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Geological and Natural History Survey

Freeman Ward, State Geologist

Bulletin 11

The GEOLOGY of a PORTION of the BADLANDS

By

Freeman Ward

The Paleontology of the Area

The Badlands as a National Park

By

W. C. Toepelman

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LETTER OF TRANSMITTAL

Vermillion, S. D.,
August 1, 1922.

Hon. T. W. Dwight, President,
State Board of Regents.

Dear Sir:

During the last few seasons the Survey has been making a detailed investigation of the Badlands of the State. Enough ground has now been covered to warrant a report, which I am herewith submitting as Bulletin 11.

Respectfully,

FREEMAN WARD,
State Geologist.

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INTRODUCTION

PURPOSE OF INVESTIGATION

A complete bibliography of all literature bearing on the geology of South Dakota would include considerably more than one thousand titles. But in spite of this array of publications, the geology of all parts of the State is far from being intimately known. The main geologic facts of South Dakota as a whole are well understood and have been known for many years. But there are very few areas concerning which there are publications giving detailed geologic information.

Similarly, the general facts concerning the Badlands of South Dakota are well understood. It has been a classic field for exploration and investigation for more than fifty years. Indeed, the names of many famous men and institutions are associated with this part of the State. But detailed geologic knowledge is lacking except in certain restricted spots. Some of the publications discuss so large an area that the Badlands are only a minor part of the whole. Much of the work thus far done in the Badlands was carried on chiefly for the purpose of collecting fossils, little attention being given to geologic problems.

Those who desire an account of the Badlands as a whole are referred to the excellent compilation prepared by Professor C. C. O'Harra. It is entitled "The White River Badlands," and is published as Bulletin 13 of the South Dakota School of Mines.

With an appreciation of this background and with the general geologic facts known, the region has been studied with the express purpose of securing details.

This particular portion of the Badlands was chosen partly because it is typical of the whole; and even more so because a belief was current that it is an oil region. No geologic work had ever been done in this part of the State for the express purpose of investigating the possibility of oil. It was necessary to make a detailed field examination in order to get evidence bearing on this problem.

FIELD WORK

Three seasons (1919, 1920, 1921) of two months each have been spent in the area. The formations were mapped with plane table, telescopic alidade, and stadia rod. The land survey corners were taken as horizontal control, and all mapping was done on a scale of 1,500 feet to the inch. Many lines of levels were run in working out the structure.

The following acted as rodmen:—Earl Thorson (1919), Henry Sage and Nathan White (1920), and William E. Horkey (1921).

ACKNOWLEDGMENTS

I take pleasure in acknowledging the courtesy of the ranchers who very kindly gave the Survey parties the privilege of camping on their properties. Thanks are due also to several of the citizens of Interior who provided storage facilities or who aided in other ways. Through the enterprise of Messrs. White and Campbell of

Interior the Survey was enabled to cover a larger area than would otherwise have been possible. They "staked" the party of 1920 for four weeks. An especially valuable feature of their assistance was an automobile. Up to this time the work had all been done on foot. The amount of time lost—especially in going to and from work—by this method accounts for the fact that three seasons instead of one were required to cover the area.

The microscopic determinations were made by Dr. Roy A. Wilson, one of the Survey staff. The chemical analyses were made by Mr. Orin B. Jacobson, a University of South Dakota student majoring in chemistry.

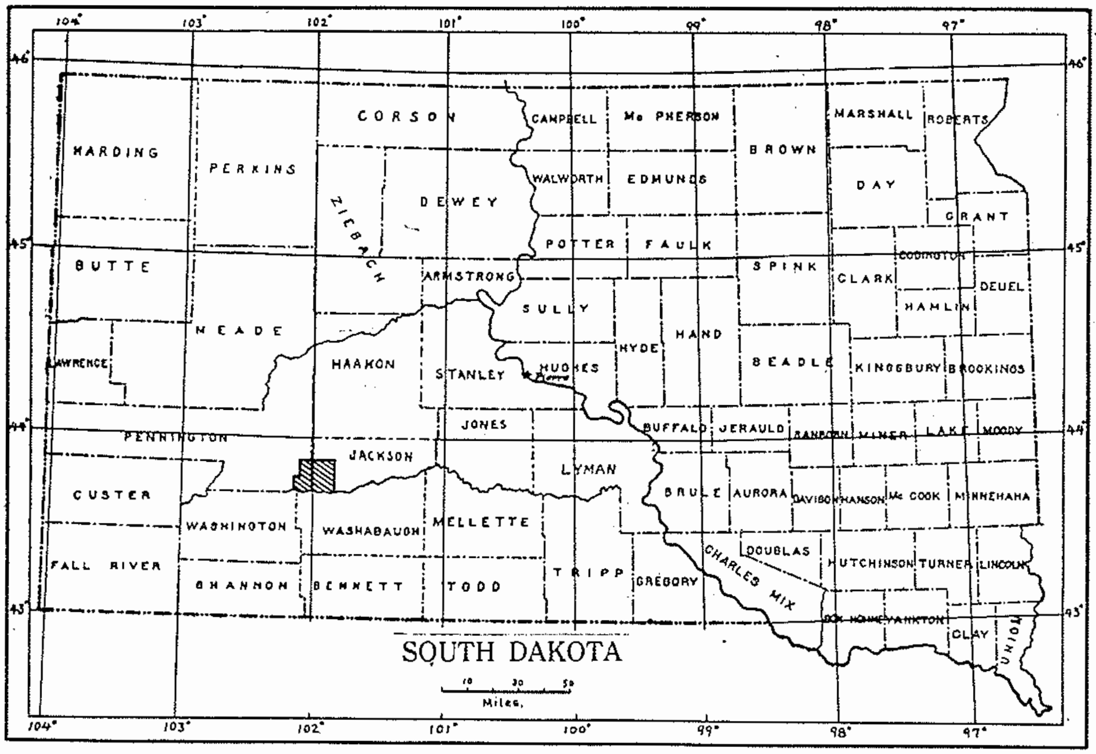


Figure 1. Index Map

LOCATION AND SETTLEMENT

The area under discussion is in the western part of South Dakota. As shown by the index map (Figure 1), it is situated in western Jackson and eastern Pennington counties. The 102nd meridian and the parallel of 43° 45′ North Latitude intersect some two and one half miles south of its geographic center. It is an irregular, rectangular tract, with its greater length (17 miles) east and west, being 13 miles in width (north and south). It includes most of Towns 2, 3, and 4 south, and Ranges 16, 17, 18 and 19 east, and is very nearly two hundred square miles in area. White River has been taken as the southern boundary.

The town of Interior, with a population of two hundred, is an important distributing center and shipping point for the surrounding ranch country and the Pine Ridge Indian Reservation just across the river to the south. It is the only town in the area, though Conata is just beyond the edge of the map to the west. They both are on the C. M. & St. P. R. R., which provides one passenger train a day each way.

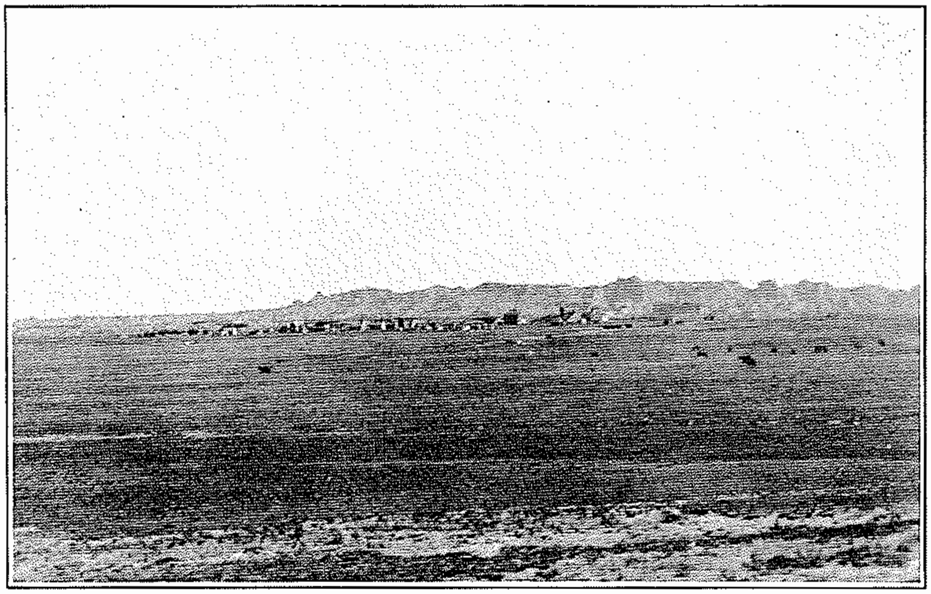


PLATE II A

LOOKING ACROSS LOWER PRAIRIE. TOWN OF INTERIOR IN MIDDLE DISTANCE; THE "WALL" TWO AND ONE HALF MILES BEYOND

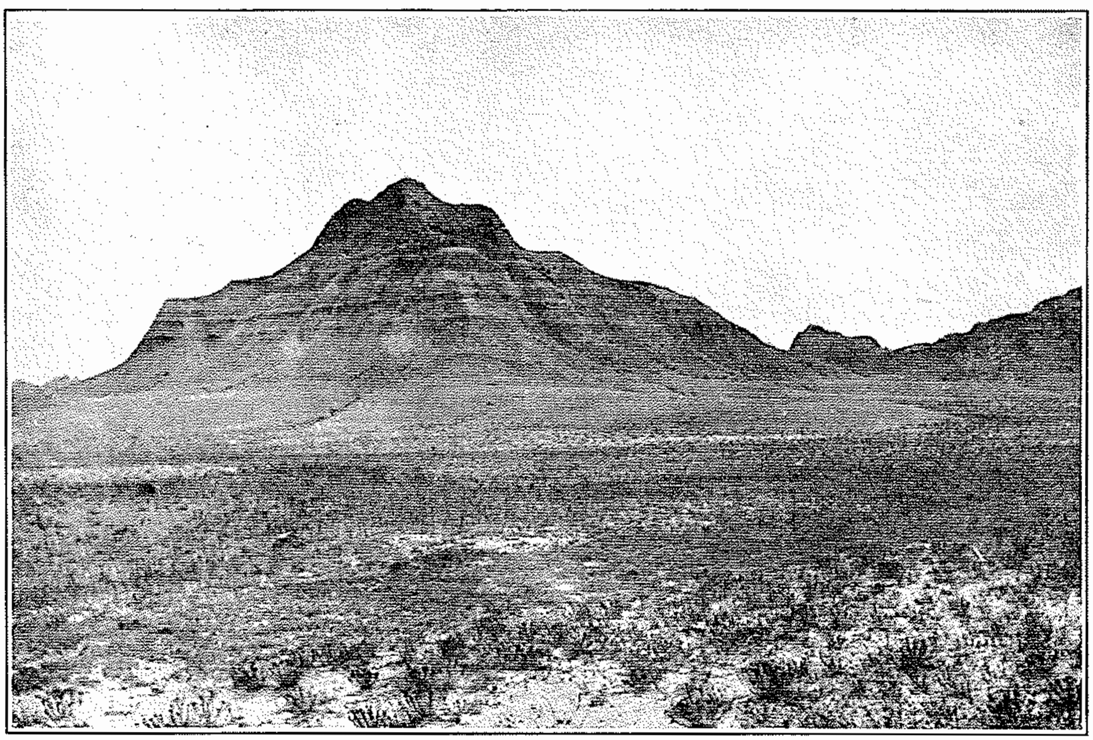


PLATE II B

BUTTE, RISING ABOVE LOWER PRAIRIE

The Washington National Highway traverses the area from east to west in the southern part. The Custer Battlefield Highway passes through the northeastern part. These two arteries of travel join by way of Cedar Pass. The former is especially well placed to give the tourist an excellent opportunity to see the wonders of the Badlands.

CLIMATE AND SOILS

The climate is the typical semi-arid sort which is characteristic of the plains region west of the 100th meridian. The average annual rainfall, as shown by the records of the co-operative weather station at Interior, is 15.09 inches, the extremes in a ten year period ranging from 10.10 to 22.25 inches. Probably this maximum was exceeded in 1915, which was an unusually wet year, but no records were kept at this station for that year. Nearly three quarters of the precipitation falls between April 1 and October 1. The summer rainfall is almost invariably of the thunderstorm variety.

Temperature extremes, as is true of all South Dakota, are to be expected. The winters have plenty of cold weather; and the summers are hot. In the Badlands proper, where the slopes are bare and the rocks light colored, the reflection adds glare and intensity to the summer heat: but the altitude is sufficient to insure comfortable nights for sleeping. The sensible temperatures of both the extremes of cold and heat are ameliorated because of the dryness of the air. A large proportion of the days the year around are invigorating and healthful.

In tables 1-3 are given meteorological data for Interior and two other co-operative stations. Kadoka is twenty-five miles to the east and Cottonwood about twenty miles to the north of Interior.

The character of the native vegetation reflects well the type of climate. There is a general absence of trees and shrubs except along

	Temperature			Precipitation
	mean	max.	min.	
1898	....	....	....	10.10
1899	....	....	....	16.15
1900	....	....	....	14.75
1901	....	....	....	13.25
1916	....	104	....	13.25
1917	....	104	—33	12.50
1918	46.8	100	—30	22.25
1919	45.9	105	—27	12.89
1920	46.3	106	—25	17.77
1921	48.9	108	—15	18.02
Average	....	....	....	15.09

Table 1. Meteorological Data—Interior

	Temperature			Precipitatio
	mean	max.	min.	
1910	49.2	106	—20	11.19
1911	47.5	104	—21	14.14
1912	47.0	103	—28	14.18
1913	....	105	—24	12.50
1914	47.8	107	—28	18.14
1915	45.3	101	—23	30.27
1916	45.7	103	—36	14.01
1917	....	109	—33	12.80
1918	48.0	103	—32	24.70
1920	....	106	....	21.20
Average	....	....	....	17.31

Table 2. Meteorological Data—Kadoka

	Temperature			Precipitatio
	mean	max.	min.	
1911	48.8	103	—23	12.31
1912	....	104	—30	14.07
1913	47.6	105	—33	10.48
1914	48.0	107	—32	15.01
1915	43.9	101	—28	27.62
1916	43.6	105	—42	12.29
1917	43.8	110	—38	13.16
1918	46.3	102	—34	15.03
1919	45.1	105	—30	15.99
1920	45.1	108	—31	19.38
1921	44.3	105	—19	11.09
Average	....	....	....	15.13

Table 3. Meteorological Data—Cottonwood

White River, where a good stand of timber and brush is found. Th courses of some of the larger creeks and draws have a moderat to scattering amount of tree growth, especially north of the "Wall' The springy character of the slump topography at Cedar Pass ha permitted the growth of sufficient cedar trees to name the place.

The native grasses are abundant and are unsurpassed as rang for stock. Sage brush and related types of vegetation, and severa varieties of cacti are the common associates of the grasses, an locally dominate the less productive spots.

In occasional wetter years wonderful crops are grown, but sinc on the average the rainfall is quite moderate and in some years i really scanty, general farming is not usually successful. It is a excellent country for stock, however, and stock raising and dairying are the leading occupations of the region. Dry farming methods have been conducted with gratifying results by a very few of the ranchers and should be practiced more. Such special crops as alfalfa have been grown successfully and the acreage could well be increased. Other similar forage crops suited to semi-arid conditions no doubt would make equally good yields and should be more freely introduced. Garden vegetables of all sorts will grow in abundance if supplied with sufficient moisture and will do well if dry farming methods are used. Irrigation is practiced to some extent, especially along White River.

TOPOGRAPHY

GENERAL STATEMENT

The term "Badlands" ("*Mauvaises Terres*") was applied by the early French Canadian trappers, who were among the first to visit the region. It was in effect a translation of the name already used by the Sioux (*Maka Sica*). The term was descriptive of the difficulties encountered in traversing the region.

The difficulties of travel are still present in certain parts of the area. Here there is an abundance of bare, steep slopes, of sharp ridges, and jagged peaks. Abrupt canyons, narrow gullies, overhanging ledges, and rough cliffs are common. These give way locally to gentler slopes, still bare, and more flowing profiles. In some places a wagon or automobile can go through only along a few restricted routes; in others a saddle horse can with difficulty make its way; in still others a good climber has a hard time of it; and some spots are inaccessible except by the aerial route. It is this type of topography which delights the soul of the nature lover and exasperates the wielder of the pen who tries to convey the scenic qualities by means of the written word. To this orderly maze of peaks, ridges, and canyons can well be applied the terms "picturesque," "wonderful," "gorgeous," and the like. It is the type of scenery which one does not tire of. He who looks more sees most. It is as impressive and satisfying as the ocean with its daily march of the tide, or the Grand Canyon region with its greater dimensions and brighter colors.

But not all the area under consideration has this type of topography. Interspersed among the bare slopes and rugged topography of the Badlands proper are stretches of flat or rolling grass land. It is on such tracts that the ranching is conducted.

The term "Badlands" is used in two ways. It stands first for a type geologic formation or region. One thus speaks of "the Badlands" or of the "White River Badlands" or the "Badland region," meaning a region in which this well known type of topography dominates, interspersed to a greater or less degree with grass land, prairie and the like. It is used frequently, also, and especially in this report, in an adjective sense (in this case not written with a capital), meaning specifically the bare slope, steep ridge and rugged peaks, etc., as previously described.

TOPOGRAPHIC TYPES

There are four types of topography. These follow the four Physiographic Provinces (Figure 2), which are roughly parallel and trend in general east and west.

1. **Flood Plain of White River.**—The White River meanders broadly on a typical flat flood plain with a nearly uniform width of a little over a half mile. Locally it has the extremes of less than a half to a full mile in width. At many places the flood plain abuts abruptly against steep bluffs or isolated badland buttes; at others it joins the neighboring prairie with only a moderate change of slope or low bank. A common bordering facies, especially where the adjoining land is higher, is a piedmont plain or slope. This is typical of its kind, though of course narrow, being usually fifty to one hundred and fifty yards across but reaching a maximum width of a little more than a quarter of a mile. Locally the flood plain is extended up the tributary valleys; these are all insignificant on the north side. The larger tributary (such as Potato Creek) valleys enter from the south. The tributary streams wind across the flood plain in trenches five to eight feet deep before joining the river.

Terracing, while not totally lacking, is quite insignificant. Such local occurrences as were seen were low and with only one level. It is possible that the piedmont slopes have buried the terraces along much of the valley.

2. **Lower Prairie.**—Between the flood plain and the "Wall" is a flat to gently rolling prairie. It averages three miles in width, ranging from half to twice that amount. The town of Interior and many ranches are located here and it is along this that the railroad and the Washington Highway extend.

It is very largely sod covered but has scattered through it single badland buttes or groups of buttes, most of them smaller and unnamed, a few larger, such as Tenderfoot Butte and Herley Butte. These stand prominently like islands in a sea of grass. There are, also, shallow badland basins scooped out below the general level. It is trenched deeply by several creek beds and dry washes, which trend across it in general from north to south. Nearer the "Wall" the prairie is less continuous, being made up of sod covered tracts separated by dry washes and small canyons, bordered by steep (nearly vertical) banks two to eight feet high. (See photographs, Plates II. and III. A.) If one stands so that his eye is on a level with the sod, or even several feet above it, the prairie seems continuous. Travel across any particular prairie tract is easy, but to get from one tract to the other with wagon or automobile requires considerable maneuvering and may be impossible without wide detours. This is one of the features that has given the Badlands their name.

In passing away from the White River towards the "Wall," there is a moderate rise of approximately fifty feet within a mile. From there on the rise is more gentle to the base of the "Wall." Northern extensions of the Prairie are in reality embayments in the "Wall" and are locally referred to as "basins."

3. **The "Wall".**—This—as may be seen from Figure 2—trends in general east and west. It is more than a narrow wall. It is an irregular zone or band of typical badland topography ranging in width from a half to three miles and having an occasional narrow extension to the south, especially in the southern part of T. 3, R. 18. The name, however, is very descriptive, for viewed from points a mile or more to the south it is seen to rise abruptly from the lower prairie and presents a formidable array of cliff and peak. (See Plate III B.) It looks like a barrier and actually is one. Only two wagon roads cross it through its whole extent in this area and even beyond, namely, at Cedar Pass and Big Foot Pass. Only a few additional

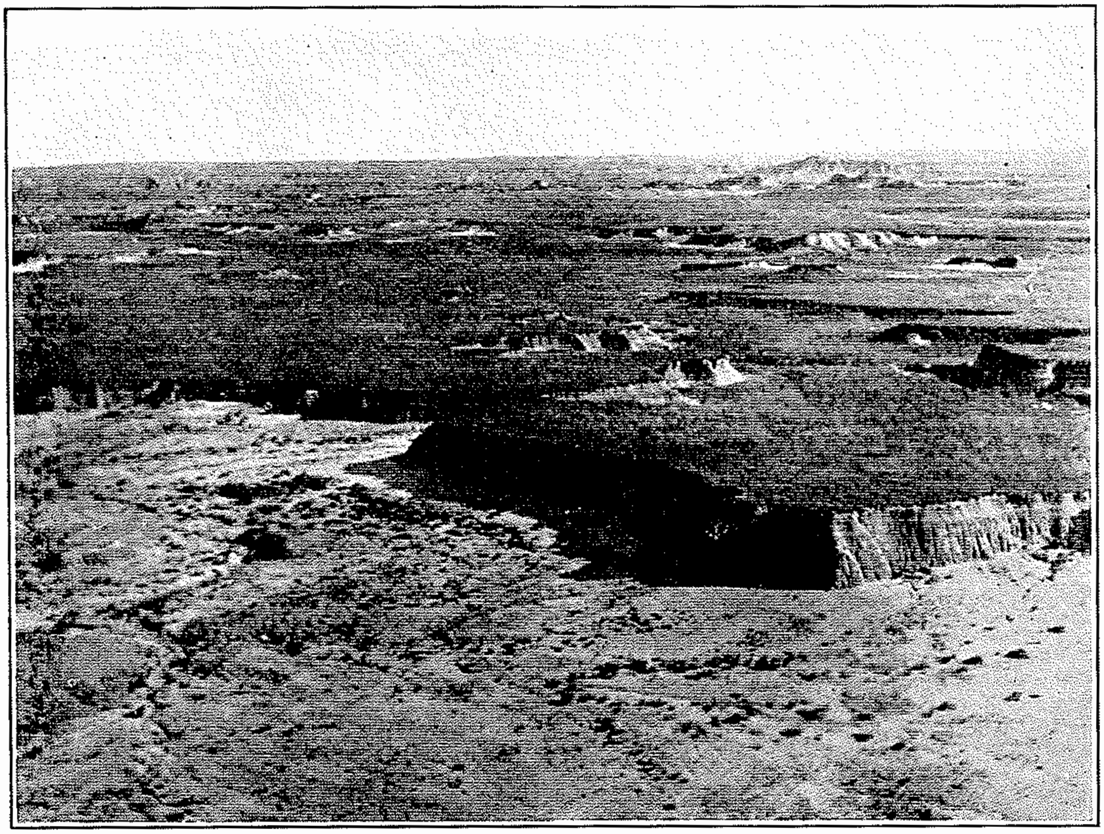


PLATE III A

DISSECTED PORTION OF LOWER PRAIRIE, NEAR THE "WALL"

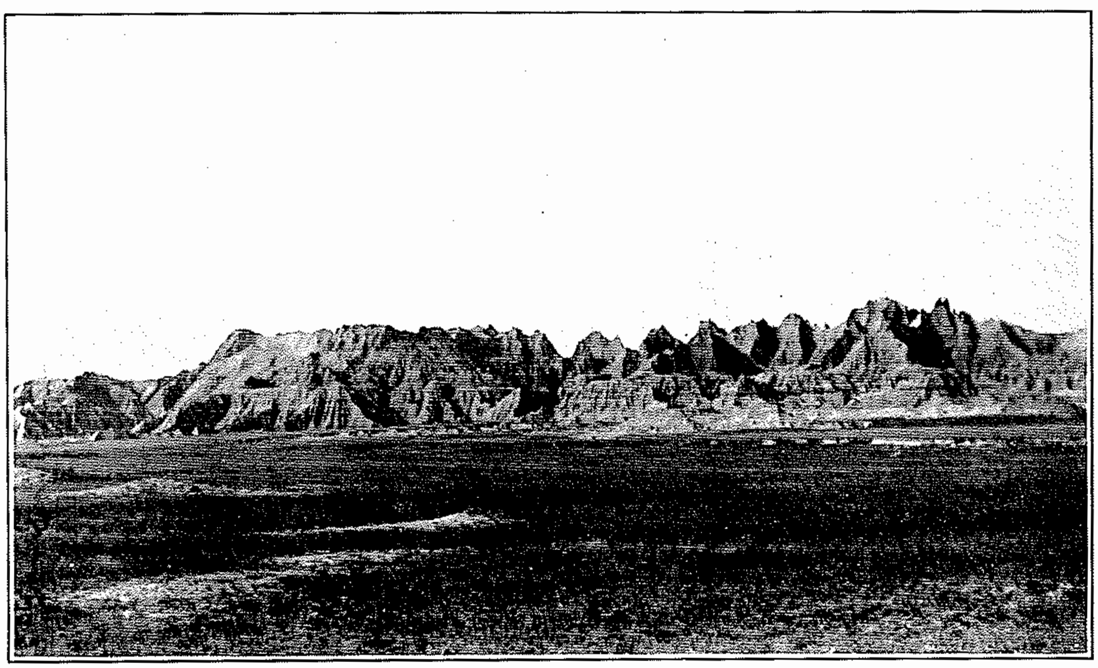


PLATE III B

THE "WALL" (SOUTH SIDE) ONE MILE AWAY

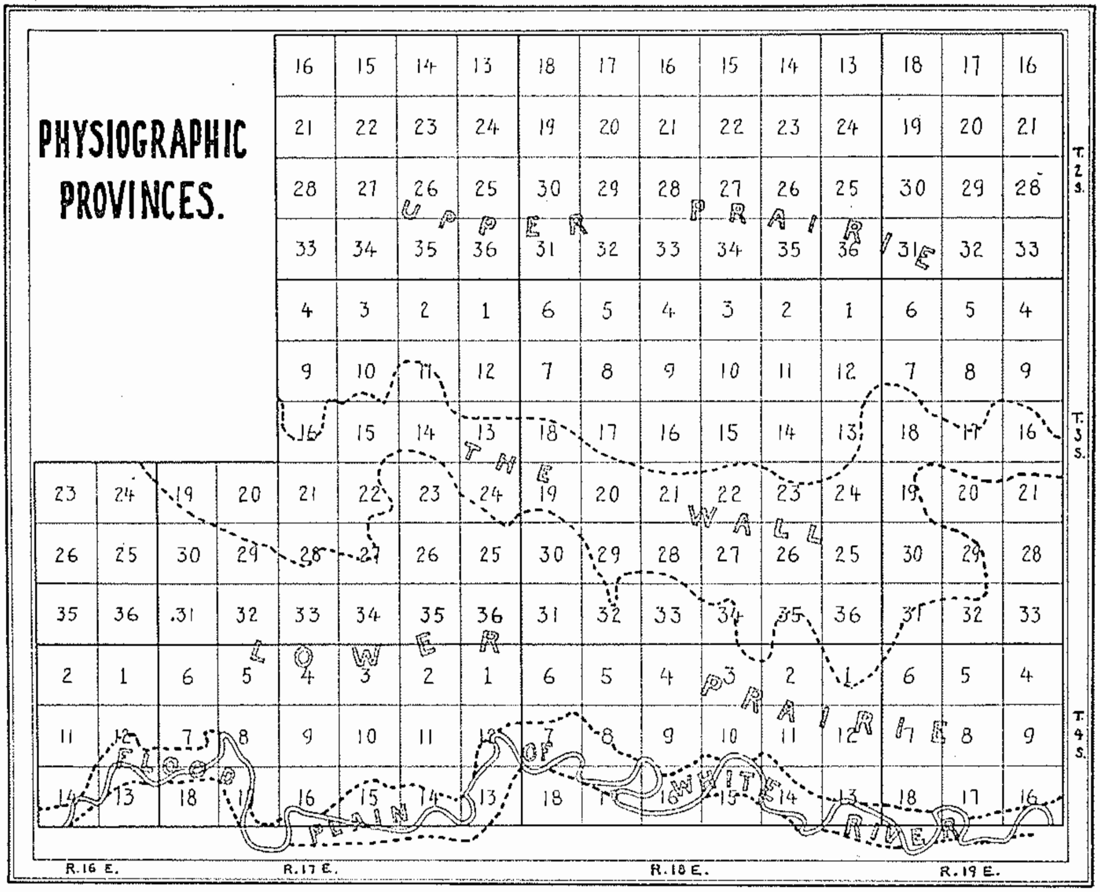


Figure 2

trails are passable on horseback. One on foot can make his way across in a great many places but there are several short stretches which are impassable.

From the north, much of the "Wall" cannot be seen, for the general level of the Upper Prairie is higher. Indeed in these places the "Wall" is merely the marginal, eroded portion of this higher tract of country. The transition from Upper Prairie to the "Wall" is very abrupt along parts of their boundary. One should, in this connection, compare photographs (Plates XA and XB). The highest parts of the "Wall." such as Cedar Pass and the "Castles," are prominent topographic features even when seen from the north.

Viewed from the distance of a mile or more, (Plate IIIB,) the "Wall" seems to consist of one or two serrated ridges with numerous spurs and gullies, but on closer approach it is found to be a maze of ridges, peaks, valleys and canyons. Some of the latter wind along for over a mile with many lengthy tributaries. It is a place where an inexperienced person might easily get lost.

All in all it is the roughest and most rugged portion of the area. The highest points of the area are here; also the greatest extremes of relief and the steepest slopes. The scenic qualities of this very typical badland tract are worth traveling many miles to see. (Plates IV. to IX.)

4. **The Upper Prairie.**—This occupies the remainder of the area, viz, from the "Wall" to the northern boundary.

It is a typical flat to gently rolling sod covered prairie, dotted with ranches. In this respect it resembles the Lower Prairie, but is about one hundred and fifty feet higher. It differs, too, in having almost no island badland buttes rising above the general level. The badland basins, cut below the general level are very much less abundant, except adjacent to the highest portion of the "Wall." In such places there are considerable stretches where the proportion of sod covered prairie remnants and badland basin are almost half and half. The term "breaks" is applied to this sort of topography. (See Plate XIIA.) The sod covered portions are only a few hundred feet across and are really miniature mesas. These naturally diminish in size and abundance as the "Wall" is approached.

As has been mentioned above, some of the Upper Prairie joins the "Wall" without transition. Since the Prairie is sloping upwards toward the "Wall" the latter cannot be seen until the edge of the Prairie is reached. It is astonishing to travel so freely over the Prairie (say in an automobile) and then to come abruptly within a few rods to a rugged topography wholly unexpected and impassable even on foot. This relation of "Wall" and Prairie has led to some losses of stock. When the latter are stampeded or are drifting in storms they may be hurled to sudden death in the steep gullies and canyons.

Shallow valleys of several northeast flowing creeks are entrenched below the general prairie level.

RELIEF

The general level of the Plains region here is about 2,500 feet, but no vertical control has been established by the Topographic branch of the U. S. G. S. The C. M. & St. P. R. R reports the town of Interior as being 1,800.7 feet above Lake Michigan, which makes its elevation above sea level 2,381.7 feet.

The lowest point in the area is along White River, the highest is on the "Wall" just east of Cedar Pass; the "Castles" are nearly as high. The range is approximately five hundred feet. The highest part of the "Wall" from the "Castles" to one and one half miles east of Cedar Pass rises rather abruptly three hundred to four hundred feet above the Lower Prairie. The latter is approximately one hundred and fifty feet lower than the Upper Prairie. The Lower Prairie slopes towards White River, the Upper Prairie slopes to the north and the northeast. The greatest extremes and rapid changes of relief are in the badland area proper, the least in the prairies.

DRAINAGE

The region is well drained. The largest stream is White River: it flows from west to east and has been taken as the southern boundary of the area. It is the only perennial stream in the area. As is characteristic of all the streams in the western part of the State, the volume of flow varies exceedingly throughout the year. Naturally its period of highest water is in the spring, when it is bank full and often overflows parts of its flood plain. In late summer it may dwindle to a series of pools connected by very shallow trickles. It can thus vary in depth in midchannel from ten feet to less than an inch. Since so much of the tributary slope, not only in the area but all along its course, is bare, its fluctuation shows a close relation to rainfall. It may vary in depth several feet over night. This close response to run-off is shown in the quantity of sediment carried. It always is turbid with fine silt and clay, indeed, the name "White"

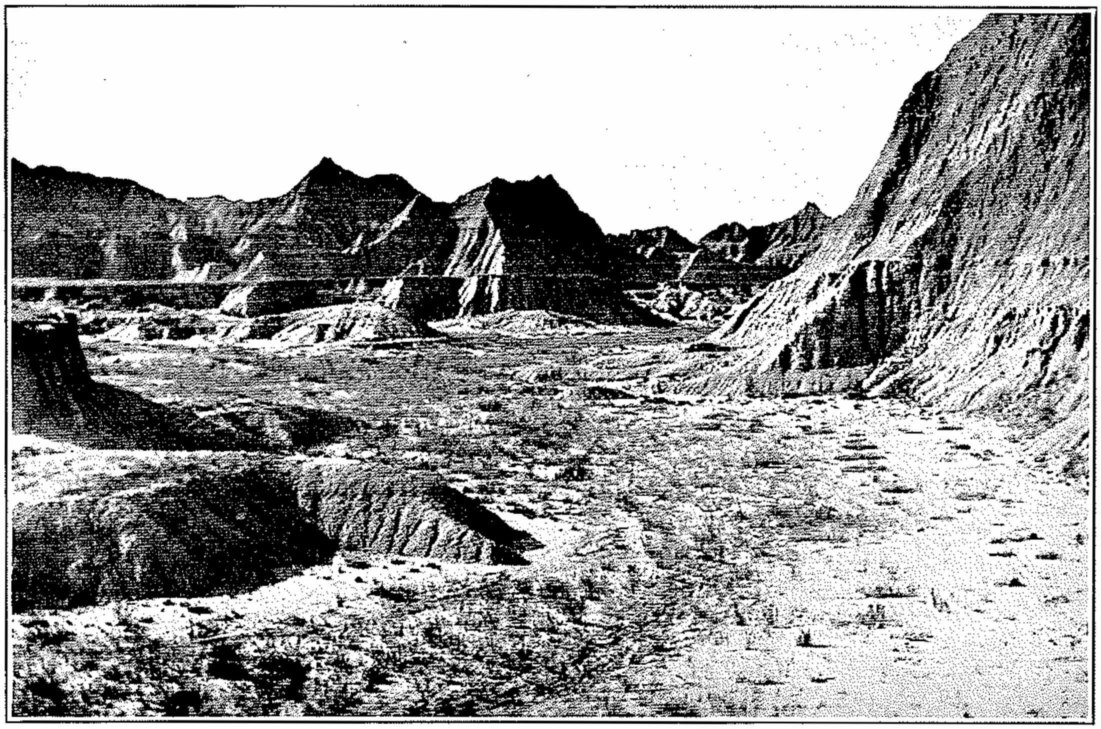


PLATE IV A
BASE OF THE "WALL," SOUTH SIDE

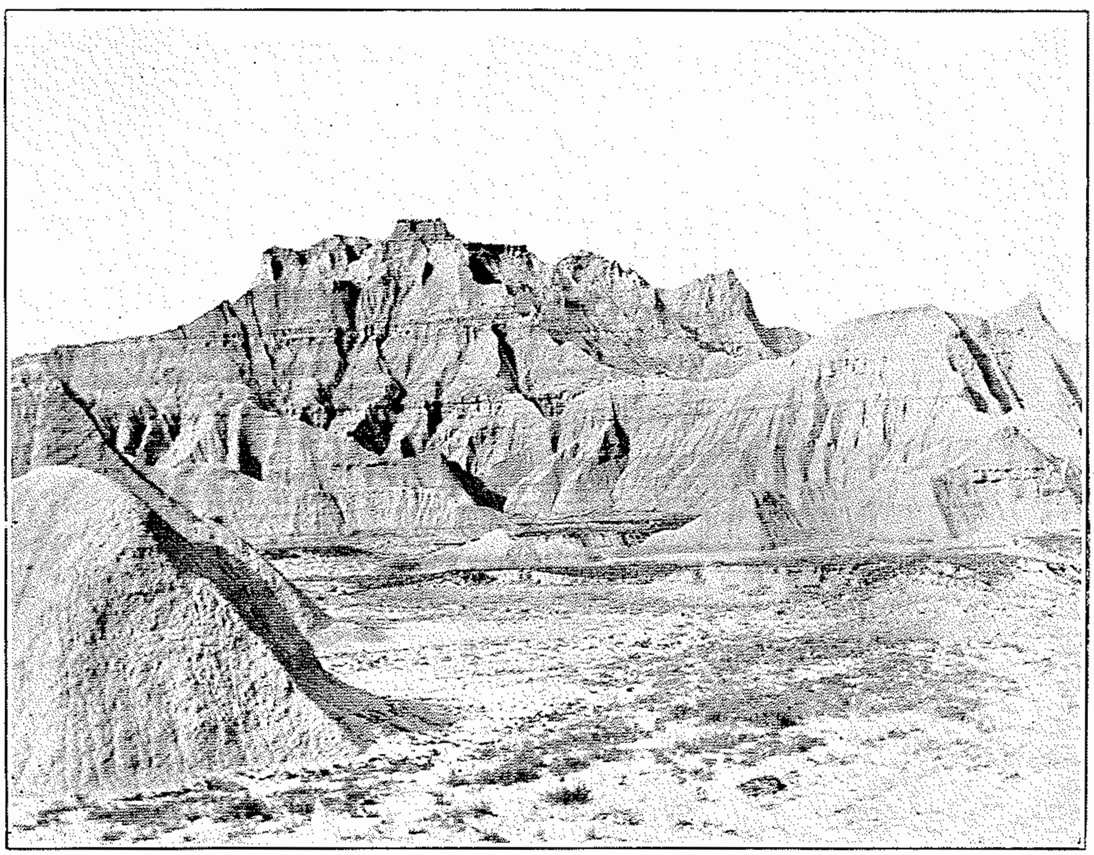


PLATE IV B
THE "WALL," SOUTH SIDE. UPPER PART PROTOCERAS

River is very descriptive, and the amount of sediment carried after a heavy shower is enormously increased. There is a corresponding decrease after a long dry spell, and during the pool-trickle stage of low water the water is nearly clear. There is a similar change in temperature; during the high stage the water is noticeably cool, and during the low stage the water is distinctly warm.

The gradient of the valley as a whole (not counting curves) is five feet a mile. This results in a rapid current, especially at the flood stage. When the water is waist deep a man has difficulty in keeping erect in it, and his feet are being bombarded by pebbles and small cobbles. At flood stage the current easily reaches the rate of ten miles an hour.

There is the expected amount of sand bar. Much of the sand is freely sprinkled with gravels. Locally, the gravel is abundant and coarse: quicksand is common.

There are several creeks (mostly unnamed) and dry washes which are tributary to White River. The larger ones head in the "Wall" and a few start in canyons that reach back north of the "Wall." They all have a general southerly trend across the Lower Prairie. The larger ones occupy trenches in the flood plain of White River and many have standing water and deep, fine textured mud for weeks at a time, a difficult combination to cross easily.

The stream courses north of the "Wall" trend north and northeast: the largest is Big Buffalo Creek. All are tributary to Bad River. In common with the tributaries of the White River none of them flows except right after a heavy rain, but at such times they may be raging torrents. Water holes are fairly common along many of their courses.

Many small tributaries ramify from the larger creeks and dry washes, so that the run-off quickly gets into circulation.

The divide between White and Bad rivers follows the crest of the "Wall" throughout most of its extent, bending to the north locally to head the longer southward trending canyons.

Except for a few feeble ones along Big Buffalo Creek, springs are entirely lacking in the area. In the past there must have been springs along parts of the "Wall," notably near Cedar Pass; the prominent slump topography is mute witness of their undermining effect.

THE FORMATIONS

GENERAL STATEMENT

All the formations in the area are of sedimentary origin and range in age from Pierre to Pleistocene and Recent. The accompanying columnar section (Table 4) gives in tabular form the names of the several formations, their age, thickness and general character. This shows, too, that the bulk of the material belongs to the Oligocene (White River).

In general descriptions of the Badlands much has been made of the fact that the beds consist of unconsolidated material. This conception is incorrect and the term "unconsolidated" is a misnomer. The first few inches on the surface are loose enough to be so described but if one has occasion to dig in a foot or so he will find the beds very substantial. Pick and chisel are required to make any headway. But they loosen by weathering at a remarkably fast rate. Blocks which, when first taken out, are difficult to break with a heavy hammer will weaken and crumble after exposure to the air

Eras	Periods	Epochs		Formations		Thickness	Description
Psycho-zoic					Recent		Chiefly wash, and flood plain.
Ceno-zoic	Quater-nary				Pleistocene	15-25	Gravels, sand, silts.
	Tertiary	Oligocene	Upper	White River: Brule	Protoceras	175-200	Very fine textured sandstone, light gray to pale pink in color: massive bedding. Local coarse, greenish sandstone.
			Middle		Oreodon	225-285	Fine textured sandstone, light gray in color, alternating with pink shale. Well bedded.
			Lower	White River: Chadron	Titanotherium	60-70	Massive shale. Color prevailingly gray with a slight greenish cast; purplish near base. Occasional indistinct pinkish bands.
Meso-zoic	Creta-ceous	Montana		Pierre	Interior	35	Thin bedded sandy shale, predominantly yellow-brown in color but variegated with browner and purpler colors in upper portions.
					Typical	25	Typical dark blue-gray shale.

Table 4. Columnar Section.

for only a few days. Weakly consolidated is a more truly descriptive phrase.

Another rather surprising fact revealed by detailed field work is that there is much less variety of material in the White River Group than seems to be present at first sight. The many bedded appearance and the array of erosional forms no doubt are responsible for the impression of great variety of rock substance. There is a repetition of similar shales and fine sandstone, indicating a recurrence of similar conditions.

The names used for the several subdivisions of the White River are those carried in from outside the area. They are faunal names and are far from descriptive;—for instance, Oreodons occur throughout the whole series, no Protoceras fossils were found at all, and the Titanotherium beds yielded the remains of only two individuals, one of these the merest fragment. However, there are good lithologic and other grounds for making the separations, and these were followed through all of the field work.

The formation will be described in order, beginning with the oldest.

CRETACEOUS

The Cretaceous makes up but a very moderate portion of the formations occurring in this area. Only one division of this large period is present, viz, the Pierre. However, unlike most of the Pierre thus far described in this State, it is divided into two distinct parts. The new subdivision has been named the Interior phase.

The Typical Pierre.—This formation occurs in two widely separate localities, viz, the southwestern and northeastern parts of the area respectively. The former contains the best outcrops, a fine exposure showing along the White River bluffs in Section 17, T. 4, R. 17. (See map, Plate I.) But only the upper part (maximum twenty-five feet) is exposed. It is overlain conformably by the Interior phase. The contact when viewed from accross the river seems very sharp, but it is gradational. The transition takes place within a few inches, at the most a foot or so. The upper ten feet or more when weathered bears a superficial resemblance to the Interior phase.

Lithologically the Pierre is a thin-bedded shale, containing occasional thin, calcareous, concretionary lenses. In color it is a dark gray, a blue gray which when wet looks almost black. It is practically identical with the typical Pierre shale so widely exposed throughout the State. It is slightly different in that it has a very moderate content of very fine sand, and rarely has a harder, thin (one to two inch) member with a greater quantity of fine sand.

In the northeastern part of the area the contact with the overlying Interior is in most cases indeterminate. This results from lack of good outcrops. Much of the surface there is covered with continuous sod. Since the upper ten feet of the Pierre weathers to a yellow brown color, and the Interior is normally that same shade, the soils of the two are very similar. Where the weathering has not advanced too far, the Pierre shale fragments are yellow brown only on the outer portions; on breaking, the unaltered dark gray color shows plainly. Locally the contact is further obscured by the Pleistocene and Recent cover.

The typical Pierre yields a gently rolling topography not to be distinguished from the Interior.

The following fossils have been found:

Lucina occidentalis Morton
Inoceramus (Actinoceramus) fibrosa Meek and Hayden
Baculites sp. cf. *B. gracilis* Shumard

The Interior Phase.—The distribution of the Interior follows very largely the valley of White River and the adjacent gentler slopes in the western portion of the area. Only narrow extensions of this formation follow the creek beds north of the railroad. It is also found in the northeastern part of the area north of the "Wall." There is a small occurrence in the eastern portion (Sect. 21, T. 3. R. 19), and just outside the area to the east it is prominent again. The maximum thickness is thirty-five feet.

It rests conformably on the Pierre, the contact being gradational, as has already been noted. Its contact with the overlying Titanotherium is a disconformity.

The Interior is a fissile, sandy shale, the sand being in all cases very fine in texture but much more in evidence than in the typical Pierre. There is an occasional fine sandstone layer a few inches (maximum eight) thick. Such layers are not composed of clean sand but have a generous admixture of silt and some clay: on weathering, because of their greater resistence they become more prominent than the major part of the formation.

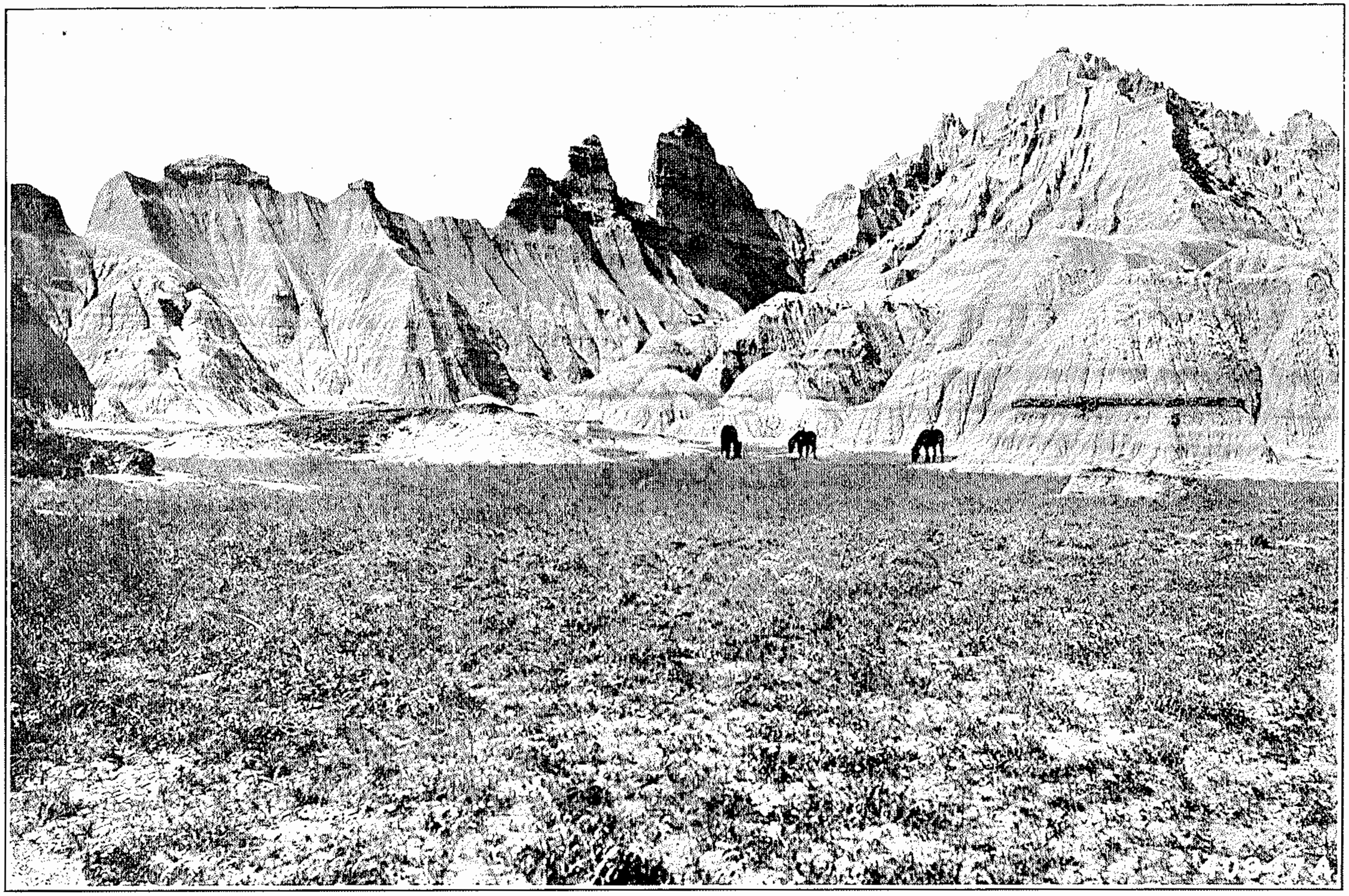
The color is prevailingly a light yellow brown. Locally darker tints of brown streak through the formation. This is especially true southwest of Interior in Sec. 11 and 12, T. 17. R. 4, where are located the so-called "Iron Beds" or "Iron Hills." This coloration results from the weathering of thin veins and concretionary lenses of impure siderite with the production of impure limonite. Here and there the larger concretionary masses contain bright, hematitic centers. Because of the iron-stained character of these particular beds a belief was current that they were valuable as iron ore; but this has proved to be unfounded, the iron content, except in selected samples of a few pounds in size, being quite insignificant. The upper part of the series is variegated in color, having various shades of purple, lavender and pink coursing irregularly along and across the laminations. This apparently is a secondary effect caused by the carrying down of coloring matter from the overlying Titanotherium, whose basal member is largely purple in color.

The formation yields subdued flowing topography similar to that developed on the typical Pierre.

Although fossils are not abundant, the following forms have been identified:

Lingula sp.
Inoceramus (Actinoceramus) fibrosa Meek and Hayden
Inoceramus (Actinoceramus) sp. *nov. (Whitii)*
Anisomyon sp. cf. *A. patelliformis* Meek and Hayden
Scaphites (Discoscaphites) nicolleti Morton
Scaphites (Discoscaphites) Cheyennenis Owen

This formation has been very provocative of discussion as to where it should be placed. When first seen, although its color and bedding were quite different, it seemed possible to consider it as a phase of the Titanotherium, especially since its upper contact was obscure. The finding of marine fossils soon disposed of this arrangement and clearly placed it as Cretaceous. The finding of the unconformable upper contact later confirmed this decision.



—Photograph by U. S. Forest Service

PLATE V

THE "WALL," SOUTH SIDE

Since the Pierre throughout the whole State is so uniformly a dark shale, the yellow brown color and sandy texture of this formation seemed more in contrast with the typical Pierre than with the Titanotherium. On these grounds the formation was, in the field, referred to as the Fox Hills. However, a thorough examination of the fossils seems to warrant placing it as an upper phase of the Pierre. While several of the forms found are known to occur both in the Fox Hills and the Pierre there are one or two which have never yet been found in the Fox Hills and are known in the Pierre. This matter is further discussed by the junior author in a later part of this report (page 62).

The senior author, despite the faunal evidence, is inclined to make it a separate formation following the Pierre without break, viz, the basal Fox Hills. The arguments upon which this opinion is based are largely physiographic and are as follows:

If this is accepted as Pierre there are two things that require explanation,—the strong color contrast and the sandier texture. It is not enough to say simply that the material is different, for that would admit a shallowing sea, a changing land and water distribution an attendant diastrophism,—all of which are given as characteristics of the normal Fox Hills. Without a difference in material the color difference at least can be explained as a result of weathering. This again brings a train of adverse consequences. Weathering means of course exposure to the air. If this uplift and exposure took place before Fox Hills time it would result in a hiatus between the Pierre and Fox Hills, but the contact of these two is known to be gradational. If it took place after Fox Hills it means the erosion of all the Fox Hills (and all later formations between Pierre and Oligocene) and the production of a pre-Oligocene peneplain; for the thickness as seen here, near Scenic, near Wall and beyond (thirty miles northwest) is rather uniform, twenty-five to thirty-five feet, which means a uniform, flat topography with a minimum of removal during weathering.

With this prominent emergence and long erosional period well established, the Lance problem is at once involved. For the Lance would clearly belong to the Tertiary if the erosion period were proved to follow immediately the Fox Hills, and would just as clearly belong to the Cretaceous if the erosion period were proven to be Post-Lance.

Furthermore, the contact between the typical Pierre and the Interior phase is not an irregular one such as would normally be produced by weathering. At a distance of twenty-five yards the contact seems to be a straight line paralleling the bedding; closer inspection shows it to be gradational in the sense of changing material, the dark carbonaceous shale beds giving way to an increasing amount of yellower, more sandy shale. Nor does the weathering readily account for the different texture.

Further objection to the weathering and erosion conception is that at least one place in the State beds similar to the Interior occur between typical Pierre and typical Fox Hills and are gradational both ways. Calvert, etc. says,[1] "The Pierre shale grades upward through fifteen to thirty feet of light drab sandy shale into the overlying Fox Hills sandstone." No opportunity has presented itself to see these beds and make a thorough comparison.

[1]Geology of the Standing Rock and Cheyenne River Indian Reservations of North and South Dakota: U. S. G. S. Bulletin 575, 1914. p. 10.

The most rational view seems to be to consider the material to have originally been just as different from the typical Pierre as it is seen to be today. Then follows the interpretation of a shallowing sea, a nearer shore line, a changing geography, an accompanying diastrophism—in other words, the normal advancing Fox Hills time.

The transitional beds mentioned by Calvert (see above) under this interpretation should be basal Fox Hills rather than Upper Pierre. That he was uncertain about their proper position is indicated by the caption on the photograph (Plate VIII-A of the work cited) of these beds, for it reads "......bottom of Fox Hills sandstone *or* top of Pierre shale................" The presence of *anisomyon* sp., *Inoceramus fibrosa* and *Inoceramus whitii* can be explained as a lingering on of these forms into these early transitional beds. For the material, while showing a coarsening, is still a shale. The forms apparently could not persist in the truly sandy condition which followed and so would be absent from the typical Fox Hill sandstones.

TERTIARY

General Statement.—The type Badlands are composed almost exclusively of Tertiary formations and the area under discussion is seen to conform to this generalization. The Cretaceous, as far as areal extent and thickness is concerned, is insignificant. All of the Badland Tertiary is Oligocene or White River in age. There are three common and widespread subdivisions: the Titanotherium, Oreodon, and Protoceras. The reader is referred to the columnar section (Table 4) and the areal map (Plate I) for a tabular and graphic representation of these members.

The Titanotherium.—The name is derived from the fossil mammal remains found in so many places in it. If it were now being named for the first time and from characteristics seen in this area a wholly different name would be chosen, for the Titanotherium fossils are not at all common here; in fact, are scarce. In other parts of the Badlands this is not the case. It has also been called the Chadron, from the town of that name in northwestern Nebraska.

The largest expanse of this formation is found in the southwestern part of the area. It occurs typically in the lower portions of the "Wall," the outlying buttes and the river bluffs, and covers most of the low-lying, undulating land between the "Wall" and the river. Another prominent tract bearing a similar relation to the lower "Wall" and adjoining lowland is found in the east central part of the area. In the northern part of the Upper Prairie this member outcrops again in wide bands with southward extensions along the creek bottoms.

The thickness of this formation is sixty to seventy feet where completely developed. The Titanotherium can best be described as a uniform, massive shale. By "massive" is meant that it does not have the usual thin bedding so characteristic of ordinary shale: it does not split into thin, slabby pieces or chips, but breaks apart into nearly equidimensional chunks, much of it in this respect resembling the fracture of lump starch. The word "shale" is a textural rather than structural term. The texture is that of a heavy clay; this is evidenced by the sticky, gumbo soil that it very quickly yields. Its clay-like texture is further indicated by its high air shrinkage (thirteen to fifteen per cent). A typical outcrop checks deeply and, where the slope is not too steep, is commonly covered to a depth of a few inches by hard, irregular fragments, a fraction of an inch to one or two inches in diameter. No grit is felt when testing this shale between the fingers, only a moderate amount is felt between the teeth.

Another fact that shows the clay-like character and high shrinkage is the presence of small slickensides where there is absolutely no possibility of diastrophism. The outcrops are so fresh and so free from soil and talus that a bodily movement of even a fraction of an inch would be shown. In such cases the slickensides can be caused only by alternate expansion and contraction as the shale becomes wet and then dries again.

The color of most of this member is a light gray, usually having a slight greenish cast (especially noticeable when wet). Much of it also has a banding of faint pink color[1]. Indeed, these faint bands are practically the only indications of bedding shown in the formation. Towards the very top the pink bands may locally be more numerous and may merge so as to give a general pink color to the upper five, ten, or fifteen feet. However, this is not uniformly the case for at many places the typical gray Titanotherium is in contact with the overlying Oreodon. The basal portion of the Titanotherium is always a deep pink—and even red—commonly with purplish or lavender tints.

A chemical analysis of the typical Titanotherium is given in Table 5, No. 1.

Other physical characteristics dealing with the ceramic possibilities are given in Table 8, Nos. 1 and 2.

While this formation is well characterized by the term "uniform," there are some variations that must be noted, as follows:

In two localities beds of sandstone were found to occur. One locality was in Sec. 12, T. 4, R. 17. An extension of this bed was found just across the river on the left side of the Potato Creek valley. This sandstone is medium to fine grained and almost glaringly white in color. It has a high proportion of quartz grains, a very few

	1	2	3	4	5	6	7	8
SiO_2	55.61	62.87	47.03	67.10	50.53	61.99	62.35	57.32
Al_2O_3	12.97	22.34	9.91	10.46	10.97	18.33	19.00	15.73
Fe_2O_3	3.03	1.59	2.44	1.80	6.69	1.81	2.55	2.56
FeO	2.59	.24	1.07	1.84	.60	2.75	.97	1.69
CaO	3.05	1.64	18.72	7.04	7.50	3.60	3.09	5.29
MgO	5.90	1.20	3.11	3.22	6.15	.97	.80	1.10
Na_2O	1.16	4.56	1.51	3.22	4.44	4.36	6.15	5.67
K_2O								
H_2O	8.74	1.77	1.47	1.14	4.93	4.74	3.24	2.98
X_2O	6.95	3.79	14.74	4.18	8.19	1.45	1.85	7.66
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

1. Typical Titanotherium
2. Local sandstone in Titanotherium
3. Oreodon—sandstone
4. Oreodon—sandstone
5. Oreodon shale
6. Oreodon shale
7. Protoceras—sandstone
8. Protoceras—sandstone

Table 5. Chemical Analyses

[1]The color "pink" as used in this report has a quality which perhaps is best described as a diluted Indian red. The intensity of this color varies from the faintest imaginable tint to deeper tones almost approaching true red.

scatterings of other mineral particles and a sufficient quantity of very fine material (kaolin-like in appearance) to prevent rating it as a "clean" sand. A chemical analysis is given in Table 5, No. 2. It has a maximum thickness of ten feet. It is conglomeratic at its base and rests unconformably on the lower pink-purple portion of the normal Titanotherium. This sandstone is quite restricted: its greatest width is two hundred yards, and it is completely absent in the adjoining territory to the east, west, and north. If connected with the Potato Creek exposure,—which is really not the case,—it would have a length of nearly two miles. The exposure along Potato Creek is thicker, coarser, and shows cross-bedding. In origin it may be readily classed as a channel deposit made by a stream which interrupted the uniform condition under which the regular Titanotherium was formed.

An exposure and drying out of the sand before the deposition of the overlying typical gray Titanotherium is indicated by the fact that the upper part of the sandstone has vertical cracks filled with gray clay.

The other locality where a sandstone was found is far removed from the first, being in Sec. 32, T. 3, R. 19. This sandstone is medium to coarse in texture and is cross-bedded freely. Its mineral composition is practically the same as that of the other sandstone, except that there is less of the fine material. It also has some calcareous cement, which the other lacks. The color is greenish and is due to the very fine material present. It occurs about twenty-five feet from the top of the Titanotherium. It has a maximum thickness of ten feet, is about twenty-five yards wide and a quarter of a mile long. This, too, is a channel deposit. It was noticeable, also, that in this portion of the area part of the Titanotherium is more bedded than usual and has some members with an appreciable amount of very fine sand in the shale. It is this locality which has yielded the only remains of Titanotherium fossils in the whole area.

Other variations from the typical Titanotherium, while not totaling a large quantity, are still rather commonly found in many parts of the area. If the sandstone above described is rated as an exceptional variation, then these others can best be rated as common variations.

One of these common variations is the presence of gypsum, which occurs only in the basal purple-red portion of the Titanotherium but is found in many localities. There are no beds of this mineral. It occurs rather as irregular, lumpy, small masses, usually only a few inches in diameter and with no alignment or evident plan of grouping. Occasionally several are connected. In some instances chalcedonic silica occurs with the gypsum and, since on weathering the gypsum is readily removed, the silica is at times found alone. A small amount of the gypsum is fibrous, occurring in narrow veins running in several directions with no well established system.

Another common variation is the presence of a cherty limestone. The carbonate portion is light gray to cream colored, which weathers sometimes to a chalky white and sometimes to a dirty gray, rough surface. The chert, while sometimes nearly clear, is usually dark colored. It is distributed very irregularly through the limestone and is very patchy and irregular in outline. The maximum thickness of the chert masses is two inches. Many times the chert is associated with plant remains preserved as carbonate of lime, and in a few instances gastropod fossils composed of silica were found.

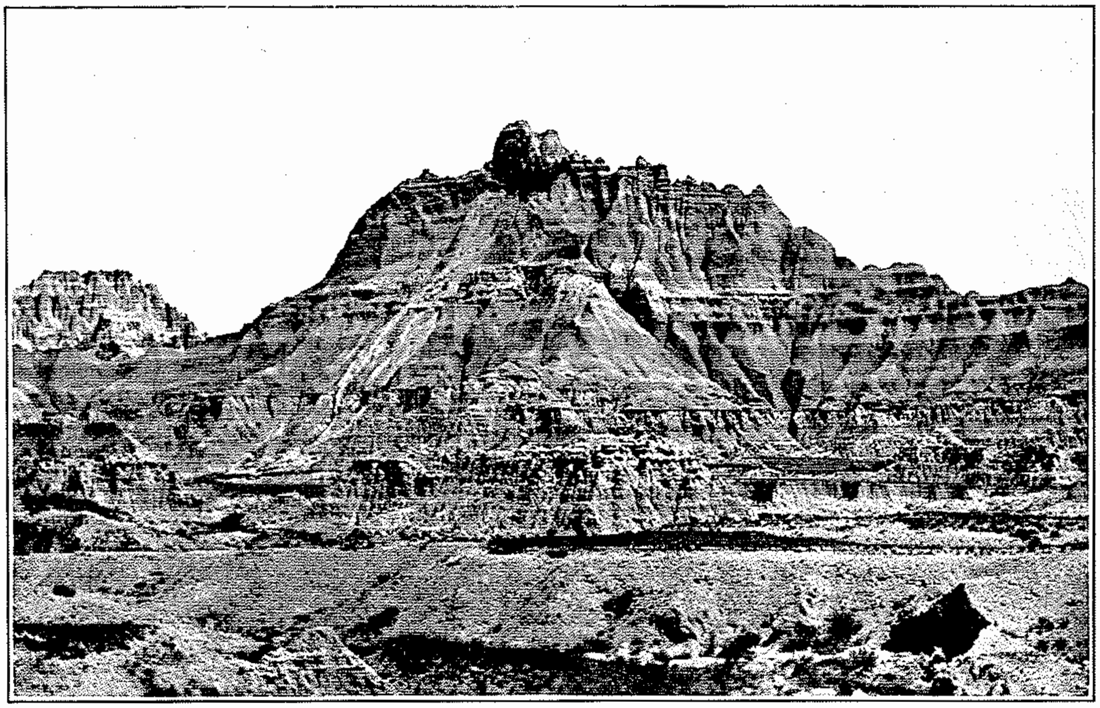


PLATE VI A

THE "WALL" SOUTH SIDE

TYPICAL SECTION, PROTOCERAS ABOVE AND OREODON BELOW: FAULTED

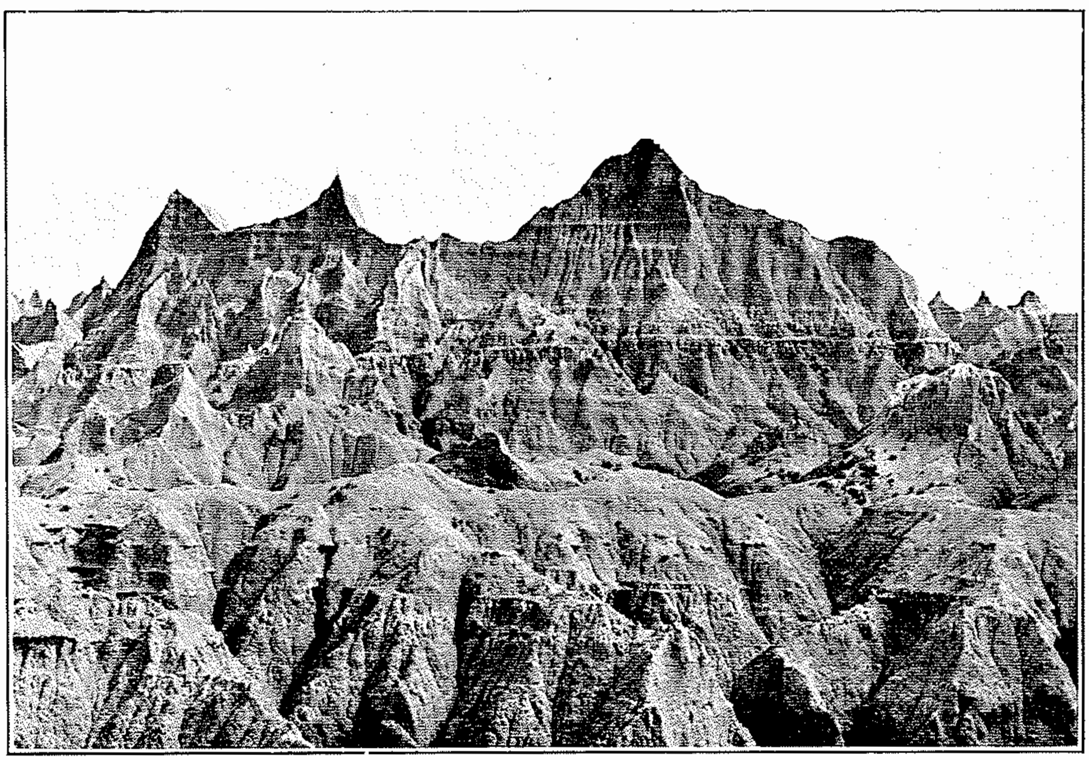


PLATE VI B

WITHIN THE "WALL"

This cherty limestone, while perhaps occurring most commonly in the lower part of the Titanotherium, has been found at several horizons. Near Herley Butte three distinct horizons were seen. These beds are small lenses, usually being six inches to a foot in thickness and with a linear extent of twenty-five to seventy-five feet. The occasional larger ones may be one to three feet thick and one hundred to several hundred feet long.

A final, common variation is the presence of impure calcareous concretions. These are rounded to reniform in shape: a common form resembles the cast of a brain and it is thought that some of them may really be casts of brains or other skeletal cavities. They are one or two to six or eight inches in diameter. Color is gray to pinkish on the outside and nearly always pinkish inside.

The Titanotherium, because of its uniformity, weathers and erodes uniformly. It yields a rounded knoll or billowy topography as may be seen in the photograph (Plate XIIIA.) This is quite in contrast to the sharper topography, steeper slopes and pointed crests of the Oreodon. It also typically differs from the rolling to gently undulating topography of the Pierre. Naturally, where erosion has reduced the elevation to a local base level, there will be a flat to gently undulating topography like that of the Pierre.

One topographic variation is caused by the cherty limestone. Where this layer is well developed it is strong enough to produce benches—as for instance, near Herley Butte. It has also produced small flat-topped buttes such as are seen in the southwestern part of the area between Herley Butte and the "Wall."

The fossils are chiefly mammals and turtles: the plant fossils are fairly common; gastropods (fresh water) have been found in only one locality. The list is as follows:

Limnaea meeki. Evans and Shumard
Limnaea shumardi. Meek and Hayden
Helileidyi. Hall and Meek
Titanotherium sp. ?
Oreodon (Merycoidodon) hullatus. Leidy
Oreodon (Merycoidodon) hybridus (?) Leidy
Elotherium (Entelodon) crassum. Marsh
Testudo brontops. Marsh

A description and discussion of these forms is given by the junior author (p. 66).

The contact of the Titanotherium and Interior is a disconformity. Because of the washing down of the purplish colors from the basal Titanotherium into the Interior the contact is often indefinite. The chief thing which determines the fact of an unconformity is of course the fossil content. Another is the well bedded and more sandy character of the Interior in contrast with the massive, clayey Titanotherium. In one locality a well displayed fault was plainly seen to cut the Interior and not traverse the overlying Titanotherium. This in itself indicates a break between the two formations.

The Titanotherium is separated from the overlying Oreodon by an unconformity. The contact is well displayed along a large part of the "Wall" as well as on a great number of outlying buttes. Reference to the map (Plate I) will disclose the fact that there are many miles of observed (full line on map) as well as inferred (dotted line) contact. Probably in two-thirds of the cases where the contact was seen it was found to be a disconformity. In the remainder of the exposures the unconformity was angular. The angle between the two formations was in almost every case low, one to three degrees

(See photograph, Plate XIIIB), but in one instance was as much as twelve degrees (See Figure 3). The upper surface of the Titanotherium is gently undulating to flat.

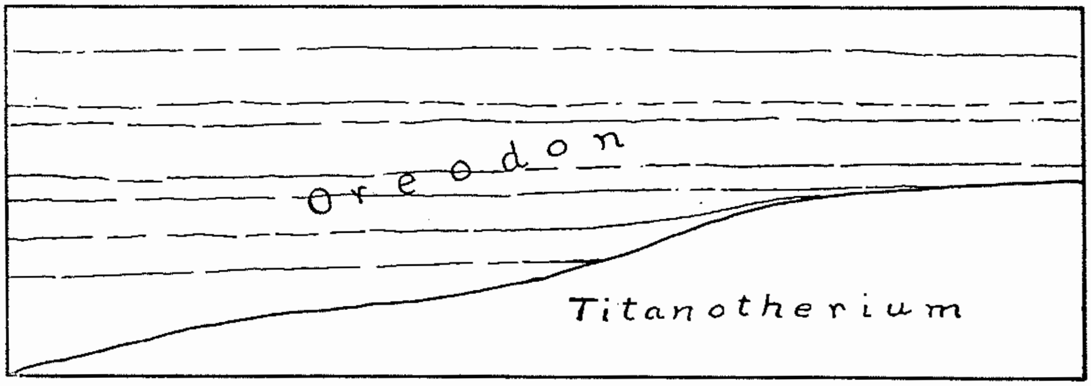


Figure 3. Unconformable Contact of Titanotherium and Oreodon

The Oreodon.—General Statement.—This formation is so named because of the abundance of the fossils of this name. While fragments of these fossils are common in this area, complete or nearly complete skeletons are rare. Oreodons are not confined to this horizon, a few being found in the Titanotherium and a generous number in the Protoceras.

The Oreodon covers about one half of the area under consideration, occupying especially the central and southeastern portions. It makes up all the upper two-thirds or more of the eastern and western division of the "Wall." In the central division of the "Wall" it is just as prominent and thick but is overlain by the Protoceras. The upper, steeper parts of nearly all the buttes south of the "Wall," as well as the main parts of the river bluffs, are composed of this formation.

In contrast to the massive Titanotherium the Oreodon is plainly seen to be bedded. It consists of an alternation of fine textured light gray sandstone and pink shale, concerning which more detail will be given below. It may be divided into three portions on lithographic grounds, as is shown in Table 6.

Upper	Massive sandy shale	35-45 feet	
	Upper Nodular sandstone	20-30 feet	
Middle	Massive shale	35-45 feet	
	Lower Nodular Layer	20-30 feet	
Lower	Bedded, alternation of shale and sandstone: contains Metamynodon sandstone.	115-135 feet	

Table 6. Divisions of the Oreodon

(1) Lower Oreodon.—This member of the formation is especially noticeable in its bedding, and because of the alternate colors is often spoken of as banded. A typical sequence of beds is given in the section shown in Figure 4, which was observed in Sec. 28, T. 3, R. 18; Plate XIV A is a photograph of it. While there are a great many

beds exposed in this sixty-four foot section, there is no great variety of materials. There are scarcely more than two rock types,—sandstone and shale.

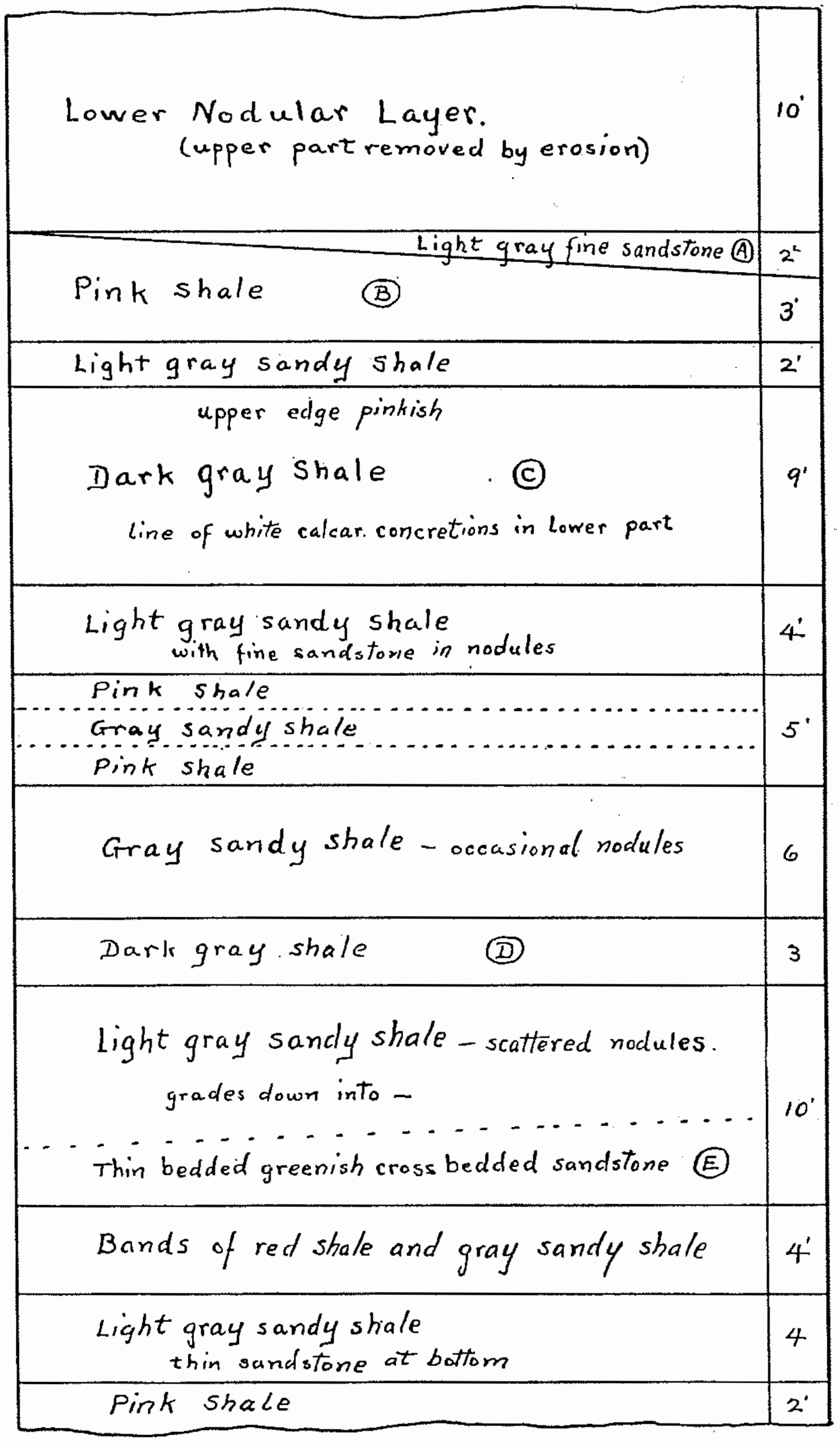


Figure 4. Section of the Lower Oreodon. (See Plate XIV A.)

The sandstones, except some phases of (E), are of a uniform, very fine texture; they contain a goodly content of silt as well. Where more sandy they tend on weathering to develop a nodular appearance; that is, the bed seems to be made up of more or less connected ball-like or rounded, elongated, knobby masses four to twelve inches in diameter, giving way at intervals to the regular, bedded sandstone. Locally this nodular habit is developed as prominently as in the typical nodular layers above. Where the sandstones are less sandy and more silty they are better described as sandy shale. In color both the true sandstone and the sandy shale are a light gray which is nearly white: these beds are quite glaring in the sunlight. The bed marked (E) in the section has often a greenish cast to the gray color. Much of the cementing material of these beds is calcareous. No. 3, Table 5, is an analysis of one of the sandstones. The fineness of the texture is indicated by the behavior described in No. 3, Table 8. This was sampled through a series of sandstone and sandy shale beds. It will be noted that the mixture had a good plasticity and a high air shrinkage.

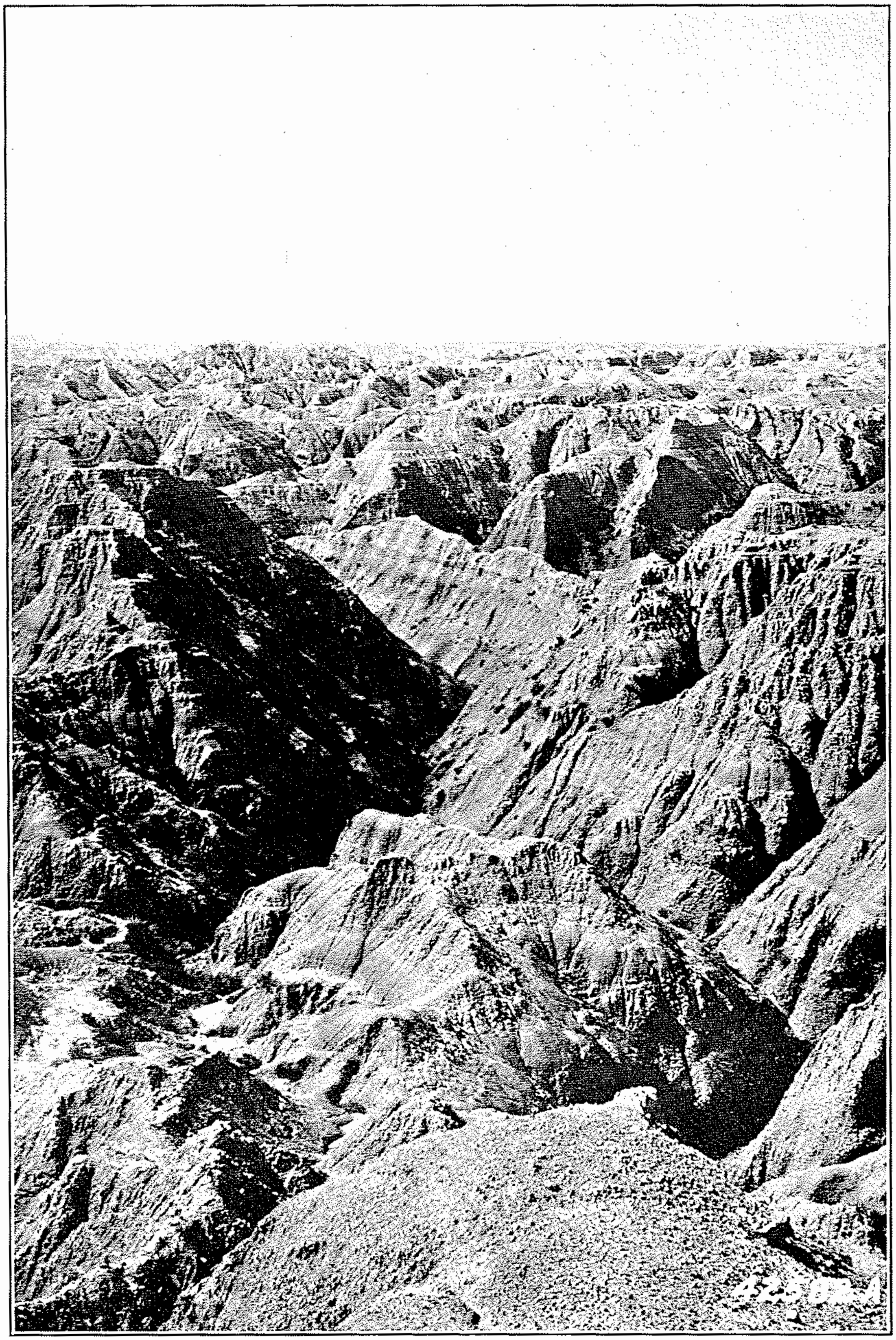
The true shales all have a high clay content with practically no grit in them. They are not at all fissile: they cannot be split into slabs or thin chips but yield practically equidimensional angular fragments; indeed, they are just as massive as the shale already described in the Titanotherium. In color most of them are pinkish to nearly red; when wet the colors are quite bright. A few of the shales are a dark gray; these seem also to have a slight content of fine grit. Some of the shales are calcareous. No. 5, Table 5, is an analysis of one of the bright pink shales.

As the beds are followed they are found to change in character and to vary in thickness. They are lense-like, as is to be expected. But many of the beds show a persistence and continuity that is surprising, considering the fluviatile origin usually assumed for them. Some of the variations can be mentioned in reference to Figure 4. Bed A, one half mile to the southeast, is five feet thick; five miles to the northwest it is fifteen feet thick and quite nodular. Bed B, one half mile to the southeast, changes to several pink shales alternating with gray shale. Bed C, to the west is a bright pink; to the east, is a pale pink. Bed E. to the east and southeast, thickens, and within a half mile is twenty feet thick. It is the Metamynodon layer spoken of in the literature. It is always rather thin bedded, has a faint greenish gray color and commonly freely cross-bedded: its texture at times is fairly coarse. It is plainly a channel deposit, the outline of the channel being readily seen in a number of cases in other parts of the area. The beds between C and the Lower Nodular range from five to twenty feet in thickness in different parts of the area.

The sandstones and sandy shales are the variable members, the variations never being abrupt, however, except in the case of the Metamynodon bed. The shales are much more persistent. Many of them can be followed for one fourth to one half a mile; a few are continuous a mile or more; one bed, C in Figure 4, is persistent practically over the whole area.

The beds below the lowest one shown in Figure 4, consist of an alternation of pink shale and gray sandstone or sandy shale. In one place in the northwestern part of the area a four-inch bed of light gray to cream colored, dense limestone was found about fifteen feet from the bottom of the Oreodon. There also occur plant remains made of limestone.

(2) Middle Oreodon.—The most striking bed of the Middle member of this formation is the Lower Nodular Layer. It is really a



—Photograph by U. S. Forest Service

PLATE VII
WITHIN THE "WALL"

group of layers rather than a single one. A typical thirty foot outcrop was found to be composed of the following: The upper ten feet consisted of an alternation of (a) pinkish, massive shale, and (b) thin layers of light colored limestone through which were scattered irregular pieces of pinkish (some greenish) clay or shale. Some of it was fossiliferous, showing plant remains, part of which had streaks of chert. These were similar to those found so abundantly in the Titanotherium and rarely in the lower member of the Oreodon. On weathering this limestone becomes cellular and has a dirty brown exterior, though almost chalky white inside: it makes thin projecting ledges a few inches thick. There is usually more shale in the upper part.

The lower twenty feet consisted of an alternation of (c) pinkish massive shale, which is like all the pinkish shales of the Oreodon, and (d) thick-bedded, calcareous, conglomeratic shale: it had an abundance of pink clay or shale fragments held in a matrix of calcareous shale. The term "shale" is again used in a textural rather than structural sense, the material showing no fissility or cleavage. The fragments are mostly angular or subangular: their maximum diameter is three-fourths of an inch, though the larger number of them are a quarter of an inch or less. In a few instances the fragments are nearly spherical and look like small marbles. The appearance of this member suggests an intraformational origin. Variations in this bed result where there is some very fine sand present, and where the shale fragments are scattering rather than abundant.

It is this bed (d) which gives the Lower Nodular Layer its nodular character, for it weathers into rounded, knobby forms. There is a resemblance between these nodules and the nodules seen in the Lower Oreodon. But the differences are that those in this bed (d) tend to run a little larger in size, are always pinkish in color, the color being retained on weathering, and the bed as a whole is more continuous. This bed is very commonly fossiliferous and is the one referred to by the collectors as the "red layer."

The Lower Nodular Layer varies somewhat in thickness and varies in the proportion of the harder and softer members, so that locally it loses its prominence: but on the whole it is easily recognized over the whole area where this portion of the Oreodon is present.

The member above the Lower Nodular is a rather uniform, massive, pinkish shale, somewhat grayer in the upper and lower portions. This is like all the shales of the Tertiary in its fine, clay-like texture and its lack of the usual slabby shale structure. In the upper portion in some localities this bed has a somewhat more sandy character, the sand being always very fine. This member stands up well under weathering. An analysis of this shale is listed as No. 6 in Table 5. Other physical qualities are given in Table 8, No. 4.

(3) Upper Oreodon.—The prominent member of this division is the Upper Nodular sandstone. This is a bedded sandstone series consisting of a sandstone made up of very fine sand, quite solid, in beds six to fourteen inches thick, alternating with material which is practically the same but is thinner bedded and softer. Occasionally there is a bed of massive, pink shale one to three feet thick, usually in the upper part of this series. The term "nodular" is not a good descriptive term. Some of the harder beds weather into partially rounded forms, but the layers are commonly continuous rather than a series of connected nodules: only locally is the nodular character prominent. The nodules are similar to the nodular sand-

stone found in the Lower Oreodon in that they are apt to weather with a faint brownish exterior and often have a pitted surface due to the more rapid weathering out of small mud-like balls. However, its high position and greater continuity serve to distinguish it. Its distinctly sandy character and lack of pink color as well as its position serve to differentiate it from the Lower Nodular.

Above the Upper Nodular is the highest member of the Oreodon. It is a massive, pinkish shale. This resembles very closely all the other pink shale in the Oreodon, i. e., clayey texture and lack of shaly structure, but differs in having a small quantity of very fine sand. In the upper portion this is more noticeable and locally approaches a shaly, fine sandstone in texture. At times a faint banding is indicative of bedding, but is not visible on close inspection.

There is no break between the Oreodon and the very bottom of the Protoceras and, since the fossil content is of no avail in making a separation, the contact chosen was determined somewhat arbitrarily. As far as the map is concerned this has made no difference, for the contact was always either along cliffs or very steep slopes and a shifting of the contact vertically ten or twenty feet would not show on the scale of the map.

The unconformable contact of the Oreodon with the Titanotherium has already been discussed.

Topographic Forms.—The Oreodon, because of its content of sandstone and sandy shale, and because of its alternation of harder sandstone and weaker shale, yields, on weathering and erosion, forms quite different from those of the Titanotherium. Steep slopes, sharp crests, peaks, and spires are the types most common. Projecting ledges, irregular outlines, bizarre imitative shapes are of frequent occurrence. Where a more resistant member is underlain by a weaker one of some thickness a true cliff (seventy to ninety degrees) results; for instance, the Upper Nodular (resistant) on massive shale (weaker). Slopes of twenty-five to thirty-five degrees are very common and slopes of forty-five to sixty degrees are of more than occasional occurrence. It yields an amazing number of sharp gullies and narrow draws and canyons. The great variety and much of the scenic quality of the "Wall" and outlying buttes are due to the manner in which this formation erodes. In this respect the Oreodon resembles very much the Protoceras. Where the contact of the Oreodon and Titanotherium is obscure it may be determined by the rather abrupt change of slope—topographic unconformity—between the two. The photographs (Plates IV to VII) show the types of forms described. Even on continued erosion and reduction of height of an Oreodon butte the slope remains steep. The miniature butte shown in Plate XIV B is in slope and form quite like its larger neighbors.

The following fossils were found in the Oreodon:

Hyracodon nebrascensis Leidy
Hyracodon major (?) Osborn and Wortham
Metamynodon planifrons Scott and Osborn
Caenopus occidentalis Leidy
Caenopus copei Osborn
Mesohippus bairdi Leidy
Oreodon (*Merycoidodon*) *culbertsoni* Leidy
Oreodon (*Merycoidodon*) *gracilis* Leidy
Leptomeryx evansi Leidy
Elotherium (*Entelodon*) *ingens* Leidy

Elotherium sp.
Perchoerus probus Leidy
Hyaenodon cf. *horridus* Leidy
Daepoenus sp. (?)
Stylemys nebrascensis Leidy

The Protoceras.—This formation, like the others of the Tertiary, is named from the fossil content. In this particular area not a single Protoceras fossil was found. Other fossils were found but no one form dominated sufficiently to warrant a biological name for the formation. The name was retained because of its application to similar beds farther west in the Badlands.

The Protoceras is limited in its distribution, being confined to the higher parts of the "Wall" from the "Castles" to about a mile and half east of Cedar Pass.

This is predominantly a sandy formation, in contrast to the sandstone-shale alternation of the Oreodon. The sand is very fine in texture, with one local exception. The chief characteristics, succession, and thickness of the beds are tabulated below (Table 7) as a basis for further description:

F	Coarse sandstone and conglomerate	0-5-20
E	Massive fine (shaly) sandstone	50-60
D	Massive fine sandstone—"Road Metal"	20-30
C	Massive sandy shale	15-25
B	Bedded sandstone	20-25
A	Massive sandy shale	30-35

Table 7. Divisions of the Protoceras

Bed A—At a distance this bed resembles the massive shale of the upper part of the Oreodon, except that it is more gray and less pink. In fact the pink colors of the Protoceras are commonly fainter and grayer than those of the Oreodon. Perhaps its color may best be described as an indistinct banding due to alternations of light grays with a faint overtone of pale pink. On closer examination it is seen to have a noticeable quantity of extremely fine sand, with the usual clay and silt. There are also a few scattered, poorly defined, fine sandstone nodules. The bottom member is a very light gray, almost white band a few inches in thickness, which is occasionally enough harder to make a projecting ledge. All this bed has calcareous material as cement, the bottom band having the most.

Bed B—Consists dominantly of a light gray, fine textured sandstone which is noticeable because of its pronounced bedding habit; beds four to ten inches thick. There are some softer shaly sandstone beds and an occasional massive pink shale similar to the massive pink shale so common in the Oreodon. When well developed this sandstone resembles the Upper Nodular sandstone. With a thinning of the sandstone and an increase of the shale the bed is locally indistinct. The Cedar Pass road, just at the crest of the Pass, touches the top of this bed.

Bed C—Massive, fine sandy shale, pinkish gray in color and with fine sandstone nodules scattered through it. Practically identical with Bed A.

Bed D—This is a very characteristic layer. It is a massive, uniform sandstone with a very fine texture. Its color is light gray to white. On weathering the outcrops develop rounded forms which yield quantities of small angular fragments. A boulder of this sandstone when struck a blow with a hammer breaks into hundreds of these small fragments, and an outcrop often looks as if it had been spread with a thin layer of half-inch size road metal; hence it is referred to as the "Road Metal" bed. The solider portions weather with small pits irregularly spaced. The weathering also brings to light harder nodular spots three to six inches in diameter, which have a pinkish brown exterior, while within they look like the main body of the bed. An analysis of this bed is given in Table 5, No. 7. Other physical characteristics possessed by this sandstone are listed in Table 8, No. 6.

Bed E—This bed resembles in a general way beds A and C, but has a greater quantity of very fine sand; it is more of a sandstone, though after weathering the surface of the softer portions yields an outer, thin layer of fine, sandy, clayey material, which in places gives the appearance of a sandy shale beneath. The greater quantity of sand present is also indicated by an abundance of fine sandstone nodules which are visible only when near the outcrop. Near at hand the bed seems wholly massive but at a distance there is apparent a vague, wide bedding or trend of the material. It stands up well under weathering, and erosion and makes steep slopes. (See No. 7, Table 8, for further physical properties.)

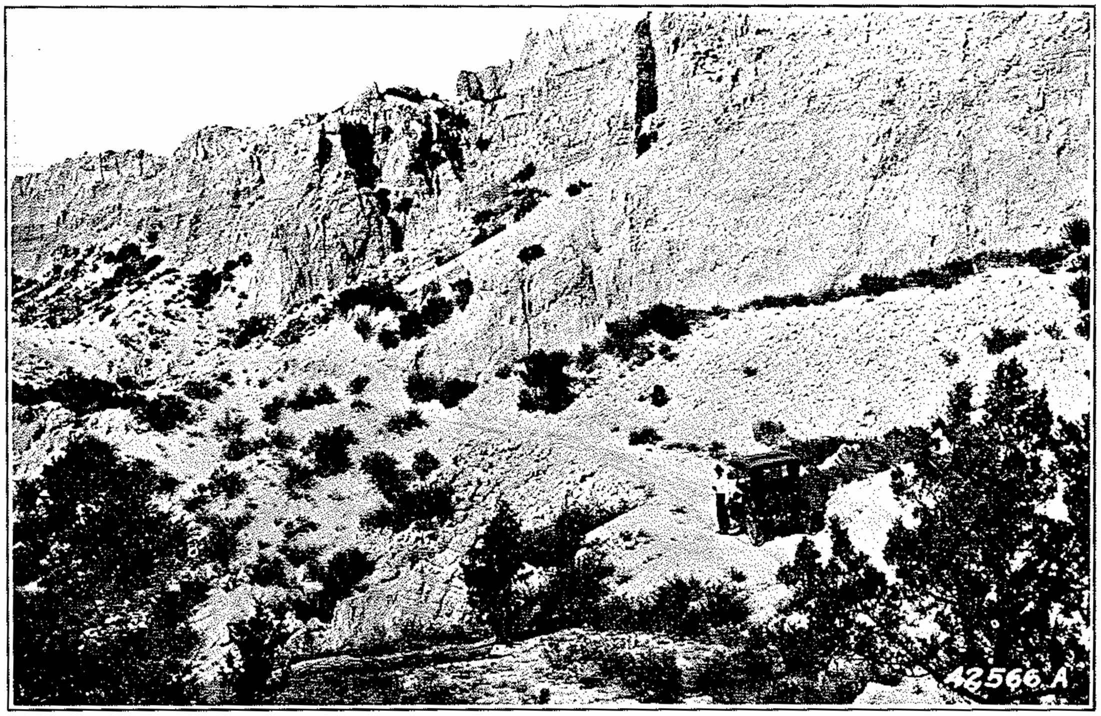
Bed F—There is hardly any resemblance between this bed and the other members of the Protoceras, for the members of this differ from all the others in texture, color and continuity. They are very local, obviously channel deposits cutting down into and across the other beds. While always in the upper part of the Protoceras they are not always the very top of the formation, though the very highest part of the "Wall," just east of Cedar Pass, is capped by this material. The bed as a whole trends more east and west than north and south.

The members of this bed are medium to coarse sandstone and conglomerate (maximum pebbles five inches in diameter). The fragments are various:—Tertiary fine textured sandstone and some shale, quartz, feldspar, mica (Muscovite) flakes, hard, siliceous, metamorphic rocks of several kinds and fossil bones (Tertiary). The sandstone and shale are well rounded, the other fragments, because possessing greater resistance, are subangular. The colors are greenish. The upper members are less green and usually have more mica flakes present; the lower members have more decided green colors and may even be bright green. In the southwestern quarter of Sec. 22. T. 3, R. 18 a typical occurrence of this series may be found: a sketch and photograph of it are shown in Figure 5 and in Plate XV.

The topographic forms that develop on weathering and erosion of the Protoceras are very rugged. Steep slopes are the rule. The pinnacled, castellated and sharp-crested character of the highest part of the "Wall" is evidence of this. Because of this fact much of the Protoceras is inaccessible and nearly all of it is difficult to climb. The few flat-topped parts of the "Wall" mark the places where the heavy-bedded, coarse sandstone and conglomerate of Bed F are present. The Middle and Upper Oreodon and the Protoceras are quite similar in topography. All the steep slopes are alike also in that they have either a very thin veneer of small fragments or are weakened enough by weathering to yield such when walked upon. As a result the climbing is made especially difficult, for the fragments are just small enough to roll beneath the foot, acting with the same effect as a lubricant against the hard, unweathered ledges beneath.

The following fossils were found in the Protoceras:

Caenopus tridactylus. Osborn
Eporeodon (?) (*Eurrotaphys*) *major.* Leidy
Perchoerus robustus (?) Marsh
Stylemys nebrascensis. Leidy



—Photograph by U. S. Forest Service

PLATE VIII A
CEDAR PASS ROAD

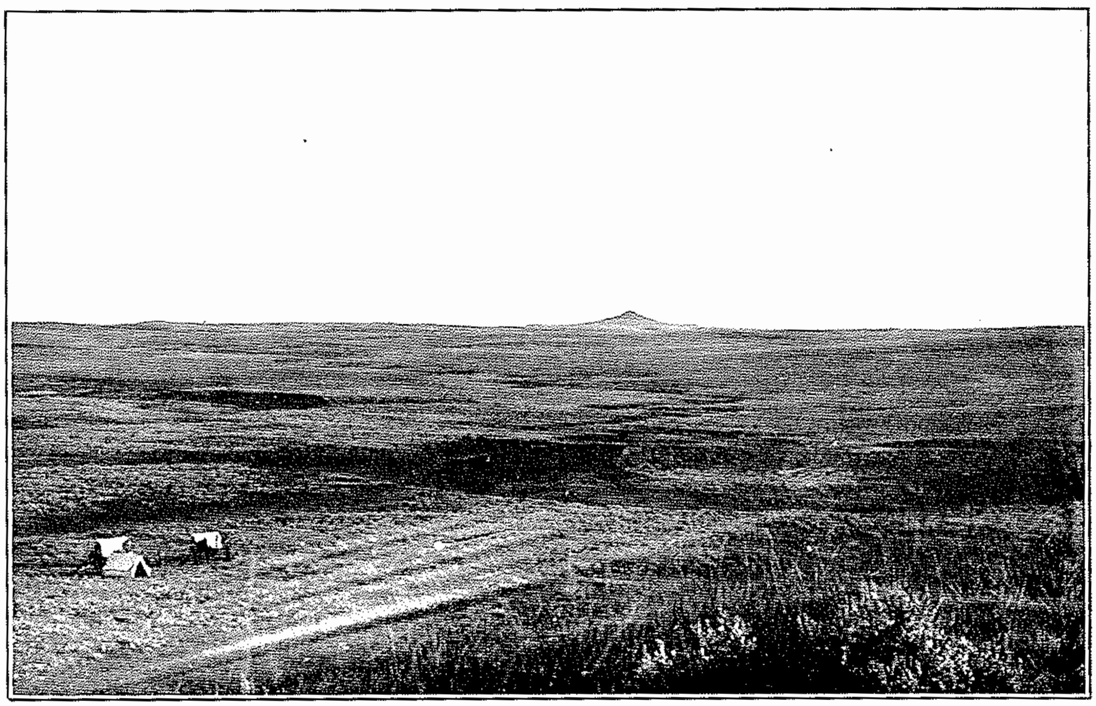


PLATE VIII B
GENERAL PRAIRIE LEVEL, ABOVE WHICH BUTTES RISE AND BELOW WHICH VALLEYS ARE CUT

Sandstone Dikes.—Nearly vertical dikes of fine sandstone are a fairly common feature of the Upper Tertiary. They are particularly common through the Protoceras, less so in the Middle and Upper Oreodon, and rare in the Lower Oreodon and Titanotherium.

They are composed of very fine-textured sandstone which resembles very closely,—in fact is practically identical with—the sandstone of the Protoceras. They are from about an inch to six or eight inches in width. Their thickness diminishes with depth and many are seen to die out completely. They rarely have a length of a few hundred yards. There seems to be no well marked system in their arrangement, as may be seen by the following strikes:

N. 10 E., N. 25 E., N. 35 E., N. 40 E., N. 55 E., N. 60 E., N. 65 E., N. 80 E., east and west, N. 15 W., N. 30 W., N. 45. W., N. 50 W., N. 65 W., N. 70 W., N. 75 W. Since their trend is somewhat undulating, the strikes were read only to the nearest five degrees. It is quite obvious that they represent cracks which have been filled from above. In the matter of origin they will be referred to again under Structure.

Some of these dikes have been channels for underground water, for they are stained with brownish and greenish colors as a result of alteration.

PLEISTOCENE

The quantity of this formation found in the area is not large but it furnishes one of the most interesting problems encountered.

The Pleistocene has two modes of occurrence which may be referred to as "In Place" and "Residual."

In Place.—This member is found almost entirely on the several flat-topped buttes which are scattered through the Lower Prairie, such as Herley Butte, Tenderfoot Butte, etc. It is absent in the "Wall" and nearly lacking in the Upper Prairie, occurring only in the northeastern portion on the rolling hills there.

It consists of a layer of coarse gravel overlain by a sandy loam through which may be scattering small gravels. Maximum thickness twenty feet, about one-third being gravel. It is unconsolidated. The very top has soil and is sodded, and it is this that gives the flat-topped form to the buttes.

The gravels and pebbles are largely the Tertiary, fine sandstone fragments, quite well rounded; but with these are mingled very hard quartzitic materials, most of which are subangular, only a few being well rounded. These harder fragments consist mostly of plain quartz, quartzite or vein quartz with many colors, especially browns, tans and reds; others are quartzitic metamorphosed materials, mostly dark colored,—some feldspar, granite rare. Diameter of larger fragments, two to six inches.

Residual.—It is quite obvious that the beds described above must have had formerly much wider distribution; at present they are mere remnants. Such material when submitted to erosion would for the most part be readily removed: the loam and sandier parts would wash away with great ease; the softer Tertiary fragments would soon be worn down to oblivion; the harder quartzitic material would persist indefinitely and would settle down on the Tertiary formation beneath. On the erosion of the Tertiary beds the resistant fragments would still remain as residuals, especially the larger ones which could not be easily swept into the stream channels. Such is the conception of the residual Pleistocene member.

These residual gravels are of wide distribution. They are found on the Pierre, Tertiary, Oreodon and Protoceras, on the low-lying Prairies, on the highest parts of the "Wall,"—indeed, they are found practically everywhere where the sod cover has been removed. Since the sod cover is more continuous in the Upper Prairie, the residual gravels are less noticeable there. In some localities the gravels are so abundant that one can walk many yards without stepping on any other material.

The fragments, with one local exception, are very hard. Most (probably ninety per cent) of them are made up of quartzitic or siliceous materials which were once part of some metamorphic group of rocks; some of them are banded or gnarled in appearance, though most of them are not, and only one was found which possessed a true schistose structure. Vein quartz and ordinary quartzite are fairly common. While being alike in their dominatingly siliceous character there is still much variety in quality and texture. Some of the siliceous fragments are Paleozoic corals. The colors are also varied—dark browns, yellow browns, reds and undeterminate dark to black colors, and light yellowish grays to nearly white, are common. Some of the tones are very rich. The remaining ten per cent consist of sandstone, conglomerate, dolerite, granite, felspar and limestone. The first three of these are very rare, only a very few fragments being seen. The granite was found sparingly and only in the western part of the area. Part of it was medium-textured gray, more of it was a coarse to pegmatitic, pinker variety, some of which contained tourmaline. The feldspar (pink to cream orthoclase) was more frequently seen, a few of the pieces being three inches long. The limestone was found only in the south central part of the area; three varieties were found. It seems to be an anomaly among all the hard, resistant types.

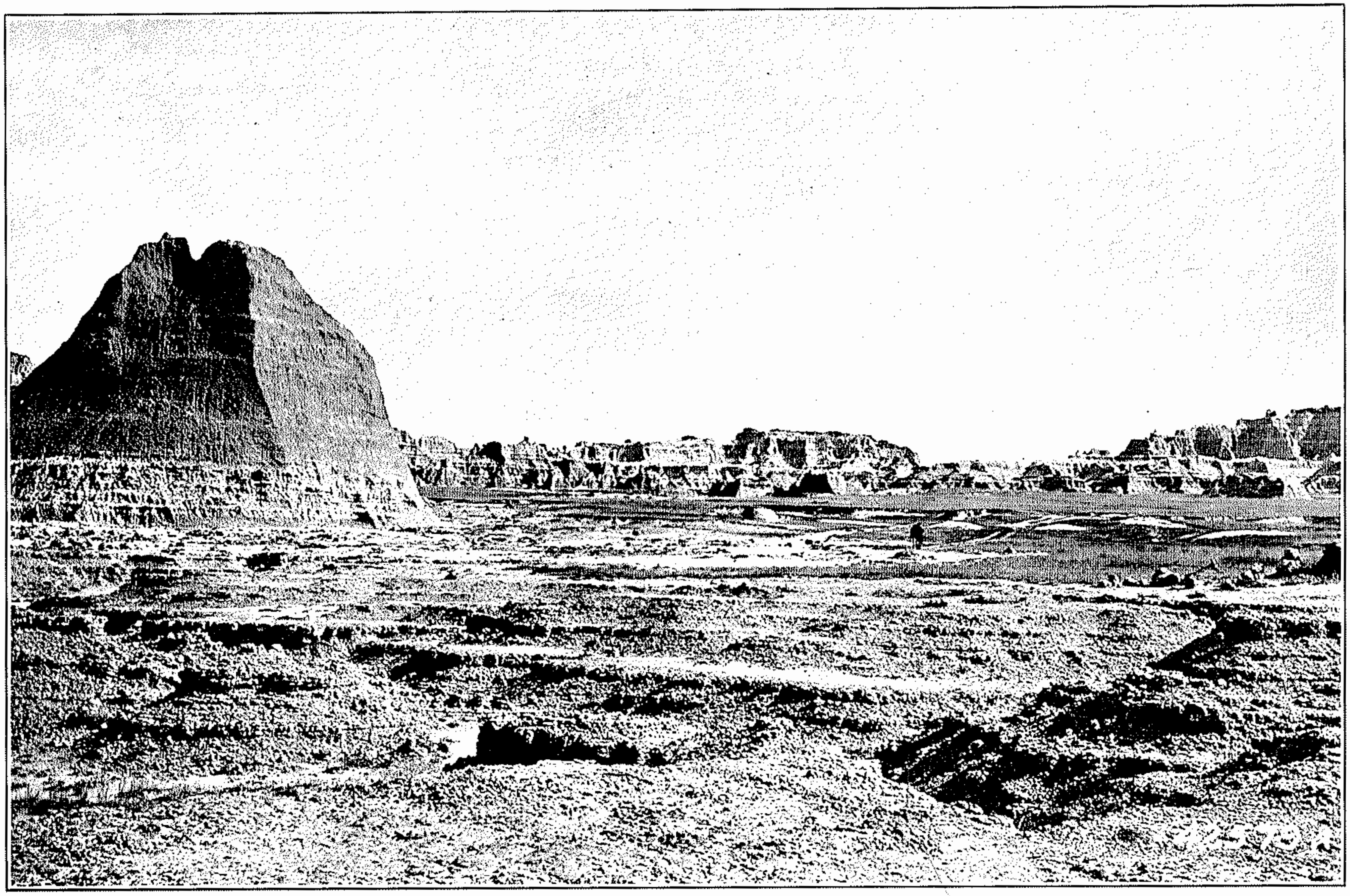
The size of the fragments usually ranges from one to four inches in diameter, but five to eight inch sizes were also fairly common. Occasional cobbles or boulders up to twelve or fourteen inches in diameter were seen.

One of the distinguishing facts about these gravels and cobbles is that fully ninety per cent of them are subangular. This is true even of some of the softer limestone fragments. Very few of the fragments were well rounded and some were angular.

The matter of giving a satisfactory explanation for this Pleistocene material, particularly the harder siliceous fragments, involves a number of difficulties. This matter is reserved for discussion in a later part of this report, under Origin.

In one sense that part of the Pleistocene listed as "In Place" is residual, for it is believed that the hard gravels were first deposited as part of Bed F in the Protoceras. The weathering and erosion of this bed (formerly more widespread) supplied materials, part of which (the coarse, more resistant fragments) were moved but a very short distance before being deposited as the "In Place" material above described.

It should be noted, too, that the term "Pleistocene" as applied to these deposits may be a misnomer. They certainly are post-Protoceras and are older than the materials rated as "Recent." There is no evidence for calling them Arikaree or Pliocene, in fact their position relative to the Valley Cycle (which see under Physiography) seems clearly to place them later.



—Photograph by U. S. Forest Service

PLATE IX

NORTH SIDE OF THE "WALL," NEAR CEDAR PASS

RECENT

The recent deposits are of two sorts, viz. flood plain deposits and Piedmont Plain deposits. No attempt will be made to discuss the more modern deposits such as wash, channel fillings, etc.

Flood Plain.—Only the flood plain along the White River will be here considered. The tributaries and smaller creeks have flood plains but they are not of sufficient size or importance to receive special treatment.

There is nothing unique in the deposits along White River. The flood plain is quite typical. The materials are fine sands and silts, rarely clays. Gravels and coarse sands are common along the present sandbars and are encountered at various depths in wells. No accurate figures are available for the thickness of these deposits. Wells and exploration with auger in the neighborhood of the bridge show a depth of twenty to thirty-two feet, which may be taken as representative.

Piedmont Plain.—Along most of the "Wall," the river bluffs, and around all the buttes and abrupt higher ground are Piedmont Plains. They are small but are typical in their position relative to the higher tracts, their gradual diminishing slope away from these heights, and their variations in bedding. In other words, their coalesced, alluvial, fan type of origin is apparent. The flatter portions farther away from buttes, the "Wall," etc.—in fact all the sod covered parts of both the Lower and Upper Prairie (except of course the Flood Plain—are here included as Piedmont, which developed as the once more extensive "Wall" and buttes receded to their present position.

As is to be expected, the materials are almost wholly the Tertiary sandstone and shale. There is some admixture of the hard, siliceous, Pleistocene fragments. There is no cementing material present, but there is enough fine silt and clay to act as a binder, so that some of the deposits are quite firm and stand up as cliffs when cut by modern streams. The colors are light gray to white and are very glaring in the bright sunshine.

While in the very nature of the case there is much variation in the beds and texture, a division generally can be made into an upper and lower portion. The lower is coarser (maximum four inches), more angular, more poorly sorted, and is more freely cross-bedded. The upper by contrast is finer in texture, beds more continuous, has less cross-bedding. Some of the more continuous beds locally resemble in general appearance and texture the sandstone members of the Oreodon.

The thickness ranges ordinarily between ten and twenty feet, although locally there are extremes exceeding both of the limits.

The process of deposition must have been halted from time to time, long enough for soil to form and vegetation to grow. The evidence for this lies in dark colored beds occurring at several horizons. These beds are nearly black in the upper part, grading down into browner subsoil. Humus fragments are plainly visible. The soil was thicker than the present soil, indicating a probable climatic difference. Further evidence of the soil origin of these beds is the fact that in some localities the beds contain flint implements and pottery fragments.

ORIGIN

GENERAL STATEMENT

In one sense the origin may be very simply stated. Since all the rocks are sedimentary there must have been at first a period of deposition during which the beds described in the preceding pages were laid down one upon the other in orderly sequence, beginning with the oldest (Pierre) and ending with the youngest (Protoceras). There were some haltings in the process, notably after the Interior and less prominently after the Titanotherium, during which erosion was active. It is now the common belief that the beds of the Badlands were brought in and built largely by rivers flowing along broad, shallow flood plains. To a very minor extent deposition has been thought to have taken place in lakes; but the present studies have shown that lakes played a more important part.

At the end of the Protoceras time the beds were a continuous cover over the whole area and beyond, and the sediments were consolidated into rocks. There was no "Wall" or prairie or river valley but the whole region was filled to a monotonous level at least as high as the present crest of the "Wall" and probably higher.

Following the process of deposition, weathering and erosion began their work of weakening and removing the material. By the beginning of the Pleistocene time a fair amount of rock had been removed. Conditions changed so that deposition again ensued. Then followed the main period of erosion, which has continued to the present time and is still going on. The great variety of topographic forms which is seen in the area today is the result of the erosive cutting and carving of the formation. An immense quantity of material has been removed. Most of it has been carried out and away by the through streams; some of it has been redeposited in the area and is known as the Recent Deposit.

The history of the formation also involves some bodily movements and warpings of the earth's crust and probably some changes in climate.

The picture of the origin of the Badlands as just drawn is essentially true. There must have been a period of deposition or formation of the beds and it is equally the case that large sections have since been removed by weathering and erosion. But the origin becomes difficult of analysis when the details of the process are sought. Further discussion will be confined to the Tertiary. The Pierre makes up such a minor part of the area that its consideration should wait until a larger extent of it is studied in other parts of the State. It is sufficient at present to say that the Pierre is of marine origin, being deposited in a shallow Cretaceous sea.

The complexity in the origin of the Tertiary is almost wholly confined to the first portion of the history, viz, the details of deposition of the formations. The main points involved are: the source of the sedimentary material, manner in which the sediments were carried to this area, and the conditions under which they were deposited.

The facts which must be accounted for are as follows:

1. The alternation of two main materials—pink shale, gray sandstone.
2. Absence of bedding planes.—This is especially noticeable in the shale, which lacks the usual laminated or shaly parting. Even in the sandy layers bedding is in many cases

not apparent except as a larger vague trend seen at a distance.

3. Very fine texture of sandstone—not well sorted, clean sand. A mixture of very fine sand, silt and some clay.

4. No progressive coarsening or fining of texture in any direction.

5. Persistence of some of the beds.—Single beds traceable one half to one mile are not uncommon: one bed traceable over practically the whole exposure of Oreodon with no variation in texture and with a constant thickness of eight to ten feet. Other beds, such as the Upper and Lower Nodular, are also extensive.

6. Great variety of accessory mineral fragments, as shown under microscope.

7. Chemical peculiarities—especially absence or very low content of potash.

8. Subangular character of the Pleistocene gravels and cobbles.

SOURCE OF THE SEDIMENTS

The present distribution of the Badlands, broadly bordering the Black Hills and diminishing away from that region, points to a genetic relation between the two. Undoubtedly the Badlands were formerly more widespread, but in their widest extension they nowhere adjoined higher tracts which could furnish the material except the Black Hills or the Rocky Mountain region still farther west.

In the particular area under discussion there are no progressive, textural changes or variations in thickness of the series in any direction which could be used to indicate the source of the material; but descriptions of these formations as they occur twenty-five or more miles nearer the Black Hills show that the total thickness is greater and that such beds as the Titanotherium are sandier. This indicates an approach toward the source.

A microscopic examination of a dozen different specimens showed that quartz or feldspar were the chief minerals present, but that there was a large assortment of accessory minerals. The most common accessory minerals were muscovite, biotite, hornblende, garnet, apatite, pyrite, magnetite; less frequently were seen zircon, titanite, chlorite; rarely epidote, tourmaline, talc, olivine and fluorite were present. The great variety of minerals here listed suggests igneous rocks as a prominent source material. Sedimentary rocks would not so readily yield an assortment of such minerals The Black Hills satisfies the demand in this respect.

The Pleistocene gravel contains several materials that can be matched in the Black Hills. Some of the limestone is strikingly like the Minnekahta limestone; the brown and red, hard, siliceous fragments could easily have come from some pre-Cambrian material such as the "Iron Dike" between Deadwood and Lead; a few of the quartzitic conglomerates seemed identical with parts of the basal Deadwood formation; the large feldspathic and coarse granite could easily have come from the pegmatitic granite of the southern Black Hills.

Thus it seems well established that the source of the material was to the west; undoubtedly most of it came from the Black Hills region. This means that the materials were transported sixty to ninety miles before final deposition.

CONDITIONS DURING DERIVATION AND DEPOSITION OF THE SEDIMENTS

Since the sediments which make up the Tertiary beds were formed from the rocks in the Black Hills, it becomes necessary to try to reconstruct the conditions under which these rocks were broken down to furnish the sediment. Such an inquiry may throw light on the character of the beds as we see them today.

Influence of Climate and Transportation.—Since the sediments, even in the sandstone, are so dominantly of very fine texture, they must have been subjected to a great deal of decomposition and disintegration. Part of this must have occurred at the source during the weathering of the parent rocks; the rest of it must have been accomplished during transportation.

The fact that the bulk of the Badlands sediments are fine textured and that there is no apparent coarsening of the texture except quite near the Black Hills indicates that weathering at the source must have been extensive and deep. At the same time the soils developed by weathering were not thoroughly leached nor completely oxidized. This is indicated by: (a) the ample percentage of soda; (b) the fact that lime is not deficient; (c) the fact that magnesium is not in excess of lime: (d) the presence in sandstone of iron-bearing minerals such as biotite, magnetite, garnet, tourmaline, hornblende and pyrite. In order that such sort of weathering could take place the climate must have been humid and temperate or cool, rather than humid and hot, and the relief moderate.

High Soda Content.—The presence of a generous amount of soda and the absence (or very low percentage) of potash need some explanation. Usually the reverse is true. This reversal of the usual arrangement has been possible because so large a proportion of source rocks in the Black Hills are soda-rich, the soda being present chiefly as albite or nephelite. Analyses (U. S. G. S., Prof. Paper 14, 1903) of a dozen igneous rocks show that albite alone or with nephelite make up fifty-two to sixty-one per cent of the rocks. Even in a quartz porphyry the albite is more than half. Orthoclase makes up about one quarter of these rocks. By the time decomposition and disintegration—either at the source or during transportation—had practically removed the potash, there would of necessity still be some of the soda left. California is another state in which the soda-rich igneous rocks are prominent, and derivative sedimentary rocks show a similar dominance of soda over potash.

Massive Character of Strata—One of the striking things about the Tertiary formation is the general absence of bedding planes. The formations are plainly bedded in one sense, but this is due to the alternating of grayer sandstone and pinker shale. The shale beds show no laminations at all and a large proportion of the sandstones have very indistinct bedding. This means that the sediments of a given bed were supplied continuously with a minimum of sorting and with but little halting in the process. The major variation in condition was that which resulted in a change from shale to sandstone and repeat.

In order that a continuous supply of sediment be provided there must have been the removal at the source of readily transported material. Hence the deep cover of soil already postulated must have been steadily, continuously, and probably rather rapidly removed by running water. (An examination of the sandstone of this area shows an absence of wind-carried sediments or volcanic ash.)

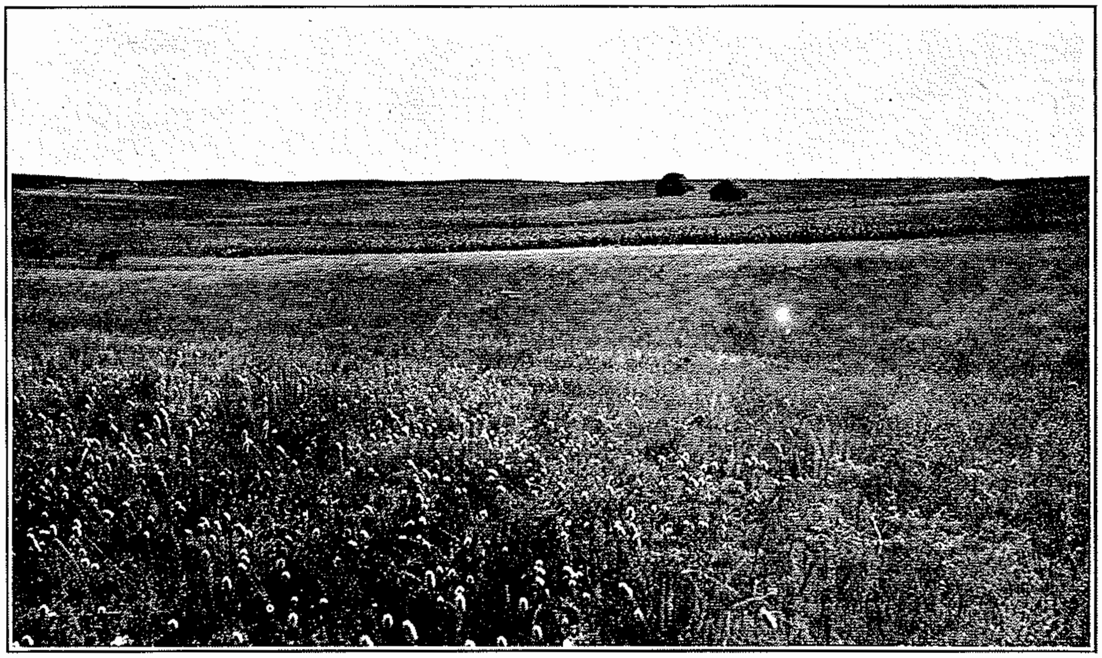


PLATE X A
LOOKING ACROSS UPPER PRAIRIE TOWARDS NORTH EDGE OF THE "WALL"

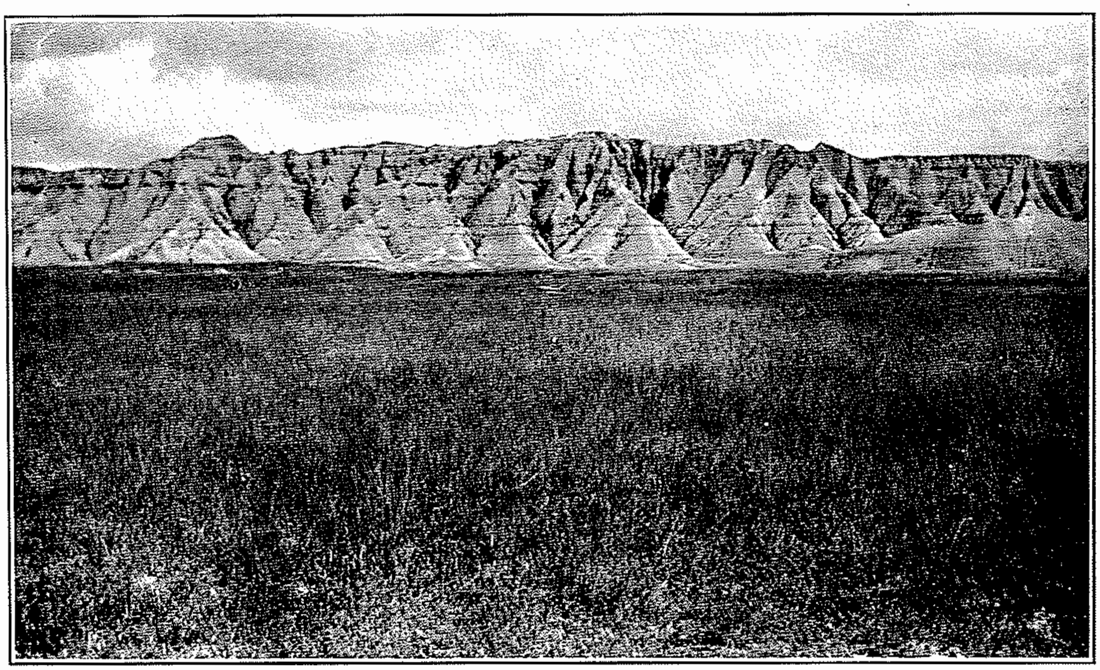


PLATE X B
SOUTH FACE OF THE "WALL" AS SEEN FROM THE LOWER PRAIRIE

This means that the ordinary balance between weathering and removal was upset, a condition that could be brought about by a climatic change resulting in the destruction of the protective cover of vegetation, or by an elevation of the land producing an acceleration of erosion.

In regard to a possible climatic change, a change in climate which would result in lessened vegetation would be either arid or frigid. In either case: (a) the removal of the soil already formed would be slow and sporadic, which is contradicted by the beds themselves; (b) and the sediment developed for the next successive beds would show a dominance of mechanical weathering which is not the case; (c) the shale gives strong evidence of being formed in lakes, which could not exist if an arid climate prevailed, and would not be likely in a frigid climate; (d) the succeeding beds show a similarity in quality and succession, which would mean an alternation between humid and arid at repeated and frequent intervals through the whole Tertiary series, a fluctuation which is far from probable. That the climate did change somewhat during deposition of the Tertiary is probably true, but it did not dominate in the successive way above imagined.

In regard to uplift, since the climatic alternative has been swept aside, the uplift seems called upon to account for the facts. The necessity of uplift may be measured by considering the result if no uplift occurred. The area at present occupied by Tertiary sediment derived from the Black Hills is about four times that of the elevated part of the Black Hills from which the sediment must have been eroded. The Badlands were certainly more extensive at the time of their completion. It is a conservative estimate to say that the Tertiary receiving ground was five times the area of the Black Hills erosive tract. This means that for every foot of sediment in the Tertiary five feet were removed from the Black Hills. (No account is taken of material removed in solution.) By the time the five hundred feet of beds were deposited in the area under discussion the Black Hills would have been reduced some 2,500 feet. And the latter members of the Tertiary should be made of the finest muds and clays. As a matter of fact the upper members are sandier than the lower. However inaccurate the above five to one ratio may be, it seems quite necessary that some uplift was required: and an intermittent and recurrent uplift fits the facts the best.

Sequence of Events.—Under this conception of uplift as the determining agent the sequence of events may be outlined as follows:

1. Stable conditions with humid and temperate or cool climate. Deep weathering of source rocks in Black Hills with moderate leaching.
2. Uplift with accelerated erosion. (a) Removal of finer, well oxidized soil which was deposited in lakes as clay which later became shale. (b) Removal of less fine and mostly unoxidized subsoil: by this time the run-off was at a maximum and this sediment was spread as sandy river deposits over the clay and later was consolidated into sandstone and sandy shale; the more active current portions made local channel deposits. Erosion dominated until reduction of elevation produced another balance between soil formation and removal.
3. Repetition of above processes.

The clays of course required water for their deposition. While some of the smaller thin beds may have been deposited as flood deposits on a flood plain, most of them must have been laid down in lake waters. The chief reason for thinking so is the marked continuity of the beds, their uniform character and considerable thickness. Clay deposits on present-day flood plains—such as the broad Missouri—are commonly thin and do not keep their continuity for more than a few hundred feet; very rarely can a bed be traced a quarter of a mile. The shale beds of the Tertiary are continuous commonly for a quarter to three quarters of a mile and a few are a mile or more in extent; while all the Titanotherium and at least one shale bed of the Oreodon are continuous over the whole area. The presence of large, succulent algal growths points also to lake conditions. It was in such lakes that the occasional thin lens of limestone was deposited, probably through the agency of the algae rather than evaporation.

The thickest deposit of clay is in the lowest member (Titanotherium) of the Tertiary. Erosion of the Black Hills did not start until a very deep cover of soil was produced. This was possible because of the nearly peneplain condition which must have resulted by the end of the Cretaceous, which in turn is indicated by the fact that the Fox Hills and Lance are so generally removed from all but the northwestern part of the State and that the Pierre is cut into to such a uniform depth. It is generally believed that intrusions of the various "porphyries" of the Black Hills took place in Eocene times; this undoubtedly was accompanied by uplift in that region. That uplift initiated the erosion which furnished the Titanotherium sediments, the lowest of which are red. The greenish cast in the upper main part of the Titanotherium indicates reduction of the iron through organic agents.

That no sandier beds (except the rare channel deposits) followed during Titanotherium time resulted because sufficient movement took place in the area of deposition so that the Titanotherium was exposed to erosion. Following the erosion interval, which probably was not very extended, the deposition of the Oreodon and then Protoceras took place with very little interruption. There was probably not much halting of deposition with exposure of the beds to the air for there is a general absence of sun cracks and no accumulation of evaporation products.

The progressive, intermittent, and moderate uplifts which controlled the deposition processes thus far described increased in amount, bringing the Protoceras to a close and inaugurating a period of erosion instead. Premonitions of this larger uplift are seen in the increased sandier character of the Protoceras and the occasional channel fillings in the upper part.

Erosion progressed sufficiently far to cut broad, wide valleys deep enough in some cases to reach through the Protoceras into the Oreodon beds.

Deposition ensued again with the laying down of the coarse Pleistocene gravel on this broadly undulating surface. Most of this was resistant residual material washed out of the upper beds during the previous erosion cycle; the rest of it was locally derived.

After the deposition of the Pleistocene there followed, probably largely because of uplift, the great erosive activity which has continued with few interruptions to the present.

Color of the Beds.—The color of the pink shale is due to the presence of ferric oxide (hematite or turgite). This is possibly the original color of the sediment, but it is more likely that the coloring material was the hydrous form of ferric oxide (limonite), and that the original colors of the sediments were yellow-browns and tans. Dehydration during and after consolidation is a common process.

The gray or white color of the sandstone does not mean an entire absence of iron compounds. Analysis shows that the total quantity of iron is only a little less than in the shale. However, most of the iron is not in the oxidized condition but is still in the original mineral fragments, such as hornblende, magnetite, biotite, garnet, and pyrite. Another reason for the more striking pink of the shale is the physical condition. The ferric oxide is in an extremely fine state of division and is evenly distributed through the fine textured clay substance.

Coarse Channel Deposits.—One more point concerning the origin of the sediment is still to be considered. This is in regard to the coarse channel deposits of the Protoceras, some of which are still found in place and which have been the original source of the residual Pleistocene gravel.

There is no doubt that these gravels and cobbles were derived from the Black Hills region, but the difficulty of the problem lies in the fact that so few of the fragments are well rounded. Most of them are subangular, some angular. If the distance of travel is long it is practically impossible for even siliceous fragments to remain unrounded during ordinary river transportation: and for such material as feldspar and particularly limestone fragments the rounding process would be still more rapid. Daubree[1] in experimenting with the abrasion of quartz and granite fragments during transportation found that they became rounded after a journey of about fifteen miles. Barrell[2] has stated that quartz, chert, or quartzite are alone able to withstand transportation for distances of one hundred miles or more. The nearest outcrop of Minnekahta limestone is sixty-five miles in a straight line and yet not only are fragments of this limestone found in the gravel but they are subangular: in fact they are no more rounded than fragments of the same limestone in the Pleistocene deposits at Hot Springs where the transportation was only a mile or so. The source of some of the siliceous fragments is seventy-five to ninety-five miles away—air line measurement—which means a river haul of at least a hundred miles.

A few of the subangular pieces are distinctly faceted. This suggests either glacial action or wind erosion. Thus far no other evidences of glaciation have been found in the Black Hills region; and there is no evidence in the sedimentary series of the Tertiary to prove aridity. Wind erosion is conspicuously absent in the present day Badlands. If the faceting by the wind took place after the gravels were laid down in the beds there is still necessity for explaining the presence of the limestone so far from the source. And if the faceting took place near the source, how could the fragments be transported so far without rounding?

The most reasonable explanation is that the fragments before traveling far enough to be rounded were frozen in blocks of river ice and so made the greatest part of their journey without abrasion. The dragging of such blocks of ice might account for some of the faceting, though faceting by wind erosion at some point along the journey is not wholly excluded.

In connection with a study of the origin of the Tertiary formations it should be kept in mind that some of the materials of which the beds are composed may have come from other mountainous tracts farther west than the Black Hills. The part this has played cannot

[1]Geologic Experimentale (1879).
[2]Relation between Climate and Terrestrial Deposits, in Journ. Geol. XVI, 1908, p. 367.

be large compared with the Black Hills source already considered, and its actual value cannot be determined until detailed studies have been made of a larger portion of the Badlands.

STRUCTURE

Under the term structure will be here included only the position or attitude of the beds, and faulting. Igneous and metamorphic structures are of course lacking, and the detailed internal structures of the sedimentary rocks themselves have been sufficiently presented in the chapter on the Formations and Origin. On the whole the structure of this area is rather simple.

ATTITUDE OF THE BEDS

The beds are essentially flat throughout the area. If they were absolutely flat there would be little else to say. But they show some, though slight, deformation.

In order to determine the attitude of the strata, lines of levels were run on the most persistent beds that could be reached, the work all being plotted and mapped by the use of plane table and telescopic alidade: measurements were all made by stadia. In using the beds in this manner the characteristics of the formations should be kept in mind, as follows:

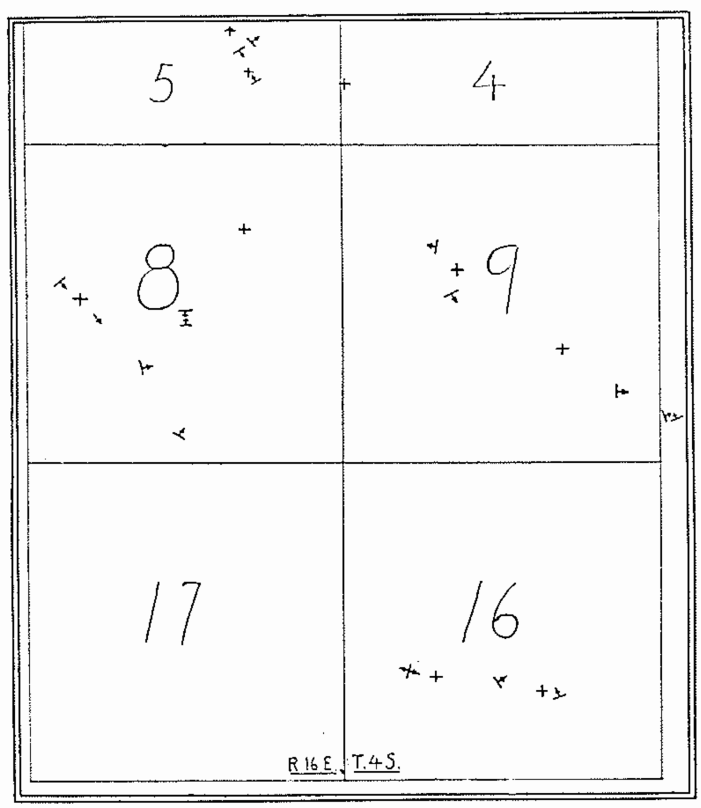


Figure 6. Dips and Strikes of the Interior

The beds in the Interior are plain enough in the individual outcrop to work out the dip and strike; but they cannot be correlated between outcrops even for short distances. It was found, too, that cross-bedding was present, which will throw some doubt on the dips worked out in the smaller exposures. The structure, as revealed by the dips and strikes in this formation, has no definite trend

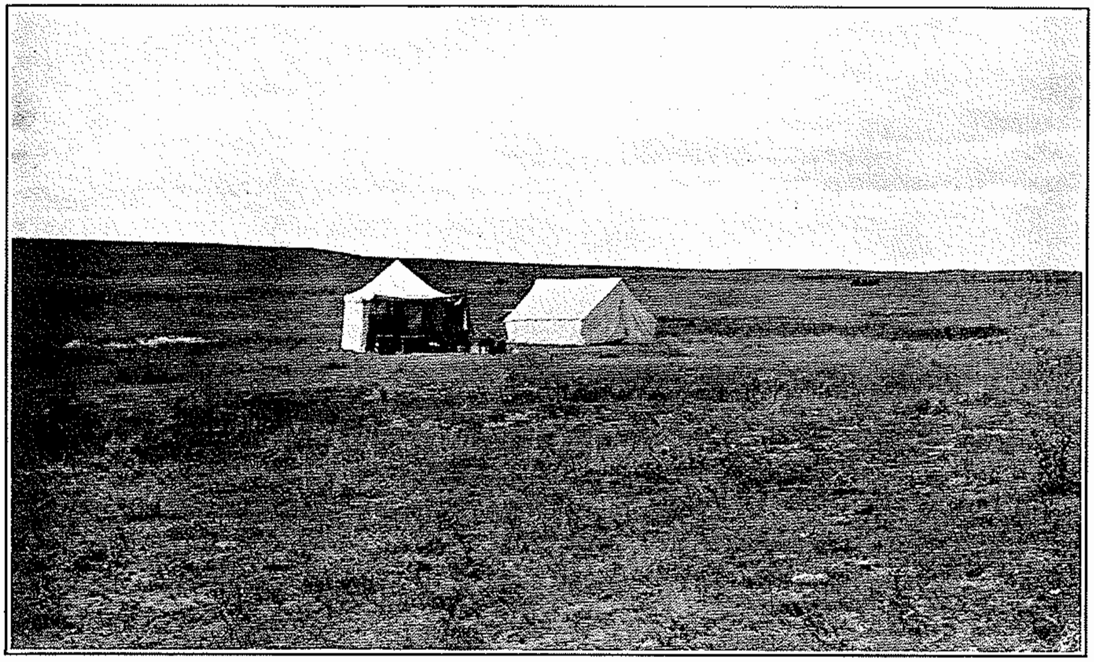


PLATE XI A
GENERAL VIEW OF THE UPPER PRAIRIE

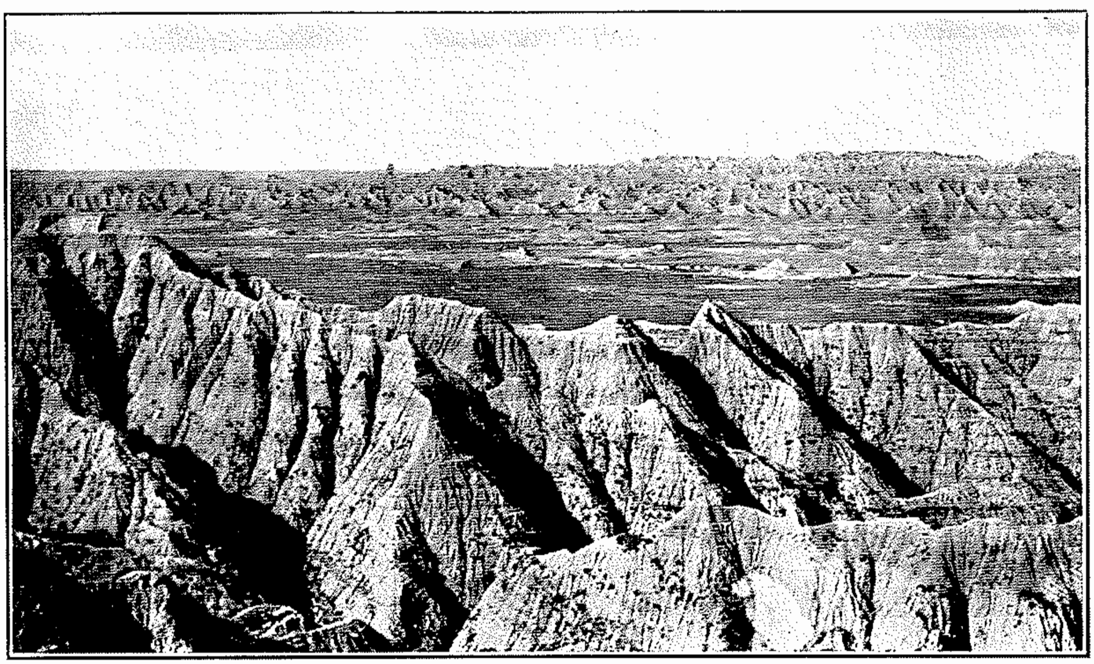


PLATE XI B
BADLAND "BASIN"

in any particular direction nor is any progressive, persistent raising or lowering of the strata indicated. This is shown by a glance at the accompanying map (Figure 6.), where a series of dips and strikes is plotted for several sections on a large scale. The dips are all low, five degrees being considered high. It is apparent that a study of the dips and strikes in the Interior formation reveals only minor undulations rather than large regional structure.

The Titanotherium is too massive and uniform to furnish index beds. It was hoped that the cherty limestone beds might be used as index beds in the places where other evidence was lacking, especially to compare one small flat topped butte with another. But it was found that there are two—and in one place three—horizons where these lenses occur. And there is nothing in the limestone to indicate which is which.

The Protoceras beds were too inaccessible to be of much aid in working out structure.

The Oreodon, then, is the only formation in which usable index beds are found. The shale beds are the most persistent and uniform and, where the outcrops are nearly continuous (as along the "Wall"), can be followed for considerable distance. Since the different shales are so much alike lithologically it is difficult to correlate them between separated outcrops and if exposures are very far apart it is impossible to do so. It must be borne in mind too that the beds are lenses and apparent dip may be due to the thinning of the sandstone on which the shale is resting rather than to true deformation. Since the Oreodon is absent over much of the area, good evidence for structure is lacking there.

The initial dip due to sedimentation should be almost due east: this is found to be the case over much of the area. It is modified in the central part of the area by a southerly component, so that the dominant dip as found is southeast.

The dips are most persistent and uniform along the whole extent of the "Wall," except in the extreme east end (Sect. 16, T. 3, R. 19), where the beds are flat. The maximum dip observed in this tract was two and one half degrees: most of the dips are less than one degree, and commonly range from forty to one hundred and twenty feet a mile.

It was found that while this gentle tilt of the formation was steadily maintained throughout the "Wall" province it was also noted that there were cross warpings and occasional local reversals.

Along the Lower Prairie away from the "Wall" the beds were practically flat. North of the "Wall" there was less evidence to be obtained. The scattered buttes for the most part were lacking in dip, though occasionally very low southeast dips were noticed.

Thus it may be said that the form the beds as a whole assume is that of a poorly defined terrace striking E. N. E. There is, however, no evidence of a closed structure.

In the southwestern part of the area the flat structures prevail except in the vicinity of Sect. 17, T. 4, R. 17, where there seems to be an anticlinal warping. This is strongly indicated because the typical Pierre outcrops along the river in this section and does not outcrop either up or down the river for twenty miles; the nearest place where it outcrops is twelve miles to the northeast, where the regional dip brings it up. As an alternative, the presence of the typical Pierre in this locality may be accounted for by considering it as a higher portion of the old surface, developed on the Cretaceous by erosion before the Tertiary formations were deposited. The Interior is thoroughly conformable with the Pierre; in fact the contact is gradational. If the old Cretaceous surface had a rolling topography and this particular spot marks one of the ridges or knolls, then one would expect the Tertiary cover to show some overlap. The facilities for observing this feature are limited by the number of outcrops. However, the Titanotherium overlies the Interior for more than a quarter of a mile at the point where Pierre is below. As far as the eye can judge it has a conformable position, giving no evidence of overlap; the contact is a disconformity rather than an angular unconformity. The same relation holds between Titanotherium and Interior at many other places where the Pierre does not show below. Hence the explanation of the presence of the Pierre as a higher point in the pre-Tertiary landscape is not convincing.

The facts better fit the theory that the typical Pierre was brought up by anticlinal warping. Other evidences of regional disturbances are the undulations of the Interior and the terrace structure already mentioned, as well as the faults discussed in the next few paragraphs. But even granting this upward warping, there is not evidence at hand to prove a closed structure, and the field conditions are unfavorable for settling the question.

FAULTS

There are four major faults: they trend approximately N. 70 degrees W. along the south face of the "Wall." As may be seen by referring to the geological map (Plate I), they are one to one and one half miles in length and are offset from each other with no appreciable overlap; each diminishes and stops before the next begins.

All are normal faults with the fault surface dipping steeply (45 to 80 degrees) to the south. In places there is a narrow zone of faulting rather than a single fault surface. The maximum throw is twenty-five feet; it is greatest along the central portion of the fault, diminishing to zero at the ends. This indicates an anticlinal position of the beds on the up-throw blocks. The different amount of shortening in the up and down-throw blocks may have a bearing on the greater number of sandstone dikes in the "Wall" proper and less in the outliers. The anticlinal arching of the up-throw blocks gave opportunity for the development of tension cracks. The filling of the cracks resulted in the sandstone dikes, which typically diminish and die out with depth.

There are several small faults, most of them less than a quarter of a mile in length and some showing in only a single outcrop. These, too, are all normal faults, with steep fault surfaces dipping both north and south where the trend is somewhere east and west. The trends are more variable than in the larger ones; maximum throw, eighteen feet.

One characteristic of most of the faults is the abruptness with which they terminate. All of those including the short ones, starting in Section, 29, T. 3, R. 18 and extending along the front of the "Wall" to the east are absolutely no longer than drawn. It is possible to determine their limits with such definiteness because of the large number of perfectly bare outcrops with their characteristic alternation of shale and sandstone. A fault will show plainly on one ridge, and the next ridge across the gully or canyon will show continuous beds absolutely undisturbed.

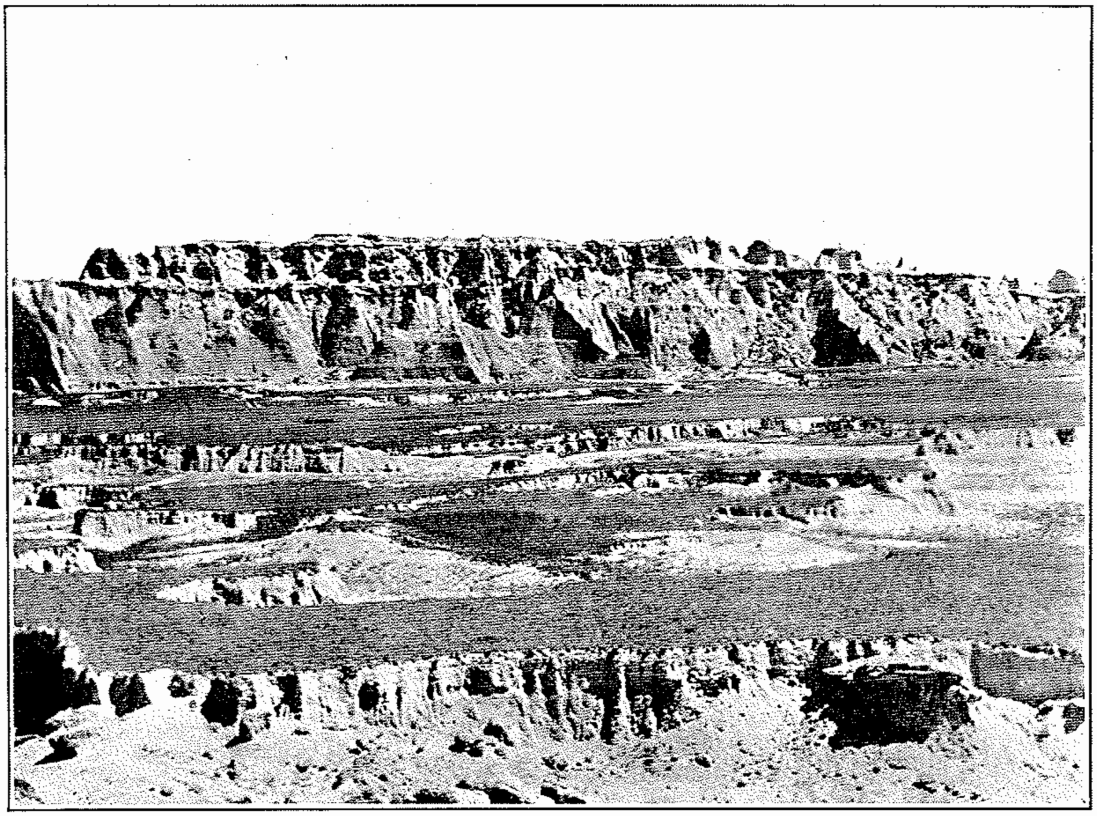


PLATE XII A
"BREAKS" BORDERING THE "WALL" ON THE NORTH SIDE

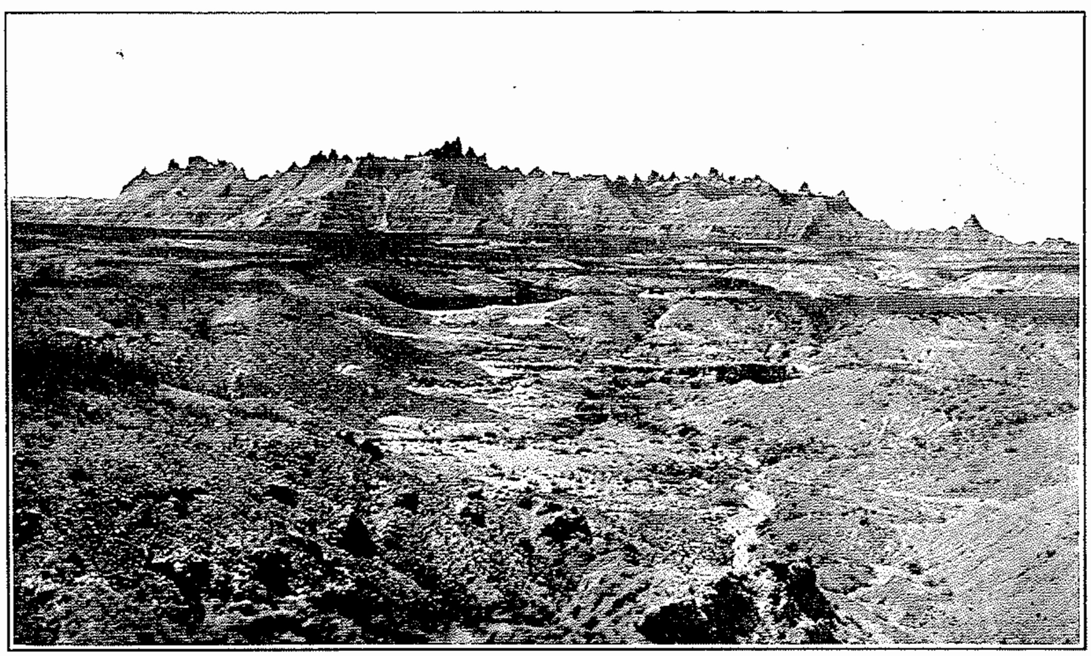


PLATE XII B
LOOKING SOUTH ACROSS "BREAKS" TO THE "CASTLES"

There were two periods of faulting. One period was post-Cretaceous and pre-Tertiary. This is indicated by only one fault—the one along the river in Section 14, T. 4, R. 17,—which cuts the Interior, while the overlying Titanotherium beds are undisturbed. The other period was post-Tertiary. Most of the faults seen in the area were produced at this time.

PHYSIOGRAPHY

INTRODUCTION

Physiography has to do with conditions at the surface of the earth. Although the conditions—land, water, air, life—are various, the greatest emphasis will be placed on land forms and their development.

In the chapter on Topography and Drainage (p. 11) some description was given of the forms of the land to be found in this area, and the division of the area into four physiographic provinces. This should be re-read in this connection.

Physiography presents a description of surface conditions as found. In this respect it is like geography, but it goes still farther, for it aims to give an account of the origin of the forms, and some of the consequences which may follow.

In the chapter on Origin it was pointed out that the beds were first formed by a process of deposition and consolidation; since then they have been cut and carved by the process of weathering and erosion. It is the purpose of this particular chapter to inquire more closely into the amount of erosion, the various periods of erosion, the relation of erosion to earth movements or climatic changes, and the details dependent on the attitude and variable resistance of the beds.

PRINCIPLES OF VALLEY DEVELOPMENT

A brief consideration of a few of the principles controlling erosion and valley development may make the discussion that follows more understandable.

Running water is able to cut into and remove rock substance, this sculpturing process constituting erosion. It is obvious that the more resistant material wears more slowly and the less resistant erodes more rapidly. The first form developed is a trench such as may form along a road or across a field after a few heavy rains. The depth of this trench depends partly on the kind of material in which it is cut, partly on the length of time the water has been running, partly on the amount and kind of tools (sand, gravel, etc.) the running water has to work with, and partly on the height of the land above the place where the trench mouths out. In regard to this last point; it is obvious that a roadside trench cannot cut down any deeper than the gully into which it opens, the gully cannot cut down any deeper than the ravine into which it open, the ravine in turn is limited in its downward cutting by the valley into which it opens, and the lowest level (base level) to which a valley can cut is the level of the lake or sea into which it empties. When a canyon or valley has cut down as low as it can it will have a graded slope from source to mouth.

While the trench is deepening and becoming a definite valley it is also getting longer, because the head is working back up stream. Many fine examples of this process may be seen on the Lower Prairie. The wagon roads commonly head these canyon draws, and again and again the road has to swing farther back to keep pace with this headward erosion. While the canyon or valley is lengthening it is also getting more tributaries. These start as small gullies which also deepen and lengthen just as the parent valley did. In time there will be developed a whole system of valleys, tributaries, trenches, ravines, and gullies, each grading into the other.

Another important operation is being carried on simultaneously with the valley deepening and lengthening above outlined; it is valley widening. This is accomplished partly by the stream itself as it slowly swings from side to side, partly by the gullying process, but particularly by loosening of the rock material of the valley sides by weathering and the removal of this rock waste by rain wash. Valley widening is not very prominent in the early stage of valley development, for the deepening process is dominant, but as soon as the stream reaches grade the deepening process ceases or becomes insignificant while the widening process becomes increasingly prominent. While a valley is lengthening and deepening up stream the deepening near the mouth has ceased and widening is in full swing. Widening follows up stream and into the tributaries as fast as grade is reached. Accompanying the widening process is a lessening of the slopes of the valley walls, the steep cliffs of the young canyon valley becoming the gentler slopes of the mature wide open valley.

With the continuation of the activity above described contiguous valleys may each widen so that the intervening divide is entirely removed, making a single flat bottomed valley twice as wide as either of the valleys alone. Naturally if all of the valleys are doing this the ultimate result will be a wide plain (peneplane) sloping gently towards the lowest outlet of the region and across which a few large rivers lazily wind their way. Before this final stage is reached there will be plain areas along the principal waterways, but along divides favored by position or more resistant material there will be elevated remnants of the former more extensive land surface. Most of the buttes in the western part of the State are such remnants and the buttes in the Lower and Upper prairies of this area are remnants rising above smaller plain tracts.

CYCLES OF EROSION

A landscape, then, must be thought of as a changing thing; the change is very slow from the human standpoint, to be sure, but changes are going on nevertheless. In the Badlands region some changes are noticeable even in so short a time as ten or twenty years; in other regions the time required for change in topographic form is measured in geologic units which are vastly longer than human units. The time required for a landscape to pass from the youthful stage with its steep-sided canyon type of valley through the mature stage with its network of open valleys to the featureless or old age stage is spoken of as a cycle of erosion. The actual number of years required for a cycle varies with the conditions.

A cycle may be interrupted before it has been completed and a new cycle inaugurated under new conditions. For instance, suppose the land was in such a position that valleys were cut to grade and widened to the stage of late maturity having wide, flat bottomed valley with moderately sloping sides. A cross section of such a valley would have the form diagrammatically shown in A, Figure 7. If now the land is elevated bodily the stream has a new grade to establish. It forthwith begins active downward cutting again until it reaches the new lower limit determined by the amount of uplift. Because the downward sawing process for the moment is dominant a trench or canyon-like type of valley is produced and the cross section will now look like that in B. Figure 7. As soon as grade is reached the widening process becomes dominant and the cross section may

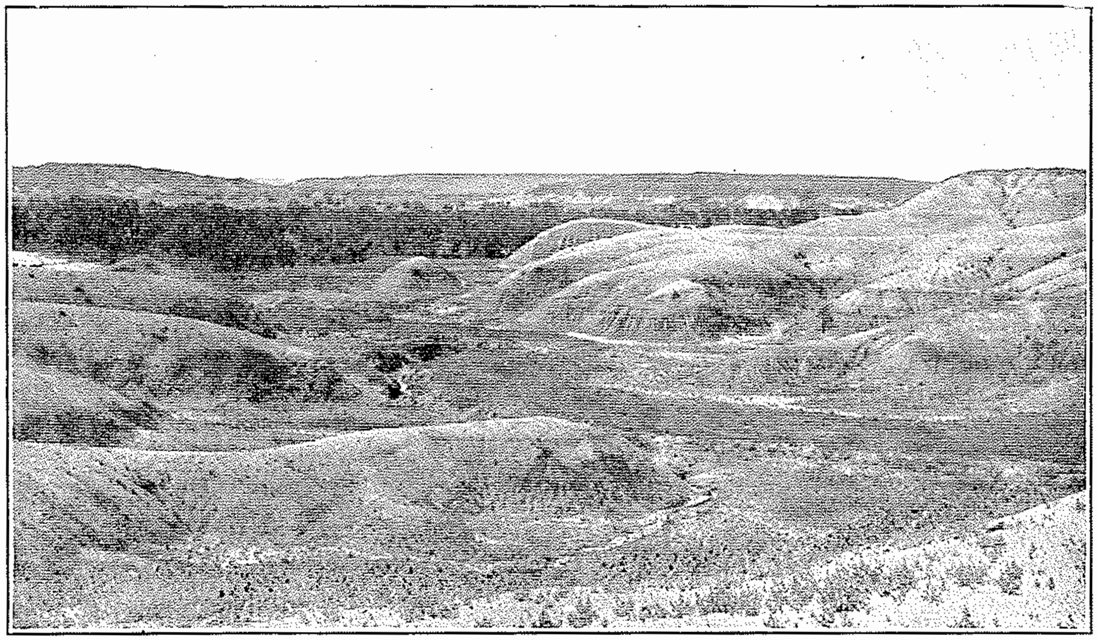


PLATE XIII A

TITANOTHERIUM TOPOGRAPHY, NEAR WHITE RIVER

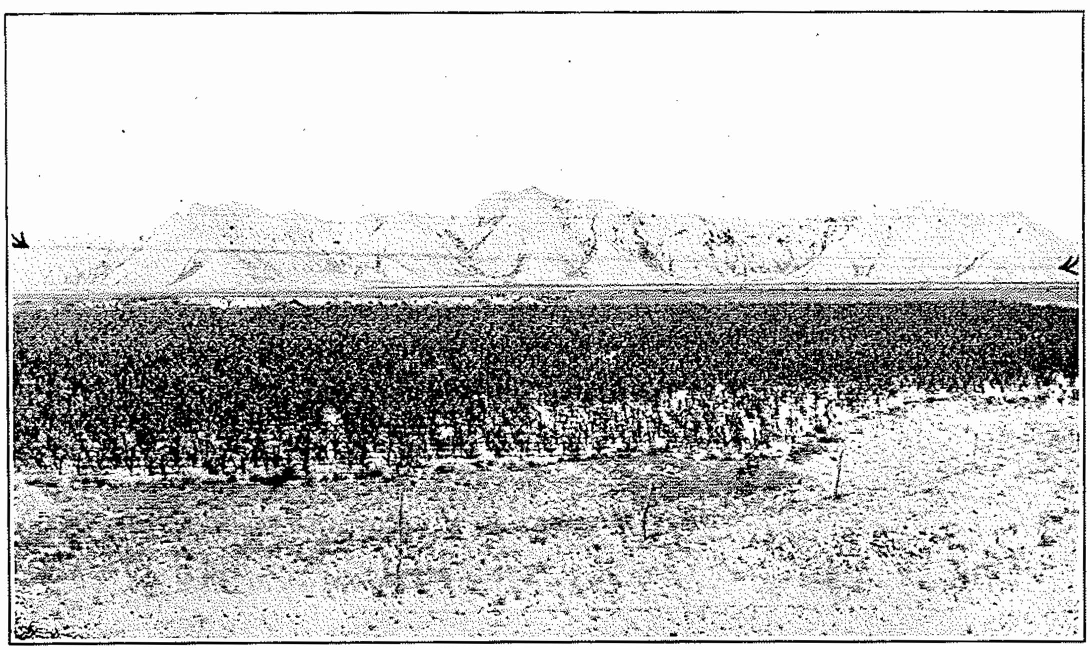


PLATE XIII B

UNCONFORMITY BETWEEN TITANOTHERIUM AND OREODON. ARROWS POINT TO THE CONTACT

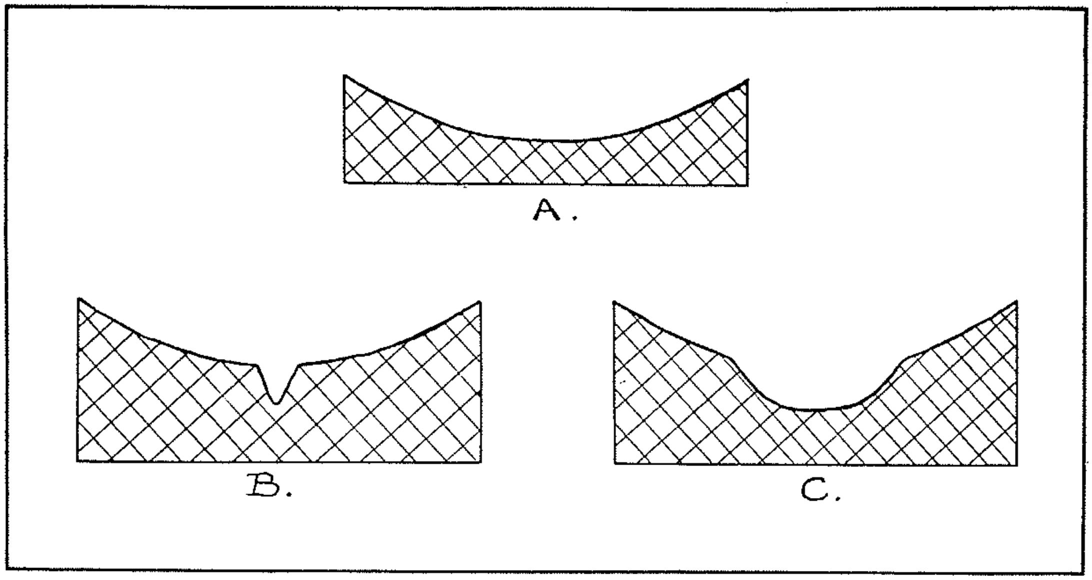


Figure 7. Cycles of Erosion

soon have the appearance shown in C. Figure 7. In other words, there is a valley within a valley, or to put it another way there are two cycles of erosion shown. If the second cycle runs its course all evidence of the first cycle will be obliterated, but until that happens the evidence for both is plainly seen. There may even be additional later cycles present in a similar way. While some of the effects just described may be produced in other ways, the basic fact holds that profiles and cross sections of topography indicate cycles of erosion.

PHYSIOGRAPHIC CYCLES IN THE STATE[1]

The physiographic history of the State as far as it is known today shows that there have been three major cycles of erosion, each probably begun by uplift. The first one is marked by the general prairie level above which the buttes rise. (See Plate VIIIB.) The buttes are remnants of the original surface upon which erosion started, and the erosion was extensive enough to produce a widespread peneplain; in other words, the cycle nearly ran its course. This cycle may for convenience be named the Prairie Cycle. In the second cycle the valley widening progressed so far that along the largest river (the Missouri) flats two to five miles wide were produced. Their remnants now stand as high benches bordering the main valleys. This may be called the Bench Cycle. During the third cycle considerable deepening and moderate widening along the main streams resulted. The present valley forms of the Missouri and main tributaries, at least in their broader features, were developed at this time, so that this may be referred to as the Valley Cycle. Since then there has been valley filling, terracing and trenching; in other words, the Valley Cycle is a composite and continues to the present time. Each of the cycles is shorter than the one before and the interruptions have come at increasingly more frequent intervals.

[1]Only a moderate amount of work on the physiography of South Dakota has been done, so that the points made in the following paragraphs are not considered by any means as final. Nor have all the details of topography noted been fitted into the scheme. It is believed, however, that the outline here given is essentially true and will serve as a basis for further discussion. Correlation with cycles outside of the State is reserved for a later bulletin.

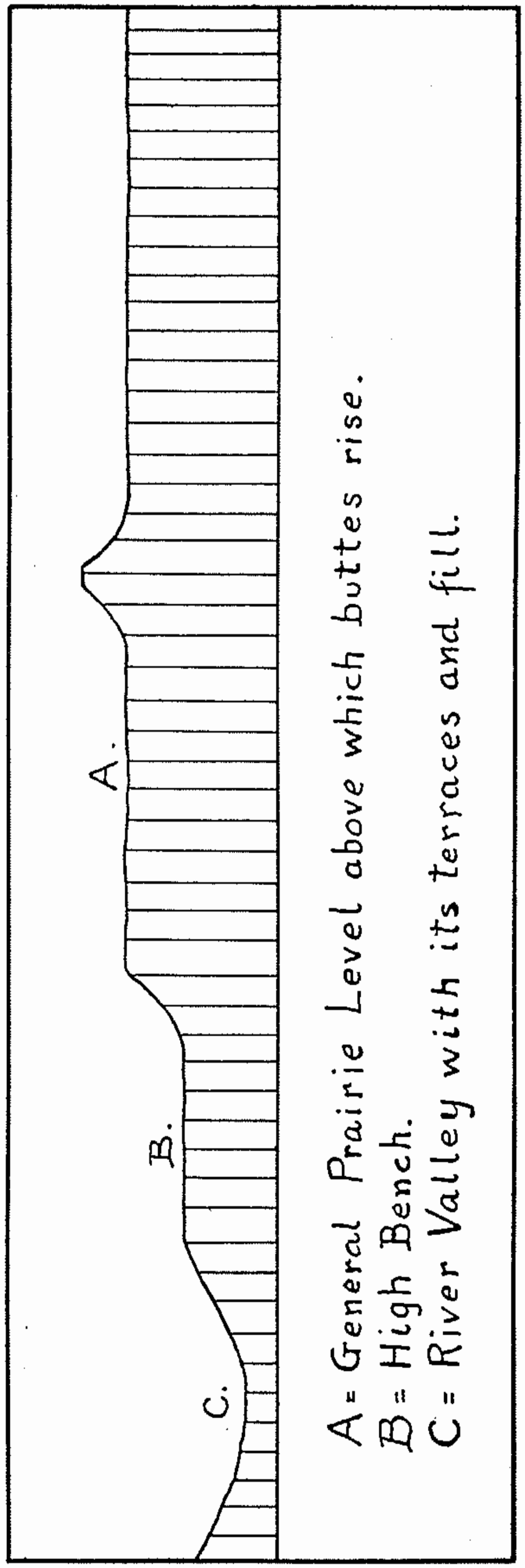


Figure 8. Diagrammatic Cross Section of the Missouri Valley

A composite diagrammatic cross section of the Missouri River will show these cycles graphically (Figure 8). The Grand, Cheyenne, Belle Fourche, Moreau and White rivers show similar cross sections, though the bench (B) is not as wide as along the Missouri River. Profiles in the Black Hills also show these major cycles.

PHYSIOGRAPHIC HISTORY OF THE AREA

The sequence of events which occurred in this area after the deposition and consolidation of the Tertiary beds is believed to be approximately as follows:

1. **Prairie Cycle.**—At the end of this very long period of erosion most of the State was a featureless plain, above which were scattering buttes, ridges, and parts of the Black Hills.

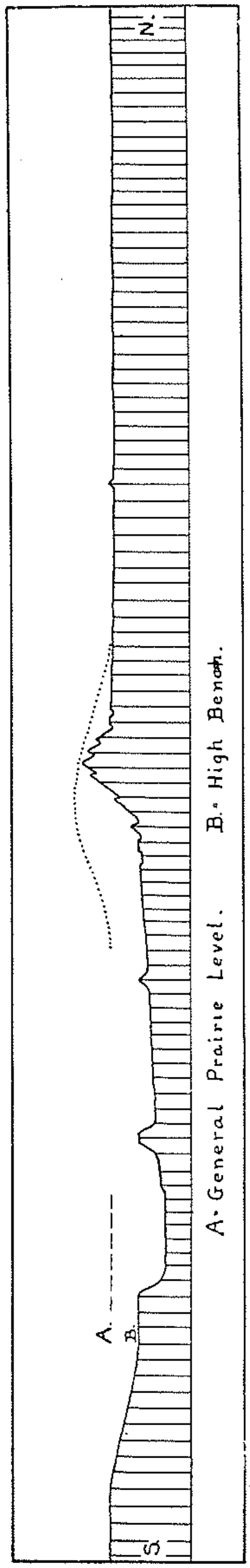


Figure 9. N to S., Cross Section of the Area, Showing Major Physiographic Features

In this area the level of the plain is marked by the tops of the buttes, which rise above the Upper Prairie well back from the "Wall"; also by the general prairie level some miles south of White River. The "Wall" rose above this plain. It is to be imagined as a ridge rather than a butte, a little higher than it is today, much broader (especially to the south), and probably smoother in outline than at present. In Figure 9 the dotted line gives a possible interpretation of the form this ridge may have had.

2. **Bench Cycle.**—By the time this cycle had closed, valleys had been cut along the main streams of the State to a depth of one hundred to one hundred and fifty feet (a measure of the amount of uplift) and then widened; the maximum width along Missouri River is five miles. Along the main tributaries the width of their valleys was probably one to three miles and still less along the smaller streams.

In this area the lower limit of this cutting is marked by a bench (one-fourth to one mile wide) above the bluff along the south side of White River. Remnants of this valley floor are also marked by the high buttes in the Lower Prairie, such as Tenderfoot and Herley buttes. Along the Upper Prairie the erosion was not so extensive, for the region was a greater distance from any main river, so that the smaller streams only headed back toward the end of the cycle. There are buried valleys there which were in part at least cut during this cycle.

During the later, waning portion of this cycle the streams became less active as erosive agents and deposition ensued, resulting in the so-called Pleistocene deposits which now cap the buttes mentioned.

3. **Valley Cycle.**—The chief erosion forms which are so prominent a part of the landscape in the area today were carved out during this cycle.

The uplift which inaugurated this cycle also tilted the land slightly towards the south. The White River by this tilting was urged more in that direction. Also, the many short tributaries running from the "Wall" to White River were made very active and the streams flowing north from the "Wall" were proportionally checked. As a result the south side of the "Wall" was eroded much faster than the north. Hence, the erosional Badland scenery is more pronounced on that side, and the general reduction of large tracts to a lower level is a prominent feature, only the high buttes standing as remnants of the former higher level of erosion. Another factor which increased the erosive processes on the south side was the action of the ground water; this would naturally follow the southward dipping beds and by its undermining action would materially aid the stream erosion, both by constant removal of rock material in solution and by aiding in the production of slumping and landslides. Results of this latter process are still visible along the high parts of the "Wall."

The lowest limit of downward cutting during this cycle was below the present level of the Flood Plain and Prairie respectively. It is evident that following this extensive period of erosion there was a period of deposition, for wells sunk in the Flood Plain show that there is twenty to thirty-five feet of fill before the bedrock is struck. Similarly, the bedrock surface beneath the Lower Prairie is buried by ten to perhaps fifty feet of gravel, wash, and Piedmont deposits; and the same can be said of the Upper Prairie.

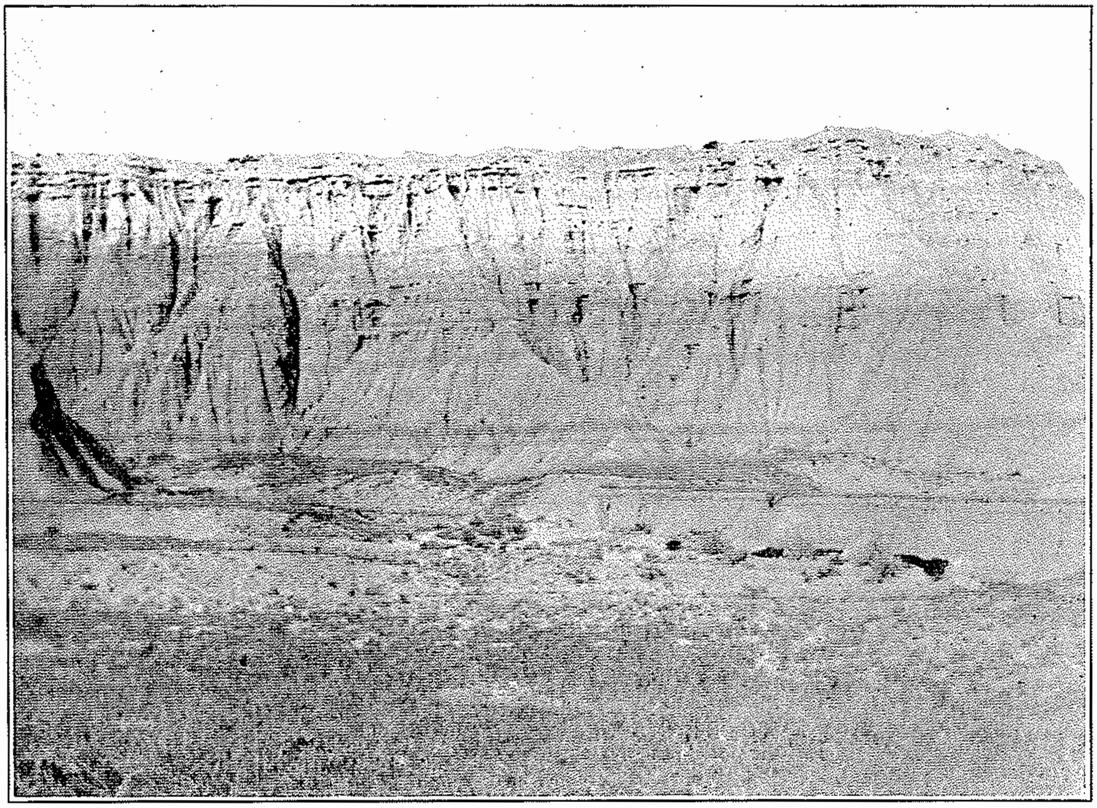


PLATE XIV A
SECTION OF THE LOWER OREODON
(See Figure 4)

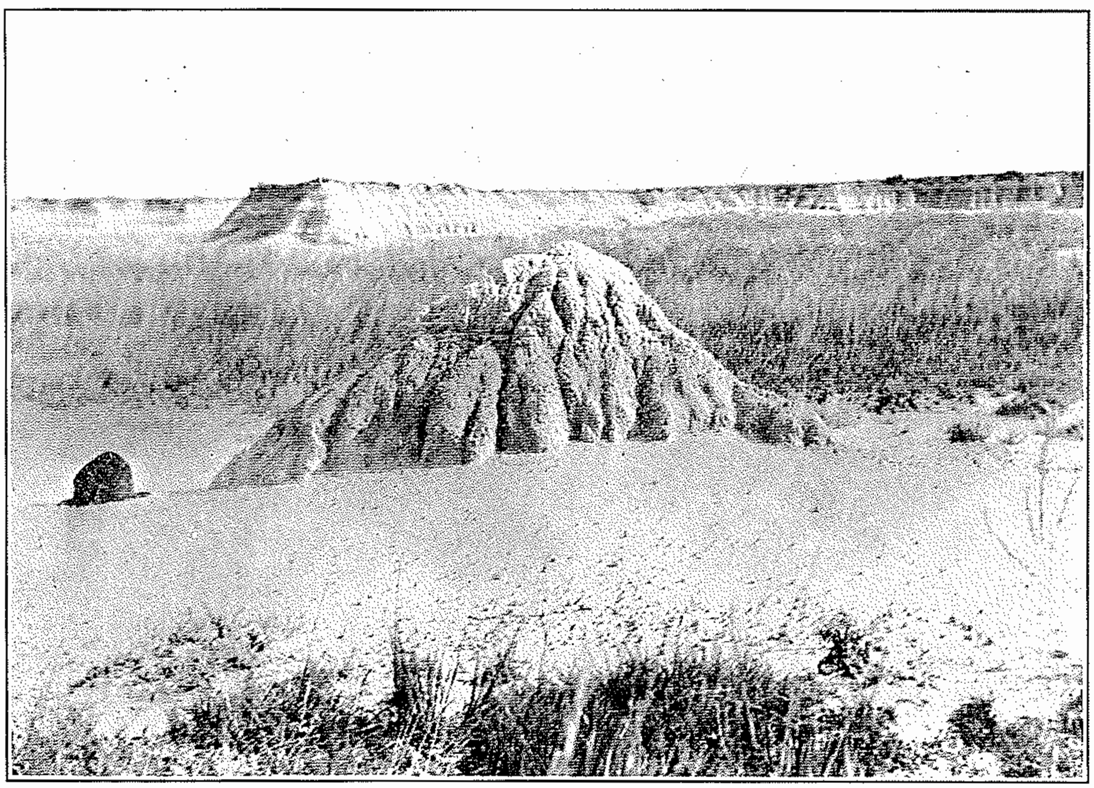


PLATE XIV B
MINIATURE BUTTE

This means that the streams were so heavily supplied with sediment that they became overloaded. The reason for this was probably a change of climate to more humid conditions, so that the uplands were wasted away more rapidly. Some of the buttes and steep slopes were so encumbered with debris that they were completely covered and bare rock was no longer exposed. Sod covered these slopes, and instead of the bare, badland ledge so common today there were flowing, grassy, steeper gradients merging downward into gentle Piedmont slopes, these in turn blending into the flatter, surrounding prairie lands.

Following this period, and probably in response to a climatic swing to more arid conditions, erosion again dominated. The sod cover began to weaken and its removal gave impetus to gullying. The steeper gradients along the "Wall" and higher buttes gave way first, the lesser slopes later. Bare ledges became prominent. The Prairies were trenched, the buttes further diminished in size and the "Wall" incised still further until the elaborate and scenic badland topography of today was produced. Some of the grassy slopes today can be seen in the process of stripping, as is illustrated in the photograph (Plate XVIA): which means that the bare badland type of topography is increasing at the expense of the sod covered tracts. If no change of condition intervenes, erosion will continue until in the not very distant geologic future the buttes will be all worn away, the "Wall" will be cut down and a featureless plain at a lower level will be left. From a human standpoint the time will be vastly long before this cycle of erosion is completed; and new conditions may step in to interrupt and modify the result.

DETAILS

Modifications and additions to the above physiographic history can here be mentioned. For instance, in some parts of the State the Bench Cycle was in two parts, yielding an upper and a lower bench. It is also possible that the first erosion period of the Valley Cycle may have been the result of two periods rather than one; and during the second erosion period of the Valley Cycle there has been some terracing. Recent trenching by most of the streams is prominent and along some creeks there have been two trenchings with filling in between. (See A, Figure 10.)

When one examines a badland outcrop close at hand, say in climbing along the "Wall," he will find a great variety of forms in a small way,—projecting ledges, small caves, odd shaped rocks, etc. All of these can be readily understood when it is realized that the rock substance varies in its power of resistance to erosion. The harder, more resistant portions of the rock stand out in prominence, while the softer, less resistant portions are worn away. This uneven (differential) erosion is the rule wherever weathering and erosion operate, but in this area the contrasts are especially noticeable. The reason why the Titanotherium yields rounded, billowy forms is because its material is so uniform. On the other hand the pinnacles, knobs, and fantastic topography of the Oreodon are the result of lack of uniformity in that formation.

One of the striking facts about the badland topography is the almost complete absence of talus slopes. The debris weathered from the steep slopes and cliffs does not accumulate. It is swept away by the rain wash practically as fast as formed. It might be thought that in such a climate the wind would be an active agent of erosion, but such is not the case: sandstorms are unknown (except locally

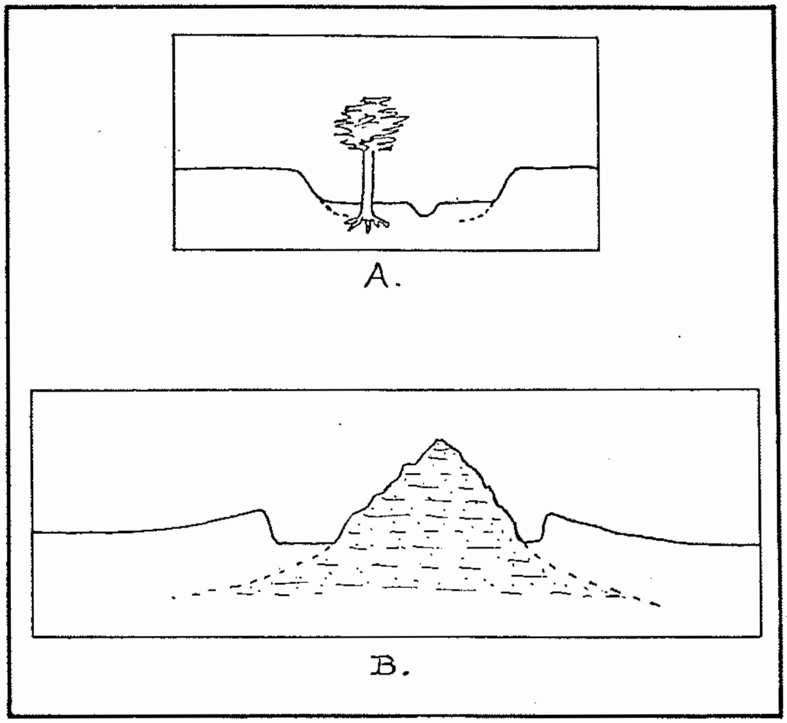


Figure 10

A. Alternate Trenching and Filling in of Recent Deposits
B. Stripping Piedmont Deposits from Butte

along river sandbars), and dust storms are rare. The rain is able to remove the debris partly because large blocks of debris are rare, and particularly because the rock debris on weathering very quickly breaks down to fine sand and silt, which is very readily swept away by every shower.

A rather common sight along the "dry washes" is rounded ball-like masses of clay and small sandstone fragments. These have been produced where the occasional torrential rain rolls along a soft fragment of shale which tends to grow in size just as a snowball picks up more snow. The diameter of these mud balls is commonly one to six inches; maximum diameter is two feet.

One characteristic of most of the buttes is the moat-like trench by which they are surrounded completely or in part. This is a detail of erosion that followed the partial burial of the buttes and the development of a sod cover well up and in most cases clear over their tops. The stripping process went forward readily on the upper slopes where the cover was thin. Once started the run-off could move down these bare rock slopes almost unimpeded, and so would be able to dig deeply into the peripheral lower fill material, which would thus be cut back concentrically and carried out through breaks in the moat-wall. (See B, Figure 10.)

ECONOMIC GEOLOGY

There are no metalliferous deposits in this area. The substances which are of some practical use and may have a commercial value are building material, road material, clays, water, and possibly oil. They will be discussed in the order given.

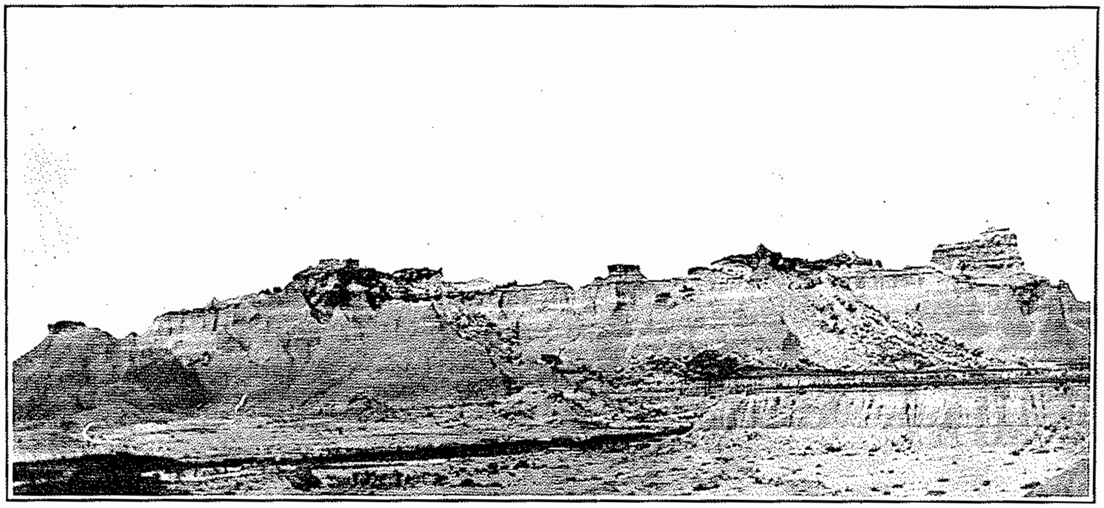


PLATE XV
CHANNEL DEPOSITS OF THE PROTOCERAS
(Compare Figure 5)

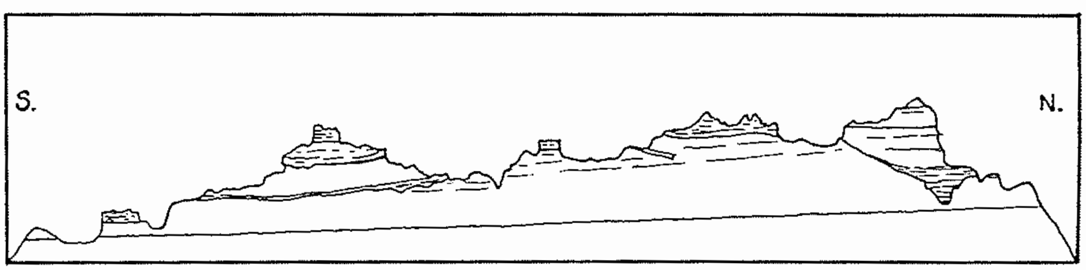


Figure 5. Channel Deposits of the Protoceras. (Compare Plate XV)

BUILDING MATERIAL

Building Stone.—Most of the sandstones are either too thin bedded or too poorly consolidated to allow dimensional stone to be secured in quantity. But certain parts of the sandstone beds are of suitable strength and thickness to be used for building purposes. The colors are all light, mostly gray, but some of the Protoceras is greenish. There are no igueous or metamorphic rocks. The only other rock that might be used is the cherty limestone, which occasionally is thick enough for the purpose.

There is sufficient stone to be used locally, but the quantity of good stone is much too limited to warrant starting a stone industry in this region.

Crushed Stone.—As may be suspected from the above statements concerning building stone, there can never be quantity production of crushed stone here. Enough strong rock could be found to provide crushed stone for local concrete work, etc. The residual Pleistocene gravels, cobbles and boulders might possibly be used but their occurrence is so scattering that it would be uneconomical to use them this way.

Sand and Gravel.—Practically all the sand for structural use will come from the White River valley. There should be plenty for local use, though some prospecting may have to be done to get material of a proper texture and quality. Good sand deposits are extremely scarce in other parts of the area.

Most of the gravel contains a large proportion of the weak Tertiary fragments, which of course impairs the quality of the whole. Better gravels are to be found in pockets and streaks in the sands along the river valley.

ROAD MATERIAL

Although strong, tough rocks suitable for crushing for general purposes are not abundant, rock fragments which could not be used in concrete work will have more value as a road dressing. This is true because the rocks of this area will work down readily, and also because they have a bonding power which naturally develops a dense, firm surface. The renewal of the dressing may have to be made at more frequent intervals, but the rocks will be less expensive to crush.

Another material which has by use already proved of value as road dressing is the wash which is the underlying fill debris of the Lower Prairie. This is in effect a mixture of crushed Tertiary fragments. Where it has been properly put on and worked down it yields a smooth, hardpan surface which stands traffic better than the natural road and is pleasant to travel over. Care should be taken to provide good drainage for such surfaces, as they tend to soften if soaked.

CLAYS

Probably all of the shales and many of the fine, shaly sandstones can be used, directly or with some modification, in the manufacture of clay products. Eight samples have been tested; the results are given in the accompanying table (Table 8). The following comments may make the records more understandable: Nos. 1, 2, 3, 4, and 8 cannot be used alone because of the high air shrinkage, No. 8 being not quite so bad in this respect as the others. In order to be used at all they must be mixed with a more sandy material. The

1. TITANOTHERIUM SHALE

Texture	Fine grained
Plasticity	High
Water of Plasticity	55.00%
HCl Treatment	No effervesence
Behavior on Drying	Cracks badly
Linear Air Shrinkage	15.00%
Modulus of Rupture	Not tested, bars cracked in drying

Fire Tests

Temperature	Fire shrinkage	Absorption	Color
950° C	2.00%	5.8%	Pink
1050° C	4.00%	4.6%	Red
1090° C	4.00%	4.0%	Red
1150° C	4.00%	3.2%	Red
1190° C	Nearly viscous		

2. TITANOTHERIUM SHALE

Texture	Fine grained
Plasticity	Good
Water of Plasticity	50.00%
HCl Treatment	Some effervescence
Behavior in Drying	Warps and cracks badly
Linear Air Shrinkage	14.00%
Modulus of Rupture	Not tested, bars cracked in drying

Fire Tests

Temperature	Fire shrinkage	Absorption	Color
950° C	3.00%	4.1%	Pink
1050° C	3.00%	3.5%	Red
1090° C	4.00%	1.2%	Red
1150° C	Viscous		

3. LOWER OREODON SHALY SANDSTONE

Texture	Fine grained, much fine silt
Plasticity	Good
Water of Plasticity	40.00%
HCl Treatment	No effervescence
Behavior on Drying	No warping or cracking
Linear Air Shrinkage	12.00%
Modulus of Rupture	850 lbs. per sq. in.

Fire Tests

Temperature	Fire shrinkage	Absorption	Color
950° C	0.	11.4%	Red
1050° C	3.0%	11.2%	Red
1090° C	4.0%	3.5%	Red
1150° C	5.0%	2.8%	Red
1190° C	Viscous		

4. MIDDLE OREODON SHALE

Texture	Fine grained
Plasticity	Good
Water of Plasticity	45.00%
HCl Treatment	Slight effervescence
Behavior on Drying	Does not warp or crack
Linear Air Shrinkage	14.00%
Modulus of Rupture	543 lbs. per sq. in.

Fire Tests

Temperature	Fire shrinkage	Absorption	Color
950° C	3.0%	8.0%	Red
1050° C	8.0%	1.6%	Red
1090° C	9.0%	0.0%	Red
1150° C	Beyond vitrification		

5. LOCAL SANDSTONE IN TITANOTHERIUM

Texture	Gritty clay
Plasticity	Good
Water of Plasticity	18.20%

HCl Treatment	No effervescence
Behavior on Drying	Dries fairly well
Linear Air Shrinkage	6.5%
Modulus of Rupture	680 lbs. per sq. in.

Fire Tests

Temperature	Fire Shrinkage	Absorption	Porosity	Color
950° C	0.00%	12.00%	30.00	Pink
1050° C	0.50%	10.23%	26.23	Pink
1110° C	0.50%	10.19%	25.83	Pink
1150° C	1.50%	9.80%	25.83	

6. PROTOCERAS SANDSTONE—"ROAD METAL" BED

Texture	Gritty Clay
Plasticity	Good
Water of Plasticity	39.00%
HCl Treatment	Slight effervescence
Behavior in drying	
Linear Air Shrinkage	5.00%
Modulus of Rupture	650 lbs. per sq. in.

Fire Tests

Temperature	Fire Shrinkage	Absorption	Porosity	Color
950° C	7.00%	16.24%	38.28%	Deep Pink
1050° C	16.00%	3.54%	6.25%	Deep Red
1110° C	14.00%	1.90%	3.00%	Deep Red

7. PROTOCERAS SANDSTONE—ABOVE 6

Texture	Gritty Clay
Plasticity	Good
Water of Plasticity	28.00%
HCl Treatment	Slight effervescence
Behavior on Drying	Does not warp much in drying
Linear Air Shrinkage	7.00%
Modulus of Rupture	800 lbs. per sq. in.

Fire Tests

Temperature	Fire Shrinkage	Absorption	Porosity	Color
950° C	2.00%	16.46%	33.70%	Pink
1050° C	14.00%	5.64%	13.80%	Deep Red
1110° C	16.00%	0.50%	0.80%	Deep Red

8. INTERIOR SHALE

Texture	Clay
Plasticity	High
Water of Plasticity	33.00%
HCl Treatment	No effervescence
Behavior on Drying	Tends to crack unless carefully dried
Linear Air Shrinkage	10.00%
Modulus of Rupture	1270 lbs. per sq. in.

Fire Tests

Temperature	Fire shrinkage	Absorption	Color
950° C	2.0%	11.70%	Red
1050° C	4.0%	2.80%	Red
1150° C	5.5%	2.30%	Deep Red
1190° C	Begins to overfire		Deep Red

Table 8.

sand along White River could be used, or specimen No. 5 would serve to make a proper mixture. Since No. 8 has the lowest air shrinkage of the five, it would require the least sand and could be molded by dry press. Numbers 1, 2, and 4 also require a high percentage of water for mixing. Numbers 6 and 7 could be used fairly well alone but would probably be improved by some admixture of more sandy material. All of the specimens with the modifications as suggested would make good common brick; No. 8 could also be used for face brick and drain tile or hollow blocks.

WATER

Contrary to general belief, the waters of the Badlands are almost without exception soft and potable: alkali waters are scarce.

The water of White River itself is objectionable only because of its turbidity and warmth. When allowed to settle and cool it is a very pleasant drinking water and not at all hard. The town of Interior derives its water supply from perforated pipes sunk in the sand bars along the stream bed. This water is thoroughly clear and altogether desirable for any sort of use.

Wells sunk in the flood plain to depths of twenty to thirty feet all yield good water, some of it fine.

It is not so easy to get wells in the Upper and Lower prairies, but all the wells that have been located furnish water of an excellent quality. The supply usually is limited, though always ample for household use; a few of the wells have water enough to water fifty head of stock. However, most of the stock is watered from ponds made by damming draws or low spots sufficient to catch the run-off.

Springs were seen in only one place, viz. along Buffalo Creek. The supply from these springs was very meager.

Artesian water could probably be obtained along White River valley and the adjoining lower parts of the Lower Prairie. Those wells on the flood plain or near that level would yield flowing water. The Dakota sandstone, which is the usual artesian horizon should be struck at approximately 2,600 feet from the surface. Occasionally artesian water is obtained from the Benton, which in this locality should be struck at a depth of approximately 1,500 feet.

OIL

Introductory.—As was stated in the introductory chapter, one of the reasons for starting detailed geologic investigation in this area was because of the belief held by many of the residents that oil was there. Their belief was so strong that an oil company was organized and a derrick erected before the Survey party arrived on the scene. In common with communities which get excited about oil the development had gone ahead without any definite evidence of oil and without any thorough geologic investigation. This "hunch" about oil apparently started from someone overhearing some "government surveyor" make a casual remark to the effect that "this looks like an oil country." The several stories (there are at least three of them) about this incident are not in good agreement and all are second or third hand. The "government surveyor" did not think well enough of the idea to report it at headquarters in Washington. At least an inquiry concerning the records of surveyors of that period reveals no mention of evidence for or upon oil in this region. Many communities, including this one, also base their faith in oil on the fact that oil has been found in Wyoming, though this faith is not strong enough to make them believe that the chances for oil are better in a neighboring community which is ten or twenty miles nearer our oily, neighboring State.

In considering the possibilities of oil in any district there are certain facts which must be determined. Oil will occur in commercial quantities only if the following conditions are satisfied:—(a) There must be source rocks, that is, there must be formations present below ground which can yield petroliferous material. Source rocks are usually dark colored marine shales or other sediments which are highly fossiliferous. (b) There must be reservoir rocks. The oil

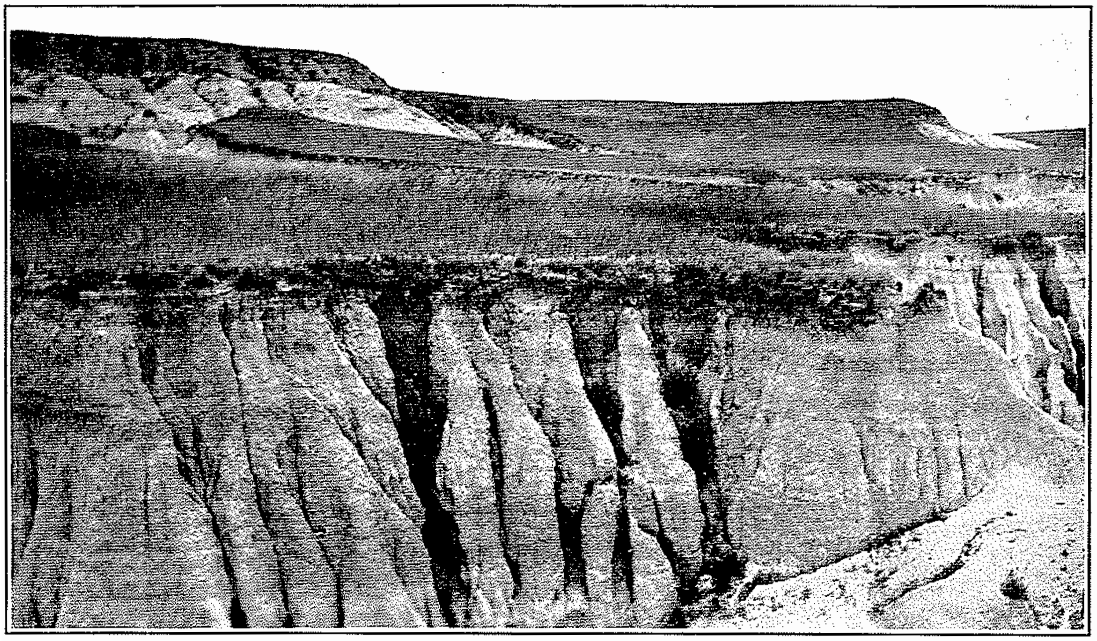


PLATE XVI A

BADLANDS IN THE MAKING
STRIPPING OF GRASSY SLOPES AND REMOVAL OF PIEDMONT DEPOSITS

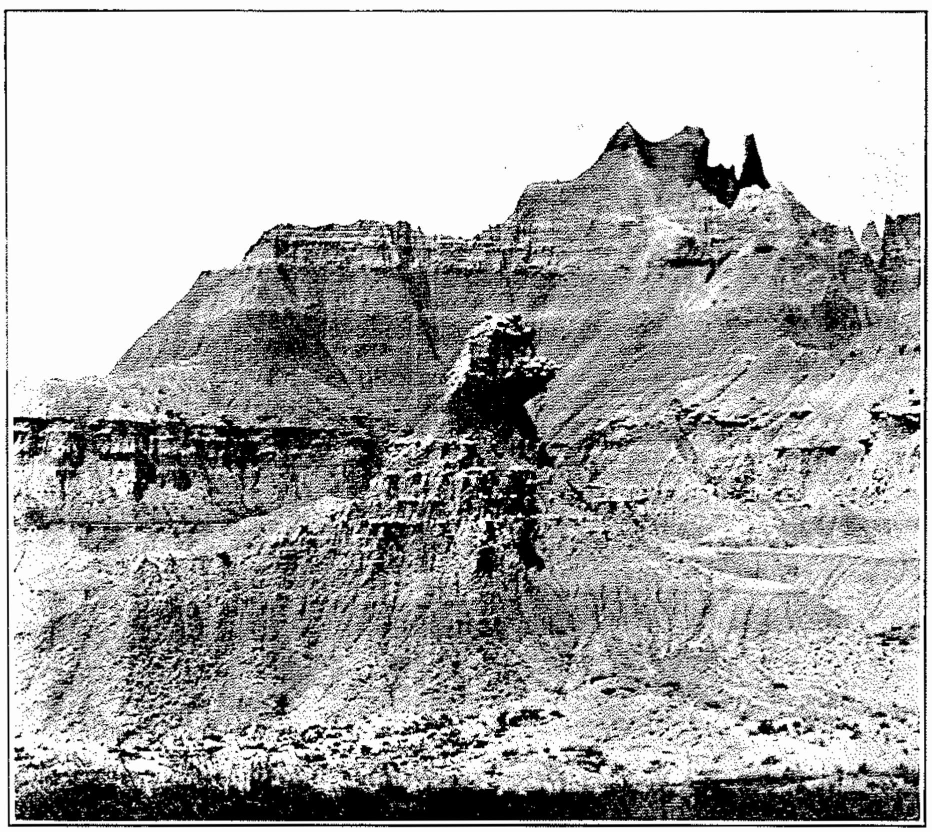


PLATE XVI B
DETAILS OF EROSION

originates in shale, but must migrate into neighboring porous and permeable rocks before it can be recovered on a commercial scale. Reservoir rocks are usually sands or sandstones, though any porous and permeable rock will serve as a collecting horizon. (c) The reservoir rocks must have above them cap rocks which are impervious, so that the oil or gas cannot escape. Thick shales are good cap rocks. (d) The reservoir with its cap rocks must have the proper structure. The oil may be collected in the reservoir rock, but if the latter is flat the oil will be so scattered that it cannot be recovered at a profit. The most common favorable structure is the anticline or dome. This gives opportunity for a concentration of the oil in commercial quantities. There are modifications of the anticline and other structures which are favorable to oil concentration. It is of course possible to have suitable structures and no oil or suitable source and reservoir rocks with no favorable structure. Oil seepages themselves have but little significance. They may represent leakage from commercial supplies; they may be the last trickles from a former supply; they may be a slow seepage from source rocks, etc. They must always be considered in connection with the other conditions. A more thorough discussion of the above items together with additional material will be found in "The Possibilities of Oil in South Dakota" by R. A. Wilson, which was publshed as Bulletin 10 of this Survey.

There are certain difficulties in the way of settling the above points for the area under discussion, chief of which is the lack of deep well records anywhere near, the nearest being at Wasta thirty miles distant.

Deeper Formations.—The Pierre shale is the oldest formation exposed in the area. A discussion of the oil problem will involve some understanding of the formations which are still deeper down.

In Figure 11 there is given in tabulated form the relative position and thickness of the formations of eastern Wyoming and South Dakota, also those of the nearest deep well records available. Since there are no deep holes in this area there is no proof that the rocks below the Pierre are exactly the same as they are in other parts of the State where the deeper formations are known. But the probability is very high that the deeper formations are quite similar at least; probably they are intermediate in character and thickness between those in the eastern Black Hills and those in the eastern part of the State. The figures given for thicknesses cannot be exact; they represent the most probable estimates.

Source Rocks.—The Pierre is a dark, marine shale which contains petroliferous material; in parts of the State it has thin beds of oil shale: it can well be considered a source rock.

The Carlile and Graneros shales are both dark shales of marine origin: the Niobrara and the Greenhorn limestones are fossiliferous; hence, all of these formations may be considered as source rocks, though the latter, because of its thinness is unimportant. The Sundance shale is also a possibility, though its presence under this area is doubtful, since it is lacking in the eastern part of the State. The Morrison has less possibility as a source rock because it is of fresh water origin.

Reservoir Rocks.—In central Wyoming the rocks which have acted as reservoirs for oil are as follows:

(a) Teapot, Parkman and Shannon sandstones, which are sandy members of the Pierre formation, though the first two are being correlated with the Fox Hills. These thin out in eastern Wyoming, and in the Big Muddy dome the Shannon is absent.

		Eastern Wyoming	Eastern Black Hills	Eastern S.Dak.	This Area	Wasta	Nowlin	Capa
Tertiary.	White River		0-600	absent	0-500	Well 2287 ft. deep; complete log not available; starts in Pierre; water-bearing ss. (Graneros ?) at 2208; Dak. ss. probably 2500-2600.	Well 1842 ft. deep; complete log not available; starts in Pierre; Dak. ss. at 1770; some gas; temperature 121° F.	Well 1690 ft. deep; complete log not available; starts in Pierre; Dak. ss. at 1500; gas at 1560; temperature 118° F.
Cretaceous.	Fox Hills	Teapot 150-175; Parkman 325	absent	absent	absent			
Cretaceous.	Pierre	Shannon; 1200 to 3000	1200-1400	1000	Interior 35; 1200			
Cretaceous.	Niobrara	100-200	150-225	150-200	150			
Cretaceous.	Carlile	Wall Creek; 600 to 800	400-800	200	? 450			
Cretaceous.	Greenhorn	50-100	65	25-50	50			
Cretaceous.	Graneros	550-650; Mowry 100; 25; Muddy 10-70; 175-250	900 to 1100; Newcastle 5-35	65-105	? 750 ?			
Cretaceous.	Dakota	Cloverly: 60	35-175	150-400 (undifferentiated)	150			
Comanchian	Fuson	Cloverly: 50	30-125	150-400 (undifferentiated)	50			
Comanchian	Minnewasta	Cloverly: 0-30	0-30	150-400 (undifferentiated)	0			
Comanchian	Lakota	Cloverly: 50-200	100-325	150-400 (undifferentiated)	250			
Comanchian	Morrison	130	0-220	absent	100			
Juras.	Sundance	350	Unkpapa ss. 0-225; Sundance ss., sh. 100-300	absent	? 100			

Figure 11. Correlation Table

(b) Frontier, Wall Creek, Torchlight, Peay sandstones are equivalent in position to the Greenhorn or lower Carlile. The Wall Creek is the one which is recognized in eastern Wyoming.

(c) The Mowry member of the Graneros carries oil but usually is not a producing horizon.

(d) The Thermopolis of central Wyoming is the equivalent of the Newcastle or Muddy sand of eastern Wyoming. This is the main source of oil in the Moorcroft field.

(e) The Dakota sandstone, sandy members of the Fuson shale, and the Lakota sandstone have yielded oil in many parts of Wyoming, mainly under the group name Cloverly, and must be considered as possible reservoir rocks, especially as the Lakota is the chief producing horizon in the Mule Creek field.

Deeper formations have produced oil in central and western Wyoming, but there is much doubt as to their value in eastern Wyoming.

In western South Dakota no sandstone member of the Pierre has been reported thus far. The Shannon cannot be expected, for it is absent in eastern Wyoming. Even if the Teapot or Parkman belong in the Pierre, no assurance can be given that their equivalents are present in western South Dakota. And since there is a strong belief that these reservoir rocks belong to the Fox Hills, it is evident that they are not present in this area. The log of the well at Wasta would be instructive if it had been accurately kept and was now available. Certainly if oil had been found in paying quantities it would have been noticed in that particular hole. The evidence is extremely strong against any reservoir rocks in the Pierre of this area.

Near the top of the Carlile there is a water-bearing horizon in parts of western South Dakota. Such a reservoir could hold oil—if oil is present.

The Mowry may be present in this area but since it makes such a poor showing even at its best, practically nothing can be expected of it here.

The Newcastle (Muddy) is the first serious possibility, since it is oil bearing in one of the two fields nearest South Dakota, viz, the Moorcroft. Not much production can be expected from this bed, however, for it is not a strong producer even in Wyoming.

The Dakota sandstone is decidedly a good reservoir rock. But since it is so filled with artesian water and also since it has not been known to carry oil anywhere in western South Dakota there can be little hope of finding oil in it in this area.

The Lakota is a good reservoir rock and is the best chance in the series, for it is the producing horizon in the Mule Creek field just over the line in eastern Wyoming. But the failure of a well southwest of Edgemont, and located on favorable structure, to get oil from this horizon throws much doubt on the prospects from the Lakota here.

There are some sandstone members in the Morrison which would serve as reservoir rocks, and the Sundance contains some excellent reservoir rocks. But neither of these formations has attractive prospects as far as oil content is concerned. In the Mule Creek field two wells have been sunk some 500 feet below the Lakota. Both are well located in respect to the axis of the anticline and are dry holes.

Cap Rocks.—The various reservoir rocks above mentioned have sufficient cover of impervious shale so that this feature of the problem is satisfactory.

Structure.—In the chapter on Structure (p 40) it was pointed out that there was a fairly well marked terrace structure through the central part of the area. The ends of this are open, so that it is not a structure that would collect and retain oil. Much of the remainder of the area is flat or has minor undulations entirely too small to be of any value as oil traps.

The one locality that is promising as a structure which may be suitable for oil accumulation is along White River in Sects. 17 and 20, T. 4 S., R. 17 E. The fact that the Pierre shale outcrops here and not anywhere else near, either up or down stream, points strongly to an upward or anticlinal arching of the formation. This matter has already been discussed on pages 41, 42, to which the reader is referred. Whether the structure is closed or not or the amount of closure could not be determined. In spite of this defect in the complete proof this is the logical locality in which to sink a test well, if any hole at all is to be put down.

It should be emphasized that even with theoretically possible source rocks, reservoir rocks, cap rocks and structure the presence of oil can only be *proved* by the drill. In an entirely new unproved field such as this area the uncertainty, especially for the first hole, is very high.

Depth to Horizons.—If drilling is to be undertaken, the depth to the several possible producing horizons (reservoir rocks) should be known. Since there is no record of the deep underground conditions in this area the figures given cannot be exact but can serve as the most reasonable estimates. The figures refer to depths of formations for a well placed along White River and starting in the Pierre formation in either Sect. 17 or 20, T. 4 S., R. 17 E. If the adjoining section 8 is to be drilled the figures should be increased 50 feet in such case. The value of the several horizons as possible oil producers has already been discussed under Reservoir Rocks, p 55.

Sandstone member near top of Carlile	1350
Wall Creek	1775
Mowry	2300
Muddy	2350
Dakota	2600
Lakota	2800

If a hole is started in the Interior or in the Tertiary formation the depth will be correspondingly increased above the figures listed.

Summary.—1. The field is entirely new. No oil showings have been found anywhere near the area: no deep well records anywhere near.

2. Surface evidence of oil is entirely lacking in the area. This signifies little if anything either for or against oil.

3. It is believed that the deeper formations contain possible source, reservoir and cap rocks.

4. No well marked domes or closed structures have been located in the area.

5. The presence of the Pierre shale in the midst of the Tertiary area is believed to indicate an anticlinal arching of the formation. This is a reasonable locality in which to place a test hole.

6. The Dakota sandstone is approximately 2,600 and the Lakota 2,800 feet below the surface in the most favorable portion of the area. Other possible sandstone horizons have been indicated.

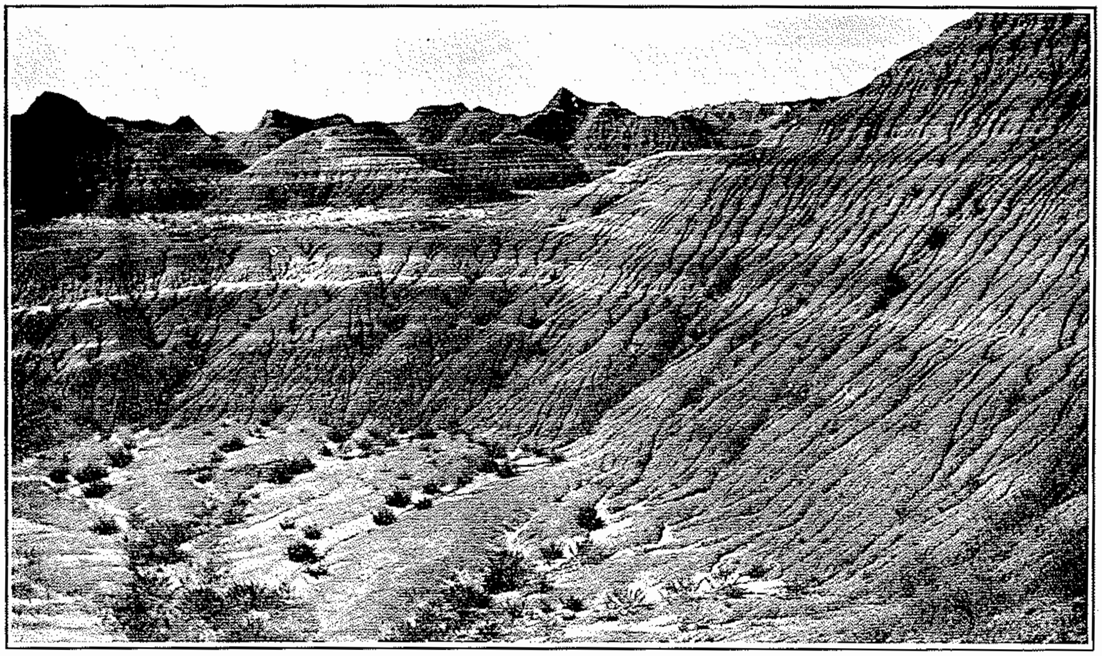


PLATE XVII A
DETAILS OF EROSION

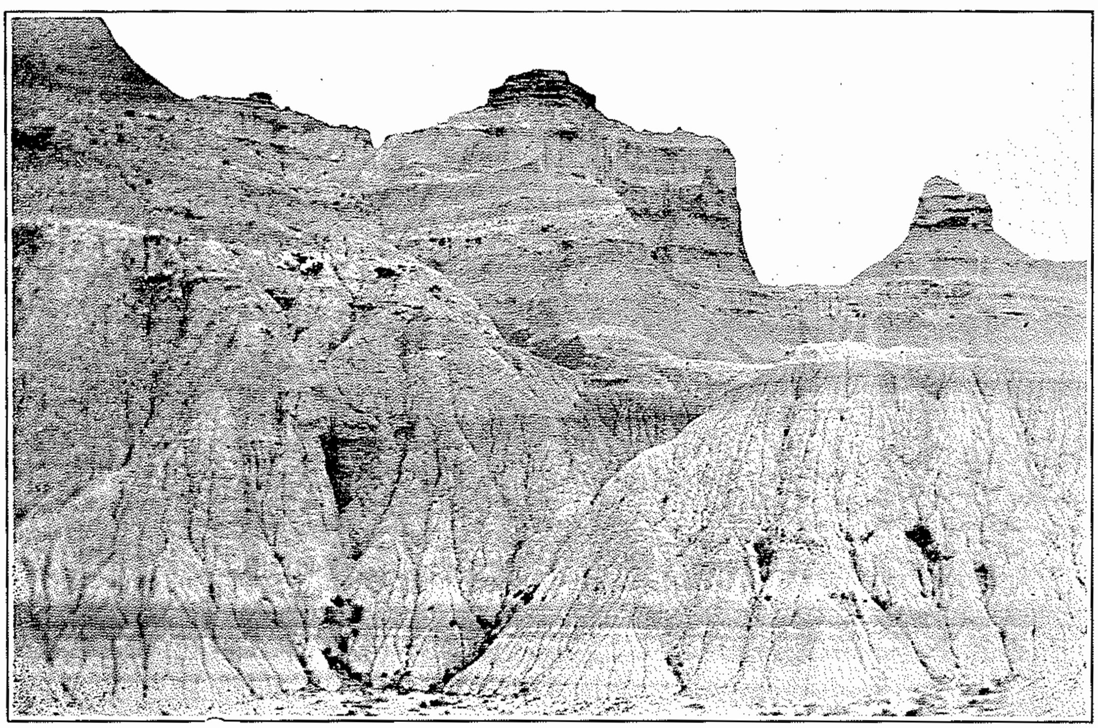


PLATE XVII B
DETAILS OF EROSION

7. There is a good chance for a flowing artesian well, even if no oil is obtained.

8. If neither oil nor water is secured, it is probably of little use to go deeper than 3,000 feet.

MISCELLANEOUS

Since the residual Pleistocene gravels are so siliceous and hard it is possible that they might be used in a ball mill, though no experiments have been run to determine their value in this connection: many of the fragments have rich red-brown and yellow-brown colors and might, on polishing, serve for ornamental or decorative purposes.

ARCHAEOLOGY

GENERAL STATEMENT

Although archaeology does not belong strictly to geology yet a brief note on this subject seems advisable simply to call attention to the possibility of the area in this connection. It is probably true also that some of the conditions that existed in prehistoric times can best be determined through the geologic record.

There are many relics of human occupancy of this region which antedated the Sioux. Stone arrowheads, scrapers and knives have been found at many points over the area: bone tools and pottery and other thing occur less freely.

The chief point of interest lies in the fact that most of the relics come from old soil layers which are buried by one to eight feet of later material. These layers appear as dark streaks through the fill material which was laid down as Piedmont deposits during the latter part of the Valley Cycle. They are black above, grading into dark brown below, just as a layer of soil shows today. They also show humus fragments. They are thicker than the soil which is on the surface today, which indicates a more flourishing growth of vegetation, probably due to more humid climate. Charcoal fragments and fire stones have also been found.

One interesting occurrence was on the top of the "Wall" at a point which could only be reached by difficult climbing. There, among quite an assortment of arrowheads, scrapers and pottery fragments, was a quantity of bone debris such as would accumulate in refuse heaps. All of this indicates an occupancy for some length of time. This means of course that the "Wall" was at that time more accessible and habitable.

All the evidence puts the time of occupancy back many hundreds and possibly several thousand of years, though not as far back as pre-glacial or glacial.

The Survey is planning at some time to devote more time to this phase of the work and to try to tie up the archaeological events here with similar ones in the central part of the State along the Missouri River.

THE PALEONTOLOGY OF THE AREA

By
W. C. Toepelman

I. INVERTEBRATE PALEONTOLOGY

Faunally the region about Interior is already well known so far as vertebrates are concerned, but little information is available upon the invertebrates. The present field work has brought to light several interesting collections of invertebrates, especially from the marine Cretaceous beds which outcrop extensively in some places.

PIERRE SHALE

The Pierre shale has been thoroughly studied only in the limited outcrops along White River southwest of Interior. The following species were taken in this section:

PELECYPODA

Lucina occidentales Morton

Inoceramus fibrosa subgenus *Actinoceramus* Meek and Hayden

CEPHALOPODA—AMMONOIDEA

Baculitis sp. cf. *Ba. gracilis* Shumard

Of the above species, *Lucina occidentales* and *Inoceramus fibrosa* are abundant at several horizons. Both are common in the upper portion of the Pierre in other localities and indicate that age for these beds. The additional fact that the typical blue black shale grades upward into a yellow brown series, the Interior Phase (p. 18) of somewhat doubtful position, seems to show that it is the extreme top of the Pierre that is here exposed.

In the extensive Pierre outcrop area in the northeastern part of the area, good exposures are rare. The few occurring are almost wholly unfossiliferous. A few specimens of *Lucina occidentales* were found but no other determinable forms were discovered. The large fossiliferous nodules so typical of the Pierre in other areas are entirely absent in this region.

INTERIOR BEDS

Perhaps the most interesting collection made during the field work upon which this work is based is that from the yellow brown beds here established as the Interior Beds of the Pierre shale. Lithologically, it has been noted above, the formation is much more sandy and distinctly lighter in color than the typical Pierre, yet the meager fauna seems to be most nearly related to that formation. Fossils occur sparingly over the whole outcrop area along the White River to the west of Interior and locally to the east and north of the town. In most instances the forms are in a very poor state of preservation and are rather difficult to preserve. The following list comprises the total number of species described to date:

CEPHALOPODA

Scaphites (Discoscaphites) nicolleti Morton

Scaphites (Discoscaphites) cheyennensis Owen

GASTROPODA

Anisomyon sp. cf. *A, patelliformis* Meek and Hayden

PELECYPODA

Inoceramus (Actinoceramus) fibrosa Meek and Hayden

Inoceramus (Actinoceramus) whitii sp. *nov.*

BRACHIOPODA

Lingula sp.

The collection was submitted to Dr. T. W. Stanton, of the United States Geological Survey, for examination and the determinations are those made by him.

The two species of *Scaphites* (sub-genus *Discoscaphites*) represent the best stratigraphic guides in the collection. Both were originally described from the Fox Hills sandstone but more recently have commonly been found, together with other Fox Hills forms, in the upper portion of the Pierre in many places. Their presence in the Interior beds, therefore, is not sufficient evidence of Fox Hills age, though the coloring of the beds is very similar to that of the lower portion of the typical Fox Hills in some places.

Of the remaining forms, the most distinctive is *Inoceramus fibrosa*, sub-genus *Actinoceramus* (formerly described as *Pteria fibrosa*). It was first described from the upper part of the Pierre shale along the Cheyenne River and later from rocks ascribed to the Fox Hills on North Platte River near the mouth of Deer Creek. According to Stanton[1], however, the latter beds are older than Fox Hills and probably of late Pierre age. Thus it is limited wholly to the latter formation. The only remaining form of value for purposes of correlation is *Anisomyon*, cf. *A. patelliformis*, which is represented by a single poorly preserved specimen. Thus far, the genus *Anisomyon* has never been reported from the Fox Hills, though common throughout the Pierre. The species of *Lingula*, though common, is too poorly preserved and is too simple a type to be of value for correlation.

The remaining species, *Actinoceramus whitii*, sub-genus *Actinoceramus*, is new. It is far the most abundant fossil in the formation occurring throughout the whole thickness of the beds and in nearly every outcrop. It exhibits a considerable variety in general outline, due probably to distortion in preservation, but shows more or less distinctly the radial sculpture characteristic of the *Actinoceramus* section of the genus *Inoceramus*. Following is a brief description of the species:

Shell thin, nearly vertically subovate, higher than greatest diameter. Hinge line short, sloping slightly posteriorly. Beak slightly gibbous, oblique, somewhat pointed, and terminal. Wings nearly obsolete, separated from umbo only by slight flattening; grading smoothly into margins. Surface marked by distinct concentric ridges and depressions crossed by several indistinct radiating lines, of which two, or more rarely one, are over central portion of umbo. Radial markings much less distinct than in *Inoceramus fibrosa* and node-like characteristic of shell of latter not evident.

The greatest difference between *Inoceramus fibrosa* and the present species is in the nature of the shell markings. The radial markings of the former are very distinct and numerous, whereas in the latter they are few in number and always rather indistinct. The present species is similar in general shape to *Inoceramus criprii*, variety *subcompressus*, described by Meek and Hayden, from brown Cretaceous sandstone on Judith River near Fort Union, but the radial striae are absent in that form.

The material upon which the description is based is very fragmentary, but the characteristics of the shell seem clearly enough marked to establish the form provisionally as a new species, *INOCERAMUS whitii*, in honor of Mr. A. S. White, of Interior, who so generously donated the services of himself and car during the 1921 season.

The above fauna, though limited, possesses considerable value for determining the age of the yellow brown beds containing it. Lithologically the formation is very similar to basal Fox Hills in other

[1]Dr. T. W. Stanton; Personal communication, 1922.

areas, a fact which led to a provisional classification with that formation in the field. The abundant fauna associated with most Fox Hills sections is wholly lacking, however, and the known range of the forms found seems to indicate Pierre age. Since the two species of *Scaphites* occur commonly in the upper part of the Pierre as well as in the Fox Hills, they are not diagnostic. *Inoceramus fibrosa* is probably confined to the Pierre, according to the latest determinations by Stanton, and *Anisomyon* surely is. Thus the faunal evidence points more clearly to upper Pierre age, and it seems best to include the beds with the Pierre. The color and lithology, however, have led the writers to establish the member as a new phase of the Pierre deposition, the Interior Phase or Member. The strict conformability and complete gradation of the typical Pierre into the sandy yellow brown beds is in line with the conclusion that the beds are Pierre in age.

Dr. T. W. Stanton has informed the writer that beds very similar to the Interior member occur in the vicinity of Crawford and Chadron, Nebraska. The Nebraska Survey has called these beds the "Rusty Member" of the Pierre[1] but no printed reference to the beds is at hand at this time.

Two explanations for the distinct difference in color are suggested: first, the beds may have been deposited in their present condition and the color thus have been inherent in them; second, they may be a slightly sandy phase of the Pierre, such as are now being made known from many localities, with the typical blue black color of the shale, and have subsequently been changed in color through the process of weathering and the circulation of waters from the overlying Tertiary. The first premise has been discussed by the senior author in another part of this paper. The second seems to the writer to be the most logical explanation.

If weathering is to account for the color, certain conditions of topography and lithology must have existed. It has been noted in the description of formations that the average thickness of the Interior member is thirty-five feet and that it departs from this thickness only slightly over the whole area. The topography must therefore have been markedly uniform for a considerable period of time. If these debated beds be of Pierre age, as seems most probable, the time interval between them and the succeeding Oligocene deposits is sufficiently long to account for a great amount of weathering and erosion, particularly if some of the later Cretaceous and Eocene beds were not deposited. A considerable thickness of beds could easily have been eroded and a base level developed before Oligocene times and still have sufficient time for weathering to alter the colors. The time element need not be stressed, for within the Lance alone unconformities representing upwards of 14,000 feet of erosion are reported in several areas in the west[2]. This break occurs between beds of late Laramie or Laramie-Eocene age, and there seems to be good reason why more erosion could have taken place in the Interior region.

That conditions of base level existed is shown by the remarkably regular contact between the Interior member and the Chadron formation. Channel markings are practically absent and indicate that the Oligocene beds were laid on a surface almost plane. Weathering upon this surface was undoubtedly uniform, and with uniform porosity and lithology may have extended down for about the same dis-

[1]E. F. Schramm; Personal communication.
[2]Cross. (—), U. S. G. S. Mono. XXVII, p. 217.

tance in all places. The brownish beds are rather uniform in all sections studied. Only local warping took place previous to the Oligocene and the contact is rather universally disconformable than angular.

It does not seem, therefore, that any peculiar conditions need be postulated to account for the change in color. Normal erosion could establish the base level, and chemical weathering change the color, as is being done now within the area of Pierre outcrop in the northeastern part of the region studied. The typical blue black shale is here changed to a distinct brown: given sufficient time it seems that the color might readily become lighter.

The red and purple tints found in the Interior member may be due to the action of ground waters after the Chadron had been laid down. Analyses show that iron is present in these clays, which when carried downward by the waters could still further alter the colors of the beds near the contact.

An explanation similar to this is suggested by Stanton for the beds in Nebraska, mentioned above. The section was not thoroughly studied by him and he has merely made a suggestion based upon hasty observation.

THE WHITE RIVER FORMATION

The White River formation is best known for its vertebrate fauna, but there are included in the beds several fresh water molluscs of the Gastropod group. These are found most abundantly in the upper part of the Chadron, or Titanothere beds in the limestone layers noted above (p 22). In these layers the shells make up a considerable proportion of the limy material; the remainder probably is algal in origin. A few small forms occur in limy-chert nodules in the middle Oreodon beds. The most abundant form, *Helix Leidi*, is found throughout the whole formation but is especially abundant in the Chadron and Protoceras beds.

None of the species have any value as horizon markers or stratigraphic guides.

The following forms have been identified:

TITANOTHERE BEDS
Lininaea meeki Evans and Shumard
Lininaea shumardi Meek and Hayden
Polygyra leidyi Hull and Meek

OREODON BEDS
Physa secalina Evans and Shumard
Monetua vetustus Meek and Hayden

PROTOCERAS BEDS
Polygyra leidyi Hayden and Meek

II VERTEBRATE PALEONTOLOGY

There is, perhaps, no other region upon this continent which has yielded such an abundance and variety of primitive mammals in fossil form as has the White River Badlands. Most of these forms have been obtained from the White River formation, especially from the Oreodon beds. In the region under discussion, no other vertebrate bearing horizons occur, the Pierre and Interior yielding none. Every division of the White River has yielded some remains but the largest proportion were collected in the Oreodon beds.

In the case of the field work a total of fifty-four specimens was taken. These are all in a more or less complete state of preservation, though in but few instances were complete skeletons taken. The latter are the exception rather than the rule, for only under the most favorable conditions can skeletons be preserved entire. It has been noted that the beds are probably in larger part laid down by running water and in broad lakes, and one should naturally expect partial skeletons or isolated bones to be the commonest things found. Furthermore, since there were many carnivores included in the faunas, the probability is against finding even such animals as died upon land areas preserved completely. Rarely does one find a complete skeleton of a horse, cow, or sheep today, the ravages of the coyotes and streams tending to scatter them widely. Similar conditions undoubtedly existed during White River times.

Skulls and crania are among the commonest remains found and the most diagnostic as well. The lower jaw is commonly lost, though a great many specimens taken during the field work have it well preserved. Other parts easily preserved are the long bones of the limbs and the centra or bodies of the vertebrae. The former were taken when in good condition, but the latter have little value unless of new species and, as a result, only the very best were taken. Certain small genera are represented only by jaw fragments or isolated teeth. These were taken when complete enough to be determined. The reptiles in the collection are all of one group, the turtles, and in most instances are represented by nearly complete carapaces (shells). Skulls and skeletal parts are almost wholly lacking; this is to be expected in terrestrial types such as these are, for in the course of preservation the carcasses would be carried and tumbled about by the streams and the loosely articulated heads and limbs thus easily lost. Very few skulls have ever been found and in these collections none were located.

TITANOTHERIUM BEDS

This, the lowest of the Oligocene formations, is one of the noted fossil bearing horizons of the Badlands but in this particular region yields very few forms. The beds outcrop widely and diligent search was made in them but the following forms were the only ones found:

MAMMALIA
- *Perissodactyla*
  - Titanotheridae
    - Titanotherium sp.
  - Artiodactyla
    - Oreodontidae
      - *Oreodon (Merycoidodon) bullatus* Leidy
      - *Oreodon (Merycoidodon) hybridus* (?) Leidy
    - Elotheridae
    - *Elotherium (Entelodon) crassum* Marsh
  - Rodentia
    - Indeterminate sp.

REPTILIA
- *Chelonia*
  - *Testudo brontops* Marsh

In the typical Titanothere beds the most characteristic animal present is *Titanotherium*. In the Interior region, however, remains of this form are exceedingly rare, but two specimens being found, both in very poor condition. One had been exposed for a considerable number of years and when first uncovered had undoubtedly been fairly complete. Ranchers and others had, however, carried off parts of the skeleton until all that remained was fragmentary bones and parts of bones that could not be determined. It is unfortunate that such finds are not reported to one or the other of the state institutions, so that they may be gathered and preserved in the museums. Individual teeth or vertebrae are undoubtedly of interest to all people but possess no great value, whereas complete skeletons are of considerable value scientifically as well as financially.

The second specimen was found within half a mile of the first and likewise was in fragmentary condition. In this case, however, the destruction had taken place during deposition and subsequent weathering. Though great care was used in uncovering and packing, the bone was so soft and decomposed that it powdered in transit and very little of value remains. The form was a rather large species but not enough material has been retained to merit specific determination.

The *Titanotheridae* reach the climax of their evolution in the beds to which they have lent their name. Several genera occur in the formation, but these differed little in general appearance. The Oligocene forms are all large, in fact they are the largest animals in the fauna. Their size approximates that of the present elephant and, except that the limbs are shorter and there are but four toes present in the front foot and three in the hind whereas the elephant has five, the body is elephantine. The shoulder is high as in the buffalo. This is caused by the elongation of the spines of the vertebrae in the forward part of the trunk. The skull varies considerably among the several species but in all closely resembles that of a rhinoceros in that there are two bony protuberances or horn cores over the nose. In size the skull is tremendous, reaching a length of over three feet and a width of two and one half feet in the largest species. The animals were undoubtedly well able to hold their own in combat with enemies, but the great specialization of body was ill adapted to meet changing environments and as a result they became suddenly extinct at the close of Chadron times.

The most abundant mammalian fossils are the Oreodons, the primitive ancestors of many of our modern ruminant, or cud chewing, double toed herbivores. The material is in rather poor condition and consists almost entirely of skulls. But one specimen is suitable for exhibition purposes. All of the specimens taken come from the upper twenty feet of the formation, which is throughout the region the most fossiliferous. The single form of *Elotherium crassum* likewise is in this part of the beds. Locally there occur numerous fragments of very small jaws and limbs that have not been determined.

The commonest fossil forms in the Titanothere beds of the Interior region are the turtles. They occur chiefly in the upper portion, being especially abundant in the reddish layer near the contact, the layer called the "Turtle-Oreodon" by [1]Sinclair. If this red layer is included with the Titanothere beds the range of the abundant upland terrestrial tortoise [2]*Stylemys nebrascensis* must be extended downward. Thus far not a single specimen of this species has been reported from the Titanothere section, and upon this basis the red layer is better included with the Oreodon beds. The turtle listed above, *Testudo brontops*, is also a terrestrial form. It is not, however, an abundant species.

It is interesting to note that the only Titanothere and the most abundant remains of other mammals are found in the only sandy

[1]Sinclair, W. J., Proc. Am. Phil. Assn., Vol. LX, p. 457.

[2]Hay, O. P., "The Fossil Turtles of North America," Carnegie Inst., Washington, Publ. 75, p. 385.

area of the Chadron beds in this region. This is located some six miles east of Interior and is very limited in extent. Except for several outcrops of unfossiliferous white sandstone west of Interior, this is the only evidence for river action in the entire Chadron outcrop area of this part of the Badlands. On the whole, the very fine nature of the clay and the absence of sand or grit in the formation are suggestive of deposits laid down in lakes or overflow areas where currents are lacking. The sandstones, on the other hand, are unmistakably stream deposits or deposits near shore, as they show decided current markings. The abundance of bones in beds near the sands may be significant in determining the origin, as there would be greater likelihood of carcasses getting into streams and into the deposits of shoreward portions of lakes. Unfortunately, the exposures of the sandstones are too limited to offer much conclusive evidence on this point.

OREODON BEDS

This series of clays and sands is the most noted of all fossil bearing horizons in the Badlands, if not the most noted upon the continent. It has yielded an abundance of species of primitive mammals and of individuals of most of these species numbering into the hundreds. There is no museum of note in the country and perhaps none in the world that is without some specimens from the Oreodon beds. Practically every outcrop will yield at least fragments of bone and a large majority contain complete bones and skulls. Several horizons are, however, more prolific in remains than others, notably the channel sandstones below the Lower Nodular Layer, (the Metamynodon sandstone), the Lower Nodular Layer (Red Layer) and the Upper Nodular Layer. Locally, however, each of these is without fossils. Between the two nodular layers and above the Upper Nodular are series of more or less barren, massive shaly beds, but excellent specimens occur locally even in these horizons. The greatest number and the best preserved of the specimens collected in the present field work are from the lower portion of the formation, particularly from the Metamynodon sandstones and the Lower Nodular Layer.

The following list comprises the species determined from the Oreodon beds. Several determinations are provisional only, as lack of time has prevented preparation of the material. In all other instances the determination is based upon material that lends itself readily to accurate study.

MAMMALIA
- Perissodactyla
  - Hyracondontidae
    - *Hyracodon nebrascensis* Leidy
    - *Hyracodon major* (?) Osborn and Wortham
  - Amynodontidae
    - *Metamynodon planifrons* Scott and Osborn
  - Rhinocerotidae
    - *Caenopus occidentalis* Leidy
    - *Caenopus copei* (?) Osborn
  - Equidae
    - *Mesohippus bairdi* Leidy
- Artiodactyla
  - Oreodontidae
  - *Oreodon (Merycoidodon) culbertsoni* Leidy
  - *Oreodon (Merycoidodon) gracilis* Leidy

Hypertragulidae
Leptomeryx evansi Leidy
Elotheridae (Entelodontidae)
Elotherium (Entelodon) ingens Leidy
Elotherium sp.
Dicotylidae
Perchoerus probus Leidy
Carnivora
Oreodontia
Hyaenodontidae
Hyaenodon, cf. *horridus* Leidy
Fissipidia
Canidae
Daephenus sp.

REPTILIA
Chelonia
Stylemys nebrascensis Leidy
Testudo laticunea Cope

The most abundant remains, with the exception of the turtles, are those of the even-toed and odd-toed mammals, the *Artiodactyla* (cattle, deer, swine, etc.), and the *Perissodactyla* (horse, rhinoceros), respectively.

The type fossils of the series are the Oreodons, which give it its name. The family includes the commonest mammals of the White River Badlands, and are limited entirely to the North American continent. They originated in the Eocene period but are most common in the Oligocene. Their exact zoological position is intermediate between the true cud-chewing, or ruminant, and the swine-like thick-skinned animals.

The White River genera represent the most typical of the family. In general, the forms are about the size of a peccary. The skull has some resemblance to the modern peccary; there is a pronounced crest in the posterior portion, much as in the camel. The teeth are distinctive, and in number, proportions, and construction are much more closely related to the ruminants than to any other group. It is upon this basis that the animals are classed with cud-chewers. The canine tooth, so often lost or reduced in size, is well developed in both upper and lower (?) jaws and gives something of the appearance of a carnivore, but this is a resemblance only and does not indicate close affinity. The skeleton is, in general, hog-like. The neck is short, the trunk elongate, the limbs short. The feet are four toed behind and in front, except in the primitive forms and in the common genus Oreodon, which has five toes on the front feet. All toes reached the ground, the digits being flat and supporting the weight. Heel and ankle were elevated. The combination of true ruminant and pig-like characteristics led Leidy in his description of the earliest specimens to call the oreodonts "ruminating hogs."

Remains of the family are exceedingly abundant throughout the Oreodon beds. Several almost complete skeletons were taken, as were numerous well preserved skulls. On the whole, Oreodons are the commonest fossil of the White River formation and the collector soon loses interest in all but the most perfect specimens. *Oreodon (Merycoidodon) culbertsoni* occurs most frequently and is represented in the collection by several complete skulls and fragmentary skeletons.

Of the other Artiodactyl families, only the *Elotheridae* are common. The family is especially abundant in the lower half of the Oreodon beds, where remains are met with almost as often as are those of the Oreodon. The animal can best be described as a giant pig, but its external appearance was quite different. In life it must indeed have presented a grotesque shape. Though considered as an ancestral hog, it is only indirectly the ancestor to our modern forms, and except for the nature of the teeth, presents few swine-like characteristics. The skull is elongate and narrow in front of the eyes. Great bony projections extend from the cheek bone and from the lower jaw, thus giving the head a very peculiar shape. The eyes were far back on the skull and were completely surrounded by bone. The brain was small and undoubtedly was smooth. At the shoulders the largest forms measure about six feet in height. From the shoulders the back slopes gradually to the hips, which are much lower. The limbs have two functional toes both front and back.

The animals far surpassed the largest of our modern pigs in size, approaching more nearly the proportions of the hippopotamus. In size the species varied considerably, the largest nearly the size of the present day rhinoceros, the head alone exceeding a yard in length in the largest. Though not along the same line of evolution as our modern swine, there is little doubt that the Elotheres are derived from the same ancestor in early Eocene times.

The Artiodactyl families *Hypertragulidae* and *Dicotylidae* are represented in the collection by fragmentary remains only. The former is present in the form *Leptomeryx evansi*, of which three fragmentary skulls and the fore part of a skeleton were taken. *Leptomeryx evansi* is best compared to the little musk deer of the Asiatic plateaus and the "deerlet" of India. In size they were scarcely as large as a small terrier dog and much more delicately built. The diminitive skull has true grazing or selenodent teeth, and is somewhat camel-like. The neck is short. The fore limbs are considerably shorter than the posterior ones and have four toes as compared to two behind. The form is an offshoot of the true ruminants and gives rise to no descendants.

The *Dicotylidae* or peccaries are represented by two skulls; one incomplete, from the Upper Oreodon beds, the other, complete, from the Protoecras sandstones. Little is known of the White River peccaries other than that they were true members of the family. The skull from the Protoceras beds is considerably larger than the Oreodon beds form and has slightly more complex molar teeth. In both the canines are highly developed; the first incisor of the upper jaw is largest. Undoubtedly these White River peccaries were similar in most respects.

The *Perissodactyla*, or odd-toed animals, occur in great abundance in the lower part of the Oreodon beds, rivaling if not exceeding even the Oreodons. The *Equidae*, or horses, are perhaps the most abundant, and numerous fragmentary limbs and jaws were passed by in the field. At least two nearly complete skeletons were taken and several isolated limbs and skulls are also included in the collection. As far as can be determined, all remains belong to the species *Mesohippus bairdi*. This species of ancestral horse is in size slightly smaller than a pointer dog. It differs from our modern genus in many other respects, however, more especially in the structure of the teeth and of the limbs. The teeth are short crowned, crested, short rooted, and adapted only to feeding upon soft types of vegetation. The skull is about seven inches in length with a large and well convoluted brain. The orbits were not fully surrounded by bone, as they are in the later horses. The neck is short, the backbone arched. The animal was slender limbed and well adapted to speed, though less specialized in this respect than our modern form. Both limbs were three-toed with the middle or third digit the larger. The hind limbs were the longer and, since the spines of the posterior ribless vertebrae were at least as long if not longer than those of the thoracic region, the rump must have been higher than the shoulders.

The habits and habitat of this early horse are suggested by its teeth and skeleton and by paleontologic facts. The food as suggested above was limited to soft, vegetable matter. The three-toed feet would enable the animal to move freely upon soft ground. It seems, therefore, that it was an inhabitant of the low, forested bottom lands along the streams which helped make the deposits which now contain the fossil bones. This forest habit has been assigned to the animal by most authorities on the subject but, in view of the fact that thus far no remains of trees or leaves have been found in the formations, the opinion is subject to some doubt. If forests had been present, it seems that some evidence for them should be found. The harsh grasses which formed the chief food of the later grazing horses and the semiarid plains which were their home had not yet made their appearance. Once they came in Miocene times, the evolution of our modern types was very rapid.

The rhinoceros group was very highly developed in White River times. The fauna contains representatives of all the families into which the rhinoceroses are generally separated.

The *Hyracodontidae* include the cursorial or upland running forms. They were small, deep chested, slender limbed types with well developed hoofs and without horns. In stature they were slightly larger and heavier than a sheep. The skull is short, deep, and thick, indicating a rather heavy, clumsy head quite out of proportion to the slender limbs and light body. The teeth, especially the grinding molars, have the unmistakable rhinoceros pattern. The neck and trunk are elongate; the neck vertebrae are, however, rather stout, as should be expected in a form with a heavy, bulky head. The limb bones bear a close resemblance to the true rhinoceroses but are much more elongate. The forearm and thigh are most affected by this elongation. Both front and hind feet are three toed and long and narrow; the body weight is borne chiefly on the middle digit.

In general appearance the Hyracondonts bear little similarity to other rhinoceroses, being more suggestive of the horses in their light build. The family reached its culmination in size and abundance in the White River epoch and became extinct at the close.

Associated with the above family in the fauna were the *Amynodontidae*, heavily built, short bodied, hornless animals resembling the modern hippopotamus in size and general appearance. The head was large and had a prehensile upper lip. The nostrils and eyes were directed upward, probably as a protection in swimming. The teeth, as in Hyracodon, are typical of the rhinoceros. The neck, body, and limbs are all heavy and massive. In the front foot there are four toes, in the hind three. Both feet are spreading, an adaptation to the soft ground of the river flood plains upon which the animal lived. The remains of this family in the collection are all referred to *Metamynodon planifrons*, a species which reached a length of nine feet and over and stood four and one half feet at the shoulders. Like the Hyracondonts the *Amynodontidae* became extinct in the White River epoch. Their remains are found most abundantly in the channel sandstones of the Oreodon beds, usually as separated and isolated bone.

The true rhinoceroses, family *Rhinocerotidae*, of the White River beds are the direct ancestors of our modern forms. In this collection but one genus, the most common Oligocene form, has been determined. All species collected are without horns and are smaller than our modern genera. The largest, *C. tridactylus*, from the Protoceras beds, reached a length of almost eight feet, and stood four feet at the rump, being thus slightly smaller than the present day Sumatran species. The neck is short, the body elongated but neither is very massive. The limbs are relatively longer and lighter, and the three toed feet slenderer than in forms from later geological periods.

The remaining mammalian remains in the collection are fragmentary carnivores. The family Hyaenodontidae include the most primitive carnivores known. They were very abundant in Eocene times but are represented only by a few species of Hyaenodon in the Oligocene. A single fragmentary skull of a young individual is referred provisionally to the species *H. horridus*, approaching in size the modern black bear and in appearance intermediate between the wolf and hyena. The life habits are not surely known but the teeth and structure of the body indicate that they lived upon carrion much as do the hyenas.

The true carnivores are present in a poor skull of the dog family. Its specific characteristics are not clear but it can be referred to the genus *Daphoenus*. The Oligocene dogs are known from a few complete specimens. All are much more generalized in structure than our modern types, particularly in the teeth, skull and feet. The several species of Daphoenus vary in size between that of the coyote and the gray wolf. The skull at hand approaches the latter in size and may belong to *Daphoenus superbus*, though this species is described from the Protoceras beds, whereas the specimen was collected in the Oreodon series.

The class Reptilia appears only in the turtles, though other regions have yielded remains of other orders. But one genus occurs, a terrestrial tortoise. This form, *Stylemys nebrascensis*, is by far the most abundant fossil in the region. Individuals vary in size from a few inches to nearly three feet in length and occur in such abundance that the surface of the ground is literally covered with broken "shells." The position in which the carapaces are found indicates that they have been transported for some distance in most cases, and the lack of skulls and other skeletal parts bears this out.

PROTOCERAS BEDS

The uppermost horizon of the White River formation is fossiliferous in this territory only in its lower part. The channel sandstones, however, contain many rounded fragments of bone that cannot be determined. As was the case in the lowermost horizon, the animal which gave the formation its name, Protoceras, was not found. The following forms were collected:

- MAMMALIA
  - Perissodactyla
    - Rhinocerotidae
      - *Caenopus tridactylus* Osborn
    - Artiodactyla
      - Oreodontidae
        - *Eporeodon* (*Eucrotaphys* ?) sp. *major* Leidy
      - Dicotylidae
        - *Perchoerus robustus* (?) Marsh

REPTILIA
Chelonia
Stylemys nebrascensis Leidy

The most abundant form is *Eporeodon major*, of which one complete skeleton and four excellent skulls were obtained. *Perchoerus robustus* and *Caenopus tridactylus*, a peccary and a rhinoceros respectively, are represented by single skulls.

Because the formation occurs only in the highest parts of the "Wall," it proved most difficult in collecting. In many places it was impossible to reach it in safety because of the almost vertical cliffs; in others the surface was covered with fragments of the weathered rock, which made progress over it hazardous. This inaccessibility undoubtedly accounts for the paucity of the collection.

The above discussion of the White River fauna is not an attempt to describe completely the various forms included, nor do the lists given contain the names of all fossils that occur in the formation. For complete descriptions and illustrations the reader is referred to W. B. Scott's "A History of Land Mammals in the Western Hemisphere," and to W. D. Matthew's "Age of Mammals." Complete faunal lists for all formations of the Badlands area may be found in the South Dakota School of Mines Bulletin No. 13, by C. C. O'Harra. Good reproductions of the best known types are also included in the latter bulletin.

THE BADLANDS AS A NATIONAL PARK

By

W. C. Toepelman

THE BADLANDS AS A NATIONAL PARK

From time to time within the past twenty years proposals have been made to establish the most scenic parts of the Badlands as a national park. It was not until the present year, however, that these proposals took concrete form and that the idea was presented to the Congress of the United States. On May 2 bills which have for their common purpose the establishment of "the Wonderland National Park in the State of South Dakota" were introduced into both houses. Senator Peter Norbeck and Representative William Williamson are the authors of the bills.

The name "Wonderland National Park" was substituted for "Badlands National Park" because of the erroneous impression the term "Badlands" gives to many people. To many, who have not been in the region, it signifies a totally worthless area in which soil, climate, and even the inhabitants are bad. This is by no means true, The soil upon the plains along White River and on the extensive grassy flats near the "Wall" is remarkably fertile when carefully tilled. Dry-farmers are working wonders in making the area an agricultural section. Lack of sufficient water is the only important drawback but careful cultivation of the land and conservation of such rain as does fall are overcoming the deficiency. The climate, though dry, is not unfavorable to either animal or plant life, as is evidenced by the numerous herds of cattle and horses and the abundant crops of alfalfa and native grasses that are produced. The inhabitants are typical western farmers and ranchers, whose hospitality is surpassed by none.

"Badlands" applies only to the typical topography in the region. When the name was first given the region by early French explorers it referred only to the minor features, the steep sided valleys of the numerous small streams which made travel difficult. Later the term came to include the major features of the "Wall" and it is today an accepted physiographic term for all topography of the type so admirably developed in the White River drainage area.

The bill as introduced seems to set aside the unclaimed public lands in seven townships near the town of Interior (Townships 2 and 3 S., Ranges 15 and 16 east of the Black Hills Meridian, and Township 3 S., Ranges 17, 18 and 19 east.) This is simply a beginning, to which the authors of the measure hope other areas may be added in the future.

As thus outlined, the park would include one of the two most scenic places, Cedar Pass. The second is Sheep Mountain, which lies a short distance south of Scenic, South Dakota, and a considerable distance west from the western boundary indicated in the bill. The region between includes large areas of true badland topography and connection should not be hard to establish. It is to be hoped that both Cedar Pass and the Sheep Mountain area may ultimately be set aside for the enjoyment of the public. Already the only good approach to Sheep Mountain is in private hands and the tourist and sightseer is taxed for the privilege of using the road.

If the efforts of the authors of the "Wonderland National Park" bill are to be successful, it is necessary for the people of South Dakota to give them all possible assistance. There will be some aid from other states but if the state which is to contain the Park is not interested and active in the matter it is not likely that Congress will take action.

In view of the fact that there are at present several movements under way to establish national parks in various parts of the country, it may be well to set forth briefly some of the characteristics a region should possess to merit its establishment as a public playground and park. First, and above all, the area should be of national interest and not merely of local or even state-wide reputation. Second, it should be possessed of unique, unusual, or typical scenic characteristics or be of particular historical significance. Third, and finally, it should be so situated as to be easily accessible to the whole public at most times. Unless a region can satisfy at least these conditions, it does not seem wise to establish it as a national park. Not that we have too many parks at present or ever shall have, but anything termed "national" and supported by national funds should surely be of interest and value to the whole nation. Many of the areas recently proposed for national parks would make admirable state parks or reservations, of which we have at present far too few.

The White River Badlands seem to fill the first requirement in several ways. From a scientific viewpoint a number of excellent reasons suggest themselves. It is stated elsewhere in this report that South Dakota "Big Badlands" were the first area of the kind to be described and that the forms and features found here are the types for all badland topography. Other badlands occur in this country as well as in others, but no other area exhibits so clearly the variety and beauty of erosional features that have come to be associated with the term. The best development in the South Dakota region is between Kadoka and Scenic and Sheep Mountain, and it is for this reason that it is desired to establish the park in that area. This section of the territory is known to geologists, paleontologists, and geographers the world over. Scientists from many countries have visited and studied the various features, a fact which in itself indicates that the fame of our Badlands is international as well as national.

It is not, however, only for its topographic development that the country is known. Included in the formations of the White River series are abundant fossils of the ancestors of many of our modern mammals, such as the horse, the camel, the cat and others. There is perhaps no area of like size that has yielded as many distinct kinds nor as many excellent specimens as has this portion of South Dakota. Since the first description of some fragmentary jaws of Titanotherium by Dr. H. A. Prouty of St. Louis in 1846-47, scarcely a year has passed during which some new form or fact of early mammalian life has not been added to the volumes of science. Likewise, very few seasons have gone by without a collecting expedition from some museum or university. The first real expedition in search of fossils came into the region in 1849, under Dr. John Evans of the Owen Geological Survey of the federal government. Since that time and more especially since 1870, Yale and Princeton universities, the American Museum of Natural History (New York), the National Museum of Washington, the Field Museum of Chicago, and many others have repeatedly sent parties into the field to gather fossil bones. Their finds have been many and have been sent over the world, so that practically every important museum has at least a few specimens of White River fossils. Not all faunal facts are yet known and parties may still be found at work nearly every summer. It is unfortunate that tourists and settlers do not know the importance of fossil remains. Many excellent specimens are absolutely ruined by the carrying away of essential parts as souvenirs.

The second point has already been touched upon. It has been shown that the area included in the proposed park has unique features, for it is considered the type of all badlands. It is unusual as well since badlands are not common topographic forms. Furthermore the "Wall" exhibits the scenic features on a grander scale than any other badland region. One finds inaccessible cliffs, miniature grand canyons and great pinnacles abundant, and it is impossible for the average person to pass even hurriedly through the region without being impressed by the unusual beauty of the scenery and its constant change. To fully appreciate it, it is necessary to linger and take advantage of the many phases of the "Wall" brought out by the varying light of the sun. The writer has spent three summers about Interior; yet even on the last day new things of interest were discovered.

Economically the true Badlands and the "Wall" are worthless, as they are barren of vegetation for forage and cannot be tilled. Aesthetically, however, they are invaluable as examples of Nature's beauty and the work of the Creator in changing and modeling our earth. It must be remembered, though, that not all of the region popularly called "the Badlands" is worthless, for even at the very base of the "Wall" are excellent farms and the flats and plains are largely taken up by settlers for farming and grazing purposes. These agricultural lands are not to be included in the park, except as some may be needed for approaches, water storage, or forage for game animals that may be propagated. Still others, as Sheep Mountain Table, south of Scenic, are of great value for the scenic effects seen from them and should be owned by the public, even though capable of cultivation.

In the matter of accessibility, the area indicated in the bill seems to fill all requirements. The Custer Battlefield Highway, or Custer Trail, a much used route to the Yellowstone National Park, runs almost to the eastern edge. Unfortunately the builders of the trail turned the road to the north of the scenic region at Kadoka, apparently to insure the tourist of a level road. By this, however, one of the most beautiful regions in the State is sacrificed for the monotonous prairie north of the "Wall." Side trips are now provided for from the trail to Cedar Pass and others could be established very easily. Good roads, however, lead from Kadoka into and through the heart of the Badlands and are in fairly good condition through most of the tourist season. The old Washington Highway is the best of these and with a few minor repairs, now under way, will be an excellent route for tourists. From this highway, side roads lead to and over the "Wall" from the larger towns. Big Foot Pass, northwest of Interior, already is possessed of a good automobile road, and Cedar Pass to the northeast can be put into condition at a slight cost, as can also the road from Scenic to Sheep Mountain. Camp sites for those wishing to camp out are numerous, but the question of a water supply is often troublesome. The towns and most settlers will, however, gladly furnish water for all camp purposes. With interest in the Badlands increasing each year it is only a question of time until free camp sites with water, fuel and other camp necessities will be established at intervals along the route. The larger towns already provide these.

For sightseers traveling by rail the region is a bit more difficult to reach, as it is away from the main lines of travel. Branches of the Chicago and Northwestern and the Chicago, Milwaukee and St. Paul railways touch or traverse the Badlands. The latter road is most convenient, as both Scenic and Interior are on it and afford the traveler fairly good hotel accommodations. If the park is established both these towns and perhaps others will undoubtedly make improvement to meet conditions.

It is only within the past few years that tourists have visited the Badlands in great numbers. The common fallacy that everything in the region was inhospitable is probably the chief cause. At present the number of automobiles going through is increasing rapidly and each year will see more and more travelers entering. The scenic fame is spreading not only through the Dakotas and neighboring states but throughout the East. Tourists much prefer routes with variety of scenery and this is given them throughout the Badlands.

Several additional reasons for establishing the "Wonderland National Park" may be suggested. A few years ago the U. S. Forest Service was advised of a report that a band of mountain sheep was still in existence in what is known as Medicine Root Badland Basin south of Scenic. With this fact in mind, together with others, an investigation was undertaken but no proof was found. Several reliable persons, however, claim to have seen them very recently and further investigation should be made. The territory is exceedingly difficult to travel over and it will be rather hard to prove the presence of the sheep. If they are found to be there, no time should be lost in establishing the basin as a refuge. At one time, as indicated by widespread remains, mountain sheep were common over the whole Badlands. This band includes the last survivors of the animals in South Dakota, if not the last east of the Rockies, and should be most rigidly protected if their presence can be shown.

It was not only because of the mountain sheep that the Forest Service recommended the establishment of at least portions of the Badlands as a game refuge. The White River region was at one time the home of the bison or American buffalo, the antelope and other grazing animals. Old settlers and Indians say that the bison did not range through the area, but the exceedingly abundant remains on the surface and in the several soil layers seem to refute this. The antelope is known to have been present until a few years ago. Today, however, in all the length and breadth of the Big Badlands, there is not a single specimen of either of these typical American game animals. Only the coyote, prairie dog and jack rabbit are abundant, presenting to us the spectacle of a complete annihilation of valuable life, whereas as is so often the case in this country, the worthless and destructive is preserved. That the territory will support buffalo, antelope, and mountain sheep cannot be disputed. It now furnishes food for many wandering bands of almost worthless horses, countless numbers of cattle, and a few sheep, and not so long since sufficient forage for game animals. That the latter will thrive is well proved by results in other places where rigid protection is afforded. It is, therefore, urged that the game refuge probabilities be kept in sight in establishing the park.

One more argument may be advanced from the Forest Service investigation. (The report of this is now in the hands of the District Forester, Denver, Colorado.) Early visitors and settlers say that the "Wall" was once fairly well supplied with cedars and that ash and cottonwood groves were much more abundant along stream courses on the flats. Today cedars occur in only a few localities along the "Wall," at Cedar Pass, Castle Buttes, and Sheep Mountain especially, and in these in limited numbers. Great numbers have been cut by settlers for fence posts, others by tourists for fire wood until the remnant is small and consists of stunted growths only. This remnant should be zealously guarded and efforts be made to reestablish cedars in other places.

Ash and cottonwoods are confined chiefly to the White River bottoms and to a few of the larger tributaries. Some elms occur in the same places. More recently settlers have planted trees about dams and it is hoped this may continue both for the protection afforded to man and beast and for the enhancement of the beauty of the landscape. The area will never be important as a forest reserve, since the Badlands are by nature a more or less treeless area, but as some trees, especially cottonwoods, will grow, their extension should be encouraged. Trees conserve moisture even if they do not increase rainfall, and moisture is the only element lacking to make the Badlands an agricultural region.

Much more could be written on the subject of the "Wonderland National Park" but it is impossible here. It is desired only to call the attention of people of South Dakota to the importance of this area as a public playground. Many of our natural wonders have passed out of public hands and those remaining will soon be lost unless action is taken at once. Thus far the public is taxed for the privilege of sightseeing in but one place in the Badlands but with rapidly increasing interest it will not be long until other places are exploited. We of the present generation do not own these scenic areas but have them for use in passing only. We owe it to the future to preserve as nearly intact as possible the wonders and beauties of our nation. Therefore it is urged once more in closing that South Dakota as a state put forth all possible efforts to aid our congressional delegation in successfully pushing the present bill. The cost to the State will be trivial, as it will be to the nation, since it is proposed, for the prosent at least, to use only the unclaimed lands in the area. Unless the people of this state make known their interest in the park, it is not at all likely that it will be established.