THESIS IN MAJOR SUBJECT GEOLOGY.

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OF

MASTER OF SCIENCE

by

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TITLE.

A Geologic Description of Township 21 North Range 5 East of the
Black Hills Meridian, South Dakota with a Discussion
of the Geologic Literature Relating to the
Field.
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Black Hills Meridian, South Dakota with a Discussion of the Geologic
Literature Relating to the Field.

PART I. RESUME OF GEOLOGIC LITERATURE.

PART II. GEOLOGIC DISCUSSION OF Tp. 21 N. Rg. 5 E.

Introduction.
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Introduction.

The field work, upon which this article is based, was done during the summer of 1911 by a party of United States Geological Survey, under the direct supervision of Mr. T. M. Parks assisted by the writer. The duty of this party was to map the coal for the

List of Publications Examined. The region examined is located in the extreme northwestern corner of South Dakota and township 21 north of latitude 44 degrees, range 6 east of the Black Hills meridian, which is the state line between South Dakota and Wyoming is taken as typical of the larger fields examined, and is described in detail in this article. This work is treated in three parts which fall under the following heads: Part I, a resume of the literature on the field abstracts of articles relating to descriptive geology but contains only mention of those articles dealing with age and origin of the formation; Part II, a detailed geologic description of Tp. 21 Rg. 6.; Part III, a historical review of the opinion in regard to age and origin of the Lance, Fort Union and White River formations.

Acknowledgments.

Invaluable aid has been rendered to the writer by Mr. T. M. Parks in supplying the data and by helpful suggestions. Acknowledgement is also due to Mr. B. W. Winchaster who worked the field immediately east of us and adjoining the one under discussion, for important data. Also to Drs. F. R. Knoviton and T. E. Stanton for separate copies of literature relating to this subject.

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PART I  RESUME OF GEOLOGIC LITERATURE.

The area under discussion is a portion of the large lignite fields
which is distributed over northwestern South Dakota, western North Dakota, central and eastern Montana and central and northeastern Wyoming. Only a few geological reports have been written on this particular part of the field and none of them in detail. However, as early as 1805 geologic observations were made on parts of the large field outlines above. In the historical review of the literature these early reports will be considered, but later the large field was more fully examined and reported on, and this review will be confined to those reports treating of that part which is situated in South Dakota or adjoining regions. The first geologic reports of the large field came from men who opened up the country for the white man. In these early expeditions the Missouri River was followed practically in all cases. Later military expeditions passed through the field and some of them entered the Black Hills country. Still later the Federal and state geological surveys sent individuals and parties into this region. At present this territory is being examined by the United States Geological Survey for the purpose of land classification, and several parties were in the field during the summer of 1911.

1805.
Lewis and Clark's Expedition up the Missouri River Vol. 1 p. 180.

probably the first authentic geologic report of any part of the lignite field was made by Lewis and Clark from observations made while on an expedition up the Missouri River in 1805. Between the mouth of the Little Missouri River and the mouth of Knife River they note "The bluffs which we passed today are upwards of 100 feet high, composed of a mixture of yellow clay and sand with many horizontal strata of carbonized wood resembling pit coal, from one to five feet in depth,
and scattered through the bluff at different elevations some as high as eighty feet above the water: the hills along the river are broken and present every appearance of having been burned at some former period; great quantities of pumice stone and lava are rather earth which seems to have been boiled and then hardened by exposure, being seen in many parts of these hills where they are broken and washed down into gullies by the rain and melting snow. Later in the same vicinity they speak of a bluff "which is in some parts on fire and throws out quantities of smoke which has a strong sulphurous smell." They also speak of a "white substance which appears in considerable quantities on the surface of the earth and tastes like a mixture of common salt with glauber salts." Above the mouth of the Little Missouri probably some fifty miles they note "The mineral appearances of salts, coal, and sulphur with the burnt hill and pumice continuous" and later note that "there is indeed reason to believe that the strata of coal in the hills cause the fire and appearances which they exhibit of being burned". On their return trip they first noticed coal at the mouth of Martha River, about fifty or sixty miles from the mouth of the Yellowstone.

1832.

In 1832, the Prince of Newwied made an expedition up the Missouri River and noted the presence of sand, clays and lignite.

1836.


In 1836 Dr. Nicollet observed along the Big Missouri a formation overlain by thick deposit of clays in which he found ammonites, belemnites, and bones which he supposed belonged to a large reptile. He
thinks it probable that this formation extends to the mouth of the Yellowstone.

In 1843 Edward Harris visited the upper waters of the Missouri River as far west as the mouth of the Yellowstone. He reports that all of the strata are horizontal and notes the following series:

At the base, No. 1, a secondary limestone; No. 2, a yellow sandstone; No. 3, a clay stone; No. 4 Nicollet clay; No. 5, Yellowstone formation, which is composed of sand, clays, shale, sandstone and coal. Clay is more prominent in the lower part of No. 5. No evidence of volcanic activities was found.

In 1855, G. K. Warren made an expedition into the Mauvises Terres, and reported the following geologic section which was taken near the stream known as l'Eau qui Court:

Top. Loose sand. Sandhills 50-100 ft. high

Hard calcareous sandstones 3-5 ft.

Sand 15 ft.

Clay and shells 3 inches.

Sand 15 ft.

Clay interstratified with sand 10 ft.

Friable sandstone calcareous 15 ft.

In the same report F. V. Hayden gives an estimated boundary to the great lignite field and speaks of the rugged topography, the concretions, and the white color the the Bad Lands along the White River.
1857.
In 1857 Meek and Hayden visited the lignite fields and other regions in the same area and reached certain conclusions relative to the age and origin of the White River and lignite formation.

1866.
In a report read in 1866 F. V. Hayden discusses the Tertiary basins along the Missouri River. He gives the following which are probably arranged in order of their age commencing with the oldest:
(1) Judith River Basin (2) Great Lignite Basin, which extends from the Heart River to the Mussel Shell, is distributed over most of the valley of the Yellowstone, extends an unknown distance north and is found as far south as the north Platte; (3) Wind River Basin; (4) The Basin of the Mauvais Terres or Bad Lands of the White River.

1868
In a publication of 1868 F. V. Hayden states that according to all evidence the lignite Tertiary beds of the west are fragments of one great basin, and that no valuable beds of lignite are found in formations older than the Tertiary in the country west of the Mississippi River.

1869.
In a publication of 1869 F. V. Hayden advances theories relative to the origin of the late Cretaceous and Tertiary formations of the Great Plains region.

1871.

During the years of 1864-5 Chas. Foebel visited the bad lands of the Little Missouri and noted the coal beds exposed along the bluff.

1875.

In this article William Ludlow gives an account of his observations which were made in 1874 while on a trip to the Black Hills. He approached the Hills from the north and passed through the field discussed later in this article. He took the following section near Ludlow's cave which location is 1 to 5 miles north-east of Tp. 21 Rg. 5 which Township is treated in Part II.

Section at Ludlow's Cave.
Top.1A descent of 10-15 ft rock not seen 10-15 ft.

2 Siliceous limestone mostly gray and very hard but sometimes porous and of a lighter color; very rough, contains silicified wood and impressions apparently of bones. This rock as seen in fragment is mostly pure silica and might be styled quartzite. 1-2"
3 Whitish sandy marl 50-60"
4 Reddish sandstone with many iron concretions 40"
5 Sandstone of Ludlow's Cave rusty and constellated 40"
6 Argillaceous and calcareous sand, white 15"
7 Bedded blue clay 35 ft.
8 Interval unseen 85 "
9 Lignite 5-6 "
10 Massive white sandstone
11 Top of Bald Butte
12 Light or Yellowish argillaceous marls with other concretions 35 "
13 Carbonaceous shale with selenite 3 "
14 Carbonaceous shale massive 4 "
15 Hard gritty clay weathering blueish 25 "

Loose fragments of the siliceous limestone are quartzite were found scattered over the surface for over thirty miles down the north fork of Grand River. These loose fragments are also reported as being found over the surface in the vicinity of the Cave Hills and some south of the Short Pine Hills.

He also took a section of the Short Pine Hills which are located in the southeastern part of the large fields treated later in this article. This section is as follows.

No. 1. White arenaceous marl, indurated, varying from a hard, arenaceous limestone to a sandstone with limy cement, cracking into small conchoidal blocks that soon crumble into soil in the air, contains but little iron, but has a few argillo-calcareous concretions about 200 ft.

No. 2. Massive, rusty sand, weathering into pinnacles and isolated peaks. This is the same as seen on the top of Castle Butte.

No. 3. Blue clay locally varying to sand seen 110 ft.
Several features are observed in connection with No. 3. First, it contains at different horizons what appear like concretions of sand. They are usually concentrically laminated and appear elongated, and the inside is usually hard and do not contain fossils. Second, regular layers of barium sulphate were found. Iron concretions of a dark color the inside of which is an argillo-siliceous limestone, four large vertebrae as well as some large bones and turtle remains were found in this formation.

1876.


In a publication of 1876 J. J. Stevenson contends that the Fort Union Group is of Cretaceous age.


In this publication J. A. Allen notes the rugged topography of the Little Missouri Bad Lands and the clinker formed by the burning of the lignite beds.

1877.


In 1877 Lesquereux states the belief that the beds immediately overlying the Fox Hill sandstone to be Tertiary and that the Fox Hills represents the last distinctly marine strata in the region studied.

1883.


In 1883 E. D. Cope wrote from Sully Springs, Dak. that he had dis-
covered a new deposit of White River age about 200 miles northwest of the nearest White River then known.

In this well E. Todd traces of the age and relations of the Fox Hills, the Laramie and the White River formations.

1885.


In 1885 Bailey Willis reported on a portion of South Dakota which is situated between the Grand and the Moraen Rivers (This region is 100 miles more or less from the territory treated later in this paper) and the upper San. Todd discusses the lignite concretions found near these two rivers, he is of the opinion that they were formed by wave action on old beaches.

In his general description he speaks of having found "erratic blocks of quartzite and granite on many of the elevations of the prairie. Some pieces of the quartzite contain silicified wood which probably identifies it with the Dakota quartzite of the Black Hills, but more frequently the fragments are pierced with casts of stems from which the core has been removed. The surfaces of the blocks are highly polished by drifting sand, as was first shown by Dr. C. A. White and the silicified wood has apparently been excavated from these casts by the same means aided by alkalies."

His geologic section in brief is as follows:

Top. Laramie - Light yellow, gray, and dark brown sandstones and arenaceous shales, with thin beds of lignite and iron nodules.

Upper Fox Hills - brownish sandstone

Fox Hills - grayish blue shale below brownish unfossiliferous sandstone

Lower Fox Hills - Fort Pierre of Hayden's in part - dark gray to blue-black, tenaceous alkaline clay.

There appears to be a gradual transition from the Fort Pierre shales to the lower part of the Laramie. The strata are practically flat lying with local dip. He notes that the lignite seams pinch out very quickly and also the presence of concretions consisting of gray iron carbonate oxidized on the outside to limonite.
In this work J. E. Todd treats of the age and relations of the Fox Hills, the Laramie and the White River formations.

J. E. Todd discusses the loglike concretions found near the head waters of the Grand and Moreau Rivers. He is of the opinion that they were formed by wave action on old beaches.

In 1895 J. E. Todd made a trip into the Northwestern portion of South Dakota for the purpose of making a geologic examination of that region. (The region he traversed is the same in part as that taken up later in this paper under Part II) The following is an abstract of a part of this article.

Topographic Features. The divide between the Little Missouri, the Grand and the Moreau Rivers constitutes a high table land, with the valleys of the above streams 150 to 200 feet below this general level. The country a few miles from these streams is gentle undulating, the exceptions being a series of buttes which rise 250-300 feet above the general level of 500-600 feet above the streams. The sides of the buttes are usually very abrupt and the larger ones have flat tops. A list of the more prominent buttes are; the Long Pine Hills, Pommes Blanches Hills, Cave Hill, Short Pine, Slim Buttes and a number of isolated buttes. The flat tops of the larger buttes lie on nearly the same plane and apparently are the remains of the original surface of an ancient lacustrine plain of Tertiary age.
11. Streams. The Little Missouri has a valley from one to two miles in width and shows terraces while the upper parts of the Grand and Moreau Rivers are usually without wide valleys. None of the streams are copious in dry seasons but are subject to great floods.

Geology. The Laramie which is classed as Cretaceous is the most prominent formation of the area. Above the Laramie is found the White River of Miocene age and overlying this is the Loup Fork also of Miocene age.

A section at the south end of the North Cave Hill was taken by J. E. Todd while on this expedition. This section is given later in this article under Part II. The following section was taken near section 23 Tp. 18 Rg. 7 in the vicinity of the western part of the Slim Buttes.

Miocene:

24. Soil and soft white sandstone
25. Hard layers of sandstone forming a cornice and a layer six inches thick at the top very hard like flint
26. Sandy white clays cracking polygonally above shading into thin bedded white sandstones below.
27. Massive white fine sandstone with small globular concretions translucent within, the rocks showing efflorescence where not exposed to the weather. There are some layers of reddish color and some even shaly.
28. Reddish flat concretions
29. Stratified white sandstone
30. Soft sandstone full of vertical stalactite-like concretions redder below
31. Massive argillaceous sandstone weathering into globular masses and containing small globular concretions.
32. Slope mostly soft white sandstone
33. Gray clays with porous sandstone fragments and with thin interrupted layers of sandstone obliquely laminated
usually dipping to the north. 18 ft.

14. Rusty clays and sand some white places and occasional thin layers of limonite. 10 "

Laramie.

13. Grey sand with thin layers of sandstone 10 "
12. Grey shale 3 "
11. Hard, compact, gray sandstone layer very even and with few joints. 10 "
10. Drab, stratified clay weathering yellow 3 1/2 ft.

9. Good lignite 5 1/2 - 6 ft.

8. Yellow sand with print of palm leaves 1 "
7. Light drab, stratified clay with leaf prints 2 3/4 "
6. Good shaly black lignite 9 1/2 "

5. Laminated Clays yellow and drab with many leaf impressions 18 "
4. Lignite 4 1/2 - 8 "
3. Dark dirt-like clay 10 "
2. Shaly with pieces of lignite 12 "
1. Lignite 2 "

Total 276 "

From other sections and data he concludes that in the upper Laramie in the vicinity of the Cave Hills there is an extensive development of sands and sandstones which are thinner south and east of the Cave Hills. "This may be due to the thickness of deposition or more likely to erosion. The appearance of the junction of the Tertiary with the Laramie in the North Cave Hill and also in the South Cave Hill strongly suggest a beach with an eroded cliff." Single lithologic units of the Laramie are not persistent for great distances, for a horizon which is represented by shale at one point may be sand at another while the two locations may be only a mile or so apart.
13.

Fossil evidence shows fresh water conditions. The lignite beds are thicker in the extreme northern and western parts of the state than they are towards the south and east.

Tertiary. The upper strata in this region are referred to later because of the apparent erosion of the Laramie surface, and from fossil evidence they are classed as Miocene. The Tertiary consists of two members, the lower in the White River and the upper is the Loup Fork.

White River. Under this is included the fossiliferous flint or bur stone which is scattered over the surface of the Laramie and especially found in abundance in the vicinity of the Cave Hills. A detailed description is given of this stratum.

The Disturbance closing the White River Group. In the vicinity of E6 Gap (a location about the center of the Slim Buttes) there appears what is taken to be an unconformity between the White River below and the Loup Fork above. The lower strata are inclined twelve to twenty-five degrees, dipping to the south and southwest with numerous sharp folds and some faults. The upper strata are horizontal and of a different character from the lower. Further south a bed of conglomerate intervenes between the upper and lower strata although both are horizontal.

Loup Fork. These rocks lie horizontally upon the inclined White River strata and consist of fine grained white friable sandstones often thickly studded with small globular concretions.
1899.


E. J. Babcock treats of the coal of North Dakota in this article. The coal is lignite in grade and has been found in beds as thick as twenty feet. It is distributed for the most part over the central and western portion of the state.

1900.


M. W. Davis urges that the western Tertiary deposits of the Great Plains be considered not wholly due to lacustrine origin but that sub-aerial agents of deposition be considered as important factors.

1901.


In a publication of 1901, Prof. Fras discusses the origin of the White River Oligocene of South Dakota.

1902.


In this paper J. B. Hatcher gives the theory for the origin of the Oligocene and Miocene deposits of the Great Plains.


Frank A. Wilder discusses the lignites of North Dakota in this report. He maintains that the Laramie, which is large composed of clays, sand and lignite beds, contains practically all of the lignite in the state.
1902. Continued.


J. E. Todd describes the changes between land and water in South Dakota during late Cretaceous and Tertiary time.

1903.

Wilder, Frank A. Possible Origin for the Lignites of North Dakota.


In a publication of 1903 Frank A. Wilder discusses the origin of the lignites of North Dakota. He supposes a condition of shifting lakes fed by streams laden with silt and timber. The shifting would be caused by the Rocky Mountain uplift.

1904.

Wilder, Frank A. The Laramie and Fort Union Beds of North Dakota.


In the above article Frank A. Wilder comes to the conclusion that the Laramie and Fort Union beds can only be separated with great difficulty. This conclusion was drawn after a study of the floral faunal and lithologic characteristics of the strata along the Missouri in western North Dakota and eastern Montana.

1905.


Albert B. Reagan in this article discusses the origin of the White River deposits in this region. Above the White River formation is found the Arikaree which is mapped as part of the Loup Fork. It is composed largely of sand of varying degrees of consolidation. "On the whole it seems to be dry delta, dune, and river channel formation". The deposits
15. are often fan shaped and show cross bedding.

1907.


A. G. Leonard in a publication of 1907 describes the coal field which is situated along the Yellowstone River about a hundred miles more or less from its mouth. Above the Fox Hill sandstone is found what is termed the "Dinosaur Bearing Beds". Over four hundred feet from the base of this formation fossil leaves were found, and were identified by Knowlton as representing approximately the base of the Fort Union. Leaves lower than the above collection were regarded as of probable Livingston age. A description of a section of these "Dinosaur Bearing Beds" is as follows: "Clay and sand, mostly dark gray in color with many brown carbonaceous layers and some beds of coal." Lower in the section occurs "sandstone at the base of the Dinosaur Bearing Beds, coarse grained and rather soft characterized by its massiveness, absence of irregularity of bedding, the great number of large sandstone concretions and its cross lamination, yellow or brown in color." Both of these members contain dinosaur bones. Above the dinosaur bearing formation is found the Fort Union which is light gray and buff colored, contains lignite but brown carbonaceous streaks are rare. Abundant leaves are found but no Dinosaur bones.

1908.


E. C. Perisho gives a section taken at the southeastern end of the Slim Buttes in 1895. This appears as follows:

Miocene.

Clay 9 ft.

Coarse sandstone 2 ft.

Whitish clay 36 ft.
17.

Light Gray Sandstone 4 ft.
Fine Argillaceous sand rock 50 "

Coarse Sandstone 9 "
White Argillaceous Limestone lower six inches full of fossils or fresh water shells very hard 2-3 "

White clay 18 "
Sandy white clay 8 "

Oligocene.
Fragments of bur stone and yellow flint 1 ft.

Isramie

1909.


This contains a discussion of the geology of South Dakota. The geologic report on the northwestern part of the state is large a compilation of previous literature. However the formation which had been classified as Louf Fork is further classified by Darton as Arikaree, a subdivision of the Loup Fork. The outcrops of this are especially well developed in the Slim Buttes, which are prominent topographic features in the northwestern corner of the state.


The author among other conclusions decides that the Lance Creek beds belong in the upper Cretaceous.

This paper is an argument to prove that the above named beds are stratigraphically, structurally, and paleontologically inseparable from the Fort Union and are of Eocene age.


T. W. Stanton reaches the conclusion in this paper that: "In the interior of North America the formation between the uppermost marine Cretaceous and WasatcheH constitute a real transition from the Cretaceous to the Tertiary."

1910.


The purpose of this paper is to show that over widely separated areas there is a real transition from the marine Fox Hill Cretaceous below to the Fresh water Lance above and that sedimentation was practically continuous from the one into the other and probably on through the Fort Union.

1911.


This is a summary of the observations during two field seasons work in eastern Wyoming, Montana and adjacent portions of North and South Dakota relative to the stratigraphic position of the Lance formation. In this paper additional evidence is used to prove that the Lance formation is conformable with the overlying Fort Union and is unconformable with the underlying formations. Dr. Knowlton assigns the Lance to the Tertiary
and places the line between the Tertiary and Fort Union at the base of the Lance formation.

Comment.

In the above resume of the literature on the field those articles relating to the age and origin of the formations have been treated briefly. Views on these points are treated in Part III of this work.

PART II

GEOLOGIC DISCUSSION OF Tp. 21 N. Rg. 5 E.

Introduction.

Location and General Relations. Township 21 north of latitude 44 degrees, range 5 east of the Black Hills, which is the state line between South Dakota and Wyoming, is situated in the northwestern corner of South Dakota. It is between 23 and 24 miles from the Montane-South Dakota line on the west and between 8 and 9 miles from the North Dakota line on the north. The southeastern corner of this township has the position 45° 44' N. latitude and 103° 26' W. longitude. It is representative of the field shown on map No. 2 which field is bounded on the north partly by the state boundary between North and South Dakota and on the west it is limited by the boundary of the state of South Dakota. The large field contains about 1596 square miles, while Tp. 21 N. Rg. 5 E. is approximately six mile square and hence has an area of 36 square miles. The large field lied wholly within Harding County, South Dakota.

In the present work Tp. 21 N. Rg. 5 E. will be described in detail and it is taken as representative of the large field spoken of above. Its relation to this field and also features which are better developed in other parts of the large field will be treated. However, no attempt
will be made to describe the large fields in detail.

Outline of Geography and Geology. Northwestern South Dakota forms a part of that region between the Rocky Mountains and the Mississippi Valley known as the Great Plains. This region in general is not level but is characterized by long rolling slopes of slight relief. The principal elements of relief are flat topped, steep sided ridges called mesas. Tp. 21 N. Rg. 5 E. contains the above characteristics of the general region and is typical of the Plains both physiographically and geologically. It is below the southern limit of the continental ice sheet and hence is unglaciated. A columnar section of the strata in this township shows three formations which are the Lance (the oldest) the Fort Union, and the White River. The age of the two upper members is Tertiary while the age of the Lance is not definitely settled. Towards the north the Fort Union outcrops over a wide expanse of country extending into Canada while towards the south the Pierre shale a Cretaceous formation has a large areal distribution.

Topography.

Relief. The relief in this township is not great but is marked. Mesas, known as the North and South Cave Hills constitute the high portions of the region and are three hundred feet more or less above Bull Creek which is the lowest part of the township. On top of these mesas several slight eminences are found which are 20 to 30 feet above the surrounding level. The greatest difference in altitude in the large fields is about 1000 feet and is measured from the Grand River to the top of the Slim Buttes, the horizontal distance is six or eight miles.

The surface of the township under discussion presents three principal kinds of topography. Briefly stated these types consist of stream flats, steeps of the mesas, and the mesas proper. The streams, as a general rule, have remarkably broad valleys and meander in their...
flood plains. The running streams, but especially the larger intermittent ones, often have a narrow gorge in a broad level stream valley. These stream flats grade into a gently rolling topography. The second type is characterized by its ruggedness, which is due to rapid erosion and slumping. Rapid erosion produces what is known as bad land topography, which consists of deep narrow gullies with sharp divides, the whole surface of which is ungrassed. Slumping produces an uneven surface consisting of numerous minor slopes dipping into the main slope of the mesa. This is caused by blocks from the side of the mesa slipping down from their original position. They are comparable to landslides, the sliding material however in the case of a slump remains intact. The blocks range in length from a few yards to a half mile, and in width usually measure a rod or more. They are developed to a slight extent along the slopes of the Cave Hills in Tp. 21 N. Rg. 5 E., but are found on an extensive scale at the north end of the Slim Butte in the large field. The third type of topography consists of mesas, whose separate tops are level and lie in practically the same planes with each other. The sandstone which makes the Cave Hills varies in thickness from 10 to 80 feet and is locally called the "rimrock". This forms a perpendicular cliff around the edge of the mesa, the height of which is the thickness of the "rimrock". Streams which have cut back into the mesa form what are known as "box canons", so called because they are walled in by the rimrock except where the stream leaves the mesa. In the township under discussion the Cave Hills stand about 200 feet above the surrounding country and with their steep slopes sharp edges and flat tops form a very characteristic type of "Plains topography".

The lignite group is found in the Fort Union and the upper parts of the Lance, in many cases has been burned and in burning has fused and baked the overlying material to a red or black mass. This hardened
material is more resistant to erosion than the unconsolidated sediments
and is often found capping isolated buttes which are conical shaped
with steep sides and sharp pointed tops. Such buttes are scattered
over the whole lignite field and examples are found in this township.
In other cases the lignite has burned fusing or baking the overlying
material which material subsequently has caved in.

Drainage. All of the surface water in Tp. 21 N. Rg. 5 E. drains
directly into Bull Creek, which is the only persistent stream in the
township. This flows in a southeasterly direction outside of the township
into the Grand River which in turn is a tributary to the Missouri River.
In the large field the Grand and the Little Missouri Rivers are the
principal streams. Both are tributaries to the Big Missouri, and are
approximately equal in size. The Little Missouri follows a northeasterly
course and empties into the Big Missouri several hundred miles up-
stream than the Grand which flows in an easterly direction. This gives
the Grand a greater fall than the Little Missouri, and this is
strikingly shown by the divide between the two rivers. On the Little
Missouri side of the divide the surface has a general slope, while
on the Grand River side for a short distance over the divide the slope
is precipitous and the topography is bad land in character. In some
places the Grand has cut back to within 5 or 6 miles of the Little
Missouri which will ultimately result in stream piracy.

Descriptive Geology.

Stratigraphy.

General Statement. The formations outcropping in Tp. 21 N. Rg. 5 E.
are Tertiary or late Cretaceous and Tertiary in age. The strata have
only a slight dip and are underlain by Cretaceous sediments. The areal
distribution of these formations is shown on map No. 1 and the structural
relations are shown by structure contours on map No. 3. A single detailed section of the Lance of Fort Union does not mean much because of the variable nature of their individual strata. Below is given a detailed section taken by J. E. Todd$^\#$ in 1895 at the south end of the 


<table>
<thead>
<tr>
<th>Formation</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>57. Yellow fine grained quartzite or flint with casts of plant stems</td>
<td>2 ft.</td>
<td></td>
</tr>
<tr>
<td>56. Whitish layers of limestone above</td>
<td>18 &quot;</td>
<td></td>
</tr>
<tr>
<td>55. Purple sandstone, massive</td>
<td>27 &quot;</td>
<td></td>
</tr>
<tr>
<td>54. Gray and white clay, plastic</td>
<td>12 &quot;</td>
<td></td>
</tr>
<tr>
<td>53. Yellow sandstone, massive</td>
<td>50 &quot;</td>
<td></td>
</tr>
<tr>
<td>52. Soft yellow stratified sand</td>
<td>16 &quot;</td>
<td></td>
</tr>
<tr>
<td>51. Hard sandstone</td>
<td>1 &quot;</td>
<td></td>
</tr>
<tr>
<td>50. Yellow sand</td>
<td>50 &quot;</td>
<td></td>
</tr>
<tr>
<td>49. Gray sand</td>
<td>6 &quot;</td>
<td></td>
</tr>
<tr>
<td>48. Dark plastic clays</td>
<td>70-75 &quot;</td>
<td></td>
</tr>
<tr>
<td>47. Lignite</td>
<td>3/4 &quot;</td>
<td></td>
</tr>
<tr>
<td>46. Dark plastic clay</td>
<td>11 &quot;</td>
<td></td>
</tr>
<tr>
<td>45. Good lignite</td>
<td>5 &quot;</td>
<td></td>
</tr>
<tr>
<td>44. Dark brown laminated clays</td>
<td>4 &quot;</td>
<td></td>
</tr>
<tr>
<td>43. Yellow sand</td>
<td>2 &quot;</td>
<td></td>
</tr>
<tr>
<td>42. Yellow laminated clay 1</td>
<td>10 &quot;</td>
<td></td>
</tr>
<tr>
<td>41. Dark laminated clays</td>
<td>3 &quot;</td>
<td></td>
</tr>
<tr>
<td>40. Loam</td>
<td>4 &quot;</td>
<td></td>
</tr>
<tr>
<td>39. Shaly limestone</td>
<td>1/2 &quot;</td>
<td></td>
</tr>
<tr>
<td>Layer Number</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>24</td>
<td>Loamy clay</td>
<td>5 ft.</td>
</tr>
<tr>
<td>37</td>
<td>Dark laminated clay</td>
<td>3&quot;</td>
</tr>
<tr>
<td>36</td>
<td>Lignite</td>
<td>1/2&quot;</td>
</tr>
<tr>
<td>25</td>
<td>Yellow loam</td>
<td>5&quot;</td>
</tr>
<tr>
<td>34</td>
<td>Laminated ripple marked concretionary limestone</td>
<td>1&quot;</td>
</tr>
<tr>
<td>33</td>
<td>Cream colored laminated silt</td>
<td>8&quot;</td>
</tr>
<tr>
<td>32</td>
<td>Lignite</td>
<td>1/2&quot;</td>
</tr>
<tr>
<td>31</td>
<td>Grey sand</td>
<td>55-60&quot;</td>
</tr>
<tr>
<td>30</td>
<td>Laminated clays with lignite in the middle</td>
<td>1 1/2&quot;</td>
</tr>
<tr>
<td>29</td>
<td>Light colored sand and silt</td>
<td>6&quot;</td>
</tr>
<tr>
<td>28</td>
<td>Lignite</td>
<td>2/3&quot;</td>
</tr>
<tr>
<td>27</td>
<td>Cream colored sandy silt with some yellow calcareous sandstone concretions</td>
<td>4 1/2&quot;</td>
</tr>
<tr>
<td>26</td>
<td>Dark laminated clays and two inches carbonated layer at top</td>
<td>4&quot;</td>
</tr>
<tr>
<td>25</td>
<td>Quite pure lignite</td>
<td>5&quot;</td>
</tr>
<tr>
<td>24</td>
<td>Light cream colored silt</td>
<td>6&quot;</td>
</tr>
<tr>
<td>23</td>
<td>Light colored silt flat concretions at the top</td>
<td>15&quot;</td>
</tr>
<tr>
<td>22</td>
<td>Dark laminated shale about 1/2 impure lignite</td>
<td>4&quot;</td>
</tr>
<tr>
<td>21</td>
<td>Very light laminated shale</td>
<td>3&quot;</td>
</tr>
<tr>
<td>20</td>
<td>Black shale</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>19</td>
<td>Light coarse sand some small concretions</td>
<td>10&quot;</td>
</tr>
<tr>
<td>18</td>
<td>Plastic clay with three black bands of lignite</td>
<td>7&quot;</td>
</tr>
<tr>
<td>17</td>
<td>Black, very pure lignite</td>
<td>3 1/2&quot;</td>
</tr>
<tr>
<td>16</td>
<td>Light clay</td>
<td>3&quot;</td>
</tr>
<tr>
<td>15</td>
<td>Break in section</td>
<td>30-35&quot;</td>
</tr>
<tr>
<td>14</td>
<td>Cream colored silt stratified</td>
<td>5&quot;</td>
</tr>
<tr>
<td>13</td>
<td>Thin shaly calcareous sandstone</td>
<td>1&quot;</td>
</tr>
<tr>
<td>12</td>
<td>Brown and gray clay silt</td>
<td>14&quot;</td>
</tr>
<tr>
<td>11</td>
<td>Gray clay</td>
<td>1&quot;</td>
</tr>
</tbody>
</table>
Nos. 57 and 56 are White River in age and the remainder of the section is classed as Laramie which includes both the Lance and the Fort Union of this paper.

Lance.-Late Cretaceous or Early Tertiary.

This is the oldest formation which outcrops in Tp. 21 N. Rg. 5 E. and is classed as late cretaceous or early Tertiary. Since the strata dip very slightly it is found topographically lower than the overlying formations. Reference to Map No. 1 will show that it outcrops in the stream valleys but is covered on the divide. Outcrops are best exposed in cut banks along the stream. In the large field it has a very extensive areal distribution. The higher points are covered by younger formations such as the Cave Hills, Slim Buttes, the Short Pine Hills and other high Buttes and divides. In the southwestern part of Tp. 16 N. Rg. 2 E. the Fox Hill sandstones outcrop which formation immediately underlies the Lance. Besides these exceptions the Lance covers the remainder of the large field.
Lithologic Characteristics. The Lance has been called by some writers the "Somber beds", and as a descriptive name this is appropriate. In general it is made up of dark colored shales, clays, sands and in its upper part beds of lignite. In Tp. 21 N. Rg. 5 E. there is exposed a thickness of 80 feet of this formation. This however represents only a small part of the total thickness in this region for the base is not exposed in the above township. The total thickness in the large field is between 450 and 500 feet. The contact with the overlying Fort Union formation is conformable, and cannot be confined to any one definite stratum by lithologic characteristics. The line as mapped divides strata which are light or yellow colored from those that are dark or somber, and follows a general horizon but not a single stratum. At the contact there is often found a coal bed which outcrops in this township in the north west one-fourth of section 19 and also in the N.W. one-fourth of section 16. Stratigraphically beneath the coal beds there is about 65 feet of dark gray clays and shales mixed with sand and lenses of sandstone. Below this is found a coal bed which ranges in thickness from a few inches to five feet. This is underlain by clays and shale but only 10 or 20 feet of strata beneath this coal bed is exposed in this township. In the large field the Lance consists of dark shales and clays with some sand in its upper portion but in its lower portion it is made up largely of sand. A noticeable feature of this formation is the presence of sandstone lenses surrounded by unconsolidated sediments. These are usually a rod or more in length and a yard or two in their thickest parts. They are not confined to any one horizon, and have been suggested as representing old stream channels. Cross bedding is a common feature of the formation. Another characteristic of the Lance, especially in its upper portion, is the shape and appearance of certain erosion forms.
Bare buttes or hills, shaped like a thimble or a hemisphere, are common. These are generally surrounded at their base by a ditch which drains the surface water. Lime bad lands present this same rounded characteristic appearance. Concretions as a rule are abundant in many Cretaceous and Tertiary formations. The most typical concretions of the Lance are composed of iron carbonate. These weather on the outside to limonite and are usually an inch or two in diameter. The Lance is to be correlated with the Hell Creek beds of Montana and the Ceratops beds of Wyoming. In reference to the palentological character of this formation the following quotation is given: "The fauna of the Hell Creek beds is a comparatively rich one, comprising a few mammals numerous dinosaurs belonging to the family Ceratopsidae, Trachodontidae, etc., together with crocodiles, turtles, scales, and vertebrae of fishes, and some thirty species of invertebrates, mainly Unio."

The relation between the Lance and the underlying Fox Hill is a much disputed question. The Fox Hill does not outcrop in Tp. 21 N. Rg. 5 E. and in only one locality in the large field and this locality was not visited by the writer. The question in brief is, does the Lance rest unconformably on the Fox Hill, and if it is unconformable how great an erosion interval does it represent? The overlying Fort Union formation is conformable on the Lance, not only in this township and larger field, but in every locality at the contact has been examined.
Fort Union. - Tertiary Eocene.

The Fort Union formation is generally accepted as Eocene in age. In Tp. 21 N. Rg. 5 E. it outcrops both topographically and geologically immediately above the Lance. It occupies the divide between Bull Creek and Dry Creek and covers the southwestern and northeastern corners of the township with the exception of small outliers of the White River. Reference to the map will show that both the north and south cave hills are composed almost entirely of this formation.

In the large field it is distributed over points on high divides, around the sides of the Slim Buttes, a belt several miles wide through the northeastern part of the field and a few scattered isolated Buttes.

Lithologic Characteristics. A detailed stratigraphic section of the Fort Union is not significant, but a generalized section gives an idea of the nature of the formation as a unit. A detailed section is given under the heading General Statement under stratigraphy. A more or less generalized section is given in the columnar section of this township which is found on plate No. 5. A discussion of this columnar section is instructive. The Fort Union as a whole is a yellow colored formation composed of sand, sandstone, clay, shale and lignite, and is about 325 feet thick in this region. Immediately below the Fort Union is the Lance, and as has been stated before the contact between the two formations does not follow any one definite stratum. Above the contact there is about 45 feet of clay, yellow in color, which distinguishes it from the Lance below. Above this there is a horizon between 45 and 50 feet thick which is composed largely of lignite and carbonaceous shale. This is especially developed in the south Cave Hills in the southeastern corner of Tp. 21 N. Rg. 5 E. In some places, as at point R 65 (S.W. 1/4 of section 19) This horizon is composed almost entirely of shale with only a thin seam of coal near its base, while at a distance of...
about a mile at point R 63 (S. E. portion of Section 30) The horizon is represented by two thick coal beds each eight or nine feet thick, separated by about thirty feet of shale. This variability in thickness of the beds is very characteristic of the Fort Union coal beds of this general region, but while individual beds are not continuous a general horizon can usually be followed for long distances. Above this formation there is approximately 120 feet of strata which contains two thin beds of lignite, and which consists largely of sand and clay with a predominance of sand near the top. Above this is found a sandstone member which ranges from 10 to 80 feet in thickness, and is locally known as the "rimrock". This is a cliff and hill forming member of the Fort Union and on fresh fractured surfaces appears homogenous. However after it has been exposed to weathering agents the surface becomes pitted with holes varying in size from that of a marble to caverns large enough for a man to stand erect in. Above this sandstone member there is about 6 feet of white calcareous clays which is overlain by about 25 feet of red crossbedded sandstones. This is overlain by the White River. The line between the White River formation and the Fort Union is arbitrarily placed here. No fossils were found in the calcareous clays or red cross bedded sandstone and it is possible that these two members belong to the White River formation.

The thick sandstone member is not found southwest of the Cave Hills, but is well developed in Tp. 21 N. Rg. 5 E. Its top has been suggested as representing the top of the Fort Union practically uneroded before White River deposition began. The difference in thickness of this sandstone at different points is in accord with the same circumstance relative to the coal beds. The pits or holes which are found on weathered surfaces are in some cases arranged with apparent regularity. In other cases they are distributed heterogeneously over the surface. On weathering the
sandstone becomes very friable and in this state wind erosion undoubtedly is important. In the northeast 1/4 of section 31 and the northwest 1/4 of section 32 in the township under discussion examples of wind structure are well developed. Boulders 10 to 15 feet high stand with their base largely cut away by the shifting sand. Thin slabs are worn completely through resulting in fantastic shapes and forms. But it is hard to believe that these fantastic forms have been produced solely by wind acting on apparently homogenous and fairly hard sandstone. Now suppose that this is a lime sandstone or a sandstone containing some soluble material such as lime. It is known that this and practically all of the Tertiary formations of this region are concretionary or there is a tendency towards a segregation of like materials in the strata. This would result in much soluble matter at one place and little at another and under certain conditions possibly account for a more or less regular distribution of the two. When this surface has been exposed to the action of surface waters and the atmosphere the soluble matter would be dissolved leaving the sandstone in a friable state. With the sand grains once loosened the wind would become an important factor in furthering the disintegration. The inside of some of the cavities in the sandstone were found to be coated with a white substance, presumably some salt. This theory is offered as a possible explanation of the above phenomenon and it supposes an unequal distribution of soluble and insoluble material, with a disintegration of the soluble part first.

The concretions of the Fort Union are composed largely of ferric oxide and are colored a lighter brown than those of the Lance. Fort Union bad lands have steep gullies and contrasted with the rounded forms of the Lance. Sandstone members are commoner in the Fort Union than in the Lance and hence Buttes or hills are more abundant in the former than in the latter. Plant remains are more abundant than fossils of
animals and the fossil plants are generally conceded to be of Eocene age.

The contact between the Fort Union and the Lance as has been stated before shows continuous sedimentation. The contact between the Fort Union and the overlying White River is an unconformable one. The strata show no discordance of dip between the two formations but since the White River rests upon Lance in the vicinity of the Short Pine Hills, and upon Fort Union in the Cave Hills and Slim Buttes the unconformable relation is evident. The top of the Fort Union section in the Cave Hills probably represents the highest stratigraphic position in the formation found in the large field.

**White River. - Tertiary Oligocene.**

**Areal Distribution.** The White River deposits, which are now classed as Oligocene in age outcrops in Tp. 21 N. Rg. 5 E. in the western half of section 32, eastern half of section 31, section 12 and southern part of section 1. Topographically it occupies the highest part of the township. It is much fuller developed in other parts of the large field. The Slim Buttes and Short Pine Hills are both capped with strata of White River age.

**Lithologic Characteristics.** J. E. Todd from a section taken

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**Todd, J. E.** First & Second Biennial Rept. on Geology of South Dakota. pp. 51-52. 1893-1896.

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at the south end of the North Cave Hills found the following succession of strata which he classifies as White River in age.

Top. Yellow fine grained quartzite or flint with casts of plant stems 2 ft.

Whitish marl with thin layers of limestone above 18"
Below this he gives 27 feet of purple sandstone which is underlain by 12 feet of gray and white plastic clay. These two members may also be White River. The main feature of the White River of this section is the two feet of yellow fine grained quartzite. This is known to outcrop in place only in this vicinity of the Cave Hills but loose boulders are scattered over much of this township and in many places in the large field. The description given by Todd of this member is as follows: "Under this head we include the fossiliferous flint or bur stone which is found widely scattered over the surface of the Laramie, not only around the Cave Hills, but as far east as the principal moraine east of Napoleon, North Dakota. This resembles very closely in texture and color the bur stone from the Paris Basin. It also has irregular cavities in it and many of them clearly traceable to the stem of plants which vary in size from one sixteenth of an inch to three or four inches in diameter, and have such positions as would correspond with the view that the stone was formed around the stems in position. The angle, the branching and the roughness of the surface all agree with this supposition. A few cases have been found where the wood was still in the cavity. It was solidified, although not so solid as the surrounding rock. About the Slim Buttes of this horizon are found frequently deposits of an impure opal of a yellowish or gray color, and very generally the clays are scattered with silica which has been deposited either in the form of thin veins or of coralloidal masses. In this respect the beds of the Slim Buttes resemble those described by Dr. Hayden along the White River. It seems not unreasonable to suppose that while the lake to the east and south was deep enough for the accumulation of marl, silt and sand, there were extensive marshes around the border of the lake in which silica was deposited around the stems of plants while they were in their natural position. While for the most part the blocks of
this fine grained quartzite are bur stone are scattered over the surface of the Laramie they are rarely found in what may be considered a natural position.

One place of this sort was found about a mile north of Ludlow's Cave, another towards the south end of the North Cave Hills. My observation agrees with that reported by Prof. Winchell, namely, that they are never found over an area occupied by the thicker development of the White River formation. It would seem, therefore, that some such theory as we have stated would be corroborated by this peculiar distribution. It seems unreasonable then to refer to the Laramie for in that case we could find them underlying the Tertiary. They form a most suggestive fact concerning the history of this region during the early Miocene."

These loose boulders are angular but their edges are rounded and their surfaces usually polished. Their wide distribution and since they are unquestionably from the White River should give a good criterion for extending the boundaries of this formation. Examination of a thin section of this siliceous member shows that it is composed of angular fragments of quartz cemented by silica. How a quartzite could be formed distributed as this is distributed and in the midst of unconsolidated sediments can hardly be explained with the present amount of evidence. Possibly it is a replacement of lime by silica in a calcareous sandstone.

In the Slim Buttes the strata above the Fort Union are exhibited in section 1 Tp. 17 N. Rg. 7 E. as follows:

Top of Mesa.
1 Sandstone, greenish gray to gray calcareous, rather thin bedded, fine grained and clayey, some thin beds hard and brittle, some evidences of crossbedding 68 ft.

2. Sandstone like No. 1 but heavier bedded and less clayey. Some horizons wholly composed of globular concretions of concentric structure and interior sometimes translucent. Some of the concretions are stalactitic. Surface of this sandstone weathers rough like a complicated
carving. Large cross bedding but not so marked as in No. 6

No. 3 Conglomerate, pebbles up to 4 inches. Cement is sand and lime carbonate. 114 ft.

No. 4 Sands one thin bedded much like No. 2 0-15 "

No. 5 Sandstone and clay, interbedded surface of sandy beds show mud cracks 6 "

No. 6 Clay, flesh colored, plastic, shows remarkable cross-bedding. This is the top of lower member. 12 "

No. 7 Sand variable coarse to extremely coarse sharp grit contains much quartz, fresh felspar crystals, some clay pebbles, calcareous. 62 "

No. 8 Banded variable, sandy clays with limonite concretions and some hard sandy layers, shows remarkable cross bedding. 66 "

The lower member is largely made up of clays and this composes the strata of White River age. These are fossiliferous and upon a detailed study of their fauna it might be possible to divide them into the titanotherium, orendon, and protoceras beds, as the White River of the type locality, southern South Dakota, has been subdivided. This formation is characterized by remarkable cross bedding. This is seen both on a small and large scale. So pronounced is this that it was mistaken for angular unconformities by J. E. Todd # in the vicinity of (note: there is a typographical error in the number)


F. L. Gap. That it is not a discordance of dip was proven conclusively by Mr. B. E. Winchester # who was chief of a party doing work in that region during the summer of 1911. He traced the coal beds beneath the

# Winchester, D. E. Personal Communication.
inclined strata and this coal bed did not follow the apparent dip of the strata but was almost horizontal. Hence the strata must represent cross bedding on a large scale. Some arenaceous phases of the White River have abundant concretions and this is emphasized by weathering. On a fresh fractured surface the rock appears homogenous but on weathering stalactitic and other forms are developed.

Above the White River group are the lower member of the section given above is found about 200 feet of strata consisting largely of sand and sandstone which rest in apparent conformity but with distinct lithologic characteristics upon the White River. Upon microscopic examination of a section from No. 1 or No. 2 of the section given above it was found to be practically a nyalite tuff. This is now classified as arikaree in age, a subdivision of Loup Fork.

These strata are often concretionary are resistant to weathering and form the capping of the highest points in the whole region. They are the youngest strata that outcrop in the large field.

Structure.

The structure of Tp. 31 N. Rg. 5 E. is represented in map No. 3 by structure contours. These represent elevations on the lowest coal bed which outcrops in the township. From these contours it appears that the strata are gently dipping with no fault or sharp folds. The most noticeable structural feature of the township is the syncline developed in the vicinity of the North Cave Hills in the northeastern corner of the township and the relatively steep dip of the strata between Dry Creek, and Bull Creek. In the eastern part of the large field the strike in northwest and the dip is northeast. There are several minor undulations in the region the most pronounced of which is an anticline which is shown in the southeastern corner of the field. Here the Fox Hill
sandstones is brought to the surface in Tp. 16 N. Rg. E. This is possibly an extension of the Glendive Anticline which is found in eastern Montana not far from South Dakota.

**Historical Geology.**

**Sedimentary Record.**

Fox Hills. This was the last distinctly marine formation deposited in the northwestern Great Plains, and represents the last of the Cretaceous sea which covered this region. This retreat of the sea was probably caused by the Rocky Mountain uplift aided perhaps by the Black Hills uplift. The Fox Hill sandstone represents shallow water conditions as would be expected from a retreating sea.

Lance. The Lance is thought to be a transition member from the Fox Hill Cretaceous below to the Tertiary Fort Union above and hence at its base would properly be marine while higher in the formation brackish water forms would be developed, and later these would grade into strictly fresh water types. The theory opposed to this is that the contact between the Lance and the Fox Hill sandstone is a part of a wide spread unconformity, and hence the Lance is not a transition member. At all events, during the Lance epoch, especially during the latter part, sedimentation was largely in fresh water and the climate and conditions were suitable for supporting large reptiles. It is also strongly argued that the Lance is of fluvial origin which theory is borne out by the sediments indicating deposition in shallow water cross bedding, which would point to swift currents, and lenses of sandstone which strongly suggest filled-up stream channels. This would mean that over a vast expanse of country rivers meandered and deposited their loads. Also at the point where the gradient first flattened, and where deposition abruptly took the place of erosion there would be the greatest point of deposition. It is supposed that
the Rocky Mountain uplift drained the sea from this whole lignite field which had covered parts of South Dakota, North Dakota, Montana, and Wyoming. This would result in a gentle slope towards the east from the foot of the Rocky Mountains. The mountain drainage would require a steep gradient of the stream and at the junction of the gentle slope towards the east there would be a sharp break in the gradient of the stream. Hence at the foot of the mountain the thickness of the deposit would be great while eastward the formation would become gradually thinner. It would be comparable to a large alluvial fan or a confluent of alluvial fans. Thus we may suppose that during lateocene times rivers with very broad flood plains deposited material aided perhaps by small shallow bodies of water. During Fort Union time it may be supposed that this same process continued but perhaps with more extensive bodies of shallow water. These shallow bodies of water were often swamps in which much vegetable matter accumulated and resulted in the formation of peat bogs. During late Fort Union time in the vicinity of the Cave Hills conditions were favorable for the deposition of sand.

White River. During White River age the country was again covered by a system of rivers which probably had their origin in the Black Hills. Thick deposits of clay, sands, and sandstone resulted often showing cross bedding which indicates swift and changing currents. Some of the pebbles found in local conglomerates are composed of igneous material which would point to there Black Hill source.

Arikaree. During this time the deposited material was largely igneous in nature and the rock has been compared to a tuff. The source of this material again is probably the Black Hills.
Physiographic Record.

The history of the origin of the present topographic forms may be begun after arikaree deposition had ceased. The region was uplifted to an elevation probably represented by the top of the Slim Buttes at present. Erosion became active and tributaries of the Big Missouri River cut back into this elevated plain. Since the sediments are unconsolidated with only local hard resistant phases and are flat lying there has been produced the forms spoken of above. A factor of prime importance in this region is the climate, which is semi-arid.

For several months there will be no rain, but at intervals torrential showers will occur. Again snow frequently covers the country during the winter which is melted during the late spring. Both of these causes of erosion will be violent, and will be concentrated at certain intervals of time. Thus the streams will be capable of great erosion and also will be heavily loaded because of their steep slopes in the badlands, the unconsolidated nature of the sediments, and the large volume of water. This heavily loaded condition will prevail until the slopes become more level and then deposition will take place. The above condition is shown by the rough eroded surface of the badlands in the slopes of mesas and minor valleys partially filled with recent deposits.

The lower part of the stream will flow over its own deposits and will empty into some larger stream which will be lower than its tributary and especially so since the lower part of the valley of this tributary has been raised by deposition. After the high waters have subsided then, beginning at the mouth of the tributaries, a second channel will be cut back into the recently deposited material. This is explanation of the inner gorges found in the minor streams of this region. The larger streams such as the Grand River usually have a fall of 5 or 6
feet per mile and often meander in broad flood plains. Traces of former meanders are found in meander terraces along the streams.

Economic Geology.

The economically valuable materials in Tp. 21 N. Rg. 5 E. named in order of their importance and abundance are coal, clay, and building stone. Iron nodules are found as concretions in both the Lance and Fort Union Formations but are not abundant or concentrated enough to be classed as ores. Likewise crystals of selenite are very common but are too scattered to be commercially valuable. Water on the surface as streams and springs is fairly abundant in this township, but the chance of finding promising artesian water is small.

Coal. The coal in Tp. 21 N. Rg. 5 E., as well as the large field, is lignite in grade and is found in the upper part of the Lance and throughout the Fort Union formations. Map No. 1 shows the position occupied by the coal beds relative to the surface by red dashed lines. These beds have a very gentle dip as is shown by the structure contour on Map No. 3. The lowest coal horizon is found in the Lance about 65 or 70 feet from the contact between the Lance and the Fort Union and is usually of good quality. This coal is very lenticular but is found at various places in the large field as just about the horizon. In the township under discussion it is found as a lens occupying the central and east central parts of the township. In the northeast portion of section 16 at point 116 this bed is represented by 18 inches of coal while at point 119 this lens attains a thickness of about 5 feet with two shale partings. In the southwest 1/4 of sec. 36 this bed is represented by carbonaceous shale and in the N. E. 1/4 of Sec. 25 it measures 3 1/2 feet of coal, the upper portion consists of thin bedded coal over a foot in thickness separated by thin
of which is poor. At point 139 in N. E. 1/4 of Sec. 4 a bed measures over 3 feet 9 inches in thickness which is to be possible correlated with this Lance coal.

The contact between the Lance and the Fort Union is often represented by a coal bed but in this township it is found in only one place as thick as three feet. This is at point 148 in the N. W. 1/4 of Sec. 19.

One of the most persistent and important beds in this township is about 50 feet above the Lance-Fort Union contact. In the South Cave Hills it outcrops at 151 in the S. W. 1/4 of Sec. 19 and 150 in the S.E. 1/4 of Sec. 30. At point 151 it measures 26 inches thick while at 150 the section consists of two beds approximately six feet thick separated by 25 feet of shale. In the North Cave Hills this bed is represented at 133 in the N.W. 1/4 of Sec. 13 by 5 feet 4 inches of coal and at 34 in the N.W. 1/4 of Sec. 15 by 14 inches of coal.

This bed is doubtfully represented by 128 in the S.W. 1/4 of Sec 12 by 30 inches of coal and by 138 in the S.W. 1/4 of Sec. 2 with 47 inches of coal. In the N.W. 1/4 of Sec. 3 at about this horizon the bed outcrops at 135 which measures 15 inches. The outcrop in N.W. 1/3 Sec. 6 at 141 which consists of two or three beds of coal the thickness of which is eighteen inches separated by 5 or 6 feet of shale is probably to be correlated with this bed.

Between 80 and 90 feet higher than the above horizon is the highest coal bed outcropping in the township. Wherever it was possible to obtain outcrops at this horizon some trace of this bed was practically always found. In the South Cave Hills in the N.W. 1/4 of Sec. 30 at point 145 the bed measures 56 inches in thickness, in the S.W. 1/4 of Sec. 28 at 144 it consists of about 3 feet of coal with several shale partings and at 143 in the S.E. 1/4 of Sec. 28 it consists of thin beds none over a foot in thickness separated by thin
partings of shale. In the North Cave Hills at point 24 in the S.E. 1/4 of Sec. 12 it measures approximately 4 1/2 feet of coal, at 126 N.E. 1/4 of Sec. 10 it consists of about 5 feet of coal, and at 129 N.W. 1/4 sec. 12 it is represented by about 4 1/4 feet of poor coal.

The coal in Tp. 21 N. Rg. 5 E. is representative of that found in the large field and the general horizon can usually be recognized throughout the large field, but as has been emphasized before a single stratum of coal or rock is not usually persistent for long distances.

Clay. The clays that outcrop on Tp. 21 N. Rg. 5 E. are found in all three of the formations present, namely, the Lance, Fort Union and White River. The Lance clays are usually dark gray in color, due to carbonaceous matter contained in them, and concretions of iron carbonate are common. In texture these clays vary from fine grained argillaceous material to coarse grained sandy material. They frequently underly and in some cases overly coal beds. The Fort Union clays like the Lance are quite frequently associated with coal beds but there are exceptions to this rule. The clays are usually lighter in color than the Lance and often grade into sand. The Lance and Fort Union clays as a rule are inferior in quality to those found in the White River formation. In Tp. 21 N. Rg. 5 E. the outcrops of the White River are poor and the formation is not as well developed as it is in the Slim Buttes. In the latter locality the following section is found in Tp. 17 N. Rg. 7 E.

<table>
<thead>
<tr>
<th>Top. No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Sandstone and clay</td>
<td>6 ft.</td>
</tr>
<tr>
<td>3</td>
<td>Clay, flesh colored, plastic</td>
<td>12 &quot;</td>
</tr>
<tr>
<td>2</td>
<td>Sand, calcareous and some clay</td>
<td>62 &quot;</td>
</tr>
<tr>
<td>1</td>
<td>Banded sandy clays limonite concretions some sandy layers</td>
<td>66 &quot;</td>
</tr>
</tbody>
</table>

No. 3 is probably the best for economic purposes and No. 1 possibly contains some valuable material. However, the banded nature of the latter
would be a drawback. These Tertiary clays are important commercially in North Dakota.


Building Stone. Tp. 21 N. Rg. 5 E. probably contains as much of this product as any township in the large field. The "rimrock" of the Fort Union is used locally for house building in the vicinity of the Cave Hills. However, its use is local only at present. It is not homogeneous, for as stated earlier in this article, it weathers unevenly, and is too porous to make a commercially valuable building stone. Local sandstone lenses are common but these are not persistent enough to encourage the industry. Some of the consolidated Miocene sediments in the vicinity of the Slim Buttes possibly would be valuable commercially, but their concretionary nature and lack of homogeneity would have to be taken into consideration.

PART III

The object of Part III of this article is to follow the historical development of the views concerning the Lance, Fort Union, and White River formations with especial attention to their age and origin. The review is not exhaustive but it should convey the most important opinions held about the age and origin of these formations in the vicinity of the region discussed in this article.

Lance. The type locality of the Lance is Converse County, Wyoming and the term adopted 1910 is an abbreviation of the full form, the "Lance Creek Beds", which J. B. Hatcher applied to them in 1903. These strata are to be correlated with the Hall Creek beds of Montana, the
Ceratops beds of Wyoming, and Laramie or part of the Laramie and the lower Fort Union of some writers. Since it has been considered by some to be a part of the Laramie it has figured in the much discussed Laramie problem. A reason for the late recognition of the Lance as a separate formation is its close association to the Fort Union, the lithologic difference between the two being largely a matter of color, and in some regions this difference is not very distinct. In the earlier works which described the Lance formation the term Laramie was used which included both the Lance and the Fort Union of today.

Fort Union. The name of the Fort Union formation was originally given by Dr. F. V. Hayden to his great lignite group which "occupies the whole country around Fort Union, extending into British possessions to unknown distances; also southward to Fort Clark". In the earlier investigations the Fort Union was thought to be of Miocene age but later was conceded to belong to the Eocene. Since these two formations were so often grouped together and described as one their historical summary given below will treat both of the Lance and of the Fort Union.

(10) In 1868 J. S. Newberry after a study of fossil plants collected along the Missouri River pronounced the Fort Union formation to be of Miocene age.

(11) F. V. Hayden in an article of 1869 is of the opinion that during late Cretaceous time during which marine conditions prevailed the country west of the Mississippi was elevated. The lowest strata of the Tertiary show that brackish water conditions prevailed at that time, thus indicating a transition from salt to fresh water condition...
(18) As early as 1875 the problem of the age of these formations was a matter of discussion. At this time J. J. Stevenson writes concerning the great lignite series of Fort Union Group. (which very probably included the Lance) that those who studied the plants show the beds into the Tertiary while faunal and stratigraphic evidence would indicate that the greater part of the mass is Cretaceous in age. However the top is generally conceded to be of Eocene age. The top of the Cretaceous and the great lignite series are conformable but the top of the latter is unconformable with known Tertiary sediments. He concludes that the great lignite series is Cretaceous in age.

(20) In an article of 1877 Lesquereux is of the opinion that the beds immediately overlying the Fox Hill sandstones are of Tertiary age.

(23) Bailey Willis in 1885 describes the strata in a part of northwestern South Dakota and states that these appear to be a transition from the Fort Pierre shales below to the lower part of the Laramie.

(26) J. E. Todd in 1894 reported on the general geology of South Dakota. In regard to the age of the Laramie he is inclined to classify it as Cretaceous but states that these beds have caused much discussion in regard to their age and they have been classed by some as representing a transition from the Mesozoic to the Cenozoic. He agrees with Dr. White that the Laramie sea was inclosed by land and became a body of fresh water and this body received sedimentation.

(30) In an expedition of 1895 J. E. Todd examined a part of northwestern South Dakota. He classifies the Laramie as Cretaceous in age and of fresh water origin.

(38) M. W. Davis in a publication of 1900 urges that more attention be paid to subarctic agents in considering an origin for the fresh water Tertiary formations of the Great Plains. He cites instances of rivers
which have developed flood plains of great extent and depth, drill records showing a depth of over 1000 feet in some places. In a region where the streams issue from a mountainous area and which later flow over a broad flood plain and especially if part of this plain is slowly sinking conditions will be favorable for deep accumulation of fluvatile deposits.

(39) In an article published in 1902 J. E. Todd gives a hydrographic history of South Dakota during the late Cretaceous and early Tertiary times. In South Dakota during Laramie times the sea had retreated until it merely verged in the northern border of South Dakota and alternated between shallow seas and marshes with lakes. The drainage was probably towards the north. During Eocene time the streams probably deepened their valleys.

(42) In an article published in 1902 Frank A. Wilder discusses the origin of the lignites in North Dakota. In offering a possible theory as to the origin he calls attention to the smaller lakes of Michigan and Minnesota which are located in the heart of the timber region. If in these lakes sufficient timber and woody material would drift and sink to the bottom the beginning of a lignite bed would be started. The streams would add foreign material to this especially at their mouths. Now if the Rocky Mountain uplift be considered to have taken place all through Laramie time it would mean that erosion was quickened in the west, deposition in the east, and lakes formed fed by streams from the west. These streams would carry much timber and as the uplift continued the region of deposition would be carried farther and farther east with a gradual shifting of the lake country in that direction. "The cross bedded sandstone which passes gradually into clay, the clay beds that are remarkably persistent in color and texture and at other times extremely variable, passing abruptly into carbonaceous clay and on into lignite, the large tree trunks that are scattered through all of the clay beds, all suggest the former presence of
shifting lakes fed by streams laden with silt and timber."

(49) In a publication of 1907 A. C. Veatch holds that the carbon field of Wyoming is a type locality for the Laramie Formation and gives the following section from there.

Lower Tertiary.
  Green River
  Knight
  Fort Union - Puerco - Terran
  Laramie

Unconformity.

Upper Cretaceous.
  Lower Laramie
  Montana
  Colorado.

(50) In an article published in 1908 Whitten Cross favors the restriction of the term Laramie to those beds immediately overlying and resting conformably upon the Fox Hill. The formation above the unconformity discovered by A. C. Veatch would more appropriately be defined by other terms. He also advocates that the Laramie be referred to the Eocene.

(48) In a publication of 1909 A. C. Peale insists that the term Laramie be used only according to the meaning given it by Hayden and King. In its original meaning it included those beds which rest conformably upon the Cretaceous Fox Hills. Also the term had no particular type locality but was used in a broad application with the above definition. The region which was studied in connection with above definition was the area east of the Front Range in Colorado. A. C. Veatch discovered an unconformity in the field near Carbon, Wyoming above the Fox Hills which represented the removal of 20,000 feet of strata. The beds between this unconformity and the Fox Hills are called lower Laramie by Veatch, and those above the unconformity and beneath the Fort Union are termed the upper Laramie. A. C. Peale
criticises Veach for using the term Laramie in this sense.

(57) The author after a comparison with European conditions concludes that: 1st, The lance Creek beds belong to the upper Cretaceous 2d. In the upper Cretaceous ought to be included also the Puerco and not improbably the Torrejon and the Fort Union. 3d. In case of a conflict between faunal and floral evidence the faunal evidence should be accepted because it is more complete and better understood. Present knowledge regarding plants seems to indicate that they were precocious, having reached something like their present stage of development long before the mammals attained anything like their present stage of differentiation. There are also indications that the floras of the eastern world were during Cretaceous considerably in advance of those of Europe. 4th. Even if it were concluded that the Fort Union belonged to the Tertiary and that the fauna and flora of the Lance are more closely related to those of the Fort Union than they are to those of the Judith River, it does not follow that the Lance Creek epoch must be included in the Tertiary.

(58) In a publication of 1909 F. H. Knowlton treats of the stratigraphic relations and paleontology of the Hell Creek beds and equivalent formations and their reference to the Fort Union formation. The following is a summary and list of conclusions reached in this article:

1. The Fort Union formation is a fresh water Tertiary formation of wide areal extent mainly east of the Rocky mountains, ranging from Wyoming and western South Dakota over western North Dakota, eastern and central Montana, the central Canadian provinces and reaching the valley of the Mackenzie River.

2. It is shown that the Fort Union formation may be separated into two members on lithologic grounds. The present paper deals only or largely with the stratigraphy and paleontology of the lower members which
includes the "Hell Creek Beds" and the so-called "Somber beds" of Montana and the "Ceratops beds" of Wyoming.

3. The areal distribution of the lower member is traced in Montana, North and South Dakota, and Wyoming and its probable extension in other areas is indicated. Complete lists of the fossil plants are given by localities for each of the areas.

4. It is shown that the lower member rests in some cases unconformably, in others in apparent conformity on the Fox Hills or Pierre and the conclusion is reached that an erosion interval is indicated during which the Laramie if ever present and other Cretaceous and early Tertiary sediments were removed.

5. It is shown that the beds under consideration, being above an unconformity can no longer be considered as a part of the conformable Cretaceous series and are hence not Laramie.

6. It is shown that the two members of the Fort Union, although usually distinct lithologically, cannot be separated structurally, sedimentation having been uninterrupted, except locally.

7. The paleontological elements of the lower members are considered at length, beginning with the plants. It is shown that of the 84 known species, 61 are common to the upper member and only 11 species to the Laramie of Colorado while 15 species are common to other American Eocenes and nine species to the Miocene. The Eocene age of the Fort Union is fixed by tying this flora to that of various old world beds of known Eocene condition.

8. In invertebrate evidence is shown to be insubstantial accord with that of the plants. There being only 4 of the 49 species, to the Colorado Laramie. All, with the single exception are fresh water forms.

9. It is shown that the vertebrates afford no positive evidence of Cretaceous age. That the dinosaurs exhibit Cretaceous affinities is not denied since being without known descendents, it is possible to compare
them only with their progenitors. It has been proved beyond question that they survived the profound orogenic movements and attendant physical break at the top of the Laramie in the Denver basin of Colorado and lived on in Arapahoe and Denver time and it is shown that in the area considered in this paper they passed over a semi erosional interval and are found in association with the Fort Union flora which is of Eocene age.

10. The mammals of the lower Fort Union show very little relationship with Jurassic or Cretaceous forms, but find their closest affinities with those of the puerco and Torrejon, which are of acknowledged Eocene age.

11. Cheloniens are shown to be of little value in their bearing on the age of the lower Fort Union especially when compared with the Judith River forms which are evidently in confusion.

12. It is held that the lines between Cretaceous and Tertiary should be drawn at the top of the true Laramie.

13. The final conclusion is reached that the beds here considered ("Hell Creek Beds," Somber Beds, "Ceratops Beds, "Laramie of many writers) are stratigraphically, structurally, and paleontologically inseparable from the Fort Union and are Eocene in age.

(59) In a publication of 1909 T. W. Stanton reaches the following conclusions relative to the age and stratigraphic relation of the Ceratops beds of Wyoming and Montana. "In the interior region of North America the formations between the uppermost marine Cretaceous and the Wasatch together constitute a real transition from the Cretaceous to the Tertiary.

Notwithstanding the fact that there are several local unconformities at various horizons and perhaps some of more general distribution there is no conclusive evidence that any one of these represents a very long period of erosion not represented by sediments elsewhere in the region.
The Fort Union formation, properly restricted, is of Eocene age, the determination resting chiefly on its stratigraphic position and its primitive mammalian fauna which is related to the earliest Eocene fauna of Europe. The very modern character of the flora tends to confirm this correlation.

The Ceratops beds are of Cretaceous age as decided by stratigraphic relations, by the pronounced Mesozoic character of the vertebrate fauna with absence of all Tertiary types and by the close relation of its invertebrate fauna with the Cretaceous. The relations of the flora with Eocene floras is believed to be less important than this faunal and stratigraphic evidence. Taken in their whole areal extent they probably include equivalents of the Laramie, Arapahoe, and Denver formations of the Denver Basin."

(60) From field work in 1909 T. W. Stanton presents more data and conclusions in a publication of 1910 relative to the Fox Hill sandstones and Lance formation in South Dakota, North Dakota, and eastern Wyoming. He writes as follows:

"The three areas discussed in this paper taken together tell a story of gradual changing conditions near the end of the Cretaceous when the uplift of the Rocky Mountain region was draining the interior sea. The uplift was not uniform nor continuous and the emergence above sea level could not have been simultaneous for all localities throughout the region. As the sea became shallow the effect of tidal currents and wave action was shown in irregular deposition, cross bedding, and local erosion, and when an area was elevated above tide the deposits formed were subjected to all the varying conditions of flood plains, deltas, and marshes. It would depend on the configuration of the coast, the topography and drainage of the adjacent lands and the rate of elevation whether at any particular locality the last marine bed would be covered by a brackish water deposit or followed immediately by land conditions."
With such a history it is not surprising that the Fox Hill sandstones vary considerably in thickness and show somewhat varying relations with the overlying formations.

The bearing which the fact here presented have on the Laramie problem is self evident. If it is true that there is a transition with practically continuous sedimentation from the Fox Hills sandstone into the Lance formation in the region discussed, then the Lance formation includes or forms a part of the Laramie."

(61) In an article of 1911 F. H. Knowlton gives further data on the stratigraphic relation of the Lance formation. This article is based on observation of two seasons of field work in which Dr. Knowlton thinks confirm the position of the Lance formation. That the unconformity between the Fox hill and the Lance is not local is emphasized and it is pointed out that an unconformity at this horizon is found over a wide expanse of country. That it is of magnitude is also emphasized and observations in Carbon County, Wyoming and in the Denver Basin of Colorado are cited. In the first locality Veach estimated that

\[\text{Am. Jour. Sci. XXIV P. 18 1907.}\]

the unconformity represents the removal of 20,000 feet of strata and "moreover this unconformity is in the same positions as regards the Laramie as that in the Denver basin of Colorado which according to Cross has involved the removal of from 1200 to 1500 feet of strata between the Laramie and the overlying formations. The conclusion is reached that the proper place to draw the line between the Cretaceous and Tertiary is at this unconformity.

White River. The type locality of this formation is in the southern part of South Dakota along the White River. The region is famous for the
great development of bad land topography and the large collection of vertebrate remains which have been found in the formation. Probably the first observation made in this region were in 1847 by Dr. Hiram H. Prout. The early views in regard to the origin of these deposits were...


and a few months later by Dr. Joseph Leidy, and since that time the...


region has been extensively visited. C. C. O'Hara summarizes the...


views held relative to the age of the White River as follows:

"The bad land formation of the Black Hills region from the earliest days of their exploration have been recognized as of Tertiary age and of marine character ... the particular horizon within the Tertiary to which the various subdivisions should be referred has been less easy to determine. Leidy in his earliest studies of the extinct animals considered the beds Eocene. Fuller study indicated to him and others a wider range in age than was first suspected and many features showed a later Tertiary character. As a result that became designated as Miocene and Pliocene, than as lower Miocene and Pliocene, the Miocene (or lower Miocene) being often referred to as the White River group. Later as the methods of correlation became more refined and as representative fossils became more abundantly and in better condition from the hands of the collectors, giving better opportunity for comparison with similar fossils in other parts of the world, the lower beds were found to
be equivalent to the Oligocene and the upper beds to the Miocene, chiefly lower Miocene, the oligocene being in many ways the more important. This is now the accepted correlation."

The early views in regard to the origin of these deposits favors lacustrian deposition. It was though that streams carrying eroded material from the Black Hills and Rocky Mountains emptied into large fresh water lakes and these deposited their loads in relatively still waters. Detailed study of the region however did not support this theory, but the evidence pointed to combined lagoons fluvatile, flood plain, and possible eolian origin.

(6) From observations made in 1856 Meek and Hayden conclude that the White River formation belongs not to the Eocene but to the Miocene and is of terrestrial and fresh water origin.

(14) F. V. Hayden in 1869 states the opinion that during late Tertiary time four or five large lakes occupied areas in the Dakota and Nebraska region. The source of the material of the White River formation is probably in the Rocky Mountains and in the Black Hills. Streams in these regions cut into the granitoid and metamorphic rocks and distributed the decomposed silica, lime and aluminum over the bottom of the lake. Evidence of a basin in which the formations were deposited was found which supported the lacustrian theory.

(21) In a publication of 1880 F. V. Hayden speaks of the White River series having been formed in a lake beginning with a small nucleus and gradually spreading over a wide expanse of country.

(33) In an article of 1893 J. L. Wortman divides the White River group into three units namely, the Titanotherium or lowest, the Oredon and the Protoceras or highest. The Protoceras beds were separated out by J. L. Wortman.

(28) In 1894 J. E. Todd gives a discussion of the geology of South
Dakota. He is of the opinion that the White River beds are of Lacustrine origin and a partial elevation of the Rocky Mountains was probably an important factor in their formation.

(30) In 1895 J. E. Todd made observations in northwestern South Dakota and from fossil evidence concludes that the White River is of Miocene age.

(41) Prof. Frass in a publication of 1901 discusses the origin of the White River Oligocene of South Dakota. He is opposed to the Eolian theory and favors water deposition. The Titanotherium beds have at their base a coarse conglomerate and often show cross bedding. The clay is commonly finely laminated. The Orédon, or middle White River, has certain layers rich in gypsum and barite. Concretions are abundant in the lower part of this formation and there is an absence of sand layers but thin layers of limestone which have been silicified are present. The Middle Orédon beds are laminated and banded. The beds above the Orédon bed are composed of uniform material and are Eolian character. In view of these and other facts the following history is produced:

"At the beginning of the Oligocene a broad slowly flowing stream spread out towards the east and formed a broad wide spread and uniform delta landscape (Titanotherium beds); this even swampy land was dry during the dry season but was flooded in every high water period; besides the water the wind frequently took part in the transportation of the dust and material. The concretions are structures of the percolating waters (lower Orédon beds). Now followed a long period in which this region was flooded by a shallow rather than a deep lake. The inflow of water did not exceed the evaporation and so through the varying concentration there was a precipitation of the dissolved materials which gave rise to the banded layers. In the same manner gypsum and barite in these layers is explained. Stronger currents poured in sand which
accumulated in low elevations (middle Oredon beds). At last there came a widespread aeolian condition in the form of loess, which spread out upon the gradually retreating or evaporated levels of the lake."

(39) J. E. Todd in Hydrographic History of South Dakota, published in 1902, described conditions during Tertiary Time. The Miocene was represented by a large fresh water lake which probably crossed the state, and was situated nearer the Black Hills during the White River stage but shifted toward the east during the Loup Fork Stage. Fluvial and aeolian agencies possible aided in deposition during this time. In the Pliocene the lakes which were then filled up were tilted causing the streams to flow towards the southeast.

(44) J. E. Hatcher in an article published in 1902 discusses the origin of the Oligocene and Miocene deposits of the Great Plains. He points out the presence of sandstone and conglomerate lenses which occur at all horizons, show cross bedding, and evidently are deposited by water and probably represent deposition in the bed of a stream. He is of the opinion that the waters were not too saline to support aquatic life and in limestone and sandstone lenses found evidences of such life. Again the remains of terrestrial mammals are not found frequently in complete skeleton but are often scattered as would be the case if they were left on the flood plain. The large number of turtles found in the clay would be contrary to the supposed condition that these clays were formed at the bottom of a large lake. Remains of forests were found which would be the case in a broad flood plain. The sandstones and conglomerates and some of the clays were deposited in river channels, limestone lenses in shallow ponds and lakes, and the finer clays by occasional inundation and through the agency of the wind. An example of the Paraguay River of South America is noted.
This river at one place has a flood plain 150 miles broad which increases in breadth in some places and consists of a "labyrinth of lakes, ponds, swamps, channels and islands in a grassy plain, the only forest being near the river." This condition might be applied to Oligocene and Miocene times and from the above facts he bases his theory that these deposits were formed in small lakes, flood plains, river channels, and high grass covered pampas.

(40) In 1905 Albert B. Reagan discusses the origin of the White River deposits found in the Rose Bud Indian reservation, South Dakota. He is of the opinion that these deposits were begun by a river, later became a lake remained in this condition for a long time, then finally the lake was filled and deposition ceased.

(62) In a publication of 1910 C. C. O'Harrá discusses the White River formation in the Black Hills region. The following is an abbreviated form of the section given of this region.

Lower Miocene - Arikaree formation.
Upper Oligocene - Brule Formation - Protoceramus beds.
Middle Oligocene - - Oredon Beds.
Lower Oligocene - Chardron Formation - Titanotherium Beds.

The three lower members are the lower, middle and upper Oligocene deposits what is commonly known as the White River formation.

In regard to manner of deposition he agrees with Osborn that "The topography of the Plains region was in Oligocene to lower Pleistocene time as now, level or gently undulating, not mountainous. On the gentle eastward slope of the Rocky mountains and the Black Hills were born broad streams with varying channels, back waters and lagoons, sometimes spreading into shallow lakes, by never into vast fresh water seas. Savannahs were interspersed by grass covered pampas, tranversed by broad
meandering rivers which frequently changed their channels. This accounts
for the presence of true conglomerate, true sandstones, calcareous
grit, gypsum, fine clays, Fuller's earth, fine loess, eolian sands and
even far out on the plains of Nebraska and Kansas (and South Dakota)
wide spread deposits of volcanic dust wind borne from distant craters
in the mountains to the west and southwest. In the early Oligocene
and Miocene the deposits were chiefly fluvial or river sandstones
and conglomerates interspersed with fine flood plains of overflow
deposits perhaps locally lacustrian partly of volcanic ashes. As the
dessication or aridity of the country increased, the mountain fed rivers
became smaller and narrower while the aeolian or loess deposits parently
became more common beginning in the middle Miocene. The deposits
also became more and more distributed in extent as the Miocene advanced.
The newer river channels cut down into the older series, thus using
the erosion material a second time.

Comment.

Numbers in parenthesis refer to references under List of Publications
Examined.

FINIS.
List of Publications Examined.

24. Newberry. Notes on Geol. of the Country Bordering the Northern


56. O'Heara, C. C. South Dakota School of Mines Bull. No. 4 1900.


Approved
May 31, 1912.
MAP showing STRUCTURE CONTOURS
in
Tp. 21 N. Rq. 5 E.
Contour Interval 20 ft.
Contours Drawn on Lowest Coal Bed