadron-Brulè contact; east side of Hutenmacher Table, Pennington County, South Dakota.

The present specimen has been discussed by Jepsen.[71] As the type is from the Middle Member, this specimen extends the geologic range of *H. o'harrai* into the Upper Member.

**Hoplophoneus mentalis** Sinclair

Type of species, Princeton Mus. no. 12515. The field label gives the locality as "2-2½ feet below Oreodon beds contact"; also, Professor Sinclair kindly indicated the exact position from which he collected the specimen, so there can be no doubt that it comes from the Upper Member.

**Hoplophoneus robustus** Adams

Skull, lower jaws, and skeleton, Princeton Mus. no. 13635. From 20 feet below the Chadron-Brulè contact, west side of Hutenmacher Table, Pennington County, South Dakota. It compares very closely with the specimens in the Princeton Museum. *H. robustus* is typically a Brulè species; this record of its occurrence in the Upper Member of the Chadron is a downward extension of its geologic range.

Family Equidæ

Subfamily Anchitheriinæ

**Mesohippus** *cf.* **latidens** Douglass

A partial cheek-tooth series, $P^{2,3,4}$, $M^{1,2,3}$, Princeton Mus. no. 13830, from a bluish clay, Upper Member of the Chadron; Quinn Draw, Washington County, South Dakota. These teeth compare with *M. latidens* in size, but differ in several of the characters listed by

[71]Jepsen, G. L., *loc. cit.*

Osborn.[72] As they do not exactly agree in tooth characters with any of the Chadron species listed by Osborn, they are referred with question to *M. latidens* on the basis of similar size. The most marked character is the presence of a large hypostyle.

Family Brontotheriidæ

Six unidentifiable fragments of Titanotheres have been observed in the Upper Member clays during the course of three field seasons. None have been seen in the sandstone lenses. The reason for the complete reversal of the Middle Member association, where Titanothere bones are found predominantly in the sandstone lenses and are almost absent in the clays, is not known.

Family Helaletidæ

**Colodon occidentalis** (Leidy)

Palate with $I^{1,2,3}$, $\underline{C}$, $P^{1,2,3,4}$, $M^1$, associated lower jaw with $P_{2,3,4}$, $M_{1,2,3}$, associated $I_{1,2,3}$; Princeton Mus. no. 13595. Top of the Upper Member, head of Big Corral Draw, about ½ mile northeast of the Microfauna locality, Washington County, South Dakota. A typical *C. occidentalis* dentition; the canine perhaps indicates that the individual was a male. The specimen comes from a few feet below the Chadron-Brulè contact.

Family Hyracodontidæ

Subfamily Hyracodontinæ

*Hyracodon* sp?; specifically indeterminable fragments of *Hyracodon*, about the size of *H. nebraskensis*, have been observed at several places in the Upper Member: (a) Various localities in the Indian Creek-Corral Draw area; (b) Horizontally banded lens along the south flank of Kube Table; (c) Horizontally banded lens south of Conata.

Family Leptochœridæ

*Stibarus* sp?; pair of fragmentary maxillæ with $P^{3,4}$, $M^{1,2,3}$, much worn; Princeton Mus. no. 13781. Microfauna locality. Identification

[72]Osborn, H. F., Equidæ of the Oligocene, Miocene, and Pliocene of North America, Iconographic Type Revision; Mem. Amer. Mus. Nat. Hist., New Series, Vol. III, part I, 1918, p. 39.

of this, as of the other Leptochœrids, must await revision of the family.

?*Leptochœrus* sp?; jaw fragment with $P_4$, $M_1$; Princeton Mus. no. 13598. From a buff clay, Upper Member, ¾ mile south of the rim of Hart Table, Pennington County, South Dakota.

Family Anthracotheriidæ

**Æpinacodon americanus** (Leidy)

Skull, somewhat crushed, with complete upper dentition, Princeton Mus. no. 13691. Upper Member, 6 feet below the Chadron-Brulè contact, head of Cain Creek along the south flank of 71 Table, Pennington County, South Dakota. The dentition compares very closely with that figured by Leidy,[73] and does not exhibit the characters described by Troxell[74] as characteristic of *A. deflectus*.

Family Suidæ

Subfamily Paleochœrinæ

**Perchœrus** *cf.* **nanus** (Marsh)

A group of associated teeth, very fragmentary, including $M^3$, $M_{2,\ 3}$, and scattered premolars and incisors; Princeton Mus. no. 13599. Upper Member, near the top of the Chadron, head of Big Corral Draw, about ½ mile northeast of the Microfauna locality.

The specific identification is based entirely upon size. The teeth are slightly larger than the measurements given by Cook[75] for *P. minor*, and agree very well with a referred specimen of *P. nanus* in the Princeton Museum.

Family Oreodontidæ

**Oreodon? (Eporeodon) bullatus?** (Leidy)

Two palates have been collected from the Upper Member. Comparison of a good skull of *Oreodon culbertsoni* and a good skull of

[73]Leidy, J., Extinct Mammalian Fauna of Dakota and Nebraska; 1869, Plate XXI.

[74]Troxell, E. L., American Bothriodonts; Amer. Jour. Sci., 5th series, vol. 1, 1921, p. 337.

[75]Cook, H. J., Oldest Known Peccary from North America; Pan-Amer. Geol., vol. 37, 1922, p. 357.

*Eporeodon bullatus* in the Princeton Museum fails to reveal any palatal characters which seem to me of positive value for distinction, therefore the two palates are here regarded simply as "Oreodonts."

Oreodont bones are relatively common in the Upper Member, in marked contrast to their almost complete absence in the Middle and Lower Members. They occur scattered through the massive clays and, while never in the tremendous abundance characteristic of the Lower Nodular zone of the Brulè, can usually be found in half an hour's search almost anywhere in the Big Corral-Indian Creek area. They have also been found in the horizontally banded lenses, associated with *Mesohippus* and *Hyracodon*, and also, but very rarely, in the bluish and greenish clays of the eastern part of the area.

### Family Hypertragulidæ

#### **Leptomeryx esulcatus** Cope

A lower jaw with $I_3$, C, $P_{1, 2, 3, 4}$, $M_{1, 2, 3}$; Microfauna locality, Upper Member, Chadron formation; Princeton Mus. no. 13834.

This specimen agrees with *L. esulcatus* as described by Matthew in 1903[76] in size and general anatomical characters, but the specialization of $P_3$ is somewhat more extreme. As in *L. esulcatus*, the internal posterior ridge of $P_3$ connects with the heel; however, the external ridge in the Princeton specimen is reduced almost to extinction, present merely as a tiny postero-external swelling on the protoconid, while in Matthew's specimen it is a definite ridge.

Many specimens of *L. evansi* in the Princeton Museum verify Matthew's statement that in that species the external posterior ridge of $P_3$, rather than the internal ridge, connects with the heel. The present specimen, therefore, is definitely *L. esulcatus*.

### Family Leporidæ

#### **Paleolagus** *cf.* **triplex** Cope

Two sets, each of two associated lower molars. Microfauna locality. These are the only specimens of *Paleolagus* which have been observed in three summers' collecting. They compare closely with the descrip-

[76]Matthew, W. D., Fauna of the Titanotherium Beds of Montana; Bull. Amer. Mus. Nat. Hist., XIX, 1903, p. 224.

tions of *P. triplex*, and are referred to that species, or to *P. turgidus* if Matthew[77] is correct in declaring *P. triplex* a synonym of *P. turgidus*.

Family Adjidaumidæ

**Adjidaumo (Gymnoptychus) minutus** (Cope)

Two lower jaws, Princeton Mus. no. 13832; Microfauna locality.

**Paradjidaumo (Adjidaumo) minor** (Douglass)

Eight lower jaws, Princeton Mus. no. 13831; Microfauna locality. These agree with the specimen figured by Matthew[78] and hence are but an extension of the range of the species to South Dakota.

Family Eutypomyidæ

**Eutypomys** sp? near **thomsoni** Matthew

Two molar teeth, comparable in size to *E. thomsoni;* Microfauna locality.

These teeth are not quite so complex as are the teeth of Matthew's type, but differences in stage of wear so change rodent molars that it is impossible to determine whether the differences are actual or merely due to age differences. The teeth are much larger than Lambe's *E. parvus*, and are if anything slightly larger than the type of *E. thomsoni*.

## REGIONAL CORRELATIONS

Matthew in 1924 published a table[79] in which he placed the Chadron in the upper Eocene. Most other authors would include the Chadron in the Oligocene. If, as Matthew stated,[80] the Equidæ are to be used as the chief guides in Tertiary continental stratigraphy, then the presence of *Mesohippus* in the Lower Member would seem sufficient evidence to place the South Dakota Chadron, with the possible ex-

[77]Matthew, W. D., A Horned Rodent from the Colorado Miocene, with a Revision of the Mylagauli, Beavers, and Hares of the American Tertiary; Bull. Amer. Mus. Nat. Hist., vol. XVI, 1902, p. 309.

[78]Matthew, W. D., Fauna of the Titanotherium Beds of Montana; Bull. Amer. Mus. Nat. Hist., vol. XIX, 1903, p. 215.

[79]Matthew, W. D., Correlation of the Tertiary Formations of the Great Plains; Bull. Geol. Soc. Am., vol. XXXV, 1924, p. 747.

[80]Matthew, W. D., *loc. cit.*, p. 745.

ception of the white basal channel fills, in the Oligocene. As the white channel fills have not yielded any identifiable bones, they are referred to the Oligocene with the rest of the Chadron until they are proven otherwise.

In order to test the applicability of the lithologic subdivision into Lower, Middle, and Upper Members, reconnaissance trips were made to the Chadron of Harding County, South Dakota, and to the Chadron near Crawford and Adelia, Nebraska.

The Harding County Chadron consists typically of 20-40 feet of greenish white, indurated sandstone, occasionally with conglomerates bearing Black Hills pebbles, overlain by 20-30 feet of bluish gray silty clays which look and weather almost exactly like the Middle and Upper clays of the Big Badlands. The Chadron rests upon the Lance except in the Cave Hills, where it lies on the Fort Union. The Chadron pinches out westward in the West Short Pine Hills, and seems to be absent in the Long Pine Hills, although extensive slumping makes exact determination difficult. In the South Cave Hills, the Chadron consists of sixty feet of clays, with occasional local sandstones at the base.

The Chadron near Crawford, Nebraska, consists of a series of red and green sands and clays with a basal conglomerate of silica pebbles, very similar in appearance to the Lower Member of South Dakota. Overlying this is a series of indurated buff clays which look extremely like lower Brulè, but have intercalated greenish sandstone lenses bearing Titanothere bones in abundance.

Obviously, the lithology in these two areas is so different from that in the Big Badlands that no regional correlations are possible on lithologic grounds. This is to be expected when dealing with continental sediments. However, the subdivision does apply over a sufficiently large area in the Big Badlands to make possible the collection of usable faunules from all three members. When such collections are made (the faunule of the Upper Member is the only one determined to my satisfaction at present, and it could be expanded to advantage), detailed correlations will be possible with lower Oligocene sediments wherever they occur, and the Chadron of the Big Badlands may be used as a standard section of the American lower Oligocene.

Due to the restricted faunules known from the Lower and Middle Members, regional correlations will be attempted only with the Upper Member at present.

Table no. 12 reveals that the Upper Member fauna is a mixture of species related to those of the "Titanothere Beds" of other localities and Lower Nodular (Brulè) species.

*Colodon occidentalis* and the rodents, except perhaps the species of *Eutypomys*, appear in all the columns, and are hence of no value for detailed correlations.

The fauna of the Upper Member strongly resembles the Lower Nodular (Brulè) fauna in many respects. *Ictops dakotensis*, *Hyænodon cruentus*, *Pseudocynodictis gregarius*, *Perchœrus nanus*, and *Eutypomys thomsoni* are all Brulè species, rather distinct from their "Titanotherium Beds" relatives of Montana and Saskatchewan. The presence of abundant Machærodonts, Oreodonts of the *Oreodon-Eporeodon* type, and Hyracodonts also produces a Brulè faunal facies.

Although the presence of *Daphœnus* and of the Machærodonts creates a resemblance to the Brulè fauna, the species of the two formations are distinct from each other. With the exception of *Hoplophoneus robustus*, none of the Machærodonts listed have been found in the Brulè; they have not been surely identified from the Chadron of Montana and Canada.

The Upper Member fauna definitely resembles the other "Titanotherium Beds" faunas and the older, Eocene faunas in four points: (1) Presence of Titanotheres; (2) Presence of the genera *Clinopternodus*, *Metacodon*, and *Sinclairella*, which are related to Eocene and Paleocene forms rather than to any known later genera; (3) Presence of *Leptomeryx esulcatus* rather than *L. evansi;* (4) Presence of *Mesohippus latidens* rather than one of the Brulè species.

The strong admixture of a Brulè element in the fauna, which is almost or totally lacking in the faunas of Montana and Saskatchewan, seems adequate evidence that the Upper Member is somewhat younger than the "Titanotherium Beds" of those areas. It does not, of course, prove that the whole of the South Dakota Chadron is younger than the Montana and Saskatchewan "Titanotherium Beds."

On the other hand, the specific differences shown in the genera *Daphœnus*, *Deinictis*, *Hoplophoneus*, *Mesohippus*, and *Leptomeryx*, all of which are common to the Upper Member and the immediately overlying Lower Nodular, are very definite evidence that there was an appreciable lapse of time between the deposition of the Upper Member and the deposition of the Lower Nodular. The contact can no longer be said to be marked by a sudden disappearance of Ti-

tanotheres. They diminished in importance during later Middle Chadron time, decreased very sharply at the end of the Middle Chadron, and were relatively rare during the Upper Chadron. The Chadron-Brulè contact marks that gap in the depositional history of the region during which the almost extinct race became totally extinct.

Correlation of the Upper Member with Oligocene formations of other continents is considerably aided by the discovery of *Parictis dakotensis* and *Mustelavus priscus*. *Parictis* is sufficiently close to *Cynodon* and *Pachycynodon* from the Phosphorites of Quercy so that an intimate relationship is evident. *Mustelavus* is similar to *Plesictis pygmæus* from the Phosphorite. These two forms added to the already long list of families common to Europe and North America,[81] strengthen Osborn's statements regarding a lower Oligocene land connection between Eurasia and North America, and his suggested correlation of the Chadron with the Sannoisien.

Correlations between the three members of the Chadron and the Mongolian lower Oligocene seem premature in the light of the inadequate faunas known from both. The general correlations by Matthew, Granger, and Simpson are as detailed as the evidence warrants.

The Duchesne River of Utah and the lower Sespe of California are known to be older than the previously known South Dakota Chadron fauna, which is composed of a mixture of Middle Member and Upper Member forms. The time relationships of the Duchesne River and the Sespe with the South Dakota Lower Member must remain conjectural until a satisfactory fauna is collected from the Lower Member.

Schlaikjer[82] has recently described a series of red and green sands and clays, underlying "typical Chadron" near Yoder, Wyoming, and has stated that this series is a distinct, pre-Chadron formation, which he names the "Yoder Formation."

The "Titanotherium Beds" of Meek and Hayden and of Hatcher have as their type section the Big Badlands of South Dakota. Here the lower portion of the beds is composed predominantly of red and

[81]Osborn, H. F., Cenozoic Mammal Horizons of Western North America; U. S. Geol. Surv. Bull. 361, pp. 57-61.

[82]Schlaikjer, E. M., A New Basal Oligocene Formation; Bull. Mus. Comp. Zool., vol. LXXVI, no. 3, January 1935.

green sands and clays.[83] Darton in 1898[84] chose as his type section for the Chadron formation the area around Chadron and Crawford, Nebraska, and stated that the lower part of the Chadron is red. This was confirmed recently by a visit to Darton's localities under the guidance of Mr. C. Bertrand Schultz of the Nebraska State Museum.

Therefore, since Schlaikjer's "Yoder formation" is lithologically similar to the lower part of the Chadron at its type localities, there is no lithologic evidence in support of the contention that it is a separate formation.

As no fauna has ever been collected and labelled as coming definitely from the red lower beds, either in South Dakota or in Nebraska (except for the almost useless group of scraps discussed in this paper as "Fauna of the Lower Member"), Schlaikjer cannot compare his fauna with the fauna of the type section, and so can have no faunal evidence for supposing that the "Yoder" is pre-Chadron rather than merely early Chadron.

Therefore, in view of the lithologic resemblance to lower Chadron beds elsewhere, and the impossibility of comparison with lower Chadron faunas, I regard the beds described by Schlaikjer under the name "Yoder formation" as Chadron until proved otherwise.

The comparison of lower Chadron red sediments in South Dakota with those in Nebraska and Wyoming, given in the preceding paragraphs, must not be construed as an attempt at correlation. The relative ages of the "lower" and "upper" portions of the formation in its various areas of exposure are not known; lithologic similarities in the stratigraphic sequences are interesting and suggestive, but nothing more.

## INTERPRETATIVE SUMMARY

The following brief interpretation of Chadron history is founded upon the evidence presented in the more or less unrelated chapters on stratigraphy, lithology, structure, and paleontology. It is offered

[83](a) Hatcher, J. B., The Titanotherium Beds; Amer. Nat., Vol. XXVII, 1893, p. 206.

(b) Wanless, H. R., Stratigraphy of the White River Beds of South Dakota; Proc. Amer. Philos. Soc., vol. LXII, no. 4, 1923.

[84]Darton, N. H., Preliminary Report on the Geology and Water Resources of Nebraska West of the One Hundred and Third Meridian; U. S. Geol. Surv., 19th Annual Report, Part IV, 1897-1898, p. 736, 759.

in order to disclose the unity and sequence of depositional phenomena which the disjunct data reveal.

Following the Laramide revolution, Red River flowed southeastward from the Black Hills, south of Sage Ridge, which formed the northern border of its drainage system. During the Paleocene, Eocene, and perhaps part of the Oligocene, it cut a wide, flat-bottomed valley through the soft Pierre shale, leaving behind local meander or tributary channel fills of gravel and white clay, hanging above the low part of the valley bottom. Chemical weathering, under the prevailingly warm, humid or subhumid climatic conditions, produced the "Interior" weathered zone of the Pierre, with a red upland topsoil.

A sudden change, probably either an uplift in the Black Hills or some climatic change, caused Red River to cease cutting its valley and to begin to fill it rapidly. The overloaded stream brought in masses of gravel, then greenish and gray sands and red clay, and filled its valley to the level of the top of the valley wall. As it built up, the current ran more slowly and less coarse material was deposited, so the last few feet of sediment were fine clays spread over the alluvial plain, which stretched from valley rim to valley rim. Deposition ceased for a while when the former valley was completely filled, with the exception of precipitation of calcareous mud in local ponds on the alluvial plain. During all this deposition, relatively few bones were buried due probably to conditions unfavorable for their preservation.

After a short period of non-deposition, and even of slight incision in its own deposits, Red River, free now to meander over its alluvial plain and over the former upland, began depositing again. The change from non-deposition to deposition was due either to stream captures in its headwaters, to climatic changes, or to renewed uplift in the Black Hills. This time it entombed within its greenish sands the bones of innumerable Titanotheres, especially during the first brief part of the depositional cycle. Wandering over its everbroadening alluvial plain, untrammelled by valley walls and ever building higher toward the side of Sage Ridge, it laid down a complex series of greenish sands and clays.

A sudden, sharp diminution in the amount of water traversing the area, and possibly even a short time of non-deposition, brought to a close this stage in the depositional history. The swamp-loving Titanotheres decreased almost to extinction; the Archæotheres and true

rhinoceroses also practically disappeared. In their place came a fauna characteristic of open grass-lands and local, restricted woodlands. Red River, probably split into several widely spaced and shifting channels as it had been before, slowly deposited thirty feet of fine clay over its earlier sediment, leaving sand only in the immediate channels.

Meanwhile, Sage Ridge had been buried and transgressed somewhere northwest of the area under observation. A very sluggish, swampy river from the northwest, more a connected train of lakes than a river, flowed southeastward over the present course of Spring Draw, then turned eastward and mingled its sediments with those of Red River. Within its course it left a series of very evenly banded, calcareous, ash-filled sediments; its clays were bluish-gray and greenish, rather than buff as were most of those which Red River was carrying at the same time.

Finally Sage Ridge was completely buried. The two streams slowly covered its highest hillocks with a few feet of clay, and then ceased depositing, at the end of Chadron time. Thus the Chadron may be considered a single great depositional cycle, with coarse sediment predominant at the bottom and fine at the top, composed of two subcycles, the Lower Member constituting the first, and the Middle and Upper Members the second.

The locality cited by Ward as showing an angular unconformity between the Chadron and Brulè gives interesting evidence of a mingling of sediments from two sources, continuing the drainage conditions of the Upper Chadron although with sediments different lithologically. The basal Brulè of the Indian Creek-Corral Draw area is the typical rusty to buff Lower Nodular, differing from the Upper Chadron clays chiefly in the amount of cement, as Wanless has shown. Starting in Sage Creek drainage basin and continuing southeastward from there over all the area around Conata, Interior, and eastward, the basal Brulè member is the red clay already described. The outcrop which Ward figures, as I mentioned in the section on structure, shows clearly the interfingering of buff clay from the west and red clay from the northwest.

Certain objections to the stratigraphic subdivision proposed in this paper, and hence also to the paleogeographic interpretation given above, should be mentioned.

First, it is impossible to separate the Middle and Upper Members

east of upper Cain Creek and Bear Creek. However, as the easily divisible sections west of there are abundantly fossiliferous while the clays of the eastern area are almost totally barren, this does not damage the usefulness of the subdivision. Also, slow and intermittent clay and limestone deposition on the alluvial plain, away from the main course of Red River, during most of Middle and all of Upper Chadron time would produce just such an indivisible clay series as is present. Therefore, the paleogeographic interpretation is apparently consistent with the facts.

Second, there are at least two places where the subdivision is not satisfactory.

At the head of the north branch of Indian Creek, near Hart Table, Titanotheres occur abundantly to within fifteen feet of the top of the Chadron. It would be perfectly justifiable to point out that over a plain of fluviatile deposition many square miles in area a topography of 10-15 feet is to be expected, and hence the Middle-Upper contact should rise a few feet, causing thinning of the Upper, in places. Nevertheless, I prefer to let this stand as an anomalous situation and say that I do not know how to interpret this particular restricted locality.

In the valley of Spring Draw, as mentioned before, there is another anomalous section. The division into three members is perfectly definite and, by assuming that deposition of the banded sediment continued into lower Brulè time, the section can be brought into agreement with the rest of the paleogeography. Once more, however, it seems better to admit that I do not understand the section than to make it fit by means of an assumption which, however plausible and possible, is not supported by evidence.

Finally, Titanotheres occur abundantly within eight feet of the Chadron-Brulè contact, in a pocket about six miles southeast of Interior. This area is close to the base of an extension of Sage Ridge, and there is no indication that the immediate valley of Red River lay near by to the south; it may have been several miles away. The Middle and Upper clays are indistinguishable here, the whole Chadron section is only twenty to forty feet thick, and deposition was probably very "spotty," with areas of Middle clay never covered by Upper clay, etc. This indivisibility of sediments in the eastern area has been admitted from the outset; as I have stated above, it does not necessarily invalidate the subdivision or the paleogeography.

The evidence presented in the foregoing study intimates that the

general course of fluviatile deposition may, under certain conditions, be divided into four stages, recognition of which might be useful in studies of other areas. These stages represent youth, maturity, and old age in the progress of deposition, even as certain assemblages of degradational features represent youth, maturity, and old age in the cycle of erosion. Age terms will be avoided in relation to the depositional stages, however, in order to preclude possible confusion with erosional stages in future discussions.

The first depositional stage consists of the deposits which fill the lakes and hollows characteristic of a youthful drainage system. It is characterized by extreme discontinuity, generally by trenching with deposition of younger sediments in the channels, and by a high degree of evanescence. No deposits of the first stage have been recognized in the Chadron.

The second depositional stage consists of typical alluvial plain deposits, extending from the bottom of the valley upward until deposition covers the rim of the valley walls. Obviously, deposits of this stage are limited areally by the valley walls, and consist of a mixture of foreign and locally derived material. This stage constitutes the Lower Chadron.

The third stage includes deposition from the level of the rim of the valley wall upward to the level of the crest of the divide. Depending upon the topography and relief of the old upland, deposits of the third stage may vary from appreciable amounts of locally derived material to little or none. The deposits are much more widely spread than those of the second stage. Due to sheet flooding and desiccation, concretionary zones are frequently developed. The Middle and at least part of the Upper Chadron represent the third stage.

Following burial of the crests of the divides, flood waters from different drainage systems spread their sediments of the fourth stage upon the depositional plain. These sediments, of course, contain no locally derived material. They show an admixture of material foreign to the drainage system which deposited the sediments underlying them. Part of the Upper Chadron and probably all of the Brulè are fourth stage deposits.

The division into four stages is suggested with the hope that it may be of assistance in the interpretation of other Tertiary sediments. In any study, the order of succession of beds must be established on stratigraphic and lithologic grounds before the fossils contained within

those beds can be arranged into accurate phylogenetic lines or can be used for regional correlations. Use of the division has permitted more detailed work within the Chadron than had been done before. It is possible that certain other favorably situated Tertiary formations might yield delicate determinations upon application of the same technique.

Obviously, continued uplift, several sources of sediment, absence of an appreciable basement topography, and other factors might absolutely preclude its application. Also, in the absence of good exposures, it might be impossible to know just when a divide was transgressed, etc. However, the difficulties of unravelling fluviatile depositional history are so great that suggestion of any once-tested method of attack seems justifiable.

## CONCLUSIONS

(1) The A, B, C, levels of Hatcher and Osborn are inapplicable.

(2) The Chadron of the Big Badlands is divisible into Lower, Middle, and Upper Members, as characterized in this paper.

(3) The Chadron may be considered as including the sediments representing one major sedimentary cycle, with two subcycles, the first consisting of the Lower Member, and the second of the Middle and Upper Members.

(4) There is both faunal and lithologic evidence of a change toward Brulè environment during or before Upper Chadron time.

(5) The fauna of the Upper Member is a mixture of forms related to the Montana and Saskatchewan faunas and forms related to the Brulè, best interpreted as somewhat younger than the "Titanotherium Beds" of Montana and Saskatchewan, and appreciably older than the Brulè.

(6) Several species from the Upper Member are very closely allied to forms from the Phosphorite of Quercy.

(7) *Parictis* is probably ancestral to *Phlaocyon*, and is related to *Cynodon* and *Pachycynodon*.

(8) *Mustelavus* may be ancestral to the Miocene and Recent Mustelinæ, and is related to *Plesictis*.

(9) The progress of fluviatile deposition, under certain conditions, may be divided into four stages, recognition of which may prove useful in interpreting the history of a group of sediments.

## ACKNOWLEDGEMENTS

During the summers of 1932 and 1933, field parties sponsored by the Scott Fund of Princeton University, under the leadership of Professor G. L. Jepsen, engaged in the stratigraphic studies which have been discussed in this paper. Messrs. A. M. Whitlock '33, J. E. Upson III '33, A. C. Whitfield '33, and J. W. Miller, Jr. '34, participated in the expeditions as part of their senior thesis research in the University. Mr. G. Barbour '31, accompanied the 1933 expedition. During the summer of 1934 the author, accompanied by Mr. A. H. Zielke of Glen Ellyn, Illinois, studied the western part of the area.

The author is indebted to the faculty of the Department of Geology for much advice and patient assistance, and especially to the late Professor William J. Sinclair for his stimulating advice and criticism in the field and his helpfulness in the course of the study. Also, the author wishes to state his appreciation of Professor Jepsen's co-operation in the field and advice in the laboratory.

Finally, gratitude is expressed to the kindly and hospitable people who live in the area, and especially to Mr. E. H. Taylor, of Scenic, South Dakota, whose ranch served as a field base for the parties.

TABLE I.

HATCHER'S STRATIGRAPHIC TABLE

(Published in The American Naturalist, vol. 27, 1893, page 218.)

| | | |
|---|---|---|
| OREODON BEDS | | Reddish brown clays, with occasional concretionary layers. Remains of *Oreodon*, *Hyracodon*, *Hyænodon*, *Elotherium*, etc. About 500 feet thick. |
| TITANOTHERIUM BEDS, 180 FEET THICK | UPPER BEDS, 30 FT. | Characterized by *Titanotheriidæ* of large size. Horns 10-18 in. long, elliptical to sub-ovate in cross-section. Nasals very short and pointed. Incisors never more than 2. Internal cingulum on upper premolars not strongly marked in either sex. Posterior inner cone on last upper molar. Third trochanter present. Trapezium absent. General form of skull shown in fig. 1. |
| | MIDDLE BEDS, 100 FT. | Characterized by *Titanotheriidæ* of medium size. Horns 4-10 in. long, circular to subtriangular in cross-section. Nasals of moderate length, with broad or pointed extremities. Incisors never more than 2. *Strong* internal cingulum on upper premolars of males only. Posterior inner cone on last upper molar. Third trochanter present. Trapezium absent. General form of skull represented in fig. 2. |
| | LOWER BEDS, 50 FT. | Characterized by *Titanotheriidæ* of small size. Horns rudimentary or from 1-4 in. long, circular in cross-section. Nasals long and pointed. Incisors occasionally as many as 3. *Strong* internal cingulum on upper premolars in males only. No posterior inner cone on last upper molar. Third trochanter somewhat rudimentary. Trapezium present in earliest forms. General form of skull shown in fig. 0. |
| UNDER-LYING BEDS | | Represented by various formations from Laramie to Archean. |

NOTE—Hatcher's figures are not reproduced here.

TABLE II

DATA GIVEN BY OSBORN ON SPECIMENS STUDIED BY HIM

| Page reference | Specimen | Species | Height above Pierre-Chadron contact (feet) | Range[1] | Level of specimen[2] |
|---|---|---|---|---|---|
| 114 | USNM 2151 | *Allops serotinus* | 80 | B3 C? | B (lower) |
| " | USNM 4251 | " | 77 | " | " |
| " | USNM 4259 | *Brontops brachycephalus* | 55.6 | A | A or B |
| " | USNM 4258 | " | 71.4 | A[3] | B (lower) |
| " | USNM 4947 | " | 14.4 | A | A |
| " | AE 327 | *Diploclonus tyleri* | 35 | B A? | " |
| " | USNM 4711 | *Megacerops copei* | 65.4 | B C? | B (lower) |
| " | USNM 4705 | *Megacerops bucco* | 46.7 | B | A |
| " | USNM 4256 | *Brontotherium medium* | 81 | C | B (lower) |
| " | USNM 1211 | *Brontotherium curtum* | 93.3 | " | B |
| " | USNM 4946 | " | 89 | " | " |
| 117 | AMNH 1447 | *Brontotherium ramosum* | 62.3 | " | B (lower) |
| 489 | USNM 4703 | *Brontops dispar* | 62 | B | " |
| " | USNM 4290 | " | " | " | B (lower) |
| 511 | FMP 6900 | *Allops marshi* | 50 | A or B | A or B |

Page references are to page numbers in U. S. Geological Survey Monograph 55.

Specimens: USNM—U. S. National Museum; Am—Amherst College; AMNH—American Museum of Natural History; FM—Field Museum of Natural History.

Range: Range given by Osborn for each species in his detailed descriptions. USNM 4258 is variously mentioned as coming from A and B levels.

Level of Specimens: Level at which specimen actually occurred, figured from Hatcher's original subdivision, A-50 ft., B-100 ft., C-30 ft. Osborn also mentions a field division into three 60 ft. levels, each of those divided into three 20 ft. levels, used for convenience in field labels, and from his text it is not always clear to which of these subdivisions he is referring. However, as most of the specimens discussed bear Hatcher's labels, it is assumed that Hatcher's stratigraphic table is the one referred to in the formal descriptions of species.

TABLE III

SPECIMENS PERSONALLY OBSERVED BY THE AUTHOR

| Specimen | Species | Height above Pierre-Chadron contact (feet) | Range | Level of specimen |
|---|---|---|---|---|
| ILL P6413 | *Allops serotinus* | 15 | B3 C? | A (lower) |
| CM 11839 | *Brontops dispar* | 60 | B | B (lower) |
| CM 11840 | " | 60 | " | " |
| CM 11841 | " | 60 | " | " |
| W 1534 | *Brontotherium platyceras* | 65 | C | " |
| P 13840 | " | 22 | " | A (lower) |
| P 13785 | *Brontops brachycephalus* | 65 | A | B (lower) |
| P 12971 | *Brontops dispar* | 70 | B | B |
| P 13620 | *Brontops robustus* | 60 | C | B (lower) |
| P 12791 | " | 90 | " | B |
| P 13778 | *Menodus giganteus* | 70 | " | " |

Ill.—University of Illinois, Natural History Museum; C.M.—Carnegie Museum, Pittsburgh; W.—Walker Museum, University of Chicago; P.—Princeton University Paleontological Museum. Other notes as in Table II.

TABLE IV

| Canada. | Pipestone Springs and other Montana localities. | Upper Member. South Dakota. | Lower Nodular or higher Oligocene. |
|---|---|---|---|
| | *Peratherium titanelix* | *Peratherium* sp. | *P. huntii* et al. |
| | *A. mediævus* | *Apternodus altitalonidus* | *A. gregoryi, brevirostris* |
| | *Micropternodus borealis* | *Clinopternodus* | |
| | | *Metacodon* | |
| | *I. major, intermedius*, et al. | *Ictops dakotensis* | *I. dakotensis* |
| | | *Sinclairella* | |
| *H. cruentus* | *H. montanus?* | *Hyænodon cruentus* | *H. cruentus* |
| | *Pseudo-pterodon minutus* | | |
| *D. canadensis* | | *Daphœnus dodgei* | *D. vetus* et al. |
| | | *Parictis dakotensis* | |
| | | *Pseudoplesictis gracilis* | *Oligobunis* |
| *D. felina* | | *Deinictis* cf. *fortis* | *D. felina* et al. |
| | | *Hoplophoneus oharrai* | |
| | | *Hoplophoneus mentalis* | *H. primævus* et al. |
| | | *Hoplophoneus robustus* | |
| *M. westoni* et al. | *M. latidens* Thompson's Creek). | *Mesohippus* cf. *latidens* | *M. bairdii* et al. |
| *Titanotheres* | *Titanotheres* sp? | *Titanotheres* sp? | |
| | *C. occidentalis?* | *Colodon occidentalis* | *C. occidentalis?* |
| *H. priscidens* | *H.* sp. | *Hyracodon* sp. | *H. nebraskensis* et al. |
| | *S. montanus* | *Stibarus* sp. | |
| | | *Leptochœrus* sp. | |
| "Ancodus" | | *Æpinacodon americanus* | *Æpinacodon rostratus* |
| | | *Perchœrus* cf. *nanus* | *P. nanus* |
| *O. culbertsoni* | Oreodonts, several genera. | *Oreodon?* | *Oreodon culbertsoni* et al. |
| *L. esulcatus* | *L. esulcatus* | *Leptomeryx* cf. *esulcatus* | *L. evansi* |
| *P. turgidus* | *P. triplex?* | *Paleolagus* cf. *triplex* | *P. triplex, turgidus* |
| | *A. minutus* | *Adjidaumo minutus* | *A. minutus* |
| | *A. minor* | *Adjidaumo minor* | *A. minutus, A. trilophus* |
| *E. parvus* | | *Eutypomys* sp. (near *thomsoni*) | *E. thomsoni* |
| *P. lippincottianus* | *P. paterculus* | *Pseudocynodictis gregarius* | *P. gregarius* et al. |

## EXPLANATION OF PLATE XXI.

UPPER FIGURE

Upper Indian Creek, showing the three members of the Chadron, with an outlier of Brulé in the distance. A heavy channel sandstone here forms the top of the middle member.

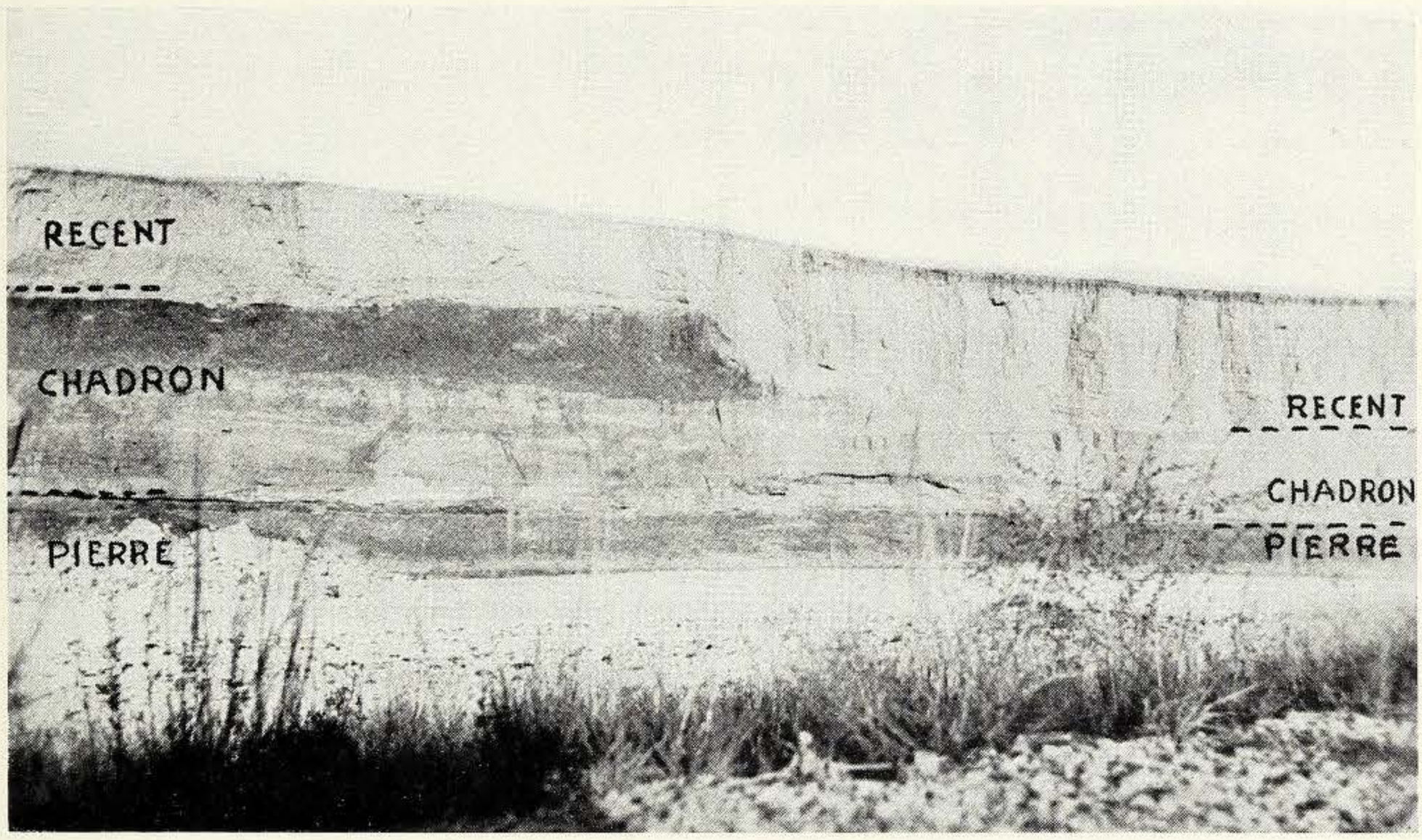
MIDDLE FIGURE

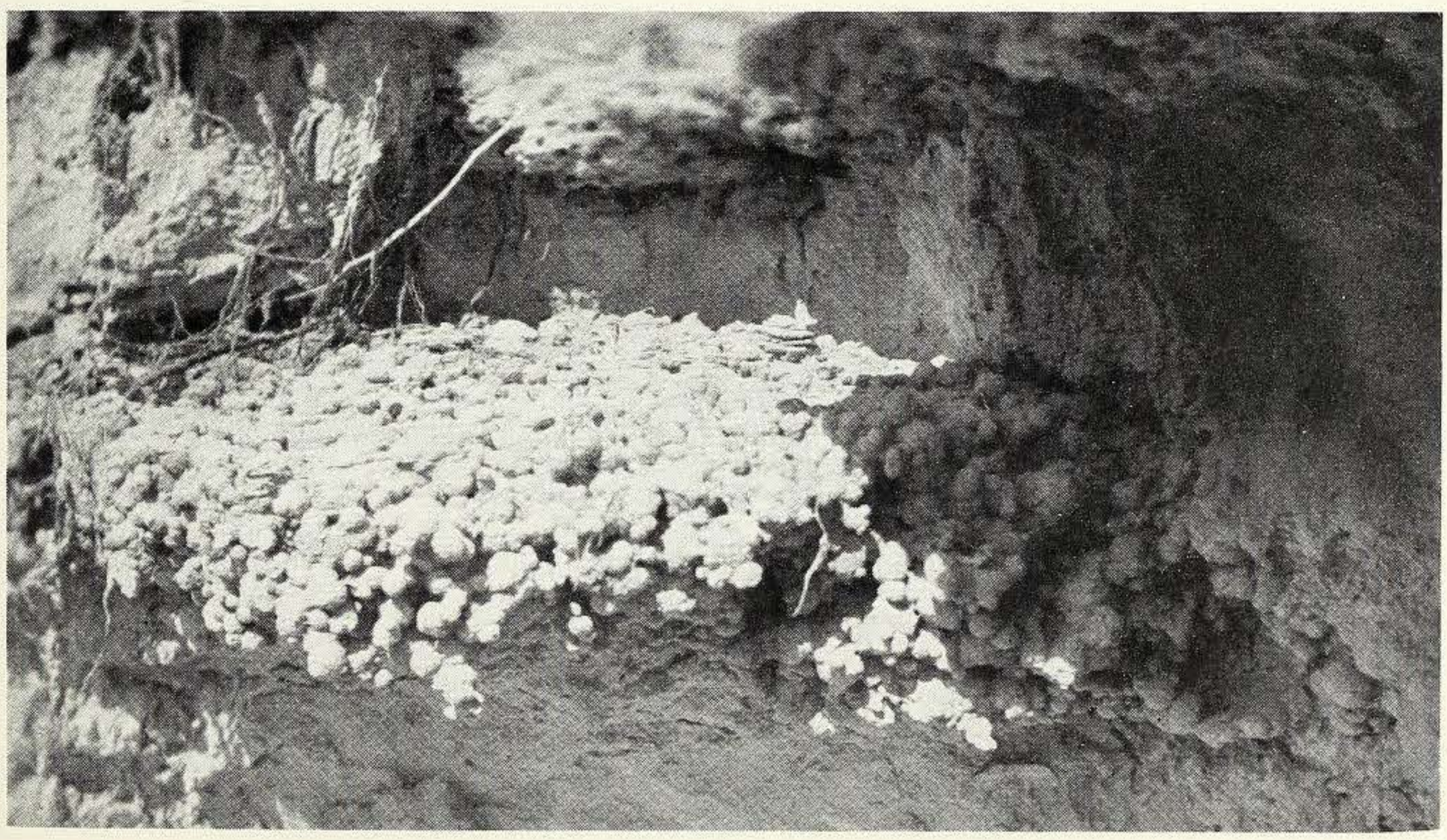
Brick-red, Lower Chadron clay with a very thin basal conglomerate, resting on Pierre shale, in Quinn Draw. The conglomerate is here cemented by pyrite.

LOWER FIGURE

Sand-calcite crystals, Lower Member, in Shoemaker Draw.

MIDDLE
MEMBER
UPPER M.
MIDDLE M.
LOWER M.
LOWER
MEMBER


RECENT
CHADRON
PIERRE
RECENT
CHADRON
PIERRE



## EXPLANATION OF PLATE XXII.

UPPER FIGURE

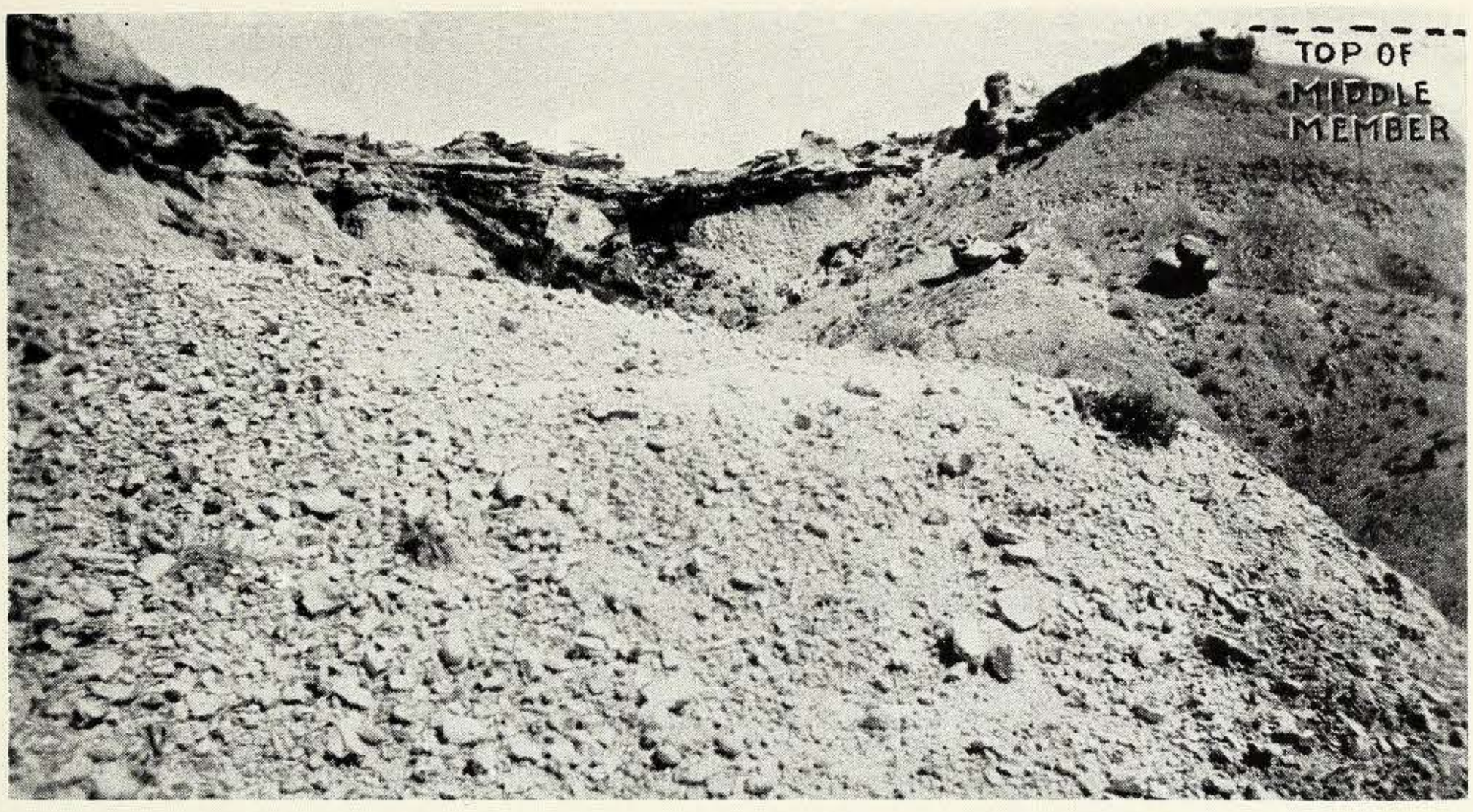
A typical "graveyard," containing chiefly Titanothere remains with some *Trigonias* and *Archæotherium*, in upper Big Corral Draw.

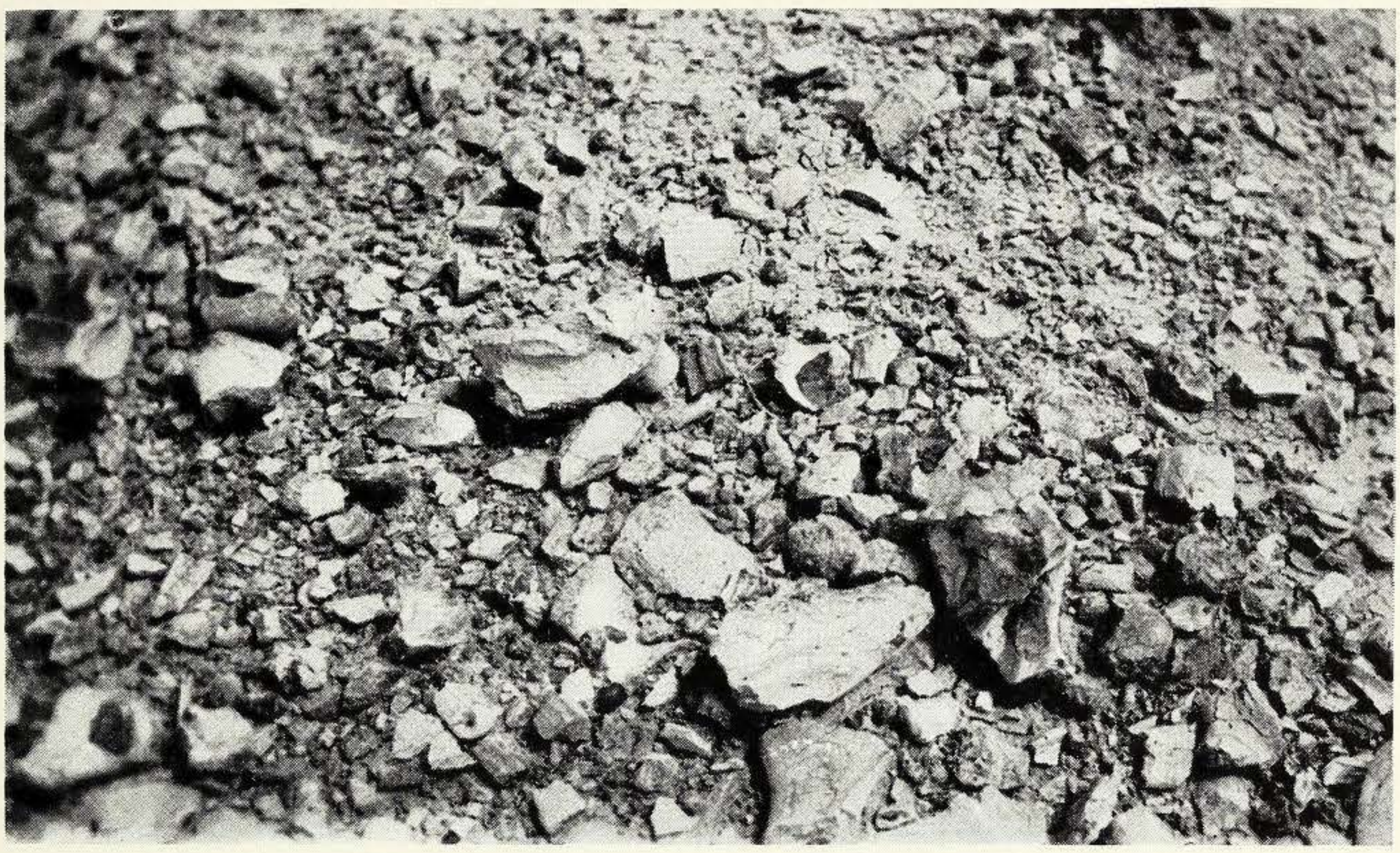
MIDDLE FIGURE

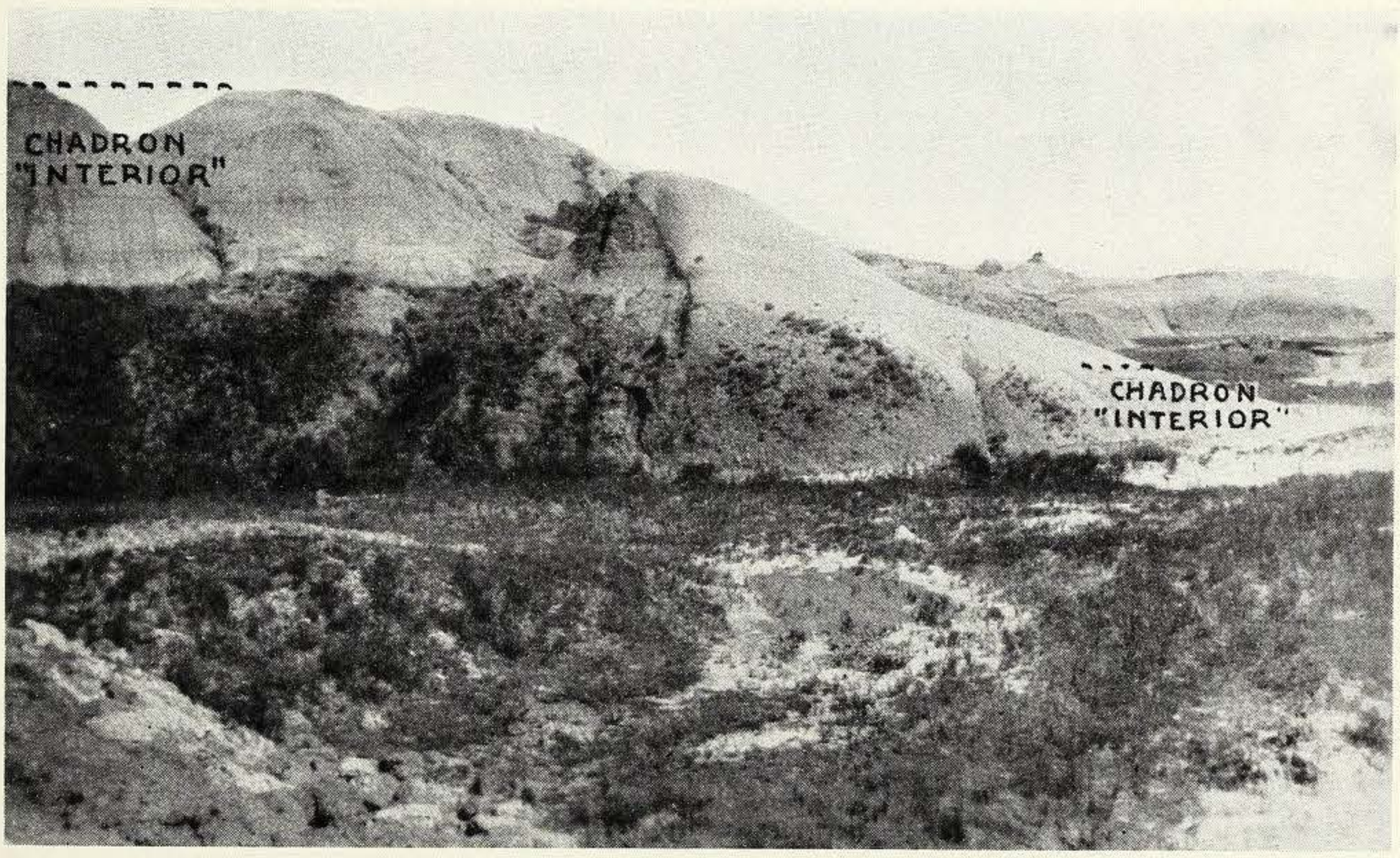
Close-up view of same subject as the upper figure.

LOWER FIGURE

Sage Fault, in Dillon Pass. Displacement about sixty-five feet. This figure is in error to the extent that the horizontal broken line in the upper left-hand corner, indicating the upper limit of the "Chadron Interior," should be lowered about one-sixteenth of an inch, and the similar line in the lower right-hand corner should be lowered about an eighth of an inch.


TOP OF
MIDDLE
MEMBER




CHADRON
"INTERIOR"
CHADRON
"INTERIOR"

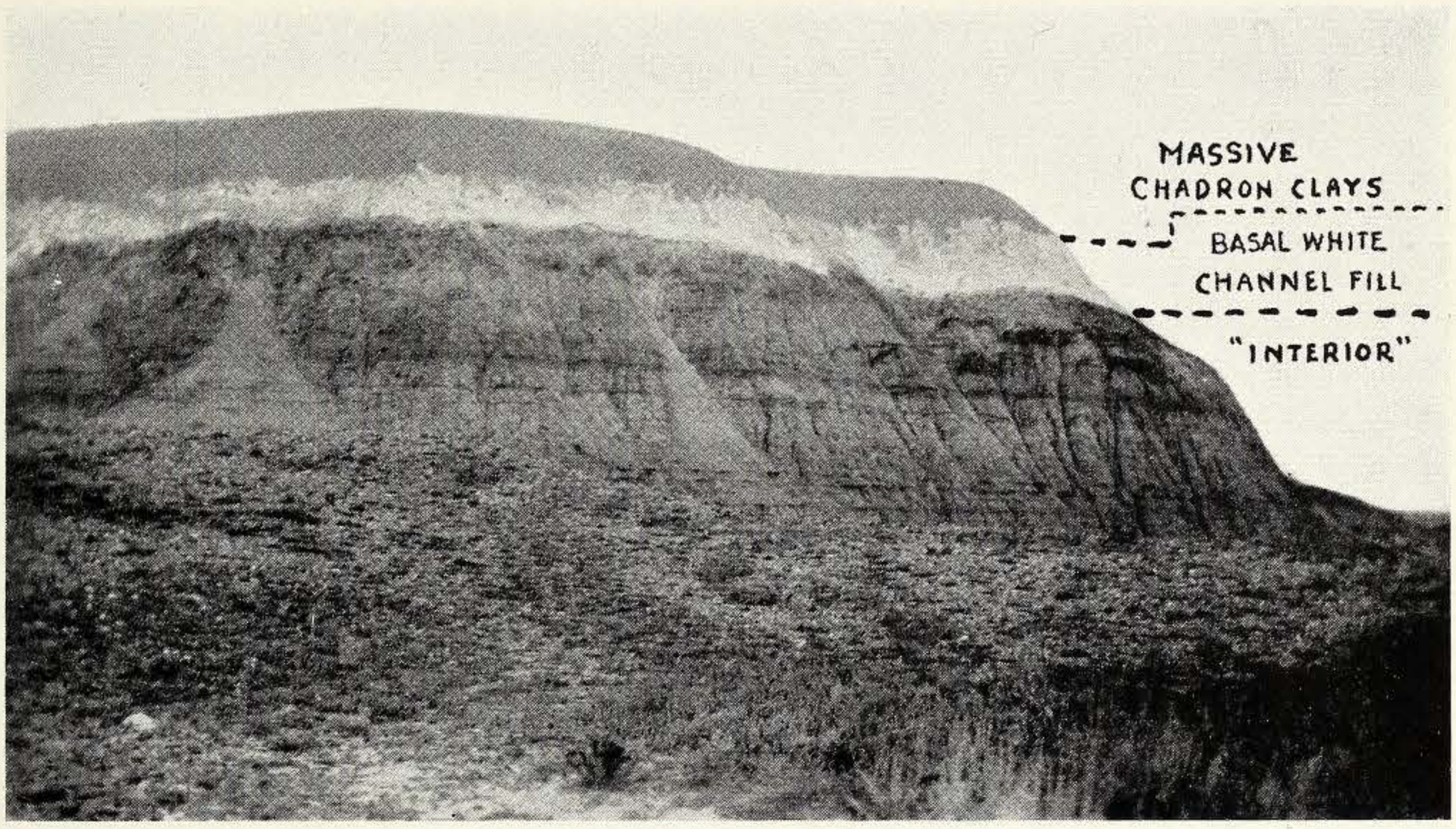
## EXPLANATION OF PLATE XXIII.

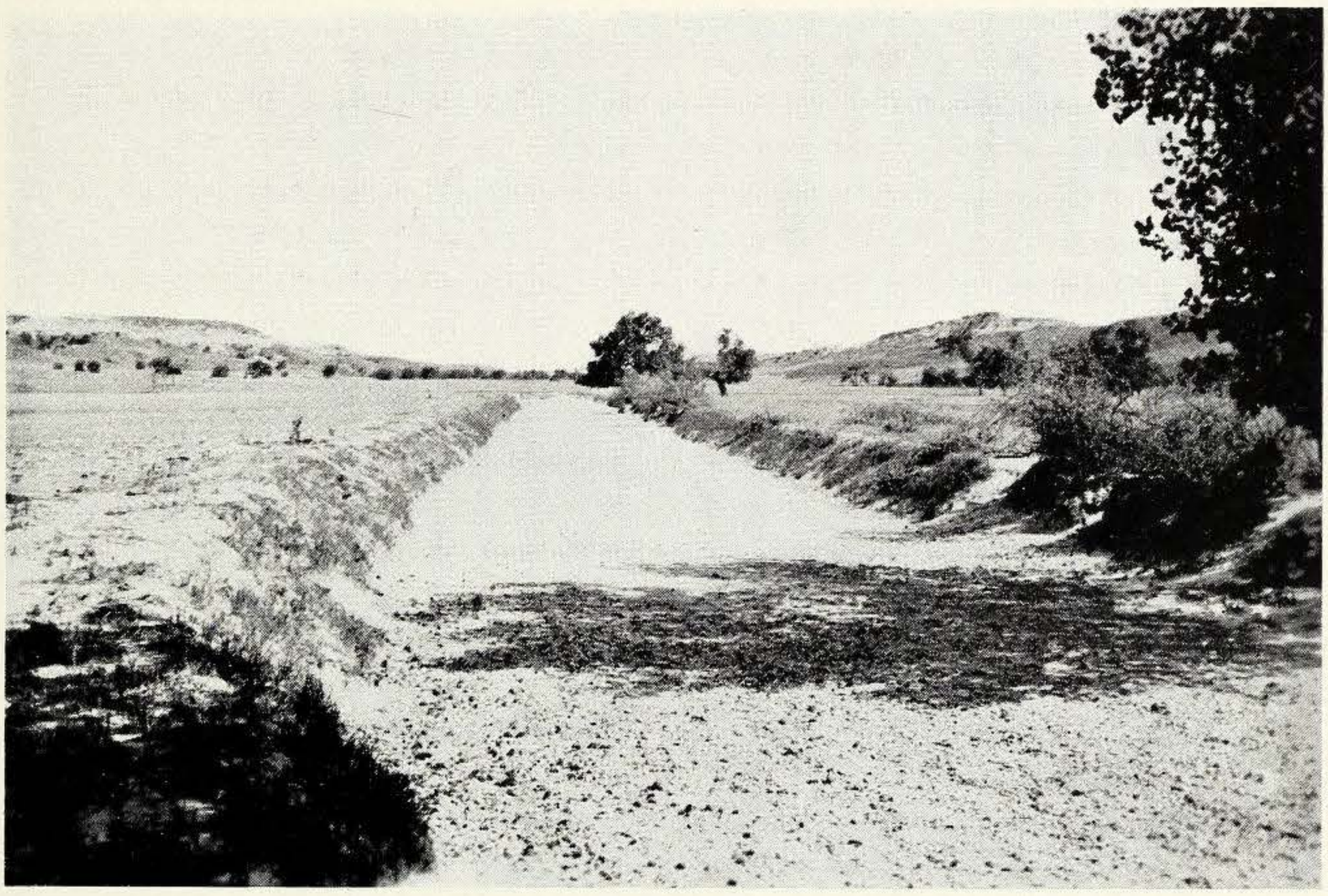
UPPER FIGURE

Chadron in the valley of White River, three miles west of Conata.

LOWER FIGURE

Lower course of Quinn Draw, an intermittent stream which is filling up its valley at present. Note the very shallow, flat-bottomed stream bed, the low natural levees, and the broad, very gently sloping, almost perfectly flat, flood plain.


MASSIVE
CHADRON CLAYS
BASAL WHITE
CHANNEL FILL
"INTERIOR"



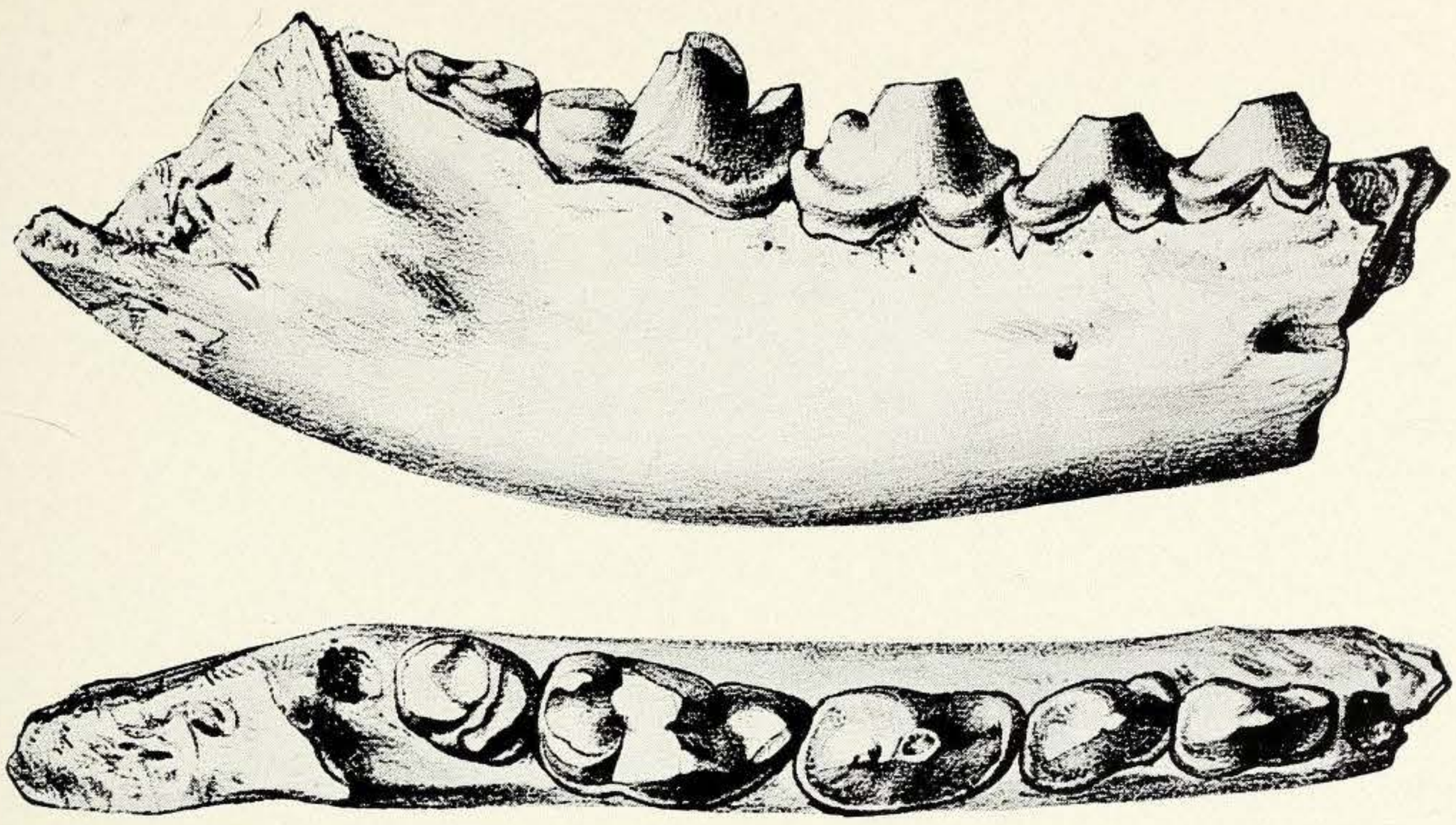
## EXPLANATION OF PLATE XXIV

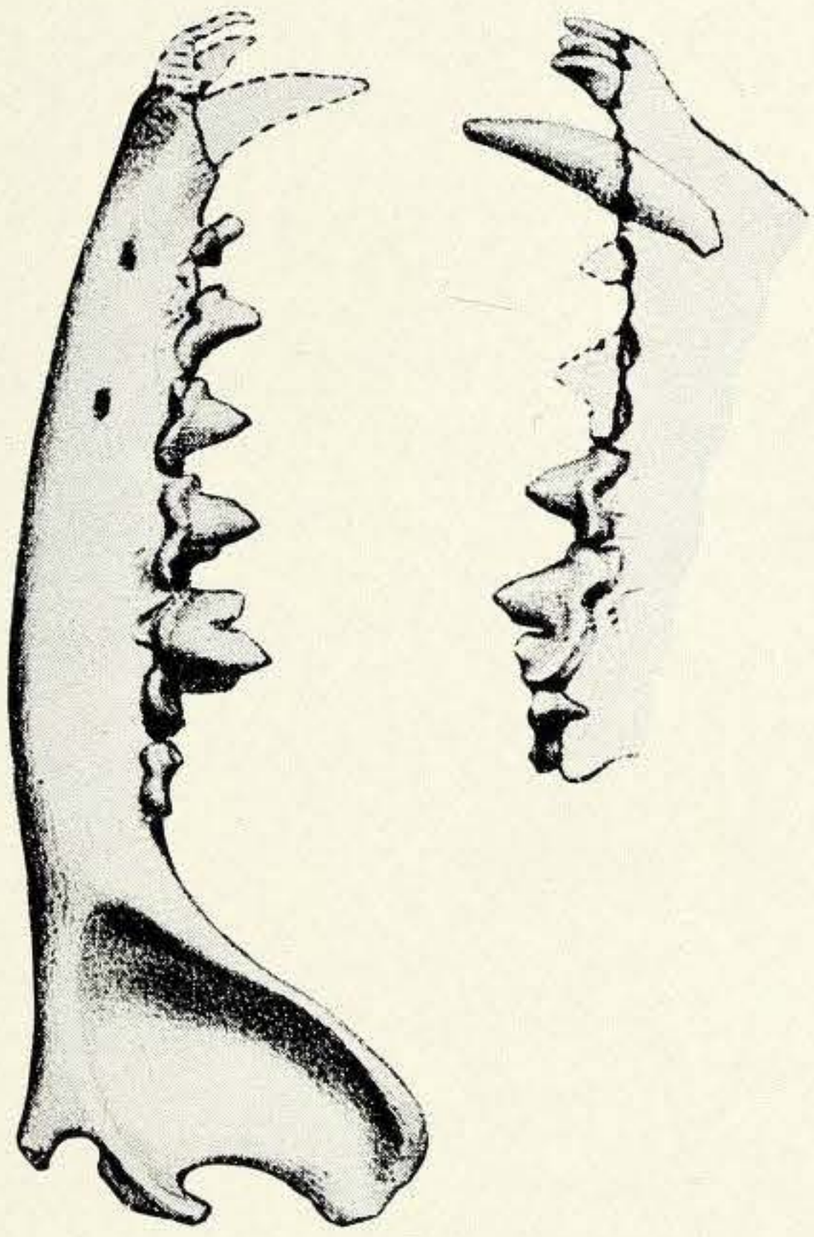
UPPER FIGURE

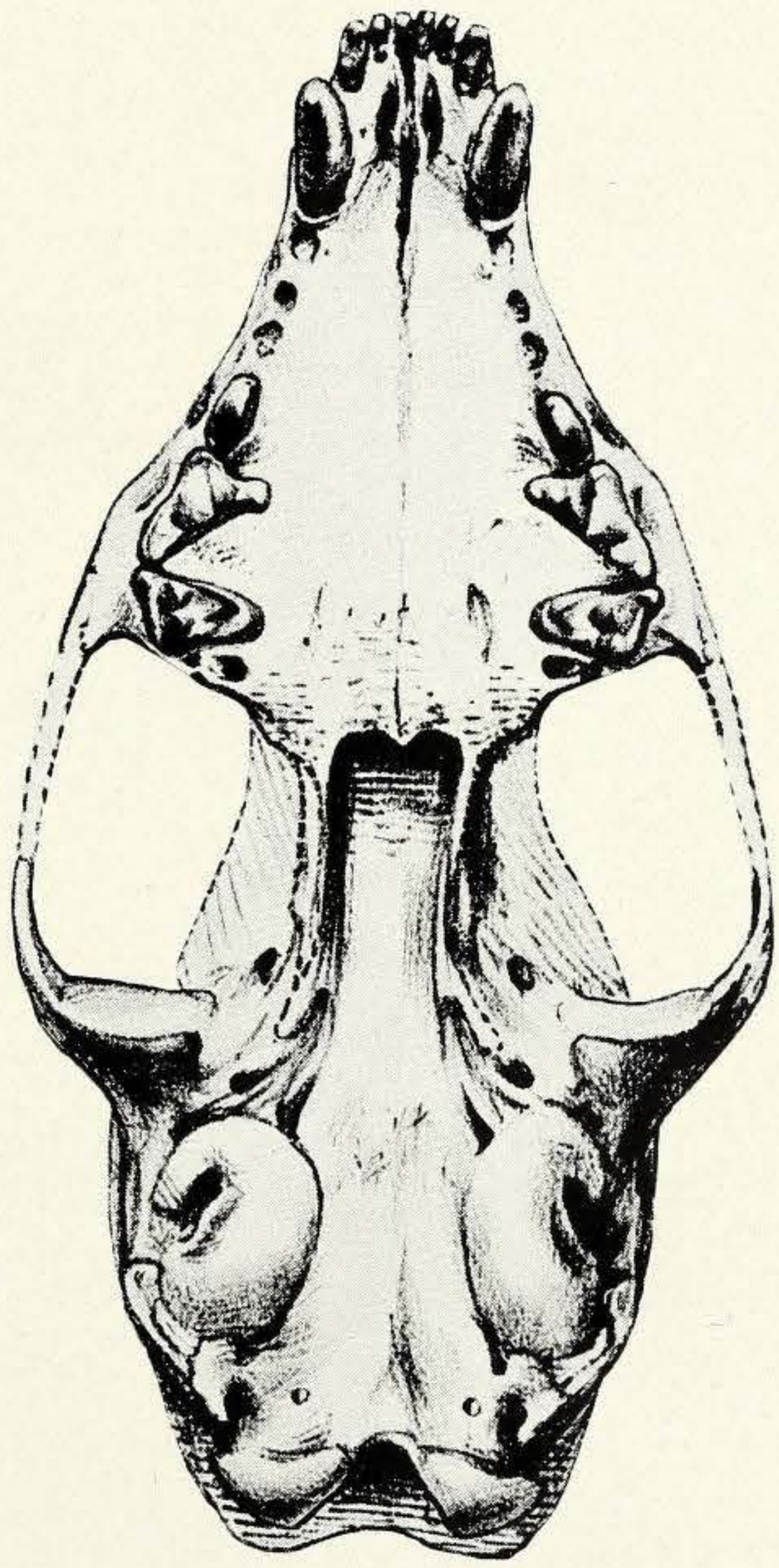
*Parictis dakotensis* Clark, × 3. Photograph of a drawing by Mr. R. B. Horsfall.

LOWER FIGURE

*Mustelavus priscus* Clark. Natural size. Photograph of a drawing by Mr. R. B. Horsfall.







## EXPLANATION OF PLATE XXV

SECTION I.

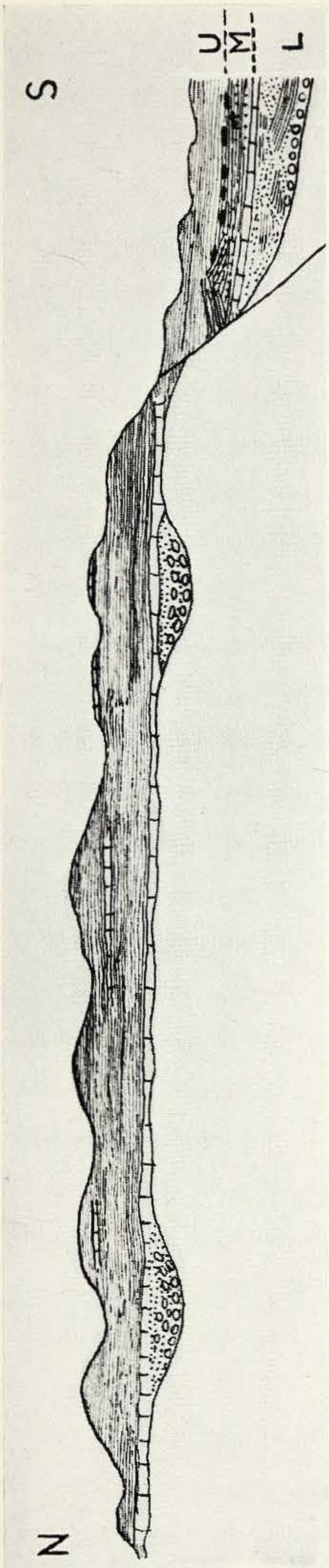
Cross-section 1½ miles long, extending southward from the southwest corner of 71 Table. Shows the edge of Red River Valley, paralleled by a local normal fault; also shows the basal white channel fills and overlying clay series of the eastern facies.

SECTION II.

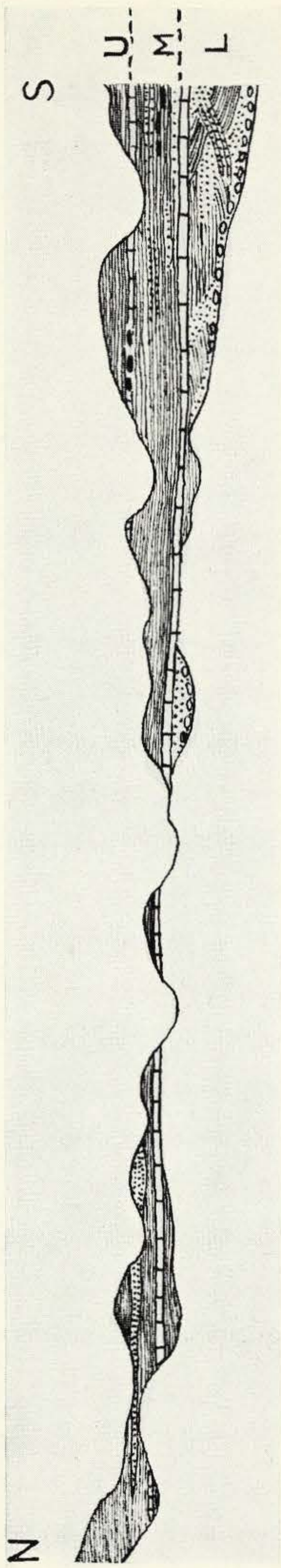
Cross-section 2 miles long, extending southward from the southeast side of Kube Table. Shows a limestone separating the Lower and Middle Members (western facies) and extending northward to overlie a basal white channel fill and underlie the massive clay series (eastern facies). Also shows gradation of the Middle and Upper Members into the clay series.

SECTION III.

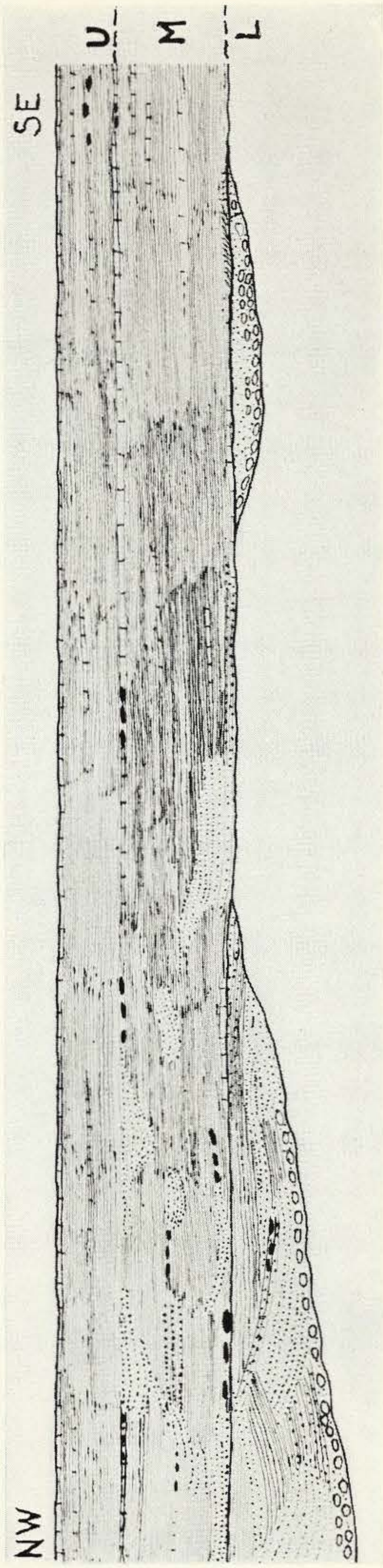
Cross-section 2 miles long, extending NW-SE in upper Battle Creek Draw. Shows the south wall of Red River Valley, also a basal white channel fill.




Section I




Section II



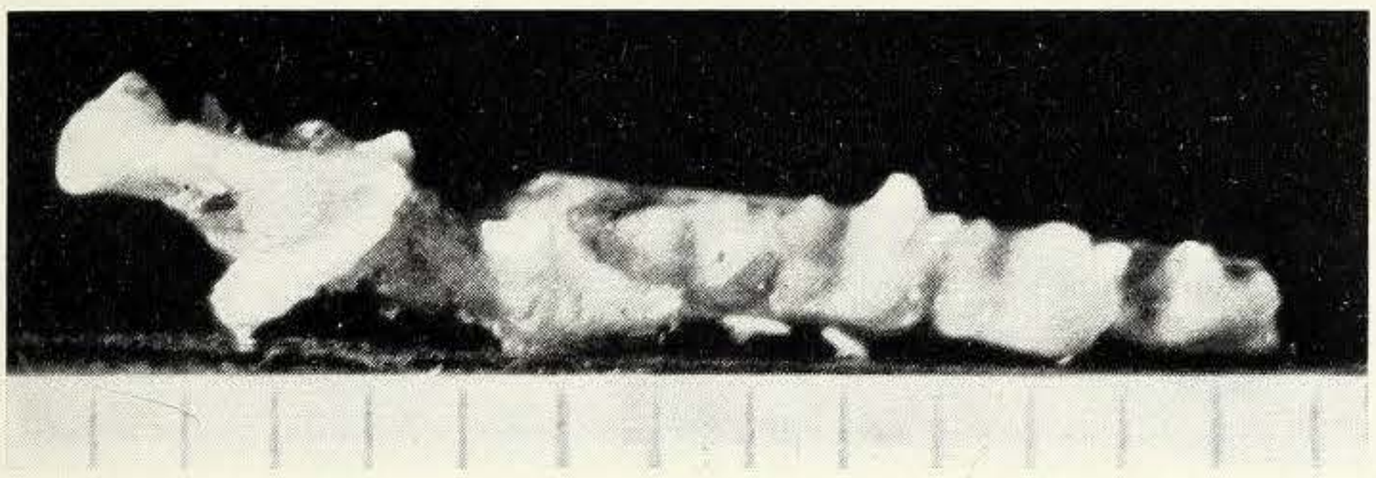

Section III

## EXPLANATION OF PLATE XXVI

FIGS. 1-2. *Metacodon magnus* Clark. Type specimen, crown and mesial views, × 5. Scale shows millimeters.

FIGS. 3-4. *Apternodus altitalonidus* Clark. Type specimen, crown and lateral surfaces, × 5. In the lateral view, $P_4$ is toward the left; in the crown view, it is toward the right. Units of the scale are millimeters.

FIGS. 5-6. *Clinopternodus gracilis* Clark. Type specimen, crown and lateral views, × 5. Anterior end to the left in the lateral view, and to the right in the crown view. Scale shows millimeters.



1

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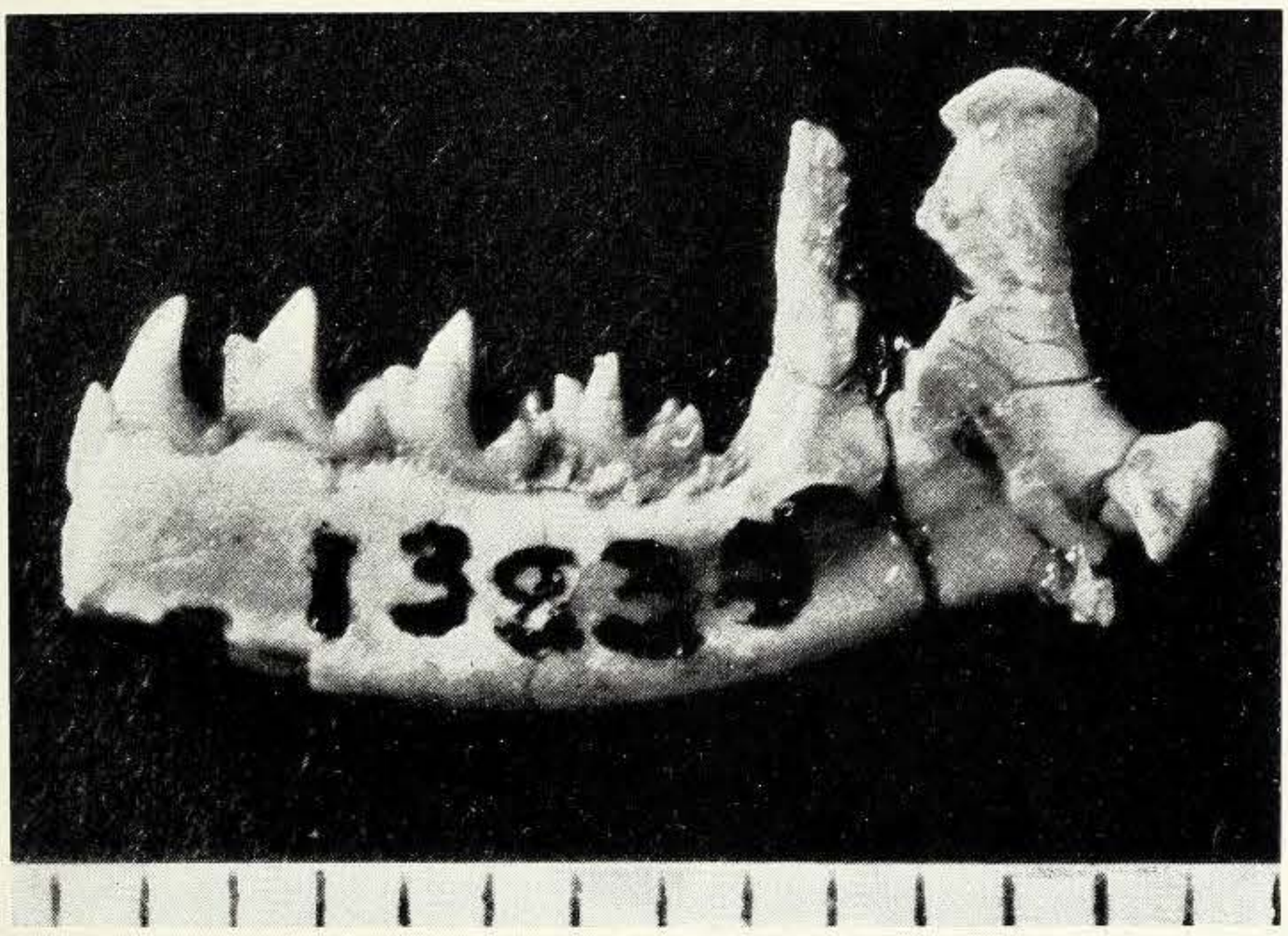
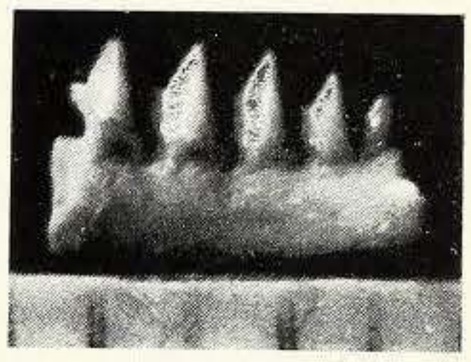



2



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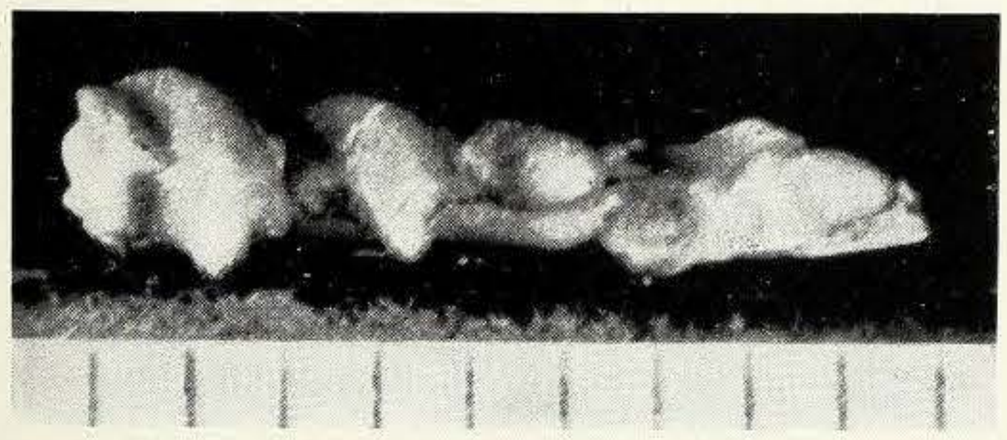

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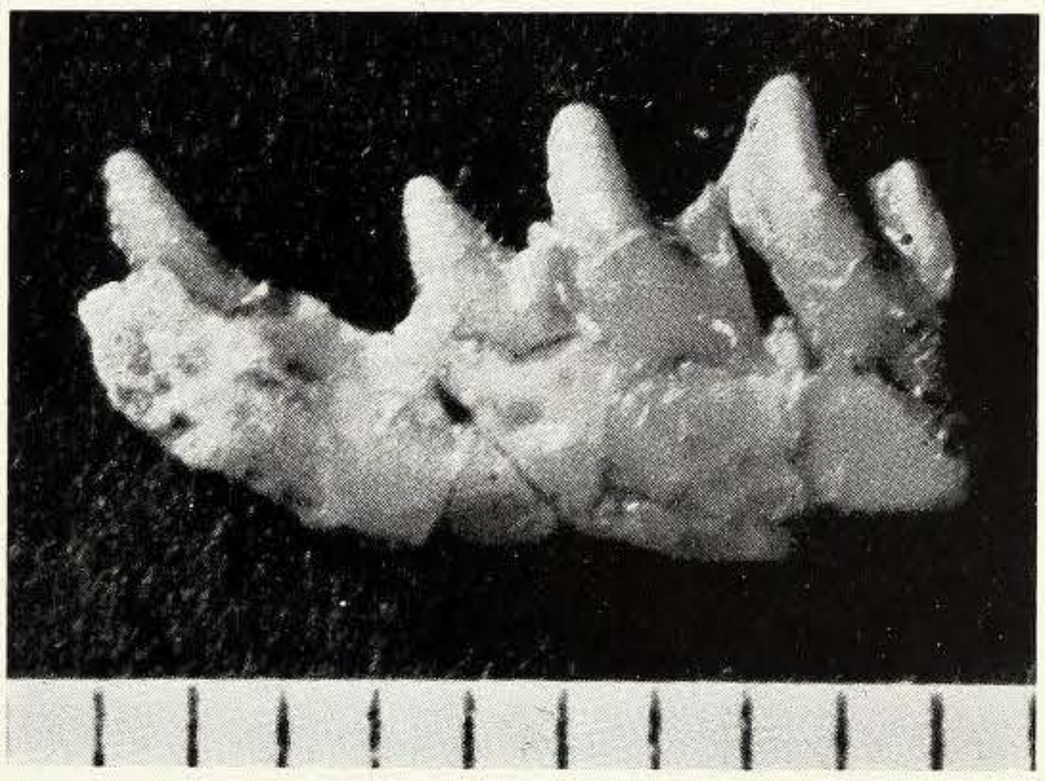

6