SOUTH DAKOTA GEOLOGICAL SURVEY.

BULLETIN No. 1.

A PRELIMINARY REPORT

ON THE

GEOLOGY OF SOUTH DAKOTA.

BY J. E. TODD,
STATE GEOLOGIST.

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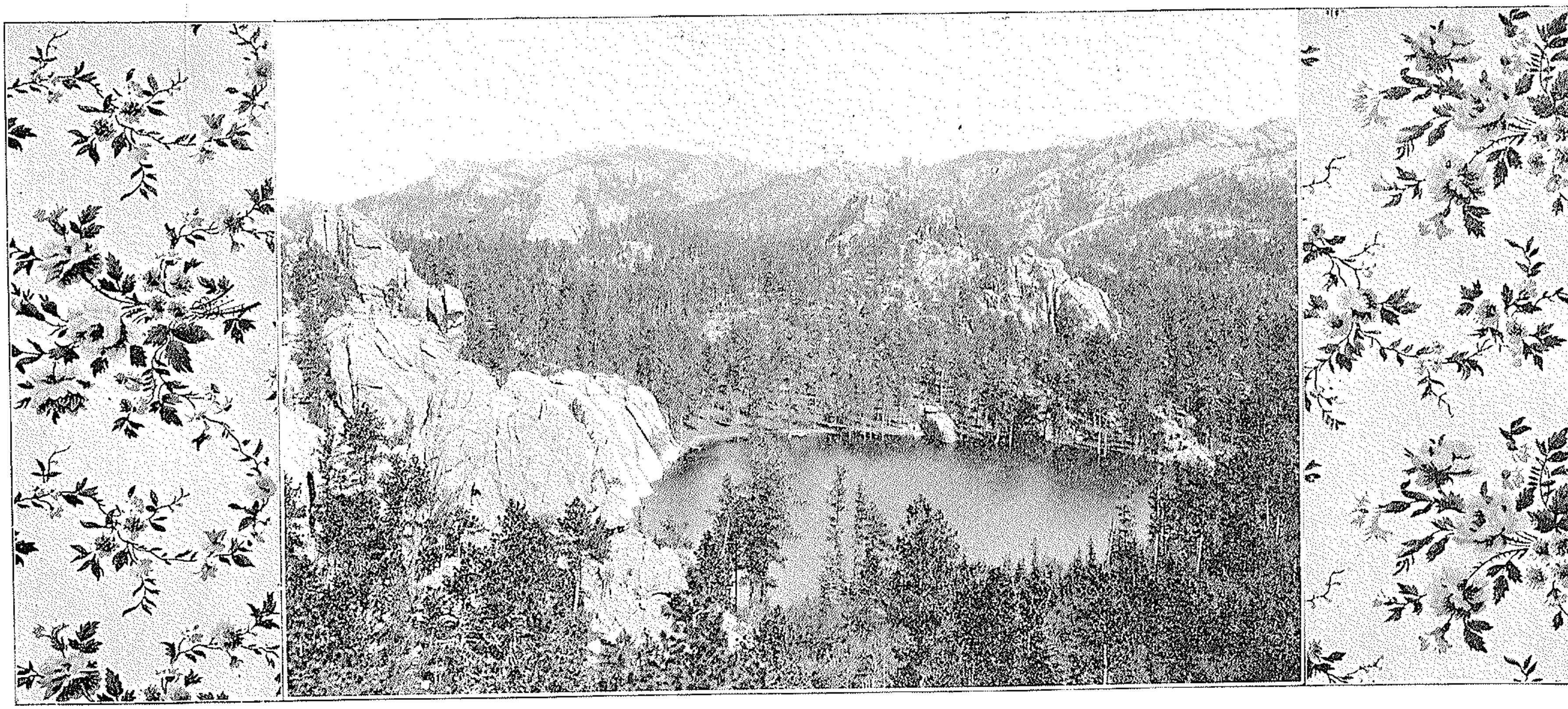

PLALE I.—VIEW OF SYLVAN LAKE NEAR CUSTER CITY. FORMED ARTIFICIALLY BY DAMMING A CANYON.

LETTER OF TRANSMITTAL.

UNIVERSITY OF SOUTH DAKOTA,
VERMILLION, S. D., Dec. 19, 1894.

To the President of the Board of Regents of Education:

DEAR SIR:—I herewith submit Bulletin No. 1 of the Geological and Natural History Survey of our State, which is a preliminary report on the Geology of South Dakota.

It is ardently hoped that it may be found of much advantage from both an educational and an economical standpoint; and that it may be but the first of a long series, which the State may, from time to time, issue for acquainting her citizens with the remarkable natural resources of our commonwealth and the best methods of utilizing them.

Very respectfully,

J. E. TODD,

State Geologist.

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PREFACE.

This volume was suggested by calls frequently made on the State Geologist, for information concerning the State.

The effort has been conscientiously made to present briefly and in popular form, the present state of our knowledge concerning the geology of our State. At the same time we have endeavored to put in such matter as would have value to the student and specialist. How successfully this has been done is now submitted to the judgment of our citizens.

Numerous technical and novel words have been necessarily used. Most of them, it is believed, will be found explained or defined at some point in the book. The Index, with the few additional definitions there added, it is hoped, will supply the lack.

The insertion of the scientific names of fossils seems about the only way to express the facts. They may lead some to further study. Most will be found defined or figured in text books on Geology.

References have been made quite generally to other works, where the subjects are treated more fully. While many of these are out of print, copies of them may yet be accessible. Some readers may be glad to know that the Bulletins of the United States Geological Survey, may be had at cost by applying to the Director of the Survey at Washington. Bulletin, No. 106, on the Colorado Formations, figures a large number of invertebrate fossils found in our State. Price 20 cents.

PRELIMINARY REPORT

OF THE

GEOLOGY OF SOUTH DAKOTA.

CHAPTER I.

INTRODUCTION.

THE AIM OF THIS VOLUME.

The survey of the Geology and Natural History of South Dakota recently inaugurated, contemplates eventually the thorough setting forth to the public of the natural resources of the State. The moderate appropriation then made, signified, however, to the chief of the survey that the time had not yet come for a vigorous prosecution of the work. The limited finances of the new State were doubtless the main reason for this delay. Little more seemed possible than the collecting and preserving of data, which are constantly accumulating from the rapid development of the State. In correspondence with various individuals, who are desirous to assist in the work as far as possible, an urgent need has been felt for a brief popular statement of what is already known, as a basis for further work, as a nucleus for the accumulation of additional data. This is more reasonable in our State, because more has been done by the general government and private enterprise, before its organization, than in most other states. The great natural thoroughfare of the Missouri river traverses it, so that from its earliest occupation by the French until its organization as a State, it has not only been accessible but of more than usual interest both from its reported mineral resources and its wonderful fossil remains. Moreover, the simplicity of its structure has rendered these early and desultory explorations more than usually instructive and helpful. To speak more to our purpose the present work is published with the hope that it may be advantageous in respect to the following points:

First. It will render available to our citizens what is already known. Knowledge, if not readily accessible, is comparatively useless. The numerous facts concerning the resources of our State, though well known to the initiated, are so mixed with those of other regions, and in volumes so difficult to obtain, that they are virtually inaccessible to the people of our State. Perhaps in no other state are these facts of more practical and greater economic value. Questions concerning the occurrence of coal, artesian waters and various minerals are constantly being raised. These, in most cases, are capable of easy answers from geological facts or discoveries. But from the ignorance of such data, citizens in some cases may squander many times the expense of publishing this volume. And in cases where the desired information has not yet been discovered, where geology cannot answer with confidence, there may yet be indicated probabilities which may be very helpful. In short, it is our aim to form a hand-book of geological information concerning our State which will be of interest and value, not only to the teacher and scientist, but also to the capitalist, who may be seeking for investment in mines, quarries or manufactures, and also to the farmer and citizen, who wishes to learn reliable information concerning facts coming to his notice.

Second. It will tend to waken interest and co-operation with the work of the survey. Not infrequently some curious phenomenon or strange specimen wakens intense interest. Many questions are raised in an active mind concerning it, but he knows not where to find answers, nor to gain light upon the subject. The result is that his interest is crowded out by more practical and imperative occupations and the germ of scientific enthusiasm is choked into a dormant or dead state. If however, he could find answers to his questions or discover the connection between his isolated fact and other facts, so as to reveal a principle of science, or gain a vantage ground for further research, either of scientific or economic value, he might not only taste the pleasure of acquiring knowledge, the joy of scientific research, but the satisfaction of contributing to the sum of human knowledge, and thereby to the welfare of mankind. It is hoped that this little volume may assist in this direction. Again, perhaps some one more accustomed to approach knowledge from the side of books may be led to become a practical and helpful observer, at least to appreciate and encourage observers in their work.

Third. As before suggested, the presentation of this work seems to be logically the first step, preparatory to collecting and classifying further information concerning our natural resources. There is not only an ignorance of geology which renders many timid in making inquiries, but also much misinformation. Many erroneous ideas are quite prevalent. These must be corrected before there can be substantial growth of knowledge. By placing this book in the hands of inquirers along this line, it is hoped that they may attain that correct view, which shall render further investigation not only possible but pleasant and successful.

In all this it is assumed that citizens of our commonwealth will cheerfully co-operate to promote the survey in every way practicable.

HISTORICAL SKETCH OF EXPLORATIONS.

The first reliable account of the upper Missouri Region, including a portion of our State, was furnished by Captains Lewis and Clark, sent out by the general government in 1804-6, to explore the great province of Louisiana, recently purchased from the French, and to acquaint the Indians with the transfer of this region to our own government.

In 1832 Prince Maximillian of Neuwied visited the region of the upper Missouri and published a magnificiently illustrated report. Little, however, of geological interest was determined by these explorations, except, that much of the region was covered with Cretaceous rocks, and the fragments of fine fossils which he brought back aroused great interest among professional geologists.

The next important expedition was made in 1839 by the distinguished geographer Jean N. Nicollet. He ascended the Missouri to Fort Pierre, thence passed northeast into the Minnesota Valley. Mr. Edward Harris, in 1843, accompanied Audubon to the mouth of the Yellowstone and returned with valuable geological notes for the benefit of the Academy of Natural Sciences in Philadelphia. An account of the specimens and fossils, collected by fur-traders and hunters, from the "Bad Lands" of White River was first published in the American Journal of Science by Dr. H. A. Prout in 1847. In 1849, Dr. John Evans was sent out by the U. S. Geologist, Dr. D. D. Owen, to explore the Bad Lands of White River. His results were published in his Final Report, 1859, pp. 194-206.

The following year Mr. T. A. Culbertson visited the White River and a portion of the upper Missouri country, in the interest of the Smithsonian Institution. Dr. Evans again, in 1853, collected important fossils from the Bad Lands and the White River on his way to Oregon.

In the same year, 1853, the region was visited for the first time by Dr. F. V. Hayden and Mr. F. B. Meek. These gentlemen were sent out to collect fossils from the Bad Land region by Prof. James Hall of Albany, N. Y. The vertebrate fossils were examined by Dr. Leidy, and the invertebrate forms, by Prof. Hall; and Mr. Meek, and furnished the subject of a memoir, published by the Boston Academy of Science, 1854. In this was a section prepared by Mr. Meek showing, for the first time, the different facts of the Cretaceous in the upper Missouri region. In 1854, Dr. Hayden, for the most part alone and unaided, traversed it in different directions, often on foot.

In 1855, an expedition was made under the command of Gen. W. S. Harney for the purpose of laying out roads between military posts. In 1856 these explorations were continued under the command of Lieutenant G. K. Warren. In this expedition he was accompanied by Dr. Hayden as geologist and naturalist. In 1857, Lieutenant Warren obtained the first reliable information concerning the Black Hills of Dakota. Their course was past "Raw Hide Butte and down Old Woman's Fork to the South Cheyenne, thence to Beaver Creek to the east branch by which they entered the Hills." From here Lieutenant Warren proceeded northward to Inyan Kara, thence back past Bear Butte, thence southeast to the Cheyenne, near Sage Creek, thence up the Cheyenne and over to White River, and thence southeast to the Niobrara. A preliminary report of this expedition was published by the War Department in 1858.

In 1859 an expedition under the command of Captain W. F. Raynolds, with Dr. Hayden as geologist, started from Fort Pierre on the Missouri, for Fort Sarpy on the Yellowstone. This expedition traversed the northern part of the Black Hills; and in the following year, other expeditions traversed portions of our State between the Missouri and the Black Hills. The reports of these explorations were not published by the government until 1868, but Dr. Hayden combined his results to date in a memoir before the American Philosophical Society in 1861.

In 1866 Dr. Hayden again visited the Bad Land Region of Niobrara and the White Rivers, and in the following year the "Geological Survey of the Territories," in his charge, was begun under the direction of the Commissioner of the General Land Office. This was continued several years. The report for the year 1870 includes most of the results obtained by Dr. Hayden, so far as concerns South Dakota.

In 1874 Colonel G. A. Custer led an expedition from Fort Abraham Lincoln to the Black Hills. Prof. N. H. Winchell was geologist of the expedition and his report was published in 1875. This expedition was accompanied by gold prospectors, who were successful in finding gold in several localities.

In 1875 a party was sent out by the Secretary of the Interior, for the express purpose of making a topographical survey of the Black Hills. This was placed under the direction of Mr. Walter P. Jenney. The personnel of the expedition, as finally organized, consisted of Walter P. Jenney, M. E., geologist in charge; Henry Newton, E. M., assistant geologist; V. T. McGillycuddy, M. D., topographer; Captain Horace B. Tuttle, A. M., astronomer and naturalist; with a number of miners and laborers.

The summer of 1875 was spent in a rapid and quite careful survey of the Black Hills, and a report of the same was published in 1880, which still remains an important and most complete manual on the natural resources of the Black Hills. In the years subsequent the Hills were visited by several prominent scientists, including Mr. Israel C. Russell, of the United States Geological Survey and Prof. Alpheus Hyatt, of Boston, and Prof. W. A. Crosby, also of Boston, whose short memoirs are valuable contributions to our knowledge of this interesting region.

In 1887 the Legislature of Dakota made a small appropriation to enable the School of Mines, at Rapid City, to examine the Geology and Mineral Resources of the Black Hills; and in 1888 a valuable preliminary report was prepared and published by Prof. Franklin R. Carpenter, dean of that school.

Much additional information was collected by the same gentleman, which the State has not yet found convenient to publish. The Bad Lands of the White River have been almost constantly visited by distinguished scientists and collectors from most of the leading educational institutions of the Eastern States and even from Europe. Important paleontological works have been written by Professors Marsh, Cope, Scott and others, of which more will be said on a subsequent page.

Other localities of our State of unusual interest have attracted eminent geologists from the U. S. Geological Survey and from adjacent States, who have quite recently published valuable memoirs, to which reference will be made in their proper connection.

It may enable one to form a more accurate estimate of the peculiar value of this work, if a brief statement is made of the opportunities for personal acquaintance with geology of the State have been enjoyed by the writer. While carrying on investigation for the United States geological survey during the summers of 1881 to 1889, inclusive, the writer became quite familiar with the geology of that portion of the State east of the Missouri river, and during the past season a short trip was taken throughout the Black Hills and Bad Lands, visiting the following points: Buffalo Gap, Wind Cave, Rapid City, Hill City, Harney Peak, Deadwood, Lead City, Elk Creek Canon, and Crystal Cave, Hot Springs, Smithville at the mouth of Elk Creek, the head waters of Bad River, and then following the Chamberlain trail from Black P. O. to Rapid City. In this way a general view was obtained of the older geological formations as displayed in the Black Hills and the more recent formations with their remarkable fossils, as found in the Bad Lands.

CHAPTER II.

TOPOGRAPHIC FEATURES.

South Dakota presents greater extremes of altitude and greater variety of topography than any other state east of the Rocky mountains. Its lowest point, at Bigstone Lake, is less than a thousand feet above the sea, (967) while the reputed highest point, Harney Peak, is given by different authorities as 7,403 and 8,700. These latter elevations, however, are merely barometric, and it seems not improbable that other points in the western portion of the Black Hills within our boundary may attain as high an elevation. These extremes surpass the greatest range of altitude found in New England or anywhere east of the Mississippi river. As to variety of surface we have not only very uniform plains, level as a floor, which are found in the James River Valley and along the Missouri, but high table lands with gentle undulations, as west of the Missouri and in smaller areas on the summit of "the Coteaus," but also narrow canyons hundreds of feet in depth, presenting on a smaller scale all the wildness and picturesqueness of the Rocky mountains, as the Elk Creek and Spearfish canons in the Black Hills, and the rugged portion and craggy needles of Harney Peak and vicinity. Not only are there areas in which stones as large as a pea may be sought for in vain over scores of square miles, but others where there are almost unbroken surfaces of rock, scarcely sustaining vegetation, as in the more barren ranges of the Black Hills, but again areas so saturated with acid and mineral solutions as to be utterly barren, as along the sides of the narrow valleys of the Missouri and Cheyenne, and in limited areas of certain "lake beds," and others where erosion without those deleterious agencies, goes on so rapidly as to produce similar barren areas, as in the Bad Lands of White river.

The surface may be classified, according to topography, as follows: First, the Black Hills, which rise as a moutainous, much eroded, domehaped uplift, pushed up above the nearly horizontal beds which cover he region around.

Second. The Table Lands, which occupy most of the region west of the Missouri, and smaller isolated areas east of that stream, formerly desigated by the French as the "Plateau du Coteau du Missouri," and the Plateau du Coteau du Prairies," but more frequently spoken of nowaays as the West and East Coteaus.

Third. River Valleys, including both the high terraces and the present flood plains, for example those of the Missouri, Cheyenne, White and James rivers, of which I shall speak more in detail further on.

Fourth. Limited areas of unique characteristics as the "Bad Land" areas about the White river and also between the Moreau and Grand rivers.

THE BLACK HILLS.

The Black Hills have an area of 5,000 square miles of a rudely eliptical form with its major axis, approximately, north-northwest. Most of this area lies within our State. The true limit of the Hills is quite distinctly marked by a sharp ridge of sandstone, 300 to 600 feet in relative height, which becomes broader and more plateau-like toward the north and south ends. This ridge is separated from the higher mass of hills within by a valley one to three miles in breadth, which is known as the Red Valley from its brick-red soil, or the "race course," which name was given it by the Indians because of its open and smooth character affording easy and rapid passage around the Hills. The junction of the outer base of the Hills with the surrounding table lands has an altitude of 3,500 to 4,000 feet. Within this Red Valley one gradually ascends the outer slope of the Hills and soon enters at an altitude of 4,500 or 5,000 feet the woody portion of the region. This outer slope varies greatly in width and is underlaid by older sedimentary rocks, cut in almost every direction by narrow deep canons. This feature covers nearly the whole of the western half of the Hills proper, where erosion has been less active on account of its distance from the main channels of drainage. Usually, from the broken interior edge of this slope or sedimentary plateau one descends a bluff or escarpment and enters the central area of slates, granite and quartzites, which is carved into high ridges and sharp peaks cut by many narrow and deep valleys and ravines and generally thickly timbered with the common pine of the Rocky Mountains. Towards the south, about Harney Peak, the surface is peculiarly rugged and difficult to traverse. Toward the north, also, about Terry and Custer peaks, a smaller rugged surface appears; but in the central area between and extending west of the Harney range is a region which is characterized by open and level parks much lower than the surrounding peaks and ridges

TABLE LANDS.

The table lands, which correspond, approximately, to the early surface of the State before the valleys of the present streams had been excavated, slopes from an altitude of about 3,500 feet along the wes boundary of the State, eastward to an altitude of about 2,000 feet nea the northeast corner of the State, and 1,450 near the southeast corne

This makes an average slope eastward of about 4 feet per mile along the northern boundary and less than 6 feet along the southern. The highland region is everywhere eroded into undulations and there are traces of higher strata, which occasionally stands out as buttes and ridges. As already stated the region west of the Missouri, outside of the Black Hills, well illustrates this feature. East of the Missouri, it is best seen on the top of the East Coteau, where it shows a greatest width of 50 miles, narrowing to a point on the north line of the State in Marshall County, and slopes gently to the south, the upper course of the Big Sioux draining its surface. Elsewhere east of the Missouri it has been cut away, except in the limited areas of the Bijou Hills, Wessington Hills, Ree Hills, Bald Mountains, the region about Bowdle, and the table land northwest of Leola; while narrow traces of this table land are found on the east bank of the Missouri below the Bijou Hills and rising into greater prominence in the Choteau Creek Hills, Turkey Ridge, and more extensively in the eastern part of Clay and Lincoln counties.

RIVER VALLEYS.

The river valleys may be briefly sketched as follows: There are two important valleys crossing our State from north to south, the Missouri and the James. Another touches upon the northeastern corner of our State, the Minnesota.

Of these the Minnesota is wide and has an altitude of about 1000 feet above the sea; the James is from 60 to 70 miles in width, and from 1300 to 1500 feet in altitude at the north line of the State and about 100 feet lower at the south. It has five important branches, broad and quite even like itelf. One extends west from Aberdeen at an altitude of 1500 to 1800 feet, another west from Huron, the Ree Valley, of similar height; and a third southwest from Scotland, from 1400 to 1200; a fourth from Marion southeast of similar altitude to the last. All these four extend through to the Missouri river. The fifth, running northeast from Aberdeen north of the east Coteau, connects this valley with that of the Minnesota river. The valleys thus far mentioned have all been smoothed by the action of glaciers and consequently their contours are much less sharply defined than those in the western portion of the State.

The Missouri flows in a narrow valley, usually less than three miles in width, which at the north line of the State is about 1,550 feet above the sea or about 250 feet above the James river on the same line. Its tributaries from the west also have narrow valleys, the larger ones the Grand, Cheyenne and White rivers, have broad, high terraces considerable lower than the adjacent country. These high terraces are a feature peculiar to the Missouri and its western tributaries.

These high terraces are usually classified into two groups. Those along the Missouri descend more rapidly than the stream and rise higher, 200 to 300 feet above the present stream, while the lower are from 50 to 100 feet below that slope. Along the Cheyenne they are equally well developed, particularly in the upper portion east of the Black Hills, where four or five high terraces were traced, ranging at the mouth of Elk Creek from 200 to 350 feet. These high terraces also show a black soil, along the streams which radiate from the Black Hills to the two main branches of the Cheyenne. The upper of these terraces has a gentler slope than the lower, and the lower decends much less rapidly than the present stream. For example, the lower terrace along Rapid creek near Rapid City, is less than 30 feet above the stream, while near the mouth it is nearly 150. More detailed discussion of these terraces naturally belongs to the treatment of the Pleistocene Formations. These terraces furnish many square miles of level ground suitable for agriculture.

Along these streams are quite extensive flood plains, affording good farm land. Oftentimes along the Missouri these are one to two miles wide, and below its junction with the James river, usually more than twice that width. These river valleys although largely prairie, are freqently studded with groves along the smaller streams and with masses of larger timber in the bends of the main streams. This timber is usually cottonwood, ash, elm and soft maple.

BAD LANDS.

The Bad Land areas have become particularly famous. Their features particularly impressed early hunters and explorers. A fuller description of them will be found on a subsequent page. We will here simply say that they are areas which are called "bad" because of the difficulty of traversing them. This was caused by the bottomless character of the mud in spring and the difficulty of obtaining water during much of the summer, and what is more pertinent to our present theme, the steepness of the hills and the multiplicity of deep, narrow ravines.

The most notable "bad lands," or "Mauvaises Terres," are between the Cheyenne and White rivers, southeast of the Black Hills. This region is exceedingly cut up by ravines and is bounded largely with high continuous clay bluffs. Most of the surface is entirely without vegetation. They are carved by rapid erosion out of the white clays, marls and sands of the Tertiary.

Somewhat similar areas of narrow extent are found along the Cheyenne and Missouri excavated in a similar way out of the lead-colored Cretaceous clays.

ELEVATION OF RAILROAD STATIONS.

All Elevations are from Railroad Levels Except Where Otherwise Stated.

LOCATION.	Elevation.
Aberdeen	1,300
Alcester	1,346
Alba	1,184
Alexandria	1,352
Alpena	1,319
Altamont	1,834
Altoona	1,693
Amherst	1,312
Andover	1,476
Appleby	1,711
Arlington	1,846
Armour	1,514
Artesian	1,313
Ashton	1,299
Athol	1,296
Aurora	1,630
Bancroft	1,562
Barry	1,107
Bath	1,301
Beardsley	1,098
Bennett, Fort (bar.)	1,440
Benton, Lake	1,759
Beresford	1,505
Berwick	1,422
Blunt	1,621
Bonilla	1,338
Bowdle	1,995
Bradley	1,796
Bramhall	1,819
Brampton	1,289
Brandon	1,319
Brandt	1,856
Bridgewater	1,420
Bristol	1,775
Britton	1,352
Broadhead	1,308
Broadland	1,300
Brookings	1,636
Bruce	1,659
Bryant	1,844
Buffalo Gap	3,263
Burbank	1,142
Burkmere	1,748
Burton	1,330
Bushnell	1,649
Butler	1,820
Butler Landing, Missouri river, (low water, 1881)	1,126
Butler Landing, Missouri river, (high water, 1881)	1,136
Canistota	1,455
Canning	1,553

ELEVATION OF RAILROAD STATIONS—*Continued.*

LOCATION.	Elevation.
Canova	1,527
Canton	1,248
Carthage	1,438
Castlewood	1,685
Cavour	1,311
Centerville	1,225 1,229
Chamberlain, Missouri river, (low water)	1,324
Chamberlain, Missouri river, (low water, 1882)	1,323
Chamberlain	1,363
Claremont	2,302
Clark	1,779
Clear Lake	1,804
Columbia	1,304
Conde	1,318
Corona	1,173
Corson	1,362
Crandon	1,305
Davis Junction (near Elk Point)	1,114
Deadwood	4,545
Dell Rapids	1,485
Delmont	1,481
Demster	1,666
Denbigh	1,485
De Smet	1,726
Doland	1,455
Dolton	1,438
Durham	1,936
East Elrod	1,818
Eden	1,223
Egan	1,525
Elk Point	1,131
Elkton	1,751
Elrod	1,807
Estelline	1,659
Ethan	1,338
Eureka	1,884
Fairmount	985
Faulkton	1,595
Ferney	1,300
Flandreau	1,565
Foster	1,381
Forestburg	1,231
Forrestville	1,868
Frankfort	1,296
Freeman	1,511
Fulton	1,332
Gardner	1,853
Gary	1,484
Gayville	1,167
Gettysburg	2,082
Goodwin	1,996
Groton	1,301

ELEVATIONS OF RAILROAD STATIONS—*Continued.*

LOCATION.	Elevation.
Grover	1,742
Harlem	1,371
Harney Peak	7,368
Harrold	1,801
Hartford	1,564
Havana	1,294
Hazel	1,765
Hecla	1,301
Henry	1,812
Herman	1,564
Hermosa	3,295
Highmore	1,890
Hillsview	1,894
Hill City	2,322
Hitchcock	1,339
Holabird	1,795
Hot Springs	3,400
Houghton	1,302
Howard	1,564
Huffton	1,307
Huron	1,285
Ipswich	1,531
Iroquois	1,401
James	1,299
James Valley Junction, near Huron	1,312
Jefferson	1,114
Joy	1,138
Kampeska	1,766
Kent	1,829
Kidder	1,295
Kimball	1,788
Kranzburg	1,982
Labolt	1,362
Lake Herman	1,646
Lake Preston	1,722
Langford	1,370
Lebanon	1,956
Lennox	1,354
Leola	1,587
Lesterville	1,385
Loyalton	1,685
McCook	1,107
Madison	1,669
Manchester	1,542
Mansfield	1,300
Marion Junction	1,447
Marvin	1,652
Meckling	1,156
Mellette	1,300
Menno	1,324
Millard	1,640
Miller	1,587

ELEVATIONS OF RAILROAD STATIONS—*Continued.*

LOCATION.	Elevation.
Miranda	1,440
Mitchell, Chicago, Milwaukee and St. Paul Railway	1,301
Mitchell, Chicago, St. Paul, Minneapolis and Omaha Railway	1,312
Montrose	1,474
Mount Vernon	1,413
Naples	1,091
New Madison	1,646
Newark	1,306
Nicholson	1,309
Nordland	1,846
Northville	1,299
Ocheeda	1,565
Oldham	1,921
Orient	1,599
Osceola	1,453
Palisades	1,457
Palmer	1,938
Parker	1,348
Parkston	1,393
Pennington	4,972
Petersburg	1,519
Pierre	1,440
Pierre, Missouri river, (extra low water)	1,526
Pierre, Missouri river, (extra high water)	1,445
Pierpont	1,510
Plana	1,302
Plankinton	1,528
Preston	1,696
Putney	1,306
Pukwana	1,538
Ramona	1,801
Ransom	1,231
Rauville	1,757
Rapid City	3,192
Raymond	1,458
Redfield	1,295
Redwood	1,631
Ree Heights	1,731
Revillo	1,208
Rockham	1,394
Rousseau	1,427
Rudolph	1,301
Running Water	1,220
Running Water, Missouri river, (low water, 1881)	1,203
Running Water, Missouri river, (extra low water, 1881)	1,202
St. Lawrence	1,580
Salem	1,520
Sargent	1,301
Scotland	1,347
Seneca	1.911
Sheffield	1,310
Sherman	1,396
Sioux Falls, Chicago, Milwaukee and St Paul Railroad	1,395

ELEVATIONS OF RAILROAD STATIONS—*Continued.*

LOCATION.	Elevation.
Sioux Falls, Chicago, St. Paul, Minneapolis and Omaha Railroad	1,397
Sioux Falls, Burlington, Cedar Rapids and Northern Railroad	1,400
Sioux Falls, St. Paul, Minneapolis and Manitoba Railroad	1,420
Sioux Falls Junction	1,514
Spain	1,325
Spencer	1,387
Springdale	1,401
Springfield	1,234
Sturgis	3,467
Sully, Fort (bar)	1,688
Toronto	1,994
Tripp	1,556
Troy	1,885
Tulare	1,317
Turton	1,323
Twin Brooks	1,954
Tyler	1,750
Tyndall	1,418
Utica	1,387
Verdi	1,771
Vermillion	1,150
Vermillion, Missouri river, (low water, 1880)	1,131
Vermillion, Missouri river, (high water, 1881)	1,144
Vienna	1,837
Vilas	1,480
Virgil	1,341
Virginia	1,206
Volga	1,636
Volin	1,181
Wakonda	1,396
Ward	1,754
Warner	1,301
Watertown	1,738
Watertown Junction	1,604
Waubay	1,813
Waverly	1,993
Webster	1,842
Wessington	1,410
White	1,778
White Lake	1,648
Whitewood	3,640
Willow Lakes	1,786
Wilmot	1,196
Wilson	1,366
Wolsey	1,348
Woonsocket	1,308
Worthing	1,364
Yale	1,340
Yankton, Chicago and Northwestern Railroad	1,206
Yankton, Chicago, Milwaukee and St. Paul Railroad	1,196
Yankton, Missouri river, (low water, 1881)	1,161
Yankton, Missouri river, (extra low water, 1881)	1,157
Yankton, Missouri river, (extra high water, 1881)	1,198
Yankton, Signal Station	1,228
Zell	1,365

ELEVATIONS OF RIVERS, LAKES, PEAKS, ETC.

LOCATION.	Low.	High.
MISSOURI RIVER—		
Bismarck	1,618	1,646
At north line of South Dakota, estimated, low water,	1,572	--------
Pierre	1,426	1,445
Chamberlain	1,324	--------
Bijou Hills	1,281	--------
Running Water	1,203	--------
Yankton	1,161	1,198
Sioux City	1,076	1,099
CHEYENNE RIVER—		
South branch, lat. 43° 30' N and about 103° W long.	2,975	--------
North branch, Belle Fourche, 44° 40' N lat., and about 103° W long.	2,550	--------
Month, estimated	1,466	--------
JAMES RIVER—		
Columbia, estimated	1,290	--------
East of Plana, railroad crossing	1,286	--------
East of Aberdeen, "	1,266	--------
East of Redfield, "	1,235	1,255
East of Huron, "	1,228	--------
East of Forestburg "	1,213	--------
East of Mitchell "	1,207	--------
East of Scotland "	1,194	--------
East of Yankton "	1,162	--------
BIG SIOUX RIVER—		
East of Waubay, railroad crossing	1,826	--------
Near Watertown, "	1,709	--------
Near Volga "	1,596	--------
Near Egan "	1,495	--------
Near Dell Rapids "	1,485	--------
Near Sioux Falls " west of town	1,403	--------
Near Sioux Falls " above the falls	1,380	1,385
Near Brandon " below the falls	1,281	1,302
Near Canton "	1,227	--------
Near Hawarden "	1,156	--------
Near Akron "	1,136	--------
Near Riverside Park "	1,098	--------
VERMILLION RIVER—		
Near Winfred, east branch, railroad crossing	1,627	--------
Near Montrose, " "	1,455	--------
Near Howard, west branch, "	1,518	--------
Near Parker, " "	1,316	--------
East of Parker, main stream, "	1,293	--------
Near Centerville, main stream "	1,195	1,209
Near Vermillion " "	1,119	--------
Andes, Lake	1,518	--------
Big Stone Lake	965	967
Blue Lake, near Waubay	1,800	--------
Herman, Lake	1,646	--------
Kampeska, Lake	1,714	--------
Madison, Lake	1,576	--------
Preston, Lake	1,696	--------
Red Lake	1,530	--------

ELEVATIONS OF RIVERS, PEAKS, ETC.—*Continued.*

LOCATION.	Low.	High.
Sand Lake or Teanchicahah, estimated,	1,290	--------
Traverse, Lake	971	976
Bear Butte, Meade county	4,573	--------
Bijou Hills, Brule county, (bar.)	·1,950	--------
Black Horse Butte, Schnasse county	2,680	--------
Black Butte, Lawrence county, (bar.)	5,950	--------
Crook's Tower, Lawrence county	7,140	--------
Crow Peak, Lawrence county	5,772	--------
Custer Peak, Lawrence county, (bar.)	6,812	--------
Dodge Peak, Pennington county	6,989	--------
Flint Rock Buttes, Rhinehart county	2,665	--------
Harney Peak, Pennington county, (bar.)	7,403	--------
Hills about Bowdle, Edmunds county ....over	2,000	--------
Hills east of Gettysburg, Potter county	2,000	--------
Hills northwest of Leola, McPherson county ....over	2,000	--------
Medicine Butte, Presho county, (bar.)	2,000	--------
Piedmont Butte, Meade county	4,173	--------
Plateau du Coteau des Prairies	1,700	2,000
Plateau south of Crook's Tower........over	7,100	--------
Rabbit Butte, Choteau county	3,000	--------
Ree Hills, Hand county, (bar.) ....over	2,000	--------
Terry Peak, Lawrence county	7,070	--------
Thunder Butte, Schnasse county	2,830	--------
Turtle Point, Wessington Hills, (bar.)	1,950	--------

CHAPTER III.

A SKETCH OF THE GEOLOGY OF THE STATE.

EXPLANATIONS AND DEFINITIONS.

For the benefit of those who are unfamiliar with the fundamental facts and principles of geology, we will give briefly a few explanations and definitions.

At nearly all points upon the earth's surface the rocks exposed or discovered by mines or borings, are found to be composed of layers of varying thickness. These are arranged like blankets, one above another, each one extending over many square miles. A single one is called a *stratum*, and the rock composed of them is said to be *stratified*. Strata (plural) lie nearly horizontal over nearly the whole of our State. When tilted, as about the Black Hills, the angle made with the horizontal plane, and the direction toward which the rock descends, together, constitute the *dip*.

Stratified rocks, with very rare exceptions, have been formed under water, as sediment, somewhat as strata of sand and mud are now forming in the Gulf of Mexico, from the material carried down by the Mississippi and by waves and currents from the shores of the gulf. Almost all the rocks of our State have been formed in the ocean, as is shown by their containing the shells and bones of marine animals. These remains of animal life, and plant life also, are called *fossils*. As new and higher forms of life have been introduced in successive ages, while strata were forming, one after and one above another, it follows that the stratified, or sedimentary rocks, constitute nature's record of the history of life from "monad to man." Also, contrariwise, the fossils in a rock enable one to tell often with great confidence, from what part of the record even a fragment has been taken, just as a picture on a leaf from a book, with which one is familiar, may tell just where it belongs. Some strata have been formed in lakes, and still others in streams. By careful study one may tell the direction in which the streams flowed, and many other curious and valuable facts.

Strata, though all soft at first, have sometimes become consolidated by pressure and the action of molecular forces, into rock of great or less hardness. Such are usually broken by vertical seams (called joints) into blocks.

In some localities, like the Black Hills, strata are profoundly, folded and fissured. Sometimes the strata on one side of the fissure have slipped down so as to lose their former position with reference to those on the other side. Such a displacement is called a *fault*. Sometimes fissures and other openings become filled with various minerals derived from the adjacent rock by the dissolving action of water. Such form the *veins*, "*leads*" and pockets of the miner.

Sometimes rocks of the earth's crust become plastic or melted and flow out through fissures. In the process of cooling they become what are called igneous rocks. When igneous rocks are cooled in a fissure they constitute a *d ke*. If they push up the overlying strata and form a lenticular, or dome-like, mass, it is called a *laccolite*.

Igneous rocks are compound of crystals of different minerals either wholly or with an imbedding paste of glassy or porcelain-like rock. The latter are called *Trachyte, Rhyolite, Phonolite, Porphyry*, &c., according to their composition or coarseness of grains.

Rocks wholly crystaline, breaking with equal ease in any direction, are called *massive rocks*, and are named *Granite, Syenite, Diorite, Diabase, Greisen*, &c., according to the kind of minerals composing them. If they break in slabs they are called *Gneiss* or *Gneissic*, if in uneven plates, *Schists*, if in even *Slates*.

The strata found in the earth's crust are classified by grouping them first into *Great System*, which are divided into *Systems*; then system ares divided into *Groups*, and groups into *Stages*. These divisions are based upon differences in the life forms found in them, the characters of the rocks, and other features or relations which make a distinction convenient. Each of these groups of strata corresponds to a division of time, in which it was formed. A great system was formed in an *Eon*, a system in an *Age*, a group in a *Period*, and a stage in an *Epoch*. Usually a group of of strata and its corresponding time division are called by the same name. The names of formations and time divisions are largely geographical, derived from some region or locality where they were first studied or typically exposed. Some are named from some phase of life or characteristic of deposits belonging to them. The reasons for the different names will generally be found in connection with their detailed treatment in subsequent chapters. Most important names commonly used in this country will be found in the table in the next section.

FORMATIONS REPRESENTED IN THE STATE.

South Dakota is also remarkable for having a greater variety of geological formations than any other state east of the Rocky Mountains. Of the different ages represented, we mention the Archean, Cambrian, Silurian, Carboniferous. Triassic. Jurassic, Cretaceous, Miocene, Pliocene and Pleistocene. The Archean is represented by two or three remarkably different formations, the correlation of which is not yet satisfactorily determined, but following Newton and Carpenter we may call them the earlier Archean schists, and the later Archean slates of the Black Hills; while the eastern end of the State presents a red quartzite, known as the Sioux Quartzite, or Sioux Falls granite, which has been classified most commonly as Huronian, and about Big Stone Lake, an area of coarse granite, probably Laurentian.

The Cambrian is represented only in the Black Hills and by the Potsdam sandstone, which manifests its common characteristics and has a thickness in places of 250 feet.

Above it there has been found near Deadwood, since the publication of Prof. Carpenter's work, a formation from 20 to 30 feet in thickness, which presents the features of the Trenton limestone and represents the Silurian.

So far as has yet been discovered the Devonian is absent, unless it is represented by 25 or 30 feet of greenish shales. which are exposed near Deadwood. between the Trenton limestone and the base of the Carboniferous.

The Carboniferous age is represented by a variety of formations, aggregating in thickness over 600 feet. All these Paleozoic formations are limited to the Black Hills.

The Triassic age is represented by 340 feet of a bright red clay bearing irregular beds of gypsum and a very uniformly developed stratum of purple limestone 40 feet in thickness, the whole entirely barren of fossils.

The Jurassic is represented by about 200 feet of sandstone and marls of various colors.

The Cretaceous is represented by several well marked formations widely developed, covering perhaps four-fifths of the area of the State. These have more frequently been classified as the Dakota formation, 200 to 400 feet in thickness; the Colorado, including the broad area of Fort Benton, Niobrara and Fort Pierre, clays, marls and limestones, aggregating in places a thickness of 1,500 feet. And the third member of the Cretaceous has been called by Dr. Hayden the Fox Hills, which shows a thickness of 100 to 150 feet, and a fourth is the Laramie or Lignitic having a thickness of 1000 to 2000 feet. The last two formations are found only in the northwestern quartér of the State.

The Eocene seems not to be represented in the State, unless possibly some of the yellowish clays in the Bad-Lands, which are without fossils to determine their age, may belong to this age.

The Miocene is widely developed in the southern part of the State.

Under this head we include, following the later classification of Prof. Cope, the White river and Loup fork formations, which are not easily distinguished lithologically, and have aggregated a thickness in this region of more than 300 feet, having more or less gray and flesh colored clays, stratified with conglomerates and marls.

The Pliocene is of somewhat doubtful occurrence. Certain beds observed along the Big Sioux seem referable to this age.

The Pleistocene or Quaternary formations are particularly prominent, and are represented, not only by a fine development of glacial deposits, loams and other features in the eastern half of the State, but also, about the Black Hills and over very much of the surface of the plains, by aqueous drift. The present topographic features, also, are mostly to be referred to this age.

The subjoined synopsis represents the Geological column represented in the State.

A TABLE OF SOUTH DAKOTA GEOLOGICAL FORMATIONS.

(ARRANGED STRATIGRAPHICALLY.)

Great Systems.	Systems.	Periods and Stages.		
Cenozoic	Quaternary,			
			Alluvium and Prairie Loam,	5–10
			Loess,	5–100
			Drift, Glacial and Aqueous,	10–150
			Equus beds, (?)	5–30
	Tertiary,			
		Pliocene,	Loup Fork beds,	25–75
		Miocene,	White River beds,	250–400
		Eocene,	Absent,	
Mesozoic	Cretaceous,			
		Later,	Laramie, or Lignitic,	1,000–2,000
			Fox Hills,	100–150
			Colorado, Ft. Pierre,	350–700
			Niobrara,	50–200
			Ft. Benton,	50–200
			Dakota,	200–500
		Earlier,	Absent,	
	Jurassic,			200–350
	Triassic,			300–400
Paleozoic	Carboniferous,			570–785
	Devonian,		Absent (?)	0–55
	Silurian,			
		Upper,	Absent (?)	
		Lower,	Trenton,	225–20
			Canadian, absent (?)	
	Cambrian,		Potsdam, Acadian, absent ?	250–300
Archean	Keweenian,		Absent,	
	Huronian,	Upper,	Sioux Quartzite,	1,000–3,000
		Lower,	Schists and slates,	10,000 ?–100,000 ?
	Laurentian,		Absent (?)	

THE GENERAL ATTITUDE OF THE GEOLOGICAL FORMATIONS.

The opposite ends of the State contain each of them a distinct center of geological growth. One is the Black Hills, the other, the Archean area about Sioux Falls. The former is an irregular dome shaped uplift with its longer axis north-northwest; the latter a low ridge with its axis west-southwest, gradually sinking below the later formations in that direction, with its north side more abrupt than its southern.

Around these two nuclei the older rocks of later formations have been arranged, somewhat as blankets might lie upon a saddle. The Cretaceous and Tertiary formations cover nearly the whole State outside of the Black Hills.

It follows from this general statement that, while the general slope of the country is toward the east, the dip of the rocks radiate from those two centers, and is slightly southward in the south central portion of the State, and northwestward in the northern portion.

CHAPTER IV.

THE ARCHEAN FORMATIONS.

Archean rocks, as the name suggests, (*arche*, beginning), are those rocks which underlie the others in the structure of the earth's crust. They are, theoretically, of world-wide extent; though exposed in detached areas, commonly in the center of mountain systems and plateaus. They are rocks in which no trace of living forms have been found. They are moreover of a crystalline character. By crystalline rocks we mean such as are formed of angular grains, interlocking as though crystallized from a fluid state. There are all gradations of rocks found in nature, from those which are wholly crystalline to those where there is not a trace of crystallization, the whole mass consisting largely of rounded grains and fragments of various shapes and sizes. The former would be illustrated by rocks commonly known as granite, which may be compared to cast iron in structure, except the grains are often times unlike in the same rock, some being black, others white, red or green of various shades and lustres. Some show a tendency to cleave with smooth and even surfaces sometimes into thin leaves, others show no trace of such cleavage. They break irregularly like glass. Some are soft, others very hard. Archean rocks are almost wholly crystalline, although some reveal traces of worn grains or fragments.

The Archean rocks include all the oldest rocks of the earth's crust. Some of them were evidently at one time laid down in water in a stratified condition, Others show no signs of bedding. The latter occur in great masses, divided only by cracks running in different directions. Rocks of this character are usually found underlying those of a clearly stratified character.

Concerning the origin of these massive crystalline rocks the following theories are held by different prominent geologists:

First. The oldest theory is, that they are portions of the original crust of the earth when it first cooled from a molten condition.

Second. That they have once been composed of stratified material deposited like the rocks above them, and that afterwards having been deeply buried under the overlying formations, and they have been completely changed by pressure and heat from the earth's interior from a fragmental condition to a crystalline. Every trace of stratification, and even of the fragmental character of individual grains, has been completely obliterated.

Third. It is supposed that the underlying crystalline rocks have never been in the form of stratified rocks, nor that they were solidified previous to the deposition or formation of the stratified rocks overlying them, but that they are a portion of a molten or plastic interior of the earth, which has risen in the center of folds, or into fissures formed in the stratified rocks above them, and which have become hardened as they have been brought nearer to the surface and cooled. This view considers them really younger than the stratified rocks, and may explain how rocks of this character may be found, not only under the stratified rocks but following great cracks and other cavities in the stratified rocks themselves. This last view is the most prevalent at the present time.

Of the Archean rocks, which are admitted to have been at sometime stratified, there are three well marked divisions recognized. One which has been called the Laurentian, named from its typical locality in the highlands, north of the Great Lakes and the river St. Lawrence. These rocks are granites, mica-schists, hornblendic rocks of similar structure, and limestones passing into marbles. The second division has been called the Huronian, because of its occurring in the vicinity of Lake Huron. These consist largely of schists or rocks which tend to split into thin irregular layers; slates, which break more evenly, and quartzites, which may be defined as intensly hard crystalline sandstone. The third division has been found in several localities and is called Keweenian or Keweenawan, after Keweenaw Point on the south shore of Lake Superior, where it is typically developed. It consists of alternate layers of quartzite and volcanic rocks with deposits of copper.

Of these different formations we have in our State only those apparently corresponding to the second division, or Huronian. The coarse granite which forms Harney Peak and covers much of the vicinity, was considered by Dr. Hayden as corresponding to the Laurentian formation, and in this respect he seems to be followed by Crosby and Carpenter. At least, these others consider that the granite was deposited like the adjacent schists in fragmental condition, and afterwards, was most completely metamorphosed, or changed to a crystalline condition. That, however, this was eruptive and introduced later than the surrounding rocks seems evident from a careful study of its relation to them. Not only does it occur in vast lenticular masses, with their axes corresponding to the planes of the bedding of the schistose rocks, but also huge fissures cutting across the planes are filled with this same material. A fine example of this may be found a few miles west of Keystone, where the planes of schistose character coincide in dip on opposite sides of the dike, on the one side dipping sharply toward the dike, on the opposite side as sharply away from it. In this case it seems clear that the granite could not have been formed from a metamorphosed stratum deposited between the surrounding rocks. The failure of the theory at this point makes it doubtful in all other cases. Moreover an examination of the detached layers of schists which are found within the granite mass near the top of Harney Peak, referred to by Prof. Carpenter show signs of having bean floated to their present position by the molten granite, rather than of having been interstratified with it when in a fragmental condition. We therefore conclude, as before stated, that the granites of the Black Hills are not Laurentian, but eruptive rocks, formed later than the schists, and in this we agree with the majority of those who have studied the matter.

THE ARCHEAN ROCKS IN THE BLACK HILLS.

These differ markedly in color and general structure from those found in the eastern part of our State. As may be seen on the geological map, they occupy a central, or nucleal, area, and their exposure is somewhat to the east of the center of uplift. The extent of country occupied by them is about sixty miles long, north and south, and twenty-five miles in its greatest width east and west, with an area of abont 850 square miles. The area underlaid by the Archean schists and slates is particularly mountainous and rough, especially where it is mingled with granite outflows. Where these quartzite deposits are absent, erosion has removed the schists and slates which are softer, so as to form park-like valleys, to which we have already aluded. As Newton says:

"Viewed from a height, like Harney Peak, the area has a billowy appearance and a succession of ridges and peaks, with now and then a stretch or spot of open park. At first it reveals no system of structure, save that is cut from west to east by the draining streams, which have eroded deep and usually narrow valleys or canyons. Though the strike of the rocks is toward the north or northwest, at first appearance, they show no feature in the topography due to this fact, but a closer and more detail study reveals the presence of a continuous ridge, or series of ridges extending on the east side of the area from the southeast to the northwest, and, on a more minute inspection of the geology along the streams, these ridges are seen to have been divided by the presence of apparently hard strata, quartzites, etc., through which the several draining streams have cut their way in intricate and deep canyons. On the western side of the area, a similar belt of resistant rock is observed, through which many of the streams have cut narrow gorges. Between these ridges the country, except in the region of the Harney Peak granite, is less rugged, and not infrequently the banks of the streams widen out into valleys, broad and gently sloping." (Geology of the Black Hills of Dakota, (Newton), page 49.) He adds: "The metamorphic rocks of the Black Hills are separable into two distinct groups, whose lithological characters are marked and persistent. Their stratigraphy was carefully studied in the hope that it would be possible to definitely determine the historical relation between them, but the result was not satisfactory. A great difference in the character of the rocks are sufficient to warrant their separation into a *western series* or *group of schists* and an *eastern series* or *group* of *slates.* The line of separation between them can be only imperfectly indicated. Its trend, so far as can be ascertained, is little west of north. Starting just east of the granite range of Harney Peak, it curves westward, about the north end of the range, and then it leans toward the north-northwest, passing near the forks of Spring Creek, (the present site of Hill City) crossing Castle Creek in the west canyon and disappears beneath the Paleozoic rocks in the vicinity of Custer Peak. At the north of the Peak it reappears with a northerly course." "A distinct discordance of dip between the rocks representing the characters of these two groups was seen by Mr. Jenney in the west canyon of Castle Creek, but in the absence of corroborative observations the fact of the unconformity of the two series cannot be insisted upon." (Ib., p. 50.)

Prof. Carpenter, in 1888, said that the unconformity, supposed by Newton to exist, between the eastern slates and the western schists, is supported by an observation made by him upon Spring Creek, east of Hill City, (Geology and Mineral Resources of the Black Hills, 1888, (Carpenter) p. 17), but more recently he has come to the conclusion that the separation between the eastern and the western, or earlier or later, rocks of the Black Hills is of questionable existence.

Newton, in discussing the formations says: "The western series consists of *quartzose schists* and *garnetiferous*, *quartzose* and *ferruginous mica schists*, together with some gneiss, chloritic and talcose (or hydro-mica) schists, hornblendic schist and quartzite. The whole series is coarse in texture and highly crystalline and it contains many seams or veins of quartz, traversing the schists, conformable with the stratification and having usually a swelling or lenticular structure. These veins are *interlaminated* and are not often of great width. They contain finely disseminated gold and have probably afforded by their disintegration the larger portion of the gold found in the valleys and gulches. The granite masses are found wholly within the areas of the schistose rocks. The eastern series is composed of metamorphic rocks, distinguished from the western, mainly by their exceedingly fine and compact texture; though as shown by Mr. Caswell, their ultimate mineral composition is quite similar." (Mr. Caswell made a report upon the microscopic structure of the rocks of the Black Hills, collected by the same survey.) "The rocks are mainly micaceous clay slate, siliceous slate and quartzite, the last forms persistent strata from 50 to 200, and sometimes 500 feet in thickness, and can often be traced for long distances with little variation. The quartzite frequently contains seams or veins of interlaminated or ribbon quartz. Frequently, the quartz seams are highly feruginous and in places they have been found to contain undecomposed pyrites. Unquestionably they are often auriferous."

"The mica-schist is the prevailing mass characterizing the rock of the western series, and its variation in character is very considerable. More commonly it is the gray, tolerable fine, highly crystalline, uniform, micaceous and siliceous schist, which, from its large proportion of mica, weathers readily and uniformly. Very frequently, especially in the western part of the area, it is so highly charged with garnets that it acquires a dark, reddish color." (Geology of the Black Hills, (Newton), page 51).

'These garnets are sometimes found, collected abundantly in the streams. The mica schist changes sometimes into a hydro mica-schist presenting the usual soapy feeling and general character of the talcose schist. This being more coherent than the very micaceous rocks, more prominent in topography and forms harder and rougher ridges.' (Ib., p. 52).

"By a similar gradation the micaceous, pass through siliceous schists into tough quartzite. The quartzites are less developed in the western, than in the eastern series. They are among the most durable rocks and in the Black Hills generally stand in abrupt dike-like ridges, running with the stratification of the rocks. They commonly contain mica in small quantities, and have an interior structure, or relation, indicating an intrusive origin, and are of true metamorphic character. "Sometimes the mica-schist passes by almost imperceptible gradation into true chloritic schist, which is usually soft and easily decomposable, of a green color and no mica readily visible to the eye. Crystals of ripidolite may often be picked out with a knife, and it frequently contains garnets in abundance." (Geology of the Black Hills, p. 52).

"The quartzites vary in thickness from seams only a few inchs wide to masses 400 or 500 feet in width, though the more moderate thickness, 75 to 100 feet, is more common. * * The color of the quartzites is varied, being sometimes an almost pure white, but more often a light or dark gray, or impure blue, or pink, or, when much iron is contained, a dark and reddish brown. In texture they are very compact and homogeneous, and on a fresh fracture, which is conchoidal or fragmental, they have a vitreous or glassy luster. They are almost pure quartz."

"Though they are found throughout the series of slates, they are of greater thickness in certain parts of the district. There exists on the eastern border of the Archean area a long ridge or succession of prominent peaks and bluffs which cuts across all of the creeks north of Harney Peak, occasioning in each one an intricate, precipitous and exceedingly rough canyon. This ridge and these canyons are due to a series of quartzite strata." (Geol. Black Hills (Newton), p. 58.) "A prominent deposit, or accumulation of quartz, is found two or three miles east of Custer Peak, to which the name of Jasper Hill was given. It is irregular in shape, about 200 feet in height without any clearly defined structure. The siliceous material composing it display great variety in color and character. Among them are a deep, red jasper and grayish quartzite of a pure white mica or translucent quartz, which in places has a bright red crystalline iron oxide running through it like the dendrites (plant-like crystals) in moss-agate." "A banded structure is found also in the quartzites. Bands of iron ore, ferruginous strata of the inclosing rock, and seams of ferruginous quartz are found in the quartzites, and though the separation between the ordinary quartz and the ferruginous or iron-bearing portion is generally ill-defined, the latter are sometimes so well marked as to run like a true vein within the body of the quartzite itself." "In many cases the ferruginous quartzite lodges are probably due to the original dissemination in the quartzite of iron oxides, which in the process of weathering, are oxidized and hydrated to brown hematite. Sometimes, however, they may arise from decomposition of pyrites."

"The dip of the strata of the eastern series is always high, 70 to 90 degrees, and though it varies in amount and direction, it is usually toward the west. The general strike is about 30 degrees west and it swings now in one direction and now in another, ranging freely between the limits of northeast and northwest." (Ib., p. 60.)

"No fossils were found in the Archean rocks; and marble and serpentine, the metamorphic rocks most likely to yield them, were not seen."

Such are some of the most instructive statements which we glean from Newton's report.

Professor C. R. Van Hise, in 1890, "finds that the prominent structures of the Black Hills, which have heretofore been taken as bedding or strata, are secondary structures produced by pressure, and as evidence of this is the fact that alternate bands of sediments of different characters are seen to cut across the prominent lamination of the rock. Sometimes these bands contain pebbles which are clearly deformed by pressure. This fact had been previously observed by Prof. Carpenter. (Geol. and Min. Res. of the Black Hills (1888), p. 22.) The longer axis of the pebbles is parallel to the slaty or schistose structures; but the belt as a whole cuts across this structure." He calls attention to the fact that the dip of the schists and slates is away from the granite area and indicates that their lamination is due to pressure attending the eruption of the granite masses in the south and of the porphyries further north. A study of the boundary between the slate and schist series, noted by Newton, leads to the conclusion that there is a graduation from the slates to the schists rather than an abrupt change. He considers that the schists and slates cannot be divided into two series. He finds also that the slates and schists are most perfectly crystalline near the granite areas and near the areas of eruptive rocks at the north end of the Hills; while more remote from these points they show more distinctly a sedimentary character. (Archean & Algonkian, 1892 (Van Hise), p. 259.) These conclusions of Van Hise seem to the writer in harmony with the facts, particularly in the vicinity of Harney Peak, where in passing from Hill City to Keystone, the variation in dip from west around through north to east was very evident. Van Hise also calls attention to the fact that the repetition of similar quartzite ridges probably indicates a folding of strata so that the thickness of the Archean instead of being 100,000 feet, as supposed by Newton, and also by Carpenter, may be indefinitely diminished.

All previous writers have failed to find traces of marble and serpentine; although Carpenter called attention to pebbles of limestone or marble in the Cambrian. (Geol. and Min. Res., Black Hills (Carpenter), p. 29 and 23.) Recently a specimen of dark gray marble, banded with lighter colors, was shown me by Mr. Lewis of Rapid City; and he informed me that a bed of it, more than twenty feet in thickness had been discovered in the slates at a point which he declined to reveal. And others informed me that recently boulders of a similar rock had been found near Rapid City. I find also that Carpenter, since the writing of the first part of his report has found calcareous rocks on Box Elder creek. (Geol. and Min. Res., Black Hills, p. 123.)

THE AGE OF THE BLACK HILLS ARCHEAN ROCKS.

The Black Hills Archean rocks exhibit a remarkable lithological resemblance to certain rocks of the iron-bearing series of the Lake Superior region, which in the past have been included under the term of Huronian; although Prof. Van Hise has, in harmony with the recent decision of the United States Geological Survey, applied to all these rocks the term "Algonkian." He considers that the tracing of this analogy, as was done by Newton, is with good reason, although Crosby, (Proc. Boston Soc. Nat. His., Vol. XXIII, p. 497), and Carpenter, (Geol. and Min. Res., Black Hills, p. 24,) have offered reasons why they should be classed with the Taconic and Blake places portions of them with the Coos group. The latter, however, rests mainly upon the presence of staurolite and, as Van Hise remarks, is little more than a guess. The division of the rocks into earlier and later members is virtually disproved and the whole may be considered as one formation, which was probably deposited as fine sediments derived from older areas further west. This formation was metamorphosed and rendered highly laminated when elevated into its present position, as the prominence of quartz and feldspar would indicate. The resemblance between the Archean rocks of the Black Hills and those of the Lake Superior region, known as Animikie, Penokee and Marquette series, Van Hise gives substantially as follows: Both have mica schists and mica slates of great thickness; both are certainly of fragmental origin and contain staurolite and garnets in certain cases. The thick beds of nearly pure quartzite and quartzose conglomerates, which occur in the Black Hills correspond to the quartzites and conglomerates in the Penokee and Marquette areas. Much of the iron-bearing formations of the Lake Superior region have been shown not to be mechanical sediments but rather chemical or organic sediments which by subsequent alteration have been changed into the various forms now found. Beds similar to these are found in the Black Hills. In the Lake Superior region beds of important iron ore are known to belong to this formation. Such have not yet been found in the Hills. In the Lake Superior region are vast quantities of eruptive rocks, which occur in dikes and intrusive beds in the fragmental series. Similar rocks in similar relative positions are found in the Hills. The chief lithological difference between the two regions is the presence in the Hills of large masses of granite. The only parallel to those in the Lake Superior iron-bearing series is found in one or two unimportant dikes. There is, therefore, a striking analogy, but to admit a closer correlation seems useless as long as geologists are not agreed as to the correlation of different portions of the Lake Superior region itself. Bulletin G. S. A., Vol. 1, p. 241.

THE ORIGIN AND AGE OF THE GRANITE.

This conspicuous deposit has been studied and remarked upon by several eminent students. Crosby and Carpenter argue that the granite is of metamorphic character, having at one time been of fragmental strata. Their reasons are mainly drawn from the relation of the granite rocks in Canada to the Huronian; and from the alteration of granite with the mica-schists in the Black Hills and the lenticular form of the granite masses. Crosby claims to have found fragments of the granite in the schists indicating the earlier existance of the former. Newton, on the contrary, early noted distinct signs of its eruptive origin, as for example, the existence of irregular fragments of schists, some small and others of immense size, imbedded in the granite as though the latter had been floated into position by the former. Prof. Van Hise in studying the matter comes to the same conclusion. We have already referred to the occurrence of granite in dikes transverse to the lemination of the schists. From the present evidence, therefore, there seems little doubt that the granite is an eruptive rock.

If the granite is of eruptive origin, it must be later than the deposition of the schists and slates. How much later, becomes an interesting question. That it was before the deposition of the Potsdam sandstone seems to have been proved by the following facts: Newton found on French Creek, as he states, "A continuous sheet of the Potsdam pass from the surface of the eroded schists to the surface of granite. There was found no intrusion of granite along the parting between the Potsdam and the schists and there was found no metamorphism of the Potsdam at the surface of contact with the granite. In these particulars the relation of the granite is strongly contrasted with those of the trachyte of the Hills. Wherever the trachyte appears beneath the Potsdam the later is uplifted as though by the insertion of the trachyte between it and the Archean. Its lowest beds are at the same time metamorphosed as though by the heat of the molten intrusion. The fact that the granite did not at this locality affect the form and constitution of the Potsdam strata in a manner similar to the trachyte does not well accord with the idea that it was introduced under similar conditions and during the same geological period." (Geology of the Black Hills (Newton), p. 78). He also discovered fragments of feldspar which apparently come from the granite in the lower portion of the Potsdam sandstone.

Prof. Headden observed similar phenomena in the vicinity of Hayward on Battle Creek. He says further, that there can be no question that the Potsdam is unconformable to the schists and that it rests upon the granite. He found also in the Potsdam conglomerate above Hayward besides quartz, mica and feldspar, abundant crystals of tourmaline. Since no crystals of this mineral, except of minute size, have been found anywhere but in the granite, this is additional proof that the granite has furnished material for the lower Potsdam. Therefore, the granite must have been thrown up before the deposition of the Potsdam or Cambrian.

THE FORMATION OF THE SCHISTS AND SLATES.

We have already noted the fact that the schists and slates, and also quartzites, are of fragmental origin. They were first deposited as shales, sandstones or beds of sand in the primary ocean. The source of the material has not yet been satisfactorily determined. Probably from areas which have been since buried by later formations. After their deposition they were upheaved and probably folded by the force acting upon the earth's crust, which doubtless forced upward the mass of granite in a molten or semi-fluid condition, which found its way through fissures and between the layers of the overlying clays and sandstones. By the heat and pressure which was generated, these rocks were changed from their from their original condition to their present form. By partial solution and chemical action, they were changed to a crystalline state; while the intense pressure acted mechanically upon their constituent grains and produced lamination of the schists and slates with a distortion of the boulders and pebbles, as has been noted in the quartzites of several localities.

The internal structure of these rocks has recently been very successfully studied by Prof. Van Hise. By a microscopic study of specimens he has learned some very instructive facts. To the unaided eye the boulders and the conglomerate quartzites, observed along the Box Elder Creek, first by Crosby and Carpenter, show remarkable distortion, being elongated vertically, as though pressed by great force from two lateral directions. In some cases the pebbles and boulders have been distorted until their lengths are three times their breadths. Crosby considers this distortion to have taken place by the slipping of individual grains of quartz upon another. But Van Hise has found that the individual grains are themselves elongated, having been subject to minute fracture and then recemented by the deposition of quartz from solution. These features have been shown in a most satisfactory way by his study. In the case of schists there has not only been pressure but a shearing stress which has ground and pressed the minute fragments, rendering them more or less easily cleavable, perpendicular to the direction of the compressing force. It is, therefore, generally agreed that the metamorphosis of the crystalline schists, probably occurred in the southern portion of the Hills at the time of the outflow of the granite, which probably took place simultaneously with one of the elevations of the Hills; and that a similar change took place in the north end of the Hills, either at the same time, attending the irruption of the masses of granite, which are not well exposed in that region, or else subsequently at the time of the outflows of trachyte and rhyolite. The deposits of ore and other points of economic value we will speak of in a subsequent chapter.

THE SIOUX QUARTZITE.

The Sioux quartzite occurs in the eastern end of the State and is a portion of the peninsular area of rocks, extending from the vicinity of Redstone, Minn., west-southwest into Dakota. Areas of similar quartzites occur further east in the ridges about Baraboo, Wis., and along the west side of Chippeway Valley, Wis. This formation is very different from those already described, consisting almost entirely of an intensely hard and compact quartzite with no trace of lamination. It occurs in strata nearly horizontal and is cut into blocks by vertical joints, from six inches to several feet apart, and crossing one another nearly at right angles. This causes the cliffs of this formation to resemble walls of masonry and not infrequently the upper surface reminds one strongly of a pavement. The occurence of it in cliffs from fifty to sixty feet in height may be well seen at Palisade and Dell Rapids. The occurrence of it, in broad and apparently level areas, is well shown about Sioux Falls, north of Alexandria and at Rockport, on the James river.

In color it varies from a light gray or nearly white, through shades of pink to a dark purple and, in some cases, a dark Indian red. The prevalent colors are the light pink and the light purple. In some localities, beds of it are beautifully variegated, the ripple-marks of the original stone being brought out beautifully by alternate layers of light and dark pink not more than $\frac{1}{8}$ or $\frac{1}{4}$ inch in thickness, producing parallel and wavy lines over the surface, reminding one of an agate on a large scale. In hardness, it varies from a rock harder than steel, which breaks with a splintery fracture, (its usual character), to beds scarcely consolidated,

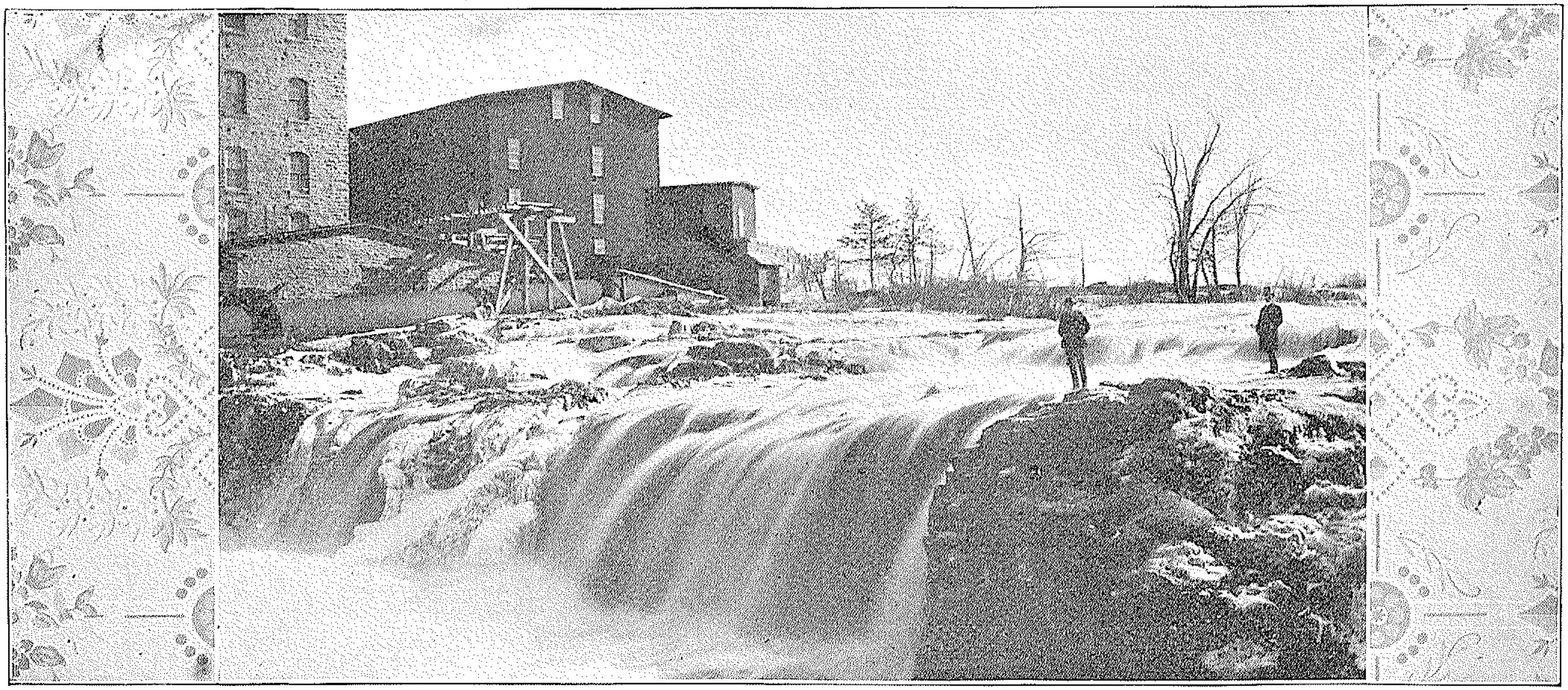


PLATE II.—PRINCIPAL FALL OF THE BIG SIOUX RIVER OVER THE SIOUX QUARTZITE AT SIOUX FALLS.

which may be easily excavated with a spade or pick. A microscopic study by Prof. Irving and Van Hise has brought to light a very instructive fact, viz.: that this consolidation has been produced by the enlargement of the grains of the original sandstone by the deposition of silica from solution, along the planes corresponding with the crystalline axes of the original grains themselves. In cases where the beds are imperfectly consolidated, these crystals, though formed, have not grown sufficiently to fill the space between, while in the compact quartzite the spaces between the original grains have been completely filled with silica or quartz, so that the present rock is nearly solid quartz. Fracture is apt to break through the original grains as readily as between them. This is particularly striking where the quartzite is conglomerate, that is. containing large pebbles of quartz, of different color from the main mass of the rock.

THE EXTENT OF THE QUARTZITE.

It is almost everywhere deeply covered with a deposit of boulder clay of comparatively recent origin, but from a few exposures which are found along the valleys of streams and in wells, the outline of the quartzite has been laid down as represented upon the map. It extends along the east line of the State from near Flandreau to a little south of the northwest corner of Iowa. Its western-most exposure is on Enemy Creek, South of Mitchell, about two miles above its mouth. In its triangular area between these points the drift is probably underlaid, generally, by the quartzite. The margin, however, is doubtless quite irregular, somewhat like the margin of a peninsula, with inlets, promotories and bays, which have been filled by rocks of the Cretaceous age.

The dip of the rocks is slight and quite irregular; no clear trace of folds has been made out. There seems to be no prevalent trend to the dip. The thickness of the formation has not been determined. Irving, from the studies of Mr. Merriam, estimated that in the eastern portion of Minnehaha county some 3,000 feet of it are exposed along the Split Rock creek, about Palisade. From our study, so great a thickness seems doubtful, and we should consider 1,500 feet a generous estimate. The dip, so far as observed, nowhere reaches 10 degrees and its average may be placed at less than 5 degrees. A list of localities where it is exposed will be found in the chapter on Economic Geology. The dip seems to be that of the original deposition rather than of flexures of the earth's crust. The other rocks associated with the quartzite are the pipestone and an eruptive diabase. The former has been longest known at Pipestone, Minn., where it occurs in a thin layer about 18 inches in thickness, lying between and conformable with the quartzite. Mr. Upham, of the Minnesota Geological Survey, in the Thirteenth Annual Report, reports the occurrence of a similar Pipestone near Palisade, S. D. He says:

"The quartzite in this vicinity embraces two layers, each several feet in thickness, of compact, fine grained, red rock, easily cut and polished, closely resembling the Catlinite of the Pipestone quarry in Minnesota. The upper one of these layers is seen a quarter of a mile from the mill on the northwest side of the creek, where it has been quarried and is called slate. Its vertical exposure in the quarry is 7 feet, and its base, though probably not much deeper, is not seen. It lies in sheets from ⅛ of an inch to 6 inches in thickness, dipping about 2 degrees, south 30 degrees west. The lower one of the chalk layers is called Pipestone and is scarcely inferior in quality to that of the noted Indian quarry at Pipestone, Minnesota. This bed is exposed about five rods east of the dam, and some thirty rods east of the mill, where it is seen to have a thickness of at least 4 feet—it may be as much as 7 feet thick; divided into sheets from a half inch to 3 or 4 inches thick. It dips 6 or 7 degrees, south 60 degrees west." (Thirteenth Annual Report Minnesota Survey, 1884, p. 94.) He also says that "twenty rods east of the dam, at the Palisades, and about 20 or 25 feet above this dam is a deposit of so-called "chalk-rock," which has a vertical thickness of 4 feet and dipping the same as the quartzite. The upper part of the bed is soft, being scarcely harder than many shale beds, is white above, being pink and harder below. By chemical analysis it has been found to correspond closely with the pipestone in composition."

He reports still another exposure twelve miles northwest of Sioux Falls. (Thirteenth Annual Report, Minnesota Survey, 1894, p. 91.) The Pipestone or Catlinite, as it has been called, is now considered to be metamorphosed clay.

An exposure of a similar formation has been found about two miles southwest of Bridgewater on Wolf creek, where it was readily used for marking, like chalk.

Eruptive rocks forming dikes have been found in the quartzites southwest of Palisades, Sections 15 and 22, Township 102, 48. This locality was found by me in 1885, and the rock examined by Prof. C. W. Hall of Minnesota University. Prof. Hobbs, of Wisconsin University, published a description in 1892. (Trans. Wis. Acad. Sci., Vol. VIII., p. 206.)

The granites near Big Stone Lake, which are barely exposed in our State, are thus described by the Minnesota geologists:

"They are generally gneissic instead of massive. They are more frequently true granite. They are always red. While their laminated structure renders them more easily wrought, and thus gives them an advantage over the firmer syenites of the Mississippi Valley, it also renders them softer and more destructible under the action of weather. They seem to have less quartz and more of the cleavable minerals, feldspar and mica. Still there are exceptions to the gneissoid structure of the Mississippi Valley granites." (Minn. Geol. Rep., Vol. 1, p. 146).

These rocks are probably the oldest in our State.

CHAPTER V.

THE PALEOZOIC FORMATIONS.

Following the deposition of the schists and slates, was a period of disturbance and erosion of indefinite length. As has already been indicated, the Potsdam formation lies upon the upturned edges of the schists. Of the different Paleozonic ages we find deposits only of the Cambrian, Silurian and Carboniferous, with a slight representation, possibly, of the Devonian. All these are found only in the Black Hills, and lie conformable to one another, and with gentle regular dip away from the Archean core of the Hills.

THE CAMBRIAN.

The Cambrian is represented by a full development of the Potsdam sandstone. This formation was first recognized from fossils collected and observations made by Dr. Hayden during Warren's reconnaissance of the Hills. The formation is very fossiliferous, containing the characteristic genera of the Potsdam, found in the east, *Lingula*, *Lingulepis*, *Obolella*, *Hyoletis*, with trilobites, fucoids, etc. The Potsdam has been found in many places along the flanks of the Rocky Mountains, but in no other locality has it been found so abundantly fossiliferous as in the area of the Black Hills. This formation is the lowest member of the fossiliferous series of rocks, and in its numerous exposures its character and relation are easily determined and studied. It consists mainly of coarse and friable sandstone, conglomerates and shaly sandstones. The ease with which the formation is eroded has caused it to be removed, except where protected by a harder and laterformation. It, therefore, is exposed mainly in a belt of cliffs or bluffs overlooking the Archean area of the Hills, on all sides, like a wall. Through this, the various streams have cut canyons whose sides are mainly formed of Carboniferous rocks, with Potsdam at their bases, resting upon the Archean. Occasionally near the cliffs the fossiliferous rocks are merely isolated beds of Carboniferous limestone with the underlying Potsdam, which have been left by denudation in the midst of the Archean; but on account of the friable and easily eroded character the Potsdam, out-liers of that formation alone are not very frequent. In the northern parts of the Hills, however, in the region northeast of Custer Peak, large areas of the Potsdam are exposed. Around Crow Peak, where the strata have been upturned by the extrusion of the trachyte which composed the mass of the peak, the Potsdam stands nearly vertical against the volcanic rock and has been transformed into a hard, white quartzite. At other points, also, the Potsdam has been similarly upturned and metamorphosed by the eruption of volcanic rocks. (Geology Black Hills, p. 83).

Upon the geological map a narrow band along the interior of the Paleozoic area may be considered as representing the Potsdam. Near Terry Peak there is considerable surface covered with it.

The formation ranges in thickness from 200 to 250 feet, but is said to attain 300 feet on the north branch of Red Water Creek. The formation distinctly thins out toward the center of the Hills. Dr. Carpenter reports an exposure of only 50 feet near Harney Peak. Its thickness corresponds well with the conception of its being formed around the Archean island, which was barely covered. The basal conglomerate varies in character and thickness in different parts of the Hills, sometimes within short distances, but is everywhere a well-worn shore deposit. The pebbles and boulders, forming the conglomerates, were examined by Newton with minute care and were found in all cases to consist of a harder variety of rocks composing the metamorphic series, quartz, hard, blue and gray quartzites, and some of the harder slates and schists. The latter usually occur as flattened pebbles similar to those found in the present streams. There are deposits containing a few felspathic pebbles and in some places crystals of tourmaline from the granite. In the upper portion of the main conglomerate and in occasional fine conglomerate, occurring in the body of the formation, the constituent pebbles are almost entirely of quartz. Sometimes the boulders or cobble stones forming conglomerates are from 1 to 4 feet in diameter. One of the best exposures of this character was noted by Newton in the canyon of Lower Rapid Creek. A similar heavy conglomerate formation is found in many other parts of the Hills. In some places the conglomerate is found above the base of the formation, in which cases the pebbles seem to have been formed from previously existing portions of the sandstone. A good exemple of this is reported by Newton, near the eastern base of Terry Peak. Prof. Carpenter made an interesting discovery that many of the pebbles in certain layers of the conglomerates were of crystalline limestone. At the time of his report he had not discovered the source, but they correspond well in color and structure to the gray marble, to which reference has been made as found in the Archean.

The cementing material of the conglomerate is generally silica and is reinforced, often with oxide of iron. The calcareous cement, sometimes occuring often contains the remains of fossils and grains of green-sand or glauconite. Some of the coarser conglomerates are sometimes scarcely cemented at all.

The Potsdam sandstone of the Hills might be described, with almost the same words that have been employed by different observers in describing the Potsdam of the eastern part of the United States. Its color is usually rusty or dark brown, although above, it may be in places nearly white. It sometimes contains small scales of mica, and grains of harder metamorphic rocks, but it generally consists wholly of quartz grains. These vary from the minutest size to that of a pin head or small grain of rice. In texture it varies from an almost incoherent mass of sand, easily crumbling on exposure to the weather, to a dense compact sandstone which forms durable cliffs. Sometimes it passes into a quartzite of siliceous grains embedded in a bright glassy, siliceous cement. The most friable kinds are light in color and usually have a ferruginous cement, while the red or brown, in which the cementing material largely exceed the iron, are usually more compact and durable. In many places the sandstone is somewhat argillaceous, and in others, of shaly character, usually with a darker color.

Though the sandstones are coarse in texture they carry in many places abundant fossil remains in an excellent state of preservation. Complete sections of the formation from base to summit are rarely met with, because of the concealment of the slope by broken fragments from the Carboniferous beds from above, as well as by those formed from its own incoherent layers. The following section from the canyon of Spring Creek is given as a representative one from measurements made by Prof. Jenney. Geol. of Black Hills, p. 88.

CARBONIFEROUS—

5. Limestone with *Spirifera*, *Productus*, etc.,............335 feet
4. Reddish brown or pinkish calcareous sandstone, thinly bedded, containing *Spirifera camerata*. *Cyathopylloid* corals and crinoid stems .... 20 feet

POTSDAM—

3. Reddish-brown sandstones, thinly bedded at base, and alternating with soft yellow sandstones, containing large fucoids, *Lingulepis* and fragments of trilobites.200 feet
2. Brownish yellow conglomerate, with quartz pebbles, resting uncomformably on the next, and dipping 25 degrees northeast............................. 25 feet

ARCHEAN—

Argillaceous slates, dipping 60 degrees west.

Another section is given by Newton from lower Rapid Creek. (Geol. Black Hills, p. 94.)

CARBONIFEROUS—

10. Gray limestone stained at base with iron .... 80 feet
9. Pinkish and yellowish limestone, thin bedded, containing a few Carboniferous corals and brachiopod fragments.................................... 33 feet
8. Pink and yellowish limestone, gray at top .... 40 feet

POTSDAM—

7. Red and yellow sandstone with bright quartz grains, cross-stratified and containing at base considerable
6. Reddish calcareous sandstone, with glauconite....... 4 feet
calcareous matter................................ 70 feet
5. Red and pink impure shaly limestone with green glauconite grains, sandy at bottom .... 50 feet
4. Red and brown shale with some thin strata of limestone and large quantities of glauconite................. 80 feet
3. Impure shaly limestone with some clay shaly, yellowish and reddish................................. 20 feet
2. Massive yellow and reddish sandstone, highly calcareous, dipping northeast 20 degrees................. 50 feet

ARCHEAN—

1. Argillaceous slates in the bed of the creek; strike north 15 degrees west; dip vertical.

Another section upon Slate Creek above its junction with Castle Creek was observed by Prof. Jenney.

CARBONIFEROUS—

8. White, pinkish and grayish and siliceous limestone with *Spirifera camerata*, Productus, etc.............100 feet
7. White compact limestone, containing some fossils....100 feet
6. Unexposed slope...................................250 feet

POTSDAM—

5. Soft brown sandstone, containing abundant fossils, *Lingulepis*, *Obolella*, trilobite fragments .... 50 feet
4. Coarse ground brownish yellow sandstone with small quartz pebbles merging into bed 3................. 50 feet
3. Conglomerate of quartz, bowlders and pebbles, cemented by sand and oxide of iron with some lime.... 55 feet
2. Unexposed slope .... 35 feet

ARCHEAN—

1. Chloritic, talcose and mica schists; dip 55 degrees west; strike north to northwest..............................

The sandstones are often riddled with small holes, perpendicular to the bedding, 1 to 3 or more inches in length, and about one-eight of an inch in diameter, often with rounded termination. These are special characteristics of the white sandstone and occur more frequently in the upper beds of the formation. These were supposed formerly to be the casts of seaweed stems, but it is now generally considered that they are worm burrows; while some consider them the casts of fleshy peduncles of certain brachiopods like *Lingula*. Their real nature is still an open question. They are known as *Scolithslinearis*, and others apply the general name *Arenicolites*. Fossils are sufficiently well preserved to be clearly recognized; though they do not occur except in a few localities and in particular layers. According to Newton near the headwaters of Red Canyon Creek in the northwestern corner of the Hills the Potsdam, with its usual soft sandstone character, is underlaid by a bed of quartzite which rests upon the upturned mica-schists. This quartzite consists of small grains. The color is deep brownish or purplish red, slightly tinted with green. The entire mass is filled with fossil remains, *Lingula*, *Lingulepis*, *Obolella*, etc., in a beautiful state of preservation, yielding the best collection of fossils obtained from the Potsdam in the Hills.

Another interesting class of fossils, quite abundant in the layers of the Potsdam, are the casts of fucoids. Commonly they are of ordinary size, and a few inches in length. But Newton reports a discovery of strata on Spring creek with casts of a fucoid, named *Paleophycus occidentalis* in the shaly argillaceous sandstone, some of the specimens of which are five or six feet in length. The main stem is nearly an inch in diameter and divides into numerous branches $\frac{3}{8}$ of an inch through. The stems usually divide into threes or twos and the smaller branches frequently terminate abruptly in rounded ends.

The Potsdam contains layers of quartzite, not only at the base and in the vicinity of igneous rocks, but at irregular intervals and different localities, in a way that is difficult to explain. Not only in the locality of Red Canyon creek, but about the headwaters of Amphibious and Beaver creeks, and on the same creek near the beginning of the limestone canyon; but also on Burnt-Wood creek, on French creek and near the Battle creek. Quartzites are found at the base of the Potsdam, where it lies in contact with the Archean. In some cases it attains a thickness of about fifty feet. This position of the quartzite has been observed elsewhere in the Rocky mountains and the Wasatch mountains. The quartzites found in the body of the formation piffer somewhat in their character from those just described. They are, according to Newton, best observed and studied on Box Elder creek. There they occur as deep red or purplish layers, interstratified with coarse red sandstone. Intercalated quartzite strata are also seen on French creek, where the color is yellowish-brown. They differ from the quartzites of the slates and schists of the Archean in consisting of smaller grains. In some cases the quartzites weather into a coarse sandstone which readily crumbles, the siliceous cement having been removed.

This unusual hardening of the sandstone can hardly be referred to ordinary causes or conditions of metamorphism, but rather to the local abundance and deposition of soluable silica. Such is known to be derived from certain organic substances of diatoms, sponges, etc. (Geol. Black Hills, pp. 89–92.)

A peculiar feature of the Potsdam, which has already been mentioned, is the abundance, in certain layers, of glauconite.

"These grains are rarely over a tenth of an inch in their larger diameter and the majority are not more than one-half that size. They are usually flattened and appears as flat flakes of irregular shape and are usually smooth and rounded as though water-worn. Their color is a dark olive green, sometimes nearly black. They are only slightly acted upon by strong hydrochloric acid. Before a blowpipe they resemble perfectly the greensand grain of the Cretaceous in New Jersey." (Geol. Black Hills, p. 95.)

Glauconite or greensand is a hydro-silicate of protoxide of iron and potash, with a variable amount of alumina.

A word concerning the general characters of the life of this first Paleozoic formation will be of interest to the general reader. There were as yet no form of vertebrate life nor of land plants. The formations most abundant were such as are now found near the surface of the sea and along the shores in shallow water. The particular types, however, were very unlike those of the present in species and even in genera. The larger forms were trilobites, which were but a few inches in length, and might be described as broad, flat, worm-like animals, adapted for creeping in mud or swimming in still water. The *Scolithus* burrows were probably formed by worms buried most of the time in the sand, somewhat like the *Arenicola*, or lobworm, of our present seashore. There were shells resembling the smaller sea-snails of the present time, and a few like the smaller clams, but the most abundant shells were those of brachiopods, which are not abundant at the present time and may be described as burrowing worms, having their heads protected by small helmet-like shells. These shells are bivalved, and are often mistaken by common observers for the bivalved shells of clams.

THE SILURIAN.

Newton in his study of the Hills discovered formations belonging to only two of the ages of Paleozoic time. Those already described he recognized as Potsdam or Cambrian, the rest he classified as Carboniferous, and makes no note of finding fossils representing the two intervening ages, the Silurian and Devonian. Dr. Carpenter in his report also speaks of but two, the Cambrian and Carboniferous, but adds in the foot-note that he has received, since writing the body of his work, certain fossils from

Prof. A. T. Free, of Deadwood, belonging to the Silurian. (Geol. and Min. Res., Black Hills, 1888, p. 34, foot-note.) Since the publication of Prof. Carpenter's report, he has visited the Deadwood locality and in the improvements going on at that point, a fine exposure has been made of the formations intervening between the top of the Potsdam and the bottom of the limestone beds containing Carboniferous fossils. He visited the locality with me where we found abundant fossils in a bluff colored limestone, 25 or 30 feet in thickness. It is argillaceous above, becoming quite sandy below. He informed me also that numerous fossils had been forwarded to the United States Geological Survey and theat several of them had been identified, as belonging to the Silurian; but I am not aware that the existence of the Silurian formation in the Black Hills, or even in the Rocky Mountains has yet been distinctly published. The knowledge of this formation began in 1888.

Between this limestone foration, which is presumably the Trenton, and the top of the Potsdam, there is found a layer of greenish laminated clay, without coarse material and without fossils. The fossils found in this limestone consist of a large species of *Orthoceras* or *Ormoceras, Maclurea*, *Halysites*, *Columnaria(?)*, *Stromatopora* and *Tetradium*. The stone is thick-bedded, and reminds one of the buff limestone found in southern Wisconsin. So far as yet known, no other exposure of this Silurian formation has been found in the Hills, yet a Cyathophylloid coral and fragments of other fossils, resembling those of the Trenton formation, were noted on the headwaters of Beaver or Amphibious Creek. This limestone may possibly represent the three prominent limestone formations of the Silurian and Devonian, corresponding to the cliff limestone found in the eastern portion of the Mississippi valley, in Ohio.

THE DEVONIAN.

Between the well defined top of the Trenton and the base of the lower Carboniferous limestone, there is found, in the Deadwood section, twenty or twenty-five feet of lead colored and laminated clay or shale without fossils. This represents the Devonian, if any formation of that age exists in that section. At other points also, between the Potsdam and the Carboniferous, has been noted this clay bed. Prof. Crosby suggests that this clay may be deep sea deposits corresponding to the deep sea siz reported from the Challenger expedition. (Proceedings of Bost. Sve. Nat. Hist., Vol. XXIII, p. 505.) He calls attention to the very slow accumulation of deposits in the deep sea areas as brought by the dredging of the Challenger. Referring to the bringing up of huge shark's teeth from the bottom of the Pacific ocean, resembling closely those of the species which existed in early Tertiary times, he infers that the rate of increase of the sediments has probably been less than one foot, and possibly not more than two or three inches, in a million of years. Thus he follows out the suggestion, made by Mr. Murray of the Challenger expedition. He suggests that, while the tens of thousands of feet of Devonian and Silurian rocks were accumulating in the Appalachian region and also in the western portion of the United States, the Black Hills were so remote from land that only a few feet of clays had accumulated there. Prof. Carpenter quotes this suggestion with approval. The discovery of the Silurian limestone will shorten the time represented by the clays very considerably; but it is still difficult to understand how this point should be so remote from land. As no trace of Paleozoic rocks have been found in the eastern portion of our State, but on the contrary signs of a surface long exposed to erosion, we are driven to the conclusion that the shore line of the ancient Silurian and Devonian seas must have been less than 300 miles from the Black Hills and probably within half that distance. Hence, the conception that the absence of deposition was mainly due to the remoteness from land seems untenable. The Devonian formations in the west are usually thin and of a soft and easily disintegrated material.

THE CARBONIFEROUS ROCKS.

These are commonly divided into a Lower or Sub-Carboniferous and an Upper Carboniferous, to which by some a third transitional period is added, the Permian. This, as the name implies, (coal-bearing) is the formation in which the vast coal beds of Europe and eastern America are found. But west of the meridian of Omaha, in the United States, it is usually without important carbonaceous deposits. Prof. Newton, from his study of the Black Hills, reports himself unable to affirm or deny the presence either of the Sub-Carboniferous or of the Permian. The rock series is definitely and constantly divided into several members, but the lowest and the highest of these members alike failed to afford him distinctive fossils. The local sub-divisions he recognized as four in number, which are distinguished purely by lithological characters. (Geol. Black Hills, p. 108.) This is his general section of the Carboniferous, arranged stratigraphically:

THE ALTERNATING SERIES—

5. A variegated sandstone, irregular, stained, reddish, yellowish and white, somewhat argillaceous and calcareous and exhibiting little stratification, weathering in peculiarly twisted, contorted (curly) bands .... 100-150 feet
4. No 5 passes below into a series of alternating beds of pink and light colored sandstones and limestones, somewhat argillaceous. The limestone, apparently somewhat magnesian and poor in fossils .... 150–200 feet

SILICIOUS LIMESTONE—

3. Weathering usually in a peculiarly brecciated manner, somewhat cavernous and often stained with pinkish and reddish streaks, containing much flinty and siliceous matter, often with a banded structure; with crystals of calcite, lining the interior of weathered caves and crevices. Fossils are found, but usually ill preserved, and only exposed and obtainable when the rock is much weathered. There have been recognized *Athyris subtilita, Spirifera Rocky-Montana, Productus,* corals, etc .... 150–175 feet

GRAY LIMESTONE—

2. Massive gray or whitish limestone uniformly pure, containing *Spirifera Rocky-Montana, Productus,* etc .... 150–200 feet

SHALY LIMESTONE—

1. Thinly bedded, impure arenaceous limestone, pinkish in color, often filled with comminuted fragments of crinoidal columns, and contains also *Productus, Cyathophylloid,* corals, etc........... 20–60 feet

It will be seen from this that the prevalent rock here, as in other portions of the west, is limestone. The sandstone or upper division seems to have been first observed by Prof. Winchell, and was named by him "Minne-Lusa Sandstone."

Everywhere the Carboniferous is conformable or parallel with the Silurian and Cambrian. This indicates that the deposition of sediments during Paleonzoic times went on continuously and quietly without any marked disturbance of the region. The Carboniferous rocks, over much of the central portion of the Black Hills, lie nearly hortizontal and pass from the high table lands in the Hills to the plain outside with an abrupt monoclinal fold. The formation of this fold is of later date. The slope of the higher level of the Hills was probably at first nearly continuous with that of the deeply covered beds around the Hills; and according to Newton they were uplifted bodily, in a comparatively short time, subsequent to the Cretaceous. (Geol., Black Hills, p. 222.) But Prof. Carpenter has pointed out that the formations of the Potsdam and the Cretaceous are thinner toward the center of the Hills. Such facts indicate that the uplifts were gradual and the later one perhaps began in the latter part of Carboniferous time. (Geol. and Min. Res., Black Hills, p. 27.)

A DETAILED DESCRIPTION OF THE CARBONIFEROUS ROCKS.

The lowest member of the Carboniferous weathers easily and is not generally well exposed, though separation between it and the heavy limestone above, is quite distinct where observable. It has a pinkish or grayish color, is never a pure limestone, commonly has an argillaceous or clayey appearance. Its strata rarely exceed 8 or 10 inches in thickness and are often so thinly bedded as to resemble calcareous shale. Though it contains many fossils, they are not sufficiently well preserved for identification. *Zaphrentis*, *Spirifera* and *Productus* are recognized. Geol. Black Hills, p. 109.) This basal member is found at various places along the eastern margin of the plateau, where it is distinguished by great quantities of fragments of crinoid stems.

"The second member, a massive gray limestone, and the third a silicious limestone are the most persistent features of the formation in the Hills. They were well seen in nearly all parts of the country visited. Along the eastern edge of the western plateau, however, there are considerable areas over which the silicious limestone and part of the gray have disappeared by denudation; and for this reason one who enters the Hills from the west obtains an inadequate idea of the true prominence of the Carboniferous formation. Complete sections of the Carboniferous are found only in the canyons cut by the streams as they pass from the hills to the plains, and even there it is not always possible to study them closely in detail." (Geol. Black Hills, p. 110.)

The gray limestone is well exposed in every examined section of the Carboniferous rocks. It is very uniform, its fossils are numerous and not easily separable from the rock, except where it has been so greatly weathered as to destroy their surface markings. The few species observed appear to be equally characteristic of the overlying silicious limestone. (Geol. Black Hills, p. 110.)

The third member, or the silicious limestone, "is a hard, white or grayish, gritty rock, which from the oxidation of its iron and perhaps also of percolation from the overlying rock, is generally stained, irregularly red or pinkish. It contains much silicious matter, concentrated in spots, either as flint, or as crystallie quartz, lining small cavaties or in concretionary or agate like deposits. From its silicious and uneven composition it decomposes very irregularly, often having a brecciated appearance and weathering with cavities or crevices, and even with caverns of considerable extent. The cavities are usually lined with crystals of calcite.

The most abundant fossils in the two limestones are *Spirifera Rocky-Montana*, *Athyris subtilita*, *Produtus*, *Euomphatus* and *Streptorhyncus*.

"Immediately overlying and conforming to the silicious limestone are the following beds: First. A series of thinly bedded sandstones and impure limestones, the latter somewhat magnesian, varying in color—pink, white, yellow and gray; the limestones contain only traces of fossil remains. These have altogether a thickness of 150 to 200 feet, and pass gradually into (second) a sandstone somewhat argillaceous and calcareous of a deep red color, but often streaked or variegated with yellow or pink. Frequently on fracture the sandstone has a somewhat lighter color or is almost white; and while much of the predominating deep coloration is derived from the oxidation of iron in the rock itself, a considerable portion is also produced through staining by a downward infiltration from the red clay above. It generally shows little or no stratification and is massive, but it weathers in a becciated or broken manner, with twisted or bent lines of decomposition parallel with the general stratification of the rocks. It has a thickness of 100 to 150 feet, making the entire thickness of the upper or fourth member of the Carboniferous 250 to 350 feet." (Geology Black Hills, page 111.)

While the lower members of the formation (Carboniferous) are well marked and easily traced and readily distinguished from each other as well as from the underlying Potsdam, a study of the upper portion was attended with no little difficulty. In the absence of distinct fossils the upper boundary of the formation had to be drawn from the lithological character of the deposits. (Geol. Black Hills, page 110.) The detailed section upon which these decisions are based have in part already been given in connection with the Potsdam, and others will be found in the discussion of the separation between the Carboniferous and the overlying Triassic rocks.

We may add that since Newton's work the cavernous character of the silicious limestone has been remarkably developed and several extensive caverns are now places of resort for pleasure seekers.

CRYSTAL CAVE.

The mouth of this cave is overlooking the canyon of Elk Creek, about six miles above Piedmont. It is about 200 feet above the level of the stream, and approximately 4,202 above the sea. By the courtesy of Mr. McLemore, the custodian of the cave, I spent several hours in exploring the various chambers of this celebrated cave. The chambers present the usual irregularities of valted caverns and narrow winding passage ways. They are commonly covered with crystals of calcite of the usual form, known as Dog Tooth Spar. Some chambers present beautiful examples of stalactites and stalagmites, and a few samples of a particular form of surface, known as "boxwork," are found, but are so deeply covered with calcite that they do not appear prominently. The passages, so far as visited, rarely showed places of dripping water, and nowhere running streams or large ponds, though Mr. McLemore assured me that in some of the deeper passages such had been found. Many of the passage ways showed such an arrangement of the crystals as indicated that they had been filled with water, and in the more open places with flowing water. This was evident, whether we conceive the crystals to have been first formed and afterwards partially dissolved, or whether the motion of the water had prevented the complete formation of the crystals about the exposed points. The crystalline surfaces were nearly smooth at points where the currents, passing through the passage ways, would naturally strike the walls, while in recesses they were sharp and complete. Crystals were of quite uniform size, generally with a diameter of one-half to three-quarter inches. Another evidence of occupation by water, and which indicated also that the forms of the crystals was probably due to solution rather than imperfect crystallization, was the coating of the crystals, very generally, with a thin film of clay. This was especially the case in the lower portions of the channels and chambers. Beautiful specimens of spongy-shaped masses of crystals, formed in shallow basins of standing water, have been found in this cave, sometimes of a straw color, but more frequently of snow white or pearly luster. This cave is the property of Keith and Allabaugh, of Deadwood, who prepared an artificial cave, lined with crystals from this cave, at the World's Fair, where they are said to have realized a handsome fortune from the sale of specimens.

The length of passages may safely be put down as several miles. From the nature of the cave it has not yet been fully explored. The depth, to the lowest point visited, below the entrance, was about 150 feet. The larger chambers, in some cases, may be roughly estimated as having a length of 200 or 300 feet. The breadth, 50 or 60 feet, and the height 30 to 40 feet. There are reports of several other caves in the vicinity, which have not yet been explored.

WIND CAVE.

The proprietor of this cave is Mr. J. D. McDonald, who has, with commendable enterprise and much labor, enlarged the passageways and furnished comfortable accommodations in various ways, so that this cave is readily accessible to the public. He showed me many courtesies during my examination of the cave, for which I here make cheerful acknowledgment. The Wind Cave obtained its name from its alternately throwing out and drawing in vast quantities of air. This phenomenon is found to correspond with the varying pressure of the barometer; and with its single opening and capacious chambers is easily accounted for. Its mouth is situated in the bottom of a ravine leading into Beaver creek, on Sec. 2, Twp. 6 S., R. 2 W. This cave is also dry and presents the usual features of narrow passages and irregular chambers like those of the Crystal Cave. Their arrangement, however, is very regular. The dip of the rock is toward the southeast, from 5 to 10 degrees. It is traversed by long vertical fissures at quite regular intervals, running northwest-southeast. The erosion of subterranean waters has widened the fissures, and has excavated small, low, irregular passageways from one to another nearly at right angles. The larger chambers lie along the line of the fissures. Three or four stories have been traced in the arrangements of the chambers. There have been no careful measurements of the distances in this cavern, but it is estimated that the easternmost point must be several miles from its mouth, which is upon the west side of the cavern. The number of passages may safely be estimated to amount to a score of miles. The lowest depth yet explored is about 225 feet below the mouth of the cave and the altitude of the mouth, according to the topographers of the United States Geological Survey, is 4040. There are but few places where trickling water is found, and these may be traced to deep ravines, traversing the vicinity east of the mouth. In fact these passages seem generally to be below the beds of the present streams. In places, under ravines, beautiful stalactites are formed, sometimes of ribbon-like outline and sometimes with stalagmites below, forming pillars, but nowhere upon so grand a scale as in some of the eastern caverns. Some of the chambers rise to a height of 60 or 80 feet and one is reported to cover nearly three acres. The cave is remarkable for the variety and delicate beauty of its encrusting crystals and other formations.

One very abundant formation, lining the cavities on all sides, is appropriately called "boxwork." This seems to have been formed in the following way: The rock is an impure limestone which has been cracked into small polygonal masses more or less rectangular in cross-sections. These blocks vary in size from an inch or two to a foot or more. The cracks have at some time been filled with calcite, often in thin plates, though in other places thick and heavy. The rock showing this condition is found exposed upon the surface in the vicinity. In the atmosphere of the cavern the process of disintegration of the original limestone, by dissolving away the natural cement, in some way not yet understood, allows the grains of sand to run out of the polygonal spaces formed by the calcite seams, somewhat as in an hour-glass. Since the boxes were emptied, the calcite partitions have been coated with calcite and aragonite crystals of various sizes and colors. Colors vary from snow white to chocolate brown and honey yellow, and display not only a "drusy" appearance and beautifully tufted and clustered forms, some rembling grapes, and others like branching corals, but also forms most perfectly resembling hoar frost. The boxwork abounds as a lining for most of the passages and chambers, and is found to be limited to certain layers. All stages in the process described may be found illustrated. Although the boxes may possibly in some cases be now closed, that feature seems to have resulted from a later deposition of crystals, and it may be assumed that they were once open for an escape of the enclosed material. The bottom of the chambers are often covered with sand. These crystalline forms occur also elsewhere than in the boxwork.

The origin of the beautiful frost-like crystals is one of the interesting problems of the cave. They occur in such localities as suggest their crystallization from mineral matter in the condition of vapor. They occur in fissures and upon points particularly exposed to the slow circling atmosphere of the cave. They are also entirely without anything like stalactitic surface or marks of water. Many of them are as delicate as the frost gathering about the mouth of a well in winter.

Another problematic form has been called mineral cotton which seems to be pushed out from the rock and is said to be in places 18 inches in length and have a uniform diameter as fine as a hair. One cluster of this formation has been significantly called "Noah's Beard." Crystals of gypsum occur in the clay, in some parts of the cave.

Another remarkable feature of these large caves in the Black Hills is the entire absence of sink-holes, upon the surface above them. One looks in vain to see upon the surface signs of drainage down into the cavern below. The sink-holes, which doubtless formerly existed, have been filled by the deposition, on a grand scale, of drift material, in broad terraces, probably by streams during the Pleistocene. In the upper chambers of the Wind Cave this filling of the sink-holes by bowlders and clay from the interior of the Hills is quite evident. Some of the chambers have a rough roof in the form of an inverted cone, with erratic pebbles and boulders cemented together with calcareous material. In other places boulders, granite and quartzite like those now occurring upon the surface, are found at lower levels in passages leading from the upper chambers. It seems therefore evident that these caverns are very ancient and that they were mainly formed previous to the distribution of pebbles and boulders from the Hills over the surrounding region. The Wind Cave is about 12 miles north of Hot Springs.

ONYX CAVE.

The Onyx Cave is about six miles above Hot Springs, up one of the branches of Fall river. This cave has recently been discovered and has derived its name from a deposit said to be quite abundant, resembling the Mexican Onyx. Quite handsome agates were shown me from a rock in the vicinity of the cave.

It seems not improbable that caves of similar interest and magnitude may be found at other points in the Carboniferous rocks belting the Hills.

FURTHER NOTES UPON THE CARBONIFEROUS.

From personal examination of the Carboniferous rocks more with reference to their fossils than to make out a careful section, which has already been well done by Newton, the following notes have been made: A fossil which very frequently occur in tha Carboniferous is a species of *Syringopora*, *Fusilina cylindrica*, which resembles wheat grains, occurs in abundance in the alternating series. In the boxwork of Wind Cave some very interesting fossils are beautifully preserved. That is, they are suspended in the open meshes of the hoxwork and coated with crystals similar to those upon the boxwork. Some of these are long and slender like reeds or slender algæ. They uniformly lie horizontal or parallel with the original embedding strata. Some attain a length of nearly a foot with a diameter of less than a quarter of an inch. Some of the shells resembling *Euomphalus* and *Pleurotomaria*, with a diameter of from 2 to 3 inches, were preserved in a similar way. Others preserved in this way were horn-shaped corals 5 or 6 inches in length, and shells resembling *Chonetes* about 2 inches in width.

The silicious limestone not only abounds, as Newton remarks, in layers of chert of irregular form but also large silicious concretions of a very symmetrical oblate spherical form often attaining a diameter of from 1½ to three feet. These are very abundant in the drift about Wind Cave and Hot Springs, and seem to be a general feature of this limestone, on all sides of the Hills. They were observed at regular intervals in horizontal rows, in the limestone west of Tilford. Specimens of *Lithostrotion* were also observed. The Carboniferous rocks, west and northwest of Tilford, contain large masses of green porphyry or trachyte which have been infused into it in huge lenticular masses and in dikes.

THE EXTENT OF THE CARBONIFEROUS.

As has already been stated, the Carboniferous formations are confined to the interior of the Black Hills, but a more detailed description may be helpful.

The geographical areas in which the Carboniferous rocks are exposed lie in an irregular ring-like formation around the Archean center of the Hills, and their exterior boundary is overlaid by the Red Beds of the Trias. Most of the Paleozoic area, marked upon the map, is Carboniferous and additional areas, not represented, are found along the eastern side of the ring. Between Rapid Creek and Spring Creek along the divide, Carboniferous rocks extend five or six miles west of their eastern limit. The Carboniferous rocks have had an important influence upon the topography, to which reference has already been made in a general way. The Carboniferous limestones are perhaps the most durable rock in the Hills. They still overlie the western portion of the Black Hills uplift. From the north, west and south, this plateau rises gradually as one approaches the interior of theHills, while on the east it has an abrupt escarpment overlooking the Archean erea. It has a width east and west of from 15 to 20 miles and a length north and south of 60 miles. Its surface is generally smooth or gently undulating, and is sharply cut by streams, with deep and steep-sided canyons. Newton remarks that, considered in its total mass, it is the greatest elevation of the Hills, and bears upon its broad back a crag, which is second to but one other in height. Crook Tower has an elevation above the sea of 7,320 feet and is only 80 feet lower than Harney Peak. It rises 200 feet over the level of the adjacent parts of the plateau. The height of this table land above the sea is about 7,000 feet. The Carboniferous strata, on the eastern margin of the Hills, are comparatively small in extent and dip everywhere rapidly toward the east. They constitute a monoclinal curve around the edge of the Archean. In the northern third of the Hills, the Carboniferous rocks are locally disturbed by eruptions of later igneous rocks. Like the Potsdam sandstone in the vicinity of the outflows, they are sometimes nearly vertical.

THE SEPARATION OF THE CARBONIFEROUS AND RED BEDS.

The upper limit of the Carboniferous is not as easily determined as the lower. Newton places it above the variegated sandstone because he found a few fossils, supposed to be Carboniferous, in some of the strata, just below that horizon. In this he differs from Dr. Hayden and Prof. N. H. Winchell. Dr. Hayden labored under the disadvantage of a hasty reconnaisance under circumstances of danger from the Indians. He failed to comprehend the thickness of the Carboniferous. He divided the Carboniferous into two portions, as follows:

G.	Hard, more or less gritty, yellowish and whitish limestone, containing *Productus, Spirifera, Euomphalus*, etc., passing down into a light yellowish calcareous grit, altogether	50 feet
H.	Very hard gray reddish limestone, containing *Syringopora, Productus, Terebratula*, etc	50 feet

Newton recognized in his G, No. 3 and in H, No. 2. The upper members, therefore, of the Carboniferous were included by Hayden in his Red Bed series. (Trans. Am. Phil. Soc., 1862, teste, Geol. Black Hills, p. 113.) Prof. Winchell, on the contrary, extends the Carboniferous upward, with much doubt, however, so as to include not only the formations recognized by Newton, but also 100 feet of red clay and 30 or 40 feet of purple limestone which seem properly to belong to the Red Bed series. The obscurity of this separation will appear by comparison of a few representative sections given by Newton. At the head of Minnekahta creek or Fall river, the following section was recorded: (Geol. Black Hills, p. 121.)

RED BEDS—

9. Purple limestone .... 4 feet
8. Red clay in places soft red sandstone .... 140 feet

CARBONIFEROUS—

7. (No. 5) A colored sandstone, red, yellow, pink, etc., with calcareous layers and limestone .... 285 feet
6. A layer of black sandy carbonceous shale .... thin
5. Sandstone .... 3 feet
4. A layer like 6 .... 1 foot
3. Sandstone, red and yellow .... 25 feet
2. Silicious and argillaceous limestone with nodules of flint .... 20 feet
1. Limestone, silicious, weathering irregularly cavernous, outcropping just at the level of the creek, probably No. 3 of the Carboniferous section ....

Near the head of Amphibious or Beaver Creek the following: (Geol. Black Hills, p. 122.)

RED BEDS—

7. Purple limestone .... 25 feet
6. Red clay, somewhat soft red sandstone .... 100 feet

CARBONIFEROUS—

5. Variegated sandstone, blended with red, yellow and white .... 100 feet
4. Alternating limestones, calcareous sandstones, yellow, reddish, white and pink, near base a stratum of deep red, calcareous sandstone, 10 feet .... 200 feet
3. Limestone, silicious, containing much flint, has a brachiated appearance .... 250 feet
2. Limestone, white or gray .... 180 feet
1. Limestone, pink, impure and siliceous, containing fragments of crinoids exposed .... 20 feet

The following section on Box Elder is somewhat abridged from Newton's description: (Geol. Black Hills, p. 126.)

RED BEDS—

14. Purple limestone .... 25 feet
13. Red clay .... 100 feet

CARBONIFEROUS—

12.	Variegated sandstone, white and yellowish below	90 feet
11.	Slope	10 feet
10.	Sandstone, red with calcareous layers	60 feet
9.	Slope	14 feet
8.	Limestone, pink	1 foot
7.	Slope	10 feet
6.	Purple limestone, alternating with pink and white, soft, thin bedded sandstone	15 feet
5.	Slope	5 feet
4.	Limestone, gray and pink, stained with red, alternating with layers of pink and reddish sandstone	105 feet
3,	Slope	6 feet
2.	Limestone, gray, compacted, fossilerous	8 feet
1.	Flinty limestone, with occasional layers of pink and yellow, thin gray sandstone, which weathers red	146 feet

Near Black Butte, in the northwertern portion of the Hills, resting on the volcanic rock of the peak, fragments of the metamorphosed Potsdam are seen, and upon them in regular order the strata, given in the following section: (Geol. Black Hills, p. 128).

RED BEDS—

5.	Purple limestone	25 feet
4.	Crumbling soft red sandstone	100 feet

CARBONIFEROUS—

3.	White, yellow, orange, and dark red, massive, soft sandstone, irregular in color weathering in fantastic shapes	250 feet
2.	Talus	200 feet
1.	Silicious limestone to the bed of the creek	— feet

Other sections given with greater detail are found in Newton's Report. They differ but slightly in general character from those already presented. They all show how, instead of a well marked horizon, there is a general transition from the Carboniferous sandstone into a sandstone or clay of the Red Beds. Even those which are recognized as Carboniferous begin to show the deep red color of the Red Beds in an irregular manner.

CHAPTER VI.

THE MESOZOIC FORMATIONS.

These comprise the most of the surface of our State and are commonly arranged under the following systems: Triassic, named from the three-fold division of the formation in Europe; Jurassic, named from its prominence in the Jura mountains in Switzerland; and the Cretaceous, (creta, chalk) named from the prominence of chalk in the European beds, as for example in southern England and northern France. All the formations are usually but imperfectly consolidated. They are mostly sandstones, clays and marls.

THE TRIASSIC OR RED BEDS.

These like the Paleozoic formation are confined to the interior of the Black Hills, where they occupy a ring-like area surrounding the Hills. They are particularly conspicuous in the topography because of the easy erosion of the clays. As a result we have the Red Valley and a ridge within formed by the harder purple limestone.

The Red Beds consist of the following members in descending order:

3. Deep red clay, sometimes becoming soft, shaly, argillaceous sandstone containing large quantities of gypsum .... 200–250 feet.
2. Pinkish, purple and argillaceous limestone ..... 15– 40 feet.
1. Deep red clay, sometimes becoming soft argillaceous sandstone containing but little gypsum .. 75–100 feet.

These three formations may conveniently be called: Lower Red Beds, Purple Limestones and the Upper Red Beds. They may be conformable to one another and to the underlying Carboniferous rocks, and yet, because of their structure and irregularities, this conclusion can hardly be demonstrated.

THE LOWER RED BEDS.

This formation consists mostly of red clay, which is more arenaceous toward the north end of the Hills and about Bear Butte. It is entirely without fossils and rarely shows traces of stratification. It varies much in thickness. The Purple limestone sometimes comes almost in contact with the Carboniferous sandstone, but in no case is it more than 100 feet above it. Traces of gypsum are sometimes observed in this formation. This is more frequent in the southern part of the Hills. Where the Carboniferous Limestone is prominent or where the outflows of porphyry occur the Lower Red Beds seem less likely to be brought out by erosion. Prof. Winchell, in his trip through the northern portion of the Hills, for this reason greatly underrates the thickness of these lower beds. The color of the clay is bright red, the cause of which we will speak of more at length further on.

THE PURPLE LIMESTONE.

This formation is a very conspicuous and constant feature of the Triassic. It very generally forms the inner slope of the Red Valley, though sometimes it is separated from the hills within by another valley caused by the Lower Red Beds. As one enters the Red Valley from the outside, the inner side appears to rise in gentle, dome-like undulations, reminding one of the contours of the hills of Loess, in Nebraska and Iowa.

The surface is largely without trees and covered with grass. As he approaches he is surprised that the whole surface is an almost continuous rock pavement, the strata dipping in all directions parallel with the present surface. Another feature impresses him also, namely: the infrequency of ravines or cliffs. These rarely occur except where streams of considerable size have cut their way through the limestone into the Red Valley. This they do by regular V-shaped gaps, whose points are scarcely wider than the present streams. These characters are very striking and are rarely seen in other formations. The impression at the first view is of a formation of immense thickness, and so it seems to have been estimated by Prof. Winchell, who makes it nearly 100 feet. (Black Hills of Dak., Ludlow). Wherever it is broken, it displays a very uniform thickness, from 25 to 40 feet. The limestone consists of thin strata of a grayish, pink or purple, somewhat mottled and often deeply stained by red, perhaps from the overlying clay. According to Dr. Ricketts, of Newton's survey, it consists essentially of carbonate of lime with traces of silicate of alumina and iron, and has an odor, when ground, like Canada petroleum. This odor is discernible when the rock is crushed and on fresh fracture. Prof. Carpenter gives several careful analyses made by Profs. Jansen and Headden, of the Dakota School of Mines, which shows that it is unusually pure carbonate of lime. (Geol. and Min. Res. Black Hills, p. 43). In the pure varieties nearly 99 per cent. was calcium carbonate. The most impure was 91 per cent. Not only is the rock thin bedded, but it is divided upon the surface into polygonal blocks, which are slightly concave or saucer shaped, above. This feature, Prof. Crosby suggests, indicates its deposition in marshy lake beds, which were frequently dried up. He attributes this concave feature to an action similar to that forming mud-cracks. (Proc. Port. Soc. Nat. His., Vol. XXIII., p. 509). Dr. Carpenter shows, however, that this feature is confined to the present surface and is due rather to the warping influence of weathering at the present time. (Geol. and Min. Res., Black Hills, p. 44.) Prof. Newton speaks of the crumpled character of the beds as follows:

"Underlaid by 75 to 100 feet and overlaid by 200 feet of soft red clay, the limestone rests between two cushions, so that in the uplifting of the rocks at the time of the elevation of the mountains, it was not shattered and dislocated so extensively as if it had been inclosed between more rigid strata. It is found bending and warping suddenly, especially about some of the volcanic peaks, and conforming to all the little irregularities of the outer slope of the hills without exhibiting any great fractures or dislocations. Though it is usually more fragmentary in its structure, filled with cracks and joints perpendicular to its bedding, they seem rather due to its composition and mode of weathering than to the bend of the strata."

This rock appears quite soluble in water, for many of the springs that flow from its base precipitates large quantities of calcareous tufa. Copious springs are found issuing from this limestone in the Red Valley, north of Rapid City, especially in the vicinity of Piedmont and Tilford.

This peculiar dome-shaped folding of the limestone has not yet been satisfactorily explained, and facts are not yet collected sufficient to justify a confident conclusion. But one significant fact may suggest a possible explanation. The deposition of gypsum and the occurrence of the deep red color correspond with the conditions favorable to the rapid evaporation of water and the deposition of salt. It is reported that salt springs are found upon the western slope of the Black Hills, but thus far no trace of salt has been found upon the eastern side. May it not be possible that the lower Red Beds, and possibly the upper, at one time contained masses of rock salt, not of uniform thickness, but deposited in irregular beds somewhat as the gypsum is now. Then suppose that in the process of elevation and subterranean drainage of the Hills these masses have dissolved out, causing an irregular thining of the Red Beds. This would have left the Purple Limestone with an attitude similar to that which it now has. The color of the Purple Limestone seems due to the small proportion of iron oxide which in the analysis of Prof. Jansen, already referred to, amounted to 37-100 of 1 per cent. This Purple Limestone receives a fine polish and has been called marble. Its use for this purpose may at some time be important. No trace of fossils are found in this limestone. The report to that effect by Dr. Hayden seems sufficiently disproved by both the observations of Newton and Carpenter, who broke to pieces tons of rocks in search of fossils. Dr. Carpenter informs me that he found not the slightest trace, except a wing of an insect.

THE UPPER RED BEDS.

These resemble closely the Lower in composition and appearance, but are two or three times as thick. They are also arenaceous in places where the Lower show that character. They abound in deposits of gypsum, which lies in knobs and cliffs in the valley partially buried in red clay. Gypsum occurs both in thin layers and of snowy whiteness and in irregular masses blotched with gray. The layers are lenticular in form and lie at different angles of inclination. They vary from one-half inch to 10 or even 25 feet in thickness. It is possible that excavation may reveal greater masses. At Hot Springs, at the Cement Works, 2 or 3 strata represent a combined thickness of 35 feet. Crystals are nowhere found abundantly, but seams of fibrous gypsum or satin spar, with a thickness of from one-half to 2 inches occur. The solution of gypsum renders the water cathartic in its effect, although its coolness and clearness renders it otherwise attractive. Copious springs sometimes issue from banks of gypsum. The Upper Red Beds vary much in thickness, like the Lower. The Purple Limestone rises in domes and gentle anticlinal folds above the surrounding clay in the bottom of the Red Valley. This is illustrated in sections given in Newton's Report. In the Red Valley north of Rapid Creek a dome perhaps one-half mile in diameter rises conspicuously from the bottom of the valley to a height of 50 feet. Near Buffalo Gap the Purple Limestone dip sunder the west side of the valley at an angle of 20 or 25 degrees, and rises in a prominent anticlinal ridge near the eastern side, at the foot of the ridge formed of the Jurassic and Cretaceous rocks. In the pass, through which the Fall River traverses the outer ridge of the Hills, a narrow anticlinal of the Purple Limestone shows itself a few feet above the waters of the stream in close contact with the lower sandstone layers of the Cretaceous. These facts seem to favor Prof. Winchell's conclusion that there was a disturbance, following the deposition of the Purple Limestone. (Black Hills of Dakota, p. 62.)

In the northern and northwestern part of the Hills, particularly west of the line in Wyoming, the gypsum attains great prominence. It seems to be deposited more abundantly at certain horizons, though the relation of these to one another cannot be definitely stated. Newton says that the first is about 75 or 100 feet above the purple limestone and the second 40 or 50 feet higher. The third is at the very summit of the red clay, and the fourth, less persistent, is a few feet lower. In that region also sinkholes abound, produced by the dissolving away of the gypsum below. Cases of this sort are found in other localities more rarely. These holes are commonly only from 2 to 5 feet in diameter, and sometimes attains a breadth of 50 feet; and are said to have a character of sink-holes in limestone countries.

THE CAUSE OF THE RED COLOR.

Newton remarks concerning this: "A large percentage of peroxide of iron in the red beds, to which they owe their bright red color bears an interesting relation to the absence of fossils. The material of which sediments are formed is derived, by the various processes of denudation, from the rocks of older land surfaces. Whatever iron they contain is dissolved from the land and transported in a condition of protoxide and some proto salt, such as the carbonate, and the process is facilitated by the presence of carbonic acid in the water. Now iron occurs in these older rocks as protoxide and peroxide, the former of which is soluable and the latter insoluable in water. The peroxide, however, by the action of organic matter, such as is held in solution in boggy waters may be deprived of a portion of its oxygen and converted into protoxide and thus be rendered soluable. If the iron-bearing water is confined first in a shallow basin and exposed long to the action of the atmosphere the protoxide of iron absorbes the oxygen and is precipitated as an insoluable red peroxide of iron. If, however, plant or animal life be present in sufficient quantities this oxidation is prevented. In case but little foreign material, clay or sand has been brought by the waters, the deposit will be an iron ore. In case of large quantities of foreign material are deposited from the waters at the same time, there will be produced, in the absence of life a brown or red clay or sandstone and in its presence, a white or light colored formation containing the iron as a carbonate. We reason therefore, from the condition in which the iron is found in the red beds, that there could have been little or no life, animal vegetable, in the water from which it was deposited. The conclusion is strengthened by the fact of the large quantities of gypsum which is usually derived from the evaporation of saline waters. The degree of saline concentration which the precipitation of gypsum indicates, would be highly inimical to life. The presence of gypsum helps to account for the absence of life and the absence of life accounts for the brilliant color. The three prominent characteristics of the formation (that is the red beds) are therefore quite in harmony with each other." (Geol. Blk. Hills, p. 138.)

Accepting this explanation of the striking red color the question remains, as to how these circumstances, favorable for its formation, were produced.

This red color is quite common in the whole Rocky Mountain region, not only on the eastern slope of the mountains, but to the various detached members of the system. We must, therefore, look for some extensive condition. If we seek some case in the present, parallel to the one already indicated, we perhaps can find none better than one on the eastern shore of the Caspian sea, where, because of dry climate and the shallow waters, the of deposition of gypsum and salt is now going on. In the gulf known as the Kara Boghaz, which is separated from the Caspian by a narrow strait, the evaporation is so rapid as to produce an almost constant flow from the sea into it. This strait and this gulf give the impression to an unlearned observer that there must be a mysterious subterranean outlet. The water flows in, carrying with it the salt and other soluble minerals. It then evaporates, leaving the salt and minerals behind. We have already noted that the Triassic formations do not appear along the Eastern side of the Mississippi Valley, nor anywhere further east than the Black Hills, with a possible exception of an area in north central Iowa, about Fort Dodge. In the eastern part of the United States, on the Atlantic slope, beds referred to this age are found in Connecticut, New Jersey and further South. There they seem to have been attended with volcanic outflows, and there are signs of a high elevation of the whole eastern half of the continent. This may have been sufficient to reduce the extent of the sea east of the Rocky Mountains to a long, narrow gulf of salt water, connecting with the open sea. This may have been subject to a dry climate, resembling that of central Asia, and in this way we account for the peculiar characteristic of this formation. Prof. Carpenter suggests (Gold & Min. Res., Black Hills, p. 51) that perhaps the effect of the "Appalachian revolution," which raised the Appalachian Mountains, was to close the southern opening of the Mediterranean, then existing between the eastern and western parts of the continent, causing it to become gradually so salt from evaporation, that save, perhaps, in estuaries surrounding this border, all life perished. He says the presence of limestone, in the clay, would seem to militate against this view, but the structure of this limestone has none of the characteristics of an organic limestone. It may be a chemical precipitate.

The evidence that these strata are Triassic consists of their stratigraphical position, and the fact that some beds, resembling them further west, have been shown to have fossils belonging to that age. Because of the doubt still lingering, the term Red Beds is more frequently used than the term Triassic, which would indicate a definite conclusion concerning their age.

THE JURASSIC FORMATION.

The Jurassic System, which is so largely developed in Europe, is noted not only for its remains of huge swimming and flying reptiles, but also for its large deposits of iron ore. For a long time it was thought to be absent from American geology. In the Eastern States red and brown sandstones were found, which were thought to correspond to this age, but were finally determined to be Triassic. The first discovery of the existence of the Jurassic in the west was made by Prof. Meek, from fossils collected in the Black Hills by Prof. Hayden in 1857. The discovery was announced in the proceedings of the Academy of Natural Sciences of Philadelphia in March, 1858. Since that announcement the formation has been found to be generally present in the Rocky

Mountain system from the extreme north to New Mexico, and from their eastern slope westward to the Wasatch Mountain. Perhaps no locality is better furnished with fossils than the Black Hills. The Jurassic rocks of the Black Hills occur in a narrow strip bounding the outside of the Red Valley, and like it forming a complete ring the Hills. Their exposure is not wide, because of their easy erosion and their being surmounted by a hard capping of Cretaceous rocks which covers them. The formation is distinguished from the Triassic, or Red Beds, most easily by a difference in color. The Red Beds gradually become more arenaceous while their color changes abruptly from a deep red to a white, yellow or gray. The thickness of the formation about the Hills is from 200 to 300 feet. They are little more than 200 in the southern portion of the Hills, and thicken to 400 at the north end, and 600 northwest along the Belle Fourche, in northeastern Wyoming.

THE CHARACTER OF THE BEDS.

We will first give a few characteristic sections from different parts of the Hills, as reported by Prof. Newton and others.

Near Camp Jenney on the northern side of the pass through which Beaver Creek flows the following section is noted: (Geol. Black Hills, p. 157.)

CRETACEOUS, No. 1.—

6. Sandstone yellow and white, somewhat lamellar and containing ripple-marked surfaces .... 50 feet
5. Sandstones, yellowish with red stains, heavily bedded, 40 feet
4. Sandstone, very white, fine grains and massive, easily decomposed into fine white sand, forming a well marked cliff, with caverns and holes .... 100 feet

JURASSIC—

3. Covered by talus and not well exposed; at intervals, outcrops the gray or greenish clays or marls, with occasional beds of limestone with fossils, also some sandstone ....
2. Marls or clays, gray and purple, with nodules of impure limestone; base covered .... 110 feet
1. Similar to the last, containing fossils to base of cliff.. 20 feet

This reaches nearly to the base of the Jurassic.

At Buffalo Gap is the following section: (Geol. Black Hills p. 158.)

CRETACEOUS, (395 feet exposed—)

16. Sandstone, capping hill; massive, white, stained, yellowish and reddish .... 300 feet
15. Unexposed .... 25 feet
14. Sandstone soft and massive, pinkish in color .... 70 feet

JURASSIC—(234)

13.	Mostly concealed, but white or reddish, soft argillaceous sandstone below	105 feet
12.	Sandstone, light red, almost sand	55 feet
11.	Sandstone, greenish and calcereous, thinly bedded	20 feet
10.	Sandstone, white or greenish, in thin layers, with many ripple-marks	20 feet
9.	Shale, red and gray and shaly sandstone	8 feet
8.	Shale, red and gray	5 feet
7.	Sandstone, red and pink, soft below, hard above, with ripple-marks	8 feet
6.	Sandstone, yellowish, greenish, reddish and thin bracciated bend	10 feet
5.	Sandstone, white	3 feet

RED BEDS—(255 feet exposed)

4.	Clay, deep red	50 feet
3.	Gypsum	10 feet
2.	Clay red, with gypsum	175 feet
1.	Limestone, pink or purple	10 feet

At the north end of the Hills, on Red Water creek, near the west boundary of the State, Mr. W. F. Patrick observed the following section: (Geol. Black Hills, p. 162)

JURASSIC—(410 feet exposed)

10.	Clay, gray, white and purple, capping the bluff	35 feet
9.	Sandstone, lamelear and yellow, uppers layers hard and brown	30 feet
8.	Sands, argillacous, yellow and greenish with layers of calcareous sandstone filled with fossils, Ammonites, Belemnites, etc.	35 feet
7.	Sandstone, white, massive, soft	20 feet
6.	Sands or sandy marls, white and calcareous with Belemnites	80 feet
5.	Sandstone, pinkish, passing into bed 4	60 feet
4.	Sandstone, yellow, massive	90 feet
3.	Sandstone, lamelear and white	10 feet
2.	Clay, white and gray with sandy layers	50 feet

RED BEDS—

1.	Red sandy clay with gypsum	———

The following is a section taken more recently by Mr. L. F. Ward a few miles southeast of Minnekahta in the southern Hills. It includes a large portion of the Cretaceous, as well as the whole of the Jurassic. He gives it in the Journal of Geology, Vol. 2, page 255.

CRETACEOUS No. 1. (275 feet)

13.	Massive, pinkish sandstone, approaching quartzite ocallly	75 feet
12.	Greenish, white sandstone, with silicified wood and Cyads	30 feet
11.	Pinkish and yellowish, soft sandstone	75 feet
10.	Clays, with indications of coal	20 feet
9.	Soft, pink and gray sandstone, with ferns and other plants	25 feet
8.	Reddish, pinkish and yellowish brown massive cross-bedded sandstone	50 feet

JURASSIC. (220 feet.)

7.	Olive gray clay, sandstone shales	50 feet
6.	Light red, soft sandstone	60 feet
5.	Olive gray clays and gray sandstone shales	40 feet
4.	Olive drab clay	20 feet
3.	Yellow sandstone shales	20 feet
2.	Olive drab clay	30 feet

RED BEDS. (Trias.)

1.	Red marls, conformably exposed at bottom of canyon	20 feet

From these sections it will appear that the Jurassic generally consists of gray and ash colored marls, more or less sandy limestone and soft sandstone, with occasional beds of green and red. The most marked single bed is the sandstone bed 50 feet thick, usually of yellow color, but sometimes quite red. On the Belle Fourche, this bed is 100 feet above the deep red clays, and forms the floor of a rude platform or slope on the borders of the river. A similar stratum is found on the Red Water separated only 50 or 60 feet from the red clays below. The clays and marls do not appear to be more confined to one place than another; though they perhaps are not so strongly developed in the extreme upper portion, as in the lower two-thirds of the formation. They often contain seams of limestone more or less impure; and these are possibly more common in the lower portion of the formation. The limestones are frequently fossiferous, but seem never to be more than a few inches in thickness, and do not constitute, so far as has been determined, continuous strata. Everywhere a large portion is composed of sandstones, which are usually light in color, sometimes snow white. They are usnally very soft or shaly passing into sandy shales. Soft incoherent sands are also met with.

THE FOSSILS OF THE JURASSIC.

In Wyoming, along the Red Water Valley, from Warren Peak eastward toward Spearfish, there are found two horizons yielding fossils in abundance; one at 135 and the other at 350 feet above the Red Beds.

A list of the fossils found by Newton, in the Black Hills, is appended: (Geol. Black Hills, p. 168.)

Ammonites cordiformis, and A. Henryi.
Astarte fragilis, and A. inornata.
Asterias dubium.
Avioula mucronata.
Belemnites densus.
Camptonectes bellistriatus, and C. extenuatus.
Dosinia jurassica.
Gervillia recta.
Grammatodon inornatus.
Lingula brevirostris.
Lioplacodus veturnus.
Myacites Nebrascensis.
Mytilus Whitei.
Neaera longirostris.
Ostea Engelmanni, and O. strigilecula.
Pecten Newberryi.
Pentacrinus asteriscus.
Pholadomya humilis.
Planorbis veturnus.
Pleuromya Newtoni.
Protocardium Shumardi.
Psammobia prematura.
Psendomonotis curta, and P. orbiculata.
Rhynconella Myrina.
Saxicava Jurassica.
Tancredia æquilateralis, T. bulbosa, corbuliformis, inomata, Postica and Warreniana.
Thracia arcueta, and T. sublevis.
Trapezium Bellefourchensis and T. subequalis.
Trigonia Conradi.
Unio nucalis.
Valvata scarbrida.
Viviparus Gilli.
Volsella pertennis.

For the benefit of those who are unfamiliar with pleontology we will say that with a few exceptions they are bivalved shells similar to those now found in the ocean, in many cases belonging to the same genera. A few exceptions are the species of Crinoid *Pentacrinus,* which may be described as a delicate flower-like starfish with a long jointed stem such as is still found living at the bottom of the sea, and another is a species of starfish. The *Ammonites* resembled the Pearly Nautilus of the present time, except that they were larger and of a much more complicated structure. *Belemnites* were animals probably resembling the modern squid, having an internal skeleton or shell, which terminated, at the posterior end in a cylinder tapering to a point, sometimes several inches in length, resembling in form the prong of a deer horn, or a cigar. A few resembled the snails found in fresh water ponds. Then there were several species of oysters, salt water mussels and salt water clams and other forms not commonly familiar.

Reference was made, at the outset, to the existence of strange gigantic reptiles in the Jurassic of Europe. Few specimen of these have been found in this country. But one species is especially worthy of note. Not only because it is found to be the largest land reptile ever in existence, but because specimens of it have been found in the Black Hills. It is called the *Atlantas aurus.* It is estimated, that it was nearly 80 feet in length, of the shape of a large lizard, and its thigh bones have been found to measure six feet in length. It is interesting to note, that distinct fragments of the skeleton of this animal have been found in a butte near Piedmont. This was discovered and reported by Mrs. Ellerman of that place, in 1886. The locality was visited and the choicest specimens were taken and studied by Prof. O. C. Marsh, who is an eminent specialist upon vertebrate paleontology. Considering the little study which has been spent upon the Jurassic beds, it seems not improbable that most interesting and possibly new forms of the strange reptiles of that age may yet be found in the Black Hills.

THE SEPARATION OF THE JURASSIC FROM THE CRETACEOUS.

Newton judges the Jurassic to pass conformably into the Cretaceous; that there was no marked change in attitude of the sea bottom at the end of the Jurassic. Both Profs. Carpenter and Crosby, however, claim to have discovered places of unconformability indicating a distinct movement of the Black Hills at the end of this age. Prof. Carpenter says there is a marked unconformability between the Jurassic and the Cretaceous beds at the gap, at Rapid City. It was shown on the southern side of the gap, where it had been excavated for a ditch. He found also a similar uncomformability upon Box Elder Creek and concludes that the Hills were uplifted and subject to erosion before the laying down of the first Cretaceous beds. This explains why they are commonly conglomeritic. The end of the Jurassic was marked elsewhere by remarkable disturbances of the earth's crust, particularly by the upheaval of the Sierra Navada Mountains and the elevation of wide areas in the western portion of our country so as to become dry land. No marked disturbance, however, have been noted east of the Wasatch Mountains. It should be remembered that the region must have been land during the early Cretaceous which is not represented in our State.

THE CRETACEOUS FORMATION.

The members of this formation, though having many characteristics in common, are yet quite distinct as regards their lithological character. They are widely distributed, covering more than half of our State. We, now for the first time in our study, pass outside of the Black Hills. It seems that this age was characterized by a slow subsidence of the central portion of the continent.

The Cretaceous rocks were divided by Háyden into five divisions named successively:

1. The Dakota sandstone, from Dakota City in Nebraska where it was first studied;

2. Fort Benton clays, from its maximum development near that fort on the upper Missouri;

3. The Niobrara, the Niobrara chalk stone, from its prominence along the Niobrara and Missouri, near their junction;

4. Fort Pierre clays, covering the central portion of the State about Fort Pierre; and

5. The Fox Hills sandstones, named from the range or hills on the divide between the Cheyenne and Moreau rivers west of the Missouri; while a sixth, the Laramie or Fort Union formation, now considered Cretaceous, he placed in the Tertiary. These formations are exposed, in the order named, as one ascends the Missouri river through our State, overlapping one another from the north in nearly horizontal positions. From a wider study of these formations they have been somewhat differently classified, although these names are still used by many.

The classification given by Dr. White in the recent correlation paper on the Cretaceous Bulletin 83, of the United States Geological Survey, is as follows:

The Lower Cretaceous, (probably not found in our State) includes the Potomac formation of the Atlantic slope; the Comanche formation of Texas; the Kootonie formation of British America and the Shasta formation of northern California.

The Upper Cretaceous includes: First, the Dakota; second, the Colorado, which consists of Fort Benton and Niobrara formations; third, Montana, which includes Fort Pierre and Fox Hills; while the Laramie he consideres partly in the Cretaceous and partly in the Tertiary.

Upon our map we have followed King in our grouping of Fort Benton, Niobrara and Fort Pierre under the Colorado, omitting the Montana and reserving the old name Fox Hills. This seems to suit best the lithological characters of the formations in this State. The Dakota is usually easily characterized by its abundance of grass and sandstone. Fort Benton and Fort Pierre clays resemble one another very much in appearance, while the Niobrara is an inconstant formation, being 200 feet in thickness in some localities while in others it is indistinguishable from the beds above and below. We shall speak of this more particularly when considering the Colorado formation. The Fox Hills consist largely of beds of sand and sandstones, but is of an arenaceous clayey character, between the Colorado and the Laramie, or Lignitic. These formations are not very distinctly marked by paleontological characters, probably differing in life little more than can be explained by the difference of biological conditions of the sea at different times. A synopsis of the Cretaceous formations of our State, slightly modified from Hayden, (Geol. Black Hills and Trans. Phil, Soc., Vol. XII, Part I) is given below.

TABLE OF CRETACEOUS GROUPS IN SOUTH DAKOTA.

No. 5. FOX HILLS GROUP.

Gray and yellowish arenaceous clays and sandstones, containing *Belemnitella bulbosa, Nautilus Dekayi, Placenticeras placenta, Scaphites Conradi, Baculites ovatus,* and a great number of other marine molluscan fossils, together with bones of *Mosasaurus Missouriensis. Localities:*—Fox Hills, near Moreau river; under the Tertiary on Sage and Bear creeks. Thickness, 100 to 150 feet.

No. 4. FORT PIERRE GROUP.

(a) Dark-gray and bluish plastic clays, containing, near the upper part, *N. Dekayi, P. Placenta, B. ovatus, Scaphites nodosus, Dentalium gracile, Inoceramus Sagensis,* etc., and bones of *Mosasaurus.*

(b) Middle zone nearly barren of fossils.

(c) Lower fossiliferous zone, containing *Ammonites complexus, B. ovatus. Heteroceras Mortoni, tortum* and *umbilicatum, Mosasaurus,* etc.

(d) Dark bed of very fine nuctuous clay, with much carbonaseous matter, seams of gypsum, masses of pyrites and numerous small fish scales. Local. filling depressions in the bed below.

LOCALITIES.—

(a) Sage creek and Cheyenne river.

(b) Fort Pierre and out to Bad Lands; also down the Missouri on the high country to Great Bend and beyond.

(d) Near Bijou Hills. Thickness, 700 feet.

No. 3. NIOBRARA GROUP.

Lead-gray, caleareous marl, weathering to a yellowish or whitish, chalky appearance above; containing large scales and other remains of fishes, and many specimens of *Ostrea congesta* attached to fragments of larger shells; passing down into light, yellowish and whiteish limestone, containing great numbers of *Inoceramus problematicus*, fish scales and *Ostrea congesta*.

LOCALITIES.—

Bluffs along the Missouri, below the Great Bend to the vicinity of the Big Sioux river and along the latter river. Thickness, 200 feet.

No. 2. FORT BENTON GROUP.

Dark-gray, laminated clays, sometimes alternating near the upper part with seams and layers of soft, gray and light colored limestones, *Inoceramus,* four species, *O. congesta, Prionocyclas Woolgari, Scaphites,* four species, *Nantilus elegans*, etc.

LOCALITIES.—

About Fort Benton; along the Missiouri river, from ten miles above James river to Big Sioux river. Thickness, 90 feet.

No. 1. DAKOTA GROUP.

Yellowish, reddish and occasionally whitish sandstone, with alternative of dark and whitish clays; seams and beds of impure liquite fossil wood, impressions of dicotyledonous leaves.

LOCALITIES.—

Near the mouth of the Big Sioux and thence southwest into Kansas. Thickness, 400 feet.

THE DAKOTA FORMATION.

This is the first formation which we find exposed at both ends of the State. It forms a prominent ridge outside of Red Valley surrounding the Black Hills. This ridge is sometimes narrow, rising to a height of 500 to 600 feet, at other places the dip is more gentle, and the formation produces tablelands, as at the north and south ends of Hills. Its exposure about the Hills is from 3,200 to 4,000 feet above the sea, and in the broadest portions about 10 miles wide. Prof. W. P. Jenny estimates that its average width is about 2 miles. It is also exposed around the west and south sides of the area occupied by the Sioux Quartzite, where the Drift clays prevent its frequent appearance. The localities where it has been observed are as follows: On the Firesteel, near the crossing of the railroad, about 4 miles from Mitchell. Upon Enemy Creek southeast of

Mitchell. Only a few feet of thickness is exposed at these localities. A more extensive exposure is found along the bank of the James river, 4 to 6 miles above Milltown. No other natural exposures are known within the borders of our State, but the position of this formation has been very well determined over wide areas by artesian wells. That it comes in contact with the drift clays over the surface, indicated upon the geological map, rests not only upon the facts already given but for various borings in the Vermillion valley about Centreville and other points; it is also inferred from the position of exposures upon the Iowa side of the Big Sioux river and the Nebraska side of the Missouri. The highest strata of sandstone in this formation dips below the ordinary surface of the Missouri at Ponca Landing in Nebraska. While the same strata not only appears at Sioux City and along the Big Sioux, at Riverside Park rising some 50 or 60 feet above the stream, but as far north as east of Elk Point, where it is found to contain a carbonaceous stratum or impure coal a few feet above the level of the water. This formation would be still more exposed on a wider and more regular scale, below the drift, were it not for the ridge of later Cretaceous clays intervening, along the east side of Brule Creek, extending past Beresford to the vicinity of Canton. So also a similar position is occupied by the clay forming the body of the East Coteau, east of the Vermillion river and northwest of Sioux Falls. The effect of these topographic features are indicated imperfectly upon the map. The Colorado should be represented as more nearly covering the Quartzite and Dakota in western Minnehaha and Turner counties.

The Dakota Formation averages over 350 feet in thickness around the Black Hills, while in the eastern portion of the State it is estimated to be nearly the same. It underlies the great plains which constitute the western slope of the Mississippi Valley. The exposures of it are found along the Platte River in Nebraska, a little above its mouth, and thence extending eastward to the vicinity of Des Moines, Iowa, and northward along the west side of the Des Moines River into Minnesota. So, also, the exposures about the Black Hills are but examples of what occurs along the foothills of the Rocky Mountains from the Canadian Line to Mexico.

THE CHARACTER OF THE BEDS.

The most conspicuous feature of the Dakota formation is the abundance of sandstone and grits. They may be grouped into from 3 to 6 different strata of sandstone that occupy probably two thirds of the thickness of the formation. There are separated by quite constant beds of impervious plastic clay, usually similar to that of the Colorado group above. This will be evident from the section of wells given further on.

THE EXPOSURES ABOUT THE BLACK HILLS.

It is in this portion of the State that we may gain the most complete knowledge of its formation, for its steep inclination, especially along the east and west sides of the Hills bring out its structure most admirably. The prominent beds of sandstones and conglomerates slope at an angle of from 10 to 40 degrees toward the east along the side of the Hills. At the various passes cut through the outer ridge of the Hills the streams have dissected it in a most interesting manner. The thickness of the formation at the south end of the Hills along the Red Canyon Creek, in the plateau portion, is about 500 feet, while at the north end of the Hills it is rarely over 200. The most complete section given by Newton is from the west side of the Hills at Beaver Creek Gap. (Geol. Black Hills, p. 178.)

8.	Sandstone	15 feet
7.	Gray shale and yellow clay	15 feet
6.	Sandstone with carbonaceous matter	10 feet
5.	Gray clay or marl with nodules of impure limestone strata with siderite, (carbonate of iron) much cone in cone and selenite	20 feet
4.	Sandstone, gray and reddish; in places thin bedded, with ripple marks	64 feet
3.	Sandy shales	20 feet
2.	Sandstone, whitish and yellowish, thinly bedded with many ripple marks	60 feet
1.	Sandstone, at base very soft, white below and yellowish above	150 feet

Other sections, giving an idea of the composition of the Dakota, have already been recorded under the Jurassic. We will add but one detailed section from the canyon of Fall River, southeast of Hot Springs, recorded by Mr. L. F. Ward of the U. S. Geological Survey, in the Journal of Geology for 1894. This is particularly valuable both for its completeness, and the careful discrimination and measurement of the strata.

FORT BENTON.

11.	Grayish black clays with layers of ferruginous concretions extending to the south fork on the Cheyenne River, contact conformable to the following	feet

DAKOTA OF NEWTON. (339 feet.)

10.	Pink sandstone, mostly thin bedded, with ripple marks and fucoid-like impressions	30 feet
9.	Soft black shales with traces of carbonified plant remains and some fragments of fossil wood	15 feet
8.	Pink and gray sandstone	30 feet
7.	Clay, shales and sandstones, latter sometimes white, all plant bearing much comminuted vegetable matter, matted beds of swamp plants and well preserved dicotyledonous leaves of Dakota type, determinable	10 feet
6.	Black clay, full of crabonaceous matter with locally 6 inches of impure coal	4 feet
5.	Quarry sandstone, massive, light pink, soft, weathering iron brown	60 feet
4.	Soft, yellowish and reddish sandstone	100 feet
3.	Drab colored clays with carbonaceous vegetable matter and gypsum crystals interbedded with yellow sandstones	30 feet
2.	Soft, yellow and reddish sandstone, with some clay layers	60 feet

JURASSIC.

1.	Olive gray drab or bluish clays with reddish and yellowish sandstone	——

Near Rapid City there were found in this formation two distinct strata of fire clay, several feet in thickness. Associated with the clay are numerous casts of dicotyledonous leaves.

No fossil animal remains have yet been reported from the Dakota about the Black Hills, and such are rare in this formation everywhere. On the other hand there are numerous traces of vegetable remains, not only the prints of leaves, but casts of pieces of wood, and in some strata vast quanitities of silicified trunks of trees. These are thrown over the slopes of ravines excavated in this formation. Near Rapid City on the slope southeast of the town, near Buffalo Gap, carloads of such material might be gathered. So far as has been observed they seem, however, not to be in position, but are rather of the nature of drift wood.

A point of special interest should be mentioned here, namely that numerous specimens of *Cycad* trunks have been found at various points. Those, which have been quite carefully studied and described by Mr. L. F. Ward, (Journal of Geology, 1894), of the United States Geological Survey and Prof. McBride (American Geologist, 1894), of the Iowa State University, were collected in the Southern part of the Hills, southwest of Minnekatha and southeast of Hot Springs. Specimens also have been found several miles north of Rapid City, and in a ravine southwest of that place. They all seem to be traceable to the lower layers of the

Dakota sandstone, and Mr. Ward partly for this reason strongly suspects that the lower layers, of this so-called Dakota formation may be older than that period. From the sandstone northwest of Mitchell, fossilwood and numerous sharks teeth have been obtained. It may be a question whether the stratum may not belong to the Ft. Benton.

THE DAKOTA EXPOSURE NEAR THE EAST END OF THE STATE.

We have already stated that very incomplete exposures exist in our State east of the Missouri. We will first give a section of the rocks obtained at Sioux City. To obtain this we combine the sections given by Prof. O. St. John in the second volume of White's report on the Geology of Iowa, page 193, with the data derived from the artesian well bored near by the exposure.

St. John's section is as follows:

7.	Soft yellow sandy rock with a nodular ferruginous bands; sometimes hard shale, brown sandstone layers	7 feet
6.	Ash colored gritty clay	1 feet
5.	Soft yellow laminated sand rock, in places tough shale, concretionary ferrugineous rocks	2½ feet
4.	Blue, slightly arenaceous clays with thin nodular ferruginous layers, thin carbonaceous seams sometimes found in upper portions	20 feet
3.	Soft, yellowish laminated fined grained sandstone with pink colored patches and rusty bands	12 feet
2.	Tough grayish, blue shale, micaceous sandstone, finely laminated, and inclined to a concretionary structure, contains leaves of willow, etc., also gasteroped shells	2–4 feet

To this is added from an exposure further up the river.

1.	Soft laminated ferruginous sandstone	10 feet
	Total	46–48 ft

From the artesian well as follows: The mouth of the well is 38 feet above the top of the sand rock or No. 7 of the section given.

1.	Soil and gravel	65 feet
2.	Gravel	25 feet
3.	Shale	54 feet
4.	Sandstone	191 feet
5.	"Chalk rock"	100 feet
6.	Gray limestone	110 feet
7.	Chalk rock ("probably Carboniferous")	100 feet

These strata probably belong to the Dakota formation, as recognized by Dr. Hayden as far down as No. 5 of the artesian section. The upper shaly portion of it has been called Woodbury Shales by Dr. White of the Iowa Geological Survey. The division between the Woodbury Shales of Dr. White and his Nishnabotna sandstone is uncertain, as is also its relation to the Dakota Group of Hayden. The former would probably overlap the latter 50 or 60 feet. This section would make a probable thickness of the Dakota Formation 300 feet at this point.

Across the Big Sioux east of Elk Point is an exposure from which the following section was taken. It is opposite the old mill site where quite recently some excitement has been produced by the supposed discovery of a workable bed of coal.

5.	Sandstone	45 feet
4.	Lignite of variable thickness and some places quite pure	3–4 inches
3.	Bluish shale	6-7 feet
2.	Sandstone, fine grained, compact	8-10 feet
1.	Shaly clay with pyrites and about four feet black carbonaceous shale	10 feet

The level of the Big Sioux.

Dr. White has given the following section over a locality from a point not far away, a little above the mouth of Broken Kettle Creek. (Geol. of Iowa, White, Vol. 2.)

14.	Light gray chalky limestone in thin shaly layers	10 feet
13.	Unexposed	47 feet
12.	Yellowish shaly layers, with large concretions	3 feet
11.	Ferruginaous shaly layers with some bluish clay	10 feet
10.	Soft gray and yellow laminated sandstone	25 feet
9.	Blue and gray, slightly gritty shaly clay	2 feet
8.	Soft yellow laminated sandstone	3½ feet
7.	Blue clay	½ foot
6.	Brown impure coal	⅙ foot
5.	Bluish gray clay	4 feet
4.	Soft yellow gray laminated sandstone	16 feet
3.	Unexposed	3 feet
2.	Bluish black clays, partly carbonecaous	3 feet
1.	Grayish clays	3 feet
	Total	130 feet

Of these numbers 1 to 10 may be considered Dakota Sandstone and number 2 is a black layer which has lately been mistaken for coal.

COAL OR LIGNITE IN THE DAKOTA FORMATION:

Though we may speak more at length concerning the matter in our chapter on Economic Geology; because of its bearing upon the structure of the Dakota Formation. we will give a few brief notes at this point.

These layers of lignite and black shaly clay have been long known in the vicinity of Sioux City and at Ponca. At the latter place it has been worked for a number of years, but it is considered a very inferior fuel. A formation corresponding has been struck in a well 2 miles north of Vermillion, at a depth of 147 feet. About Centerville a stratum of lignite was struck so frequently as to give great hopes of valuable coal deposits. But very incomplete sections were obtained from the wells. The first vein of lignite was reported to be 3 to 3½ feet in thickness, and about 3 feet below the general upland of the valley. Another purer bed 4 feet in thickness was found several feet below. The reasons given for abandoning the veins, were the lack of sufficient roof and the abundance of water which flooded the shaft which was sunk. Beds of lignite have been struck in wells north of the quartzite area; and pebbles of lignite are thrown up sometimes in considerable numbers from deep artesian wells.

THE DATA FROM ARTESIAN WELLS.

Since the discovery, 12 years ago, of deep artesian waters in the James River Valley, many wells have been bored over the portion of the State east of the Missouri river. All successful wells have entered the Dakota sandstone, and a number of them seems to have passed through it. A few sections will be given to indicate the general position and thickness of the Dakota formation at these various points. They also illustrate the structure of the Cretaceous beds of later stages overlying it.

These sections are less reliable than those already given, especially as to the nature of the rocks, for they are given by different observers not expert in the recognition of geological formations. These sections are mostly taken from the Report on Irrigation of the United States Agricultural Department for 1893.

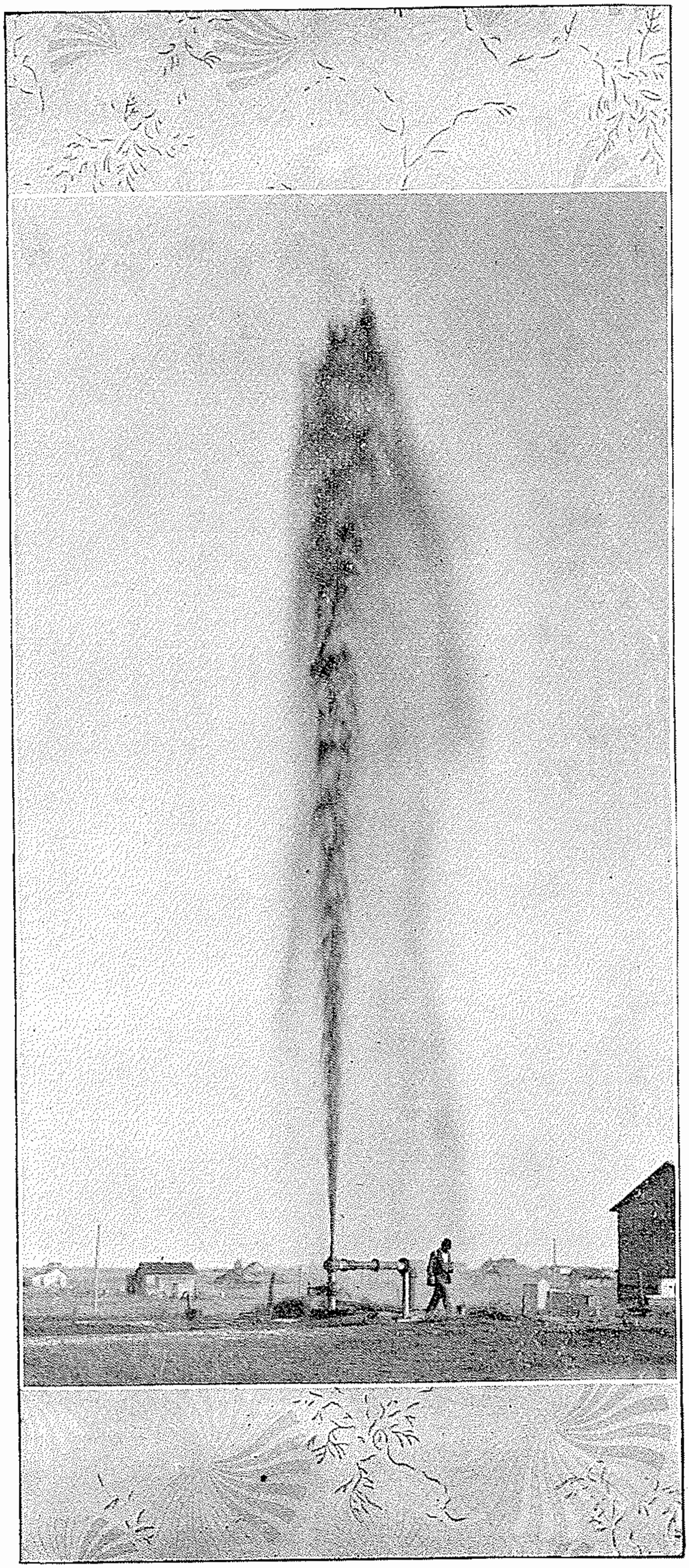


PLATE III.—ARTESIAN WELL, WOONSOCKET.

THE YANKTON WELL (ASYLUM)

ELEVATION ABOVE THE SEA LEVEL, 1285 FEET.

	Thickness.	Depth.
Yellow clay	25 feet	25 feet
Blue clay	30 feet	55 feet
Chalk	60 feet	115 feet
Shale	300 feet	415 feet
Sandy clay	185 feet	600 feet
Water-bearing sand	72 feet	672 feet
Total depth		672 feet

THE MILL WELL (YANKTON)

ELEVATION ABOVE THE SEA LEVEL, 1190 FEET.

	Thickness.	Depth.
Soil, sand and gravel	38 feet	38 feet
Chalk-like clays	62 feet	100 feet
Shale	26 feet	126 feet
Hard rock	4 feet	130 feet
Sand	34 feet	164 feet
Shale	65 feet	229 feet
Sand	25 feet	254 feet
Shale	135 feet	389 feet
Sand and clay	100 feet	489 feet
Water-bearing sand	106 feet	595 feet
Total depth of well		595 feet

THE SCOTLAND WELL.

ELEVATION ABOVE THE SEA LEVEL, 1338 FEET.

	Thickness.	Depth.
Soil	4 feet	4 feet
Drift clay, yellow above and blue below	55 feet	59 feet
Chalk rock, white above and blue below (Niobrara)	120 feet	179 feet
Blue shale (Fort Benton)	80 feet	259 feet
Gray and sand rock (Fort Benton)	100 feet	359 feet
Blue shale (Fort Benton)	40 feet	399 feet
Quicksand	30 feet	429 feet
Blue shale	35 feet	464 feet
Quicksand	30 feet	494 feet
Lime rock	13 feet	507 feet
Water-bearing sand rock	28 feet	535 feet
Quartzite	52 feet	587 feet

All between the Benton and quartzite may be considered Dakota.

THE TYNDALL WELL.

ELEVATION 1,410 FEET.

	Thickness.	Depth
Soil	4 feet	4 feet
Yellow clay	40 feet	40 feet
Blue clay	171 feet	215 feet
Shale	100 feet	315 feet
Hard rock (Niobrara)	7 feet	322 feet
Shale (Fort Benton)	75 feet	397 feet
Sand	60 feet	457 feet
Shale	245 feet	700 feet
Water bearing sand rock	35 feet	735 feet
"Stopped on quartzite."		

We may consider the last three strata as probably Dakota, though much of it is shale.

THE LAYSON WELL.

EIGHT MILES SOUTHWEST OF TYNDALL. ELEVATION 1,560 FEET,

	Thickness.	Depth
Soil	3 feet	3 feet
Yellow clay	32 feet	35 feet
Blue clay (partly drift)	55 feet	90 feet
Chalk rock (Niobrara)	280 feet	370 feet
Very hard limestone "	20 feet	390 feet
Black clay (Fort Benton)	14 feet	404 feet
Very hard stone "	1 foot	405 feet
Light gray clay or shale "	60 feet	465 feet
Soap stone "	300 feet	765 feet
Iron pyrites and tough clay	45 feet	810 feet
Sandstone, partly water (Dakota)	230 feet	1,040 feet
Coarse sand and gravel "	3 feet	1,043 feet
Hard stone "	3 feet	1,046 feet
Black mud "	27 feet	1,074 feet
Hard rock (made 1 foot and 8 inches in 3 or 4 days)	2 feet	1,076 feet

THE SALEM WELL.

ELEVATION, 1517 FEET.

	Thickness.	Depth.
Soil	2 feet	2 feet
Drift clay, yellow above and blue below	67 feet	69 feet
Quick sand	11 feet	80 feet
Blue clay	85 feet	165 feet
Soap stone	40 feet	215 feet
Blue sand (Dakota)	5 feet	220 feet
Blue shale "	2 feet	222 feet
Sioux Quartzite	25 feet	247 feet

THE MITCHELL WELL.

ELEVATION, 1316 FEET.

	Thickness.	Depth.
Soil	2 feet	2 feet
Sandy loam	38 feet	40 feet
Blue clay	90 feet	130 feet
White sand	40 feet	170 feet
Blue shale (Dakota)	115 feet	285 feet
Iron pyrites and lime "	1 foot	286 feet
Sand rock, water "	29 feet	315 feet
Blue clay "	34 feet	449 feet
Dry sand "	30 feet	479 feet
Blue shale "	50 feet	529 feet
Hard caped rock	1 foot	530 feet
Sand rock, water	18 feet	548 feet

THE PLANKINTON WELL.

ELEVATION, 1521 FEET.

	Thickness.	Depth.
Black loam	3 feet	3 feet
Yellow clay (Drift and Fort Pierre)	223 feet	226 feet
Chalk (Niobrara)	9 feet	235 feet
Shale (Niobrara and Fort Benton)	303 feet	538 feet
Sandstone, water	5 feet	543 feet
Shales (Dakota)	197 feet	740 feet
Sandstone, water "	5 feet	745 feet
Sioux Falls granite "	85 feet	830 feet

Chamberlain Well.—Elevation, 1547 feet. Struck Dakota at a depth of 716 feet and bored into it about 70 feet.

THE IROQUOIS WELL.

ELEVATION, 1403 FEET.

	Thickness.	Depth.
Blue loam	2 feet	2 feet
Blue clay	40 feet	442 feet
Shale	358 feet	400 feet
Sand rock, light flow	2 feet	402 feet
Shale	198 feet	600 feet
Shale	248 feet	850 feet
Sand rock flow	5 feet	855 feet
Sand rock, no flow	55 feet	910 feet
Soft rock, probably shale	190 feet	1100 feet

It is uncertain how much of this should be called Dakota, probably that below 850.

THE HURON WELL.

ELEVATION 1,251 FEET.

	Thickness.	Depth.
Yellow clay	13 feet	13 feet
Blue clay	76 feet	89 feet
Gray shale	151 feet	240 feet
Hard iron rock and sand	9 feet	249 feet
Gray shale	175 feet	424 feet
Hard sand rock	10 feet	434 feet
Shale, gray above and brown below	116 feet	550 feet
Conglomerate sand, shale, etc.	51 feet	601 feet
Gray shale	101 feet	702 feet
Brown limestone, cap rock	10 feet	712 feet
White sand rock, flow	50 feet	762 feet
Hard sand rock	10 feet	772 feet
White sand rock, flow	25 feet	837 feet
Gray lime rock	55 feet	892 feet
Gray shale	4 feet	896 feet
Gray limestone	10 feet	906 feet

THE MILLER WELL.

ELEVATION 1,586 FEET.

	Thickness.	Depth.
Soil, clay and gravel	220 feet	220 feet
Blue shale	710 feet	930 feet
Hard sand rock, iron pyrites	45 feet	975 feet
Shale	130 feet	1,105 feet
Hard sand rock, cap rock	6 feet	1,111 feet
Sand rock	5 feet	1,116 feet
Sand rock, no flow	29 feet	1,145 feet

THE PIERRE WELL.

ELEVATION ABOUT 1450 FEET.

	Thickness.	Depth.
"Gumbo," sandy clay and blue clay	72 feet	72 feet
Gray shale	20 feet	92 feet
Blue shale, hard streaks of rock	88 feet	180 feet
Black shale	70 feet	250 feet
Blue shale	70 feet	320 feet
Gray shale	145 feet	465 feet
Blue limestone, very hard	3 feet	468 feet
Dark gray shale	132 feet	600 feet
Blue shale	110 feet	710 feet
Dark gray shale	160 feet	870 feet
Yellow lime rock	5 feet	875 feet
Blue shale, with streaks of sand and rock below	275 feet	1,150 feet
Sand-rock, white, main flow	20 feet	1,170 feet
Shale, light color	22 feet	1,192 feet

Forty-two feet of this may be considered Dakota.

THE HIGHMORE WELL.

ELEVATION 1,900 FEET. HIGHEST WELL IN THE COUNTRY.

	Thickness.	Depth.
Soil, clay and gravel	240 feet	240 feet
Blue sbale	500 feet	740 feet
Hard gray shale and iron pyrites	75 feet	815 feet
Blue shale	271 feet	1,086 feet
Gray shale mixed with sand	224 feet	1,310 feet
Blue shale, capped with iron pyrites	120 feet	1,430 feet
Sandstone, water, not flow	12 feet	1,442 feet
Sandy shale	93 feet	1,535 feet
Hard sand cap rock	2 feet	1,537 feet
Soft sandstone, flow	15 feet	1,552 feet

The Dakota is penetrated here 122 feet.

THE HAROLD WELL.

ELEVATION 1,800.

	Thickness.	Depth.
Soil, drift	125 feet	125 feet
Blue clay	155 feet	280 feet
Limestone	2 feet	282 feet
Shale, blue above and gray below, with streaks of limestone	268 feet	550 feet
Black shale, sandy below	190 feet	740 feet
Shale, gray above, blue below, with streaks of lime	693 feet	1,433 feet
Lignite	2 feet	1,435 feet
Sandstone, main flow	16 feet	1,451 feet
Brown shale	2 feet	1,453 feet

Small flows at 1,000, 1,300 and 1,433 feet indicate the presence of sands at these levels.

ANDOVER WELL.

ELEVATION 1,505 FEET.

	Thickness.	Depth.
Soil, sand and clay	45 feet	45 feet
Blue clay, drift	30 feet	75 feet
Blue shale	500 feet	575 feet
Limestone	15 feet	590 feet
Shale, streaks of limestone	480 feet	1,070 feet
Sandstone, main flow	5 feet	1,075 feet

THE ABERDEEN WELL.

ELEVATION 1,300 FEET.

	Thickness.	Depth.
From No. 1, Pioneer Well—		
Soil and clay	16 feet	16 feet
Blue clay	78 feet	94 feet
Shale	400 feet	494 feet
Iron pyrites and shale	10 feet	504 feet
Blue shale	375 feet	879 feet
Sand, some water	10 feet	889 feet
From No. 3—		
More sandstone	22 feet	912 feet
Sandstones and lignite	5 feet	917 feet
To sandstone, capped rock	4 feet	921 feet
Sandstone, flow	20 feet	941 feet
Hard shale	25 feet	966 feet
Hard, fine sandstone	18 feet	984 feet
Sandy shale	32 feet	1,016 feet
Loose sandstone, main flow	50 feet	1,066 feet
From a fourth well, recently completed, reported by Mr. P. J. Stacy, beginning at 1,000 feet, below which he found a second flow in white sandstone	5 feet	1,000 feet
Blue shale	77 feet	1,077 feet
White sand-rock, third and main flow	23 feet	1,100 feet
Conglomerate	35 feet	1,135 feet
Blue shale	37 feet	1,172 feet
Pink and white shale	5 feet	1,177 feet
White sand-rock, no water	34 feet	1,511 feet
"Archean"	46 feet	1,257 feet
"Granite"	33 feet	1,290 feet

A specimen of granite, 4–5 inches in diameter, was submitted to me by Mr. S. W. Narregang of Aberdeen, which is said to have come from the bottom of well No. 4. It has every appearance of a granite boulder, such as is found at the surface in the Drift.

Ipswich. Elevation 1531.

No record of strata given. First flow 1000, second 1230; whole depth 1230.

From these records several deductions may be drawn.

First. The Dakota Formation varies considerable in thickness, and the line between it and the Benton cannot be drawn with confidence, because layers of sand between deposits of shale or clay seem to character. ize its upper portion.

Second. The Dakota in its junction with the promontory of Archean rocks runs out to a thin edge, and we may add with an irregular outline.

Third. From the wells in the latitude of Mitchell, we find that the lower surface of the Dakota rocks dips west, from about 1300 feet above the sea, at Salem, to 700 at Mitchell, and continues with slight declination west past Plankinton to Kimball. South of that line the Dakota formation lies at a higher level, with its base from 500 to 600 feet above the sea; but north of the latitude of Mitchell, the descent is rapid to an altitude of between 200 and 300 feet above sea, which seems to prevail extensively to the north and northwest. This agrees well with the conception that the promontory of older rocks extending from southwestern Minnesota slopes much more abruptly at the north than at the south; and that the ocean north was a few hundred feet deeper than the ocean at the south. No data have yet been collected to show the depth of the Dakota formation, below the surface west of the Missouri river, but we may presume with some confidence that it probably does not extend much below sea level. It is known from observations southeast of the Black Hills, that though the formation dips under the later formation at a high angle, it in a short distance becomes nearly horizontal. (Geol. Black Hills, p. 181.)

The proposed experimental borings to be made by the General Government will not only throw important light upon the possibilities of artesian wells west of the Missouri, but upon the depth and thickness of this formation.

Fourth. Another conclusion which seems to follow from the facts given, is that the strata east of the Missouri have not been perceptibly disturbed since their deposition. They everywhere show a gentle slope which would correspond well with the natural deepening of the ocean bottom. Moreover from the pressure of flows and the succession of strata it seems that the upper strata extend further east than the lower; as would be the case were they deposited in a gradual deepening and widening ocean.

METHOD OF FORMATION,

It was at first apparently taken for granted that the Dakota Group was marine. More recently an idea has been advanced that it is non-marine. Dr. White, in his Correlation Paper on the Cretaceous, (Bulletin 82, United States Geological Survey) takes it for granted that such was the case. The reason, so far as given, seems to be the following: The entire absence of marine life over large areas, and the occasional occurrence of fresh water forms, such as the *Unios* and *Cyrenia.* He remarks that vertebrate forms, once referred by Prof. Cope to the Dakota, have since been placed by him in the Jurassic. His conception of the formation of this deposit seems to be that it was a sub-aerial formation built up by streams upon a vast plain. He would harmonize with this view the occasional occurrence of marine forms in the southern and northern portions of the plains by supposing that the Dakota passed into marine equivalents both on the north and south. We are unable to fully accept his conclusions, for the following reasons:

First. It would seem more easy to explain the occurrence of fresh water forms in a marine formation, than the marine forms in a fresh water formation. For, not only would fresh water forms be carried to the sea by streams, but if the sea advanced over fresh water formations containing such remains, they would be redeposited like marine forms. The absence of marine forms over wide areas would afford no more objection to the marine character of this sandstone than that of many other non-fossilferous sandstones which are generally considered marine.

Second. This formation is conformable in many places, both below and above, with marine deposits, the Jurassic below and the Colorado above. Moreover beds of sand, indistinguishable from the main deposits are found interstratified with clays and shales, containing salt water remains.

Third. It is difficult to account for so wide and uniform a deposit of sand by the action of streams; while on the other hand such would be the natural result of deposits in wide stretches of open water. The sand layers would be deposited where currents and tide action prevailed; while the interstratified clays would be deposited in calm areas, which areas might in turn shift so as to cover and alternate with the sand. The boring of artesian wells has brought out in a remarkable way the constancy in thickness and wide extent of this feature. It seems to be demonstrated that they continue over thousands of square miles so as to convey subterranean waters hundreds of miles.

Fourth. We have seen that during the Triassic the region became very dry so that the waters were concentrated. During the succeeding age, the Jurassic, there seems to have been an inflow, not only of fresh water from the sea, but of new forms of life. From the overlapping of strata toward the east we cannot avoid the conclusion that during the epoch succeeding the Dakota, the sea had advanced over the whole Dakota area. Now it is commonly admitted that the advance of the shore line is usually attended with the cutting down of the gradually covered land and the deposition of sand strata over the adjacent ocean bottom. If the Dakota, therefore, were mainly fresh water deposits we would still expect to find marine sand deposits upon it. This would bring us strongly to the conclusion that the Dakota formation, so-called, must be, at least in its upper portion, marine. The rarity of marine forms and fossils in general, corresponds well with the supposition that the advance of the sea was so rapid as to be unfavorable to the preservation of shells or even to the existence of life.

Prof. Lesquereanx, the eminent paleobotonist, after a study of the formation and its numerous fossil plants. Cretaceous and Tertiary Flora. (Hayden's Final Report, Vol. VIII, p. 24.)

"We may consider the formation of the Dakota Group as produced by a very slow, gradual, prolonged depression of the western slope of the Continent, bringing up from the south or west the invasion of ocean water, charged with muddy materials, periodically heaped further and further inland by powerful tides."

ORIGIN OF MATERIAL.

Newton assumes that the formations from the Potsdam to the end of the Cretaceous were deposited with nearly uniform thickness over the whole area of the Black Hills as is exhibited in Figure 1; and Jenney seems

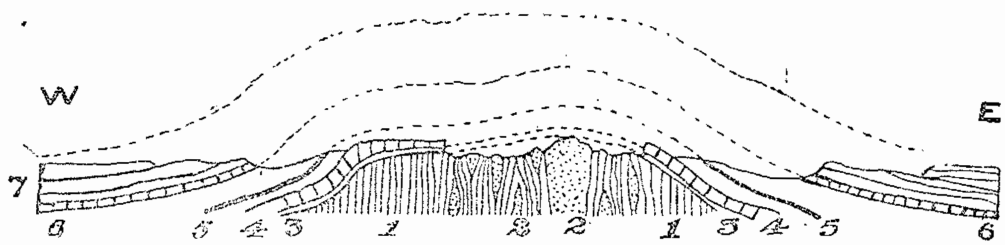


FIGURE 1. SECTION ACROSS THE BLACK HILLS, ACCORDING TO NEWTON.

1. Archean schists and slates. 2. Granite. 3. Potsdam. 4. Carboniferous. 5. Red Beds. 6. Jura. 7. Cretaceous. 8. Tertiary.
The dotted lines show amount of erosion.

to agree with this conclusion. If this were true, the origin of the material of the Dakota formation, as well as others mentioned, must have been from some area beyond the limits of our Territory. In the eastern part of Dakota the material may have been derived from the lands on the east which are now occupied by the Sioux Quartzite and further south by the Carboniferous limestone. This supposition is strengthened when we discover that the highest elevation of the Dakota, in the eastern end of our State, does not rise above 1200 or 1300 feet, while the Archean rises even at the present time to 1500 or 1700 feet. In the Triassic age the surfaces of these older areas were relatively much higher. Returning to the western part of the State we notice a serious difficulty in the conception of Newton. According to this no area is now known, nearer than the Rocky Mountains, which could have furnished material for the Dakota sandstone. Hence we find a difficulty in accounting for the thickness and uniform distribution of the sandstone about the Hills. Other students of the Black Hills have seen the difficulty of this view and have very generally come to a different conclusion. Winchell, after quoting Dr. Hayden, who presents a similar view to that of Newton, says:

"On the contrary there seems to be no reason to exempt the Black Hills from the general principles applicable to most of the mountain ranges of

North America. That after the elevation of the granite nucleus the successive sedimentary formations that surrounded it were raised by a series of paroxysms, produced by the long continued application of a cosmical force.

"The writer sees no more reason to suppose the sedimentary strata were until a comparatively late geological period entire and continuous over the region of the Black Hills, than to suppose the similar granitic and metamorphic axes of Minnesota were first covered by the continuous strata of the Silurian and Devonian, that bound it on both sides."

And he mentions as a fourth prominent movement of upheaval, one occurring after the Purple limestone with a large accession of dry land, particularly along the northern portion of the Hills. (Ludlow's Expedition, p. 65.)

As already mentioned, Prof. Carpenter found distinct unconformability between the Jurassic and Cretaceous near Rapid City, and concludes there from that the Hills were uplifted and subject to erosion prior to the lying down of the Cretaceous (Geol. and Min. Res. Black Hills, p. 46), and has strengthened this view by calling attention to the conglomerate character, around the Hills, of the lower beds of the Dakota and the occurrence of pebbles, in that stratum, which correspond in color and texture to the Archean quartzites in the Hills; and show that they were uncovered and brought within the action of the waves before the Cretaceous age began. Prof. Crosby heartily approves this view and considers that Newton's theory is really inconceivable. (Proc. B. S. N. H., Vol. XXIII, p. 510). We have not the means for knowing whether the Dakota originally ran out to a thin edge around the Hills, as we have found it around the Archean in the eastern portion of the State. But the entire absence of it inside the foothills strongly confirms such a view. If it at one time were deposited with uniform thickness over the Carboneceous plateau of the western side of the Hills, we can scarcely conceive of its being entirely removed.

THE COLORADO FORMATION.

It will be remembered that we included under this head the groups separated by Hayden, under the names of Fort Benton (or as Cope now calls it), Benton, Niobrara and Fort Pierre, or Pierre. The character and distribution of the separate sub-formations will be found given in the synopsis, at the beginning of the Cretaceous. King, in his study of the formations along the 41st Parallel, saw the justice of grouping these three formations under one head. After he had consulted with Dr Hayden, the latter gave hearty indorsement to the new classification.

Later the Canadian Geologists found an extensive formation in the Valley of the Belly River, which seemed to be overlaid by a portion, if not the whole, of the Pierre formation. This suggested the the separation of the Pierre from the two earlier formations. Besides there seems to be a clearly defined break in the continuity of life forms. In 1889, Mr. Eldrege, (American Journal of Science), of the United States Geological Survey, proposed restricting the term Colorado to the Benton and Niobrara, and also that the Pierre should be united with the Fox Hills, under the name of Montana. This classification received the full indorsement of Dr. C. A. White the veteran student of the Cretaceous (Bulletin No. 82, United States Geol. Survey.) The reasons for this latter classification, it is claimed, are found in the paleontology of the strata, but it is admitted by all that it does not well correspond with the lithological characters, which are most easily recognized. King, in his first announcement, says, with much satisfaction: (Geol. of the 40th Parallel, Systematic Geology.)

"This combination of the three areas of the old Meek and Hayden section into a new group is rendered of value for the reason already expressed, namely: The great variableness of the areas in detail; but is even more satisfactory in that it gathers into one member the great clay formations of the Lower Cretaceous.

"The whole Colorado group, composed of these three areas, is bounded on the upper surface by a heavy sandstone of the Fox Hill, and below by a still more compact sandstone of the Dakota. It is essentially a great body of shales and clays, divided in the middle by a zone of marls and conglomerate beds. Its usual mode of weathering is to form deep troughs directly upon the inclined Dakota.

"Whether horizontal or inclined the outcrop of the Fort Benton is usually below the neighboring level. Directly above it the marls and sandstones of the Niobrara group offer a great resistance to erosion and consequently form a series of slight outcropping ridges, beyond and above which the soft clays of the Fort Pierre again form depressions, and the typical appearance is therefore two depressions separated by the hard ridgy outcrops of the Niobrara."

Not only do the Pierre and Benton closely resemble one another in color and texture but also in the more common fossils. A mussel-like shell called *Inoceramus* occurs in several species througout the Colorado; though chiefly prominent in the Niobrara, where it is often very abundant in the shaly limestone. Other genera common to the three stages are, *Ammonites, Baculites, Scaphites;* while Cardium, Modiola, Tellina and Fusus are some of the forms not only common in these strata, but continuing to the present. The Benton is characterized by *Prionocyclas;* the Niobrara by large species of *Pinna* and abundant fish teeth and scales; and the Pierre by larger numbers of gastropod or snail-like shells. Marine reptiles occur in all members of this formation. Prof. Cope says (Lectures on Paleontology,) that the Benton contains vertebrate fossils, mostly of fish in poor preservation. The only reptiles yet found are of the form of a crocodile with flat articular vertebral faces. The Niobrara is rich in fish remains and also in reptiles with long necks, some resembling serpents in their long slender body. Also flying reptiles with bat-like wings and long toothed jaws; birds with reptilian tails and teeth. The Pierre formation contains *Mososaurus* and other sea serpents with huge paddles for swimming; and *Pterosaurs* with bat-like wings, and bird-like bills. Some of these winged lizards have been found with their stretch of wing 25 feet.

Mr. T. W. Stanton in a recent volume on the Colorado formation (Bulletin No. 106, United States Geol. Survey) has listed about 12 species common to the Colorado and Montana groups. He also brings out well the differences between the two faunas.

THE EXTENT OF THE FORMATION.

The Colorado group overlies the Dakota conformibly, around the Black Hills, where it dips at an angle of from 15 to 30 degrees away from them. In a short distance its beds become nearly horizontal. Along the north branch and main portion of the Cheyenne it dips gently northward under the Fox Hills. Along the south branch of the Cheyenne, along the Bad river, and along the Missouri, below the latter stream to the Niobrara, it dips southward under the Tertiary beds. It forms the bluffs overlooking the Missouri, from near the mouth of the Big Sioux to the mouth of the Moreau rivers. So also it forms bluffs along the Cheyenne everywhere east of the Hills. It forms the main body of the higher tablelands east of the Missouri; such as the Wessington Hills, Ree Hills, Bald mountains and the hills west and northwest of Aberdeen, also the East Coteau. As the map shows it covers most of the lower lands east of the Missouri. It is there, however, so covered with drift, that the true nature of the "bed rock" is often unsuspected. The bluffs near the mouth of the Vermillion river on the Nebraska side are perhaps the finest exposure of the Benton formation in our vicinity. The Niobrara "chalkstone" is finely exposed in the abrupt bluffs of the Missouri, above Yankton and, more or less, as far as Chamberlain. The top of this formation passes below the surface of the Missouri at the Great Bend.

Quarries of the chalkstone have been opened up at various points away from the Missouri river and natural exposures have attracted attention. On Clay creek, north of Volin, Spirit Mound; on Brule creek, north of Spink; northwest of Canton; 2 miles north of Brandon on the Split Rock; at Scotland; at Rockport on the James river; Mitchell, both on the James river, east, and on the Fire Steel, north; also west toward Mt. Vernon.

About the Black Hills, the Niobrara shows along the Cheyenne south of Buffalo Gap, also in the foot-hills west of the town and at numerous points along the railroad near Buffalo Gap and Rapid City. In some places it forms heavy limestone strata perhaps 20 feet in thickness. In other places it seems to be reduced to a stratum of huge concretions. East of Rapid City, it seems not to show a very hard stone, or durable character, and appears simply as a whitening and hardening of the clays.

The Colorado Formation seems to be of quite uniform thickness where remote from the margin. Like the Dakota, it runs out to a thin edge. It overlaps the edges that formation generally on the east because of its easy erosion it tends to form valleys.

The altitude of the summit of the formation may be given approximately as follows for different parts of the State: About the Black Hills, 3,400 to 3,500 feet; between the Cheyenne and the head of Bad River, 3,000; east bank of the Missouri, 1,900–2,000; in East Coteau, north, 1,800–1,900; south 1,300–1,400.

Everywhere these three members are conformable, and therefore the Pierre is always the highest and covers the lower by overlapping, except where removed by erosion. Both the Benton and the Pierre contain numerous deposits of iron pyrites, as has been shown in the sections of artesian wells. This frequently gives rise to spontaneous combustion, and produces what are sometimes thought to be volcanoes. The oxidation is sufficient to start the burning of carbonaceous matter in the shales themselves and also the organic matter surrounding. Cases of this sort have been reported from the vicinity of Iona, in Nebraska, opposite Elk Point, and more recently in Charles Mix county. Such phenomena were observed by Lewis and Clark in their first trip up the Missouri.

The decomposition of pyrites produces acid waters yielding alum and sulphuric acid, which render local areas barren of vegetation. When this sulphuric acid comes in contact with calcareous matter it forms crystals of selenite. This selenite, which is crystallized sulphate of lime, is often mistaken for mica, which is chemically a very different mineral. Carbonate of iron, sometimes in strata, and sometimes in concretionary form, occurs frequently in this formation. These layers of carbonate of iron, by their black appearance and their occurrence in the vicinity of the oxidation of pyrites, have strengthened the impression of igneous action along the Missouri Bluffs at various points. Others have mistaken these blocks of iron carbonate for coal.

These clays are usually rendered plastic by the infiltration of water along seams and over the surface, so that land-slides often occur, sometimes upon a large scale. This fact, together with the easy erosion of the clays, renders any close tracing of the strata practically impossible.

In addition to the sections from artesian wells, we will give the following, illustrative of the succession of strata in the Colorado. At the pass of the foot-hills on French Creek, Newton reports the following section overlying the Dakota sandstone at that point: (Geol. Black Hills, p. 181.)

3.	Clays, yellow, somewhat arenaceous, with thin, shaly limestone near the top, containg *Inoceramus*	50 feet
2.	Sandstone white coarse, somewhat conglomeritic at base	40 feet
1.	Clays of the Fort Benton, dark brown or black	150 feet

Nos. 2 and 3, he considered to be Niobrara, to which Prof. Winchell in the same vicinity assigned a thickness of 150 feet, while he estimated the Fort Pierre above it to be 250 feet. (Black Hills of Dakota, Ludlow, p. 49).

At the pass of the East Fork of Beaver Creek, which is on the west side of the Hills, Newton obtained the following section, from a small ridge west of the valley, and resting directly upon the Dakota sandstone.

7.	Gray clay shales	20 feet
6.	Brown sandstone, calcareous and lamellar, with a very fossiliferous layer containing imperfect specimens of *Ammonites,* teeth of *Lamna, Otodus,* and other fishes	5 feet
5.	Dark gray clay	15 feet
4.	Brown sandstone, lamellar	4 feet
3.	Dark gray clay shales	20 feet
2.	Sandstone, like number 4	10 feet
1.	Dark gray or black clay, shales, with selenite and alkaline salts	75 feet

This may be considered all Fort Benton. West of it he found fragmentary exposures of the gray yellowish clay of the Niobrara, and thin overlying colored clays of the Fort Pierre, containing many Calcareous boulders, or concretions filled with fossils.

Near the forks of the Cheyenne he found the following beds:

2.	Yellow sand or aranaceous clay (possibly Fox Hills)	20 feet
	Clay, shales, light gray, darker in streaks, within purer limestone at base, a few limestone concretions of fossils	110 feet
1.	Dark gray shale, with calcareous nodules, full of *Baculites, Inoceramus, Ammonites,* thickness to river	75 feet

1 and 2 without doubt belong to the Fort Pierre Group. This locality was visited by the writer and the statements made by Dr. Hayden and Newton as to its being a place wonderfully rich in fossils, was fully verifiled. The fossils occur in large oblate spherical concretions, having a thickness of 1 to 3 feet and a breadth of from 3 to 5 feet. These have been cracked vertically into polygonal columns and the cracks wholly or partially filled with calcite of various bright colors, as yellow, brown and red. *Baculites* of all sizes are found abundantly, also numerous bivalved shells, particularly of the genera *Inoceramus,* and also numerous gastropod

shells, such as *Fusus, Cyclonema, Fascioaria* etc. These concretions lie at irregular distances in the upper portions of the beds. Loose shells are also found in the clays particularly *Gryphea* and *Dentalium*.

CHALK IN THE NIOBRARA.

The Niobrara not only contains a few feet of shaly limestone and light colored clays with much calcareous matter, but also beds of true chalk, as has been shown by a more recent microscopic study of several investigators and well set forth by Prof. Calvin in his address to the Geological Section of the American Association, at their Brooklyn Meeting, 1894. In most text books and general writings upon the geology of the United States, the occurrence of chalk in our country has been denied. But in the common language of the inhabitants of the region extensive beds of the Niobrara have been known as "chalk," "chalk-rock" and "chalk-stone." Distinct statements have been made by scientific men of the existance of chalk on our western plains.

Prof. J. W. Bailey, in 1841, reports the discovery of abundant foraminifera in the specimen of "prairie chalk" collected by Niccolet. So, in 1843, a similar statement was made by the distinguished microscopist, Ehrenberg. In 1886, Prof. Marcou announced the occurrence of true chalk in America, before the Geological Association of France, and illustrated his paper with traces made with pieces of chalk taken from near Sioux City. Prof. Calvin brings out very distinctly the proof that extensive beds in the Niobrara are formed of *Foramenifera* and *Coccoliths*, resembling, and in some cases indistinguishable from, the corresponding forms in the chalk of Europe.

The origin of chalk is generally considered to be from the abundant growth of microscopic forms in a clear, shallow sea, remote from land. The depth, in some cases, may be as great as 2,000 fathoms.

The Pierre clays are exposed generally around the Black Hills, being overlaid by patches of Tertiary, east of the Hills, and with outliers of the Fox Hills formation, about the head waters of Bad river and north of the main part of the Cheyenne river. The region between the Cheyenne and Bad rivers is largely covered, if not wholly occupied, with this formation. East of the Missouri river, inside of the moraine, it is nearly everywhere hidden by the drift clays.

THE AGRICULTURAL EFFECT OF THE FORT PIERRE.

The effect of this member of the Colorado upon soils is thus expressed by Dr. Hayden: (Trans. Am. Phil. Soc., Vol. XII., Part 1.)

"This formation is, geologically, the most important one in the Cretaceous system of the northwest; not only from its thickness and geographical distribution, but also on account of its influence upon the agricultural capacity of the country. It is only second in interest to the succeeding bed (Fox Hill) in number, beauty, and variety of its organic remains, commencing about 10 miles above the mouth of the James river, where it is seen only in thin outliers capping the distant hills and bluffs, it gradually assumes a greater thickness as we ascend the Missouri, until we reach the great Bend, where it monopolizes the whole region, giving to the country underlaid by it the most gloomy and sterile aspect. At the Great Bend it attains a thickness of 200 feet, and continues to occupy the country bordering the Missouri to the mouth of Grand river, where it passes gradually beneath the water level of the river. These beds contain great quantities of a whitish saline substance, a yellowish material like sulphur, and an abundance of ferruginous matters, which often discolor the banks of the river."

He says further:

"It occupies the region of White river 50 miles from its mouth, and almost the whole valley of the Cheyenne, excepting the source of a few of its tributaries. It occupies an area of 200 miles in length and 100 in width."

He says:

"I have thus been particular in estimating its approximate limits and extent of surface, on account of its influence on the future destiny of that region. Where this deposit prevails it renders the country more sterile than any other geological formation in the northwest."

He estimates that it renders barren more than 30,000 square miles of the valley of the Missouri. Of this about 18,000 are in our State.

The injurious effects of this formation are considerable, mainly due to two causes: One, the soluable minerals which are popularly known as "alkali;" the other its refractory character under cultivation, which is due to its being quite pure clay. The alakali of which he speaks has been analyzed, and according to Dr. Hayes of Boston, an impure specimen obtained from Fort Benton, gave the following:

ANALYSIS OF "ALKALI."

Sulphate of lime	5.60 per cent
Sulphate of soda	43.40 per cent
Sulphate of ammonia and iron	3.25 per cent
Insoluable	44.00 per cent
Moisture and loss	3.75 per cent

This probably fairly represents the average composition of the material, though it varies in different localities. With abundant moisture it seems not injurious to vegetation; but in the later and dry portion of the summer it is concentrated so as to kill all forms of vegetable life. It rarely is sufficiently abundant to destroy vegetation, except in low closed basins which receive the drainage of considerable surface. When properly utilized it is not improbable that these ingredients will be found enriching to the soil.

The clayey character is a hindrance to cultivation in several ways. In the spring it is soaked with moisture so as to become miry and is, not only cold and moist at first, but later rapidly hardens and becomes packed into clods. It prevents rain from entering the ground and also interferes with the rising of moisture from porous strata which may exist lower down. Moreover the ease with which its surface is washed away, prevents accummulation of carbonaceous matter and other ingredients which are necessary to a fertile soil. Several counteracting influences, however, render it much less injurious than might be inferred from Dr. Hayden's sweeping statement. It should be remembered that his judgment was formed largely from seeing it in close vicinity to the Missouri river which he traversed repeatedly. On uplands away from the streams the effects of this formation are mitigated by several influences. The surface is so nearly level that soil of considerable depth is formed. This results not only from the repeated crops of vegetation but the mixing of siliceous matter and silt brought by the air from sand regions surrounding it, so that the surface has a much larger percentage of loamy material than the underlying clay. Numerous burrowing animals, such as prairie-dogs, etc., have assisted in rendering the clays more pervious to moisture. Between the Missouri and the Black Hills there are few places where the surface is not covered with buffalo grass and an even larger vegetation. In the early summer it is usually richly clothed with grass, but in the latter part of the summer it became dried into hay, which furnishes substantial food for the rest of the year. This thorough drying of the ground may be considered as partly the result of the impervious character of the clay sub-soil. The extensive cattle ranges about the Black Hills and west of Missouri are very largely occupied by this formation and with proper management it might be made a most valuable pasture region.

THE FORMATION OF THE COLORADO BEDS.

The occurrence of chalk throws an interesting light upon the origin of the Colorado beds. We have concluded that the Dakota beds were formed by the advance of the sea over the sinking land area. When the subsidence became more gradual, and especially in areas more remote from land, the accumulation of clays would take place in large quantities. This would be attended by the preservation of bones and shells of animals living in the sea, also by the deposition of pyrites from the well-known chemical reaction of decomposing animal matter and iron brought in solution from the land. Minor oscillations of the earth's crust would produce local beds of sand and variations in the composition of clays. In areas where the sediment was less abundant we should find an abundant growth of microscopic forms as foraminifera, producing beds of chalk. If this was attended with an increase of life of larger size we would have beds of chalk limestone. Where this was not abundant enough to produce continuous stratum it might produce patches, where calcareous matter would be more abundant, particularly about colonies or clusters of animals like oysters, *ammonites*, *baculites*, etc. These clusters would become a nuclei for the gathering together by molecular action of the calcareous material, mixed with clay in the vicinity, and thus we may explain not only the occurrence of the central formation of limestone, chalkstone, with its breaking up into huge calcareous concretions at some points, but the occurrence on a smaller scale of layers of concretionary masses in different portions of the Benton and Pierre members of the Colorado formation. This explanation would carry with it also the conception that the sea was gradually extending and deepening because of the subsidence of the shores, especially upon the east. This process continued from the beginning of the Dakota to the middle of the Niobrara formation; when a reverse movement probably began and gradually continued throughout the remainder of this period. The distribution of Cretaceous beds, so far as has been determined, from the fragmentary remains of its strata in Iowa and Minnesota, seems to harmonize with this theory.

THE FOX HILLS GROUP.

This formation contains many fossils similar to those found in the Pierre, but it is quite dissimilar in its lithological character. It receives its name from its prominence in the Fox Ridge, or Fox Hills, the conspicuous divide passing west-southwest, north of the Cheyenne river. It is composed largely of sand beds and shaly sandstone. Dr. Hayden, in his description of it, speaks as follows: (Trans. Am. Phil. Soc., Vol. XXI., Part 1).

"In ascending the Missouri river it first makes its appearance near the mouth of Grand river, about 150 miles above Fort Pierre. Near Butte aux Cres (a point not certainly known) it becomes quite conspicuous, acquiring a thickness of 60 to 100 feet and containing great quantities of organic remains. Here it forms the extension that is called Fox Ridge. The series of high hills, having a northeast-southwest course, crossing the Missouri river at this point. In its southwestern extent, it continues for a considerable distance nearly parallel with the Missouri, crossing the Moreau river about 30 miles above its mouth, then forms a dividing ridge between the Missouri and the Cheyenne, at which locality it has taken its name. Continuing thus its southwesterly course, it crosses the Cheyenne and is shown againin its full thickness at the heads of Opening creek and Teton river (Badriver), forming a high ridge from which tributaries to the Cheyenne and Teton take their rise. We thus find that this bed underlies an area of about 200 miles in length and 50 miles in breadth, or about 10,000 square miles."

He calls attention to its very beneficial effect upon vegetation; He says:

"It forms a much more fertile soil, sustains a more healthy and luxuriant vegetation than formation No. 4, the Fort Pierre, and abounds in springs of good water."

The writer visited the Fox Ridge a few seasons since, and was strongly impressed with the close resemblance of its vegetation, both in the abundance and species of plants, to that found in southwestern Iowa. In fact, this formation has a similar effect upon the soil to that exercised by the noted formation, called the Bluff Deposit or Loess, of the Mississippi valley.

THE EXTENT OF THIS FORMATION.

This has already been well outlined by Dr. Hayden, but later explorations have brought out additional facts concerning its distribution, particularly east of the Missouri river. Concerning its extent west of the Missouri, it need only be added that it occurs 100 feet or more in thickness in the northern part of Ziebach county, and was not seen to have many fossils. Instead of speaking of it as a ridge running directly southwest from near the mouth of Grand river, we should say Fox Ridge extends eastward north of the Cheyenne toward the bend in the Missouri at Forest City. We should associate this ridge with the highland in the eastern part of Potter county, known as Bald Mountains, whose eastern extent reaches to Faulkton. The nature of the formation, comprising this high land under the drift, has not been discovered, and the inference is drawn mainly from topographic features. North from eastern Potter county the high land extends beyond Bowdle. Upon the western slope of this high land, particularly north and west of Swan Lake, and also in the ridge known as Welland Buttes north of Forest City, a peculiar yellow loamy sand has been found which probably represents certain layers of the Fox Hills formation. No distinct fossils have been found to substantiate the conclusion. For similar reasons this formation is believed to underlie much of the ridge east of the Missouri in western Campbell county and also the high land in northeastern McPherson county. These points are represented upon the geological map, but are given as provisional only.

Considering the probable orgin of the Colorado Formation and the dip of the strata, it seems not improbable that the Fox Hills may have extended as far east as the East Coteau. The whole surface of that geographical feature is so covered with drift clays of the last geological epoch that no red rock has been clearly identified in our State north of Dell Rapids. Boulders, however, containing fossils of the Fox Hills Group have been found in the Des Moines valley in central Iowa. Considering the direction of ice movement during the glacial epoch, the most easy way of accounting for their occurrence in Iowa is by supposing that ledges of this formation formerly existed upon the East Coteau. Whether or not they were wholly removed by the action of ice during the glacial period is not yet known.

The answer to this interesting question may be found either by a boring upon the East Coteau, especially toward the northern end, or, possibly, from natural exposures in some unusually deep ravines upon the sides of this high land. The reason why Dr. Hayden considered the Fox Ridge as extending so far northward before it approached the Missouri seems to have been because erosion had been more active northwest of Forest City. This has been partly the work of Virgin Creek and partly because of local erosion which took place during the glacial period.

THE CHARACTER OF THE FOX HILLS.

This formation consists largely of gray and yellow thin-bedded sandstones, which sometimes weather to a pink color. With these are associated incoherent sands and arenaceous clays, the whole occupy 100-150 feet in thickness. The sandstones are rarely more than 6 inches in thickness and are frequently much thinner. They attain prominence in the topography of the country, especially in the vicinity of streams, by their durability. They are found capping cliffs and bluffs in a very clear cut and picturesque manner. They are cut by frequent joints, which traverse the layers in lines usually at right angles to one another. As a result of this, the buttes not infrequently show quite perfectly formed gable-like summits, of which the crest is a narrow row of sandstone blocks, and the slopes, produced by the slipping out and washing away the soft clays and sands underneath, which are covered with a loose shingle from the capping layer. These gable summits are not infrequently extending at right angles from the central portion of the butte.

The sandstones are frequently pierced with stems of plants standing vertically. In certain localities some of the layers become a very compact fine grained quartzite of a yellowish tint. Boulders from these layers, or from the overlying Laramie, are strewn over much of the region outside of the moraine and west of the Missouri river. They are usually quite smooth, and often exhibit holes, formed by the stems of plants before mentioned.

Along the streams resting on the north slope of Fox Ridge these harder layers form buttes upon which abundant fossils are found.

THE LARAMIE OR LIGNITIC FORMATION.

This formation has been the subject of much discussion, with reference to its position in the geological scale. Some have claimed that it belongs to the Tertiary and others just as strongly that it is Cretaceous. Some avoid the decision by calling it Post-Cretaceous; and others by placing part of it in the Cretaceous and part in the Tertiary, like a bridge between the well defined realms of life grouped under those names. It lies upon the Fox Hills, conformably, but there is no marked lithological character separating the two formations.

It obtains it name, Laramie, from its development in the vicinity of Laramie in Wyoming, and Lignitic from its containing numerous beds of lignite. This character, however, it is not as peculiar to this formation as was at first thought, hence it is not as expressive of its true character. The Fox Hills formation has been found to contain valuable beds of lignite in certain localities.

THE EXTENT OF THE LARAMIE.

Geographically its extent has been shown, so far as determined, upon the geological map. It occupies the northwestern corner of the State and large protions of Montana and North Dakota. Its eastern boundary may be stated as beginning on the north line of the State about 15 miles west of the Missouri and extending southwest to the northeast point of Cherry creek and west to Belle Fourche. From this line it extends as a capping formation. The Fox Hills is shown underneath it in the lower valleys of the principal streams. Eastward it forms outliers in the shape of conspicuous buttes as far east as the Missouri river, north of Grand river. The buttes in Campbell county are probably capped with this formation. From this margin as outlined in our State, it thickens toward the north and west, its thickness culminating in Montana.

THICKNESS AND CHARACTER OF THE FORMATION.

Dr. Hayden gives the maximum thickness of this formation as 2,000 feet or more, but this thickness is probably beyond our State. Mr. Baily Willis estimates that it may have been 1,500 feet thick in South Dakota, originally, although the sections measured by him in his expeditions between the Grand and Moreau Rivers near Rabbit Butte, gave only half of that thickness.

Hayden gives as his characterization of the formation, that it consists of beds of clay and sand, with rounded ferruginous concretions and numerous beds and seams of local deposits of lignite. Great numbers of dicotyledonous leaves, stems, etc., of the genera: *Platanus,* sycamore; *Acer,* maple; *Ulmus,* elm, etc., with a number of large leaves of true palms; also land snails, fresh water snails, oysters and scales of *Lepidosteus* (gar-pikes), with bones of *Trionyx* (leather-backed turtle), etc.

In 1884 an expedition was sent out by the United States Geological Survey, under the direction of Mr. Baily Willis, to examine reported finds of lignite in the great Sioux reservation. (Lignites of Sioux Reservation, Bulletin No. 21, United States Geol. Survey.) The area examined was about "2,000 square miles, lying between the Grand and Moreau rivers," including Rabbit Butte in its western extremity and Flint Creek along its eastern margin. The report of this region of "2,000 square miles" occupies less than five pages of descriptive text. From his figured sections, we transcribe the following sections of the Laramie strata. We combine the sections which he has given for the following localities, in descending order:

I. SECTION OF RABBIT BUTTE—

Top of Rabbit Butte, elevation, 2,900 feet.

Soil and sandstone	26 feet
Sand and shale	17 feet
Sand and sandstone	28 feet
Shale	2 feet
Lignite	1 foot
Sandy shale	20 feet
Lignite	1 foot
Shaly sandstone	13 feet
Lignite	½ foot
Sandy shales, with globular concretions, especially in the upper portion	112 feet
Sandstone	16 feet
Conglomerate	2½ feet
Shale, with concretions	25 feet
Sand	10 feet
Shale	5 feet
Sand	8 feet
Sandstone	50 feet

The level of Rabbit creek, 2,562 feet altitude.

II. SECTION OF BLACK HORSE BUTTE—

Top, elevation, 2,640 feet.

Sand and sandstone	20 feet
Unknown	30 feet
Sand and sandstone	15 feet
Lignite	2 feet
Shaly sandstone	5 feet
Lignite	1½ feet
Sand	5 feet
Sandy shale	24 feet
Sandstone	5 feet
Sandy shale	33 feet

Sand	2 feet
Sandy shale	4 feet
Sand or sandstone	4 feet
Sandy shale	19 feet
Sand and sandstone	41 feet
Shale	3 feet
Lignite	1½ feet
Sandy shale	9 feet
Sand and sandstone	12 feet
Base of exposure 2,404½ feet.	

III—SECTION ON GRAND RIVER—

Elevation of top, 2,375 feet.	
Soil and sand	8 feet
Sandy shale	22 feet
Sand and sandstone	12 feet
Lignite	2 feet
Sandy shale	15 feet
Sand and sandstone with conglomerate layers	68 feet
Lignite	1 foot
Sand	7 feet
Lignite	½ foot
Sand	2 feet
Lignite	2 feet
Sand and sandstone	13 feet
Lignite, only locally developed basins in sand	3 feet
Sand and sandstone	46 feet
Base 50 feet above Grand river, 2,168½ feet.	

These sections may be taken as representative of the Laramie beds. Although horizons of lignite may be considered general, as Mr. Willis remarks, the beds of sandstone, shale, lignite and iron ore pass into each other by abrupt changes in composition, He says that a bed of lignite from two feet to two feet four inches in thickness, was entirely replaced by nodules of iron carbonate within a distance of 300 feet on one side, while 400 feet away on the other side it had deteriorated into a brown clay.

We select also one of the most complete sections reported by Prof. N. H. Winchell. (Black Hills of Dakota, Ludlow, p. 26).

Section at Ludlow's Cave, Cave Hills, Ewing County.

1.	Slope, no rock seen	10 to 15 feet
2.	Silicious limestone, mostly gray and very hard, but sometimes porous, and of a lighter color; very rough; containing silicified wood and impressions of bones. This rock might be styled a quartzite	1 to 2 feet
3.	Whitish, sandy marl	50 to 60 feet
4.	Reddish sandstone with many concretions	40 feet
5.	Sandstone of Ludlow's Cave, rusty and castellated, about	40 feet

6.	More argillaceous and calcareous sand, white	15 feet
7.	Bedded blue clay (seen at a distance)	35 feet
8.	Unseen	85 feet
9.	Lignite	56 feet
10.	Massive white sandstone	
11.	Top of Bald Butte	
12.	Light yellowish, argillaceous marl, with ochre concretions, about	35 feet
13.	Carbonaceous shale, with selenite	5 feet
14.	Marbonaceous massive shale	4 feet
15.	Hard, gritty clay, weathering bluish	25 feet
16.	Sandstone and sand of Wolf Butte	
17.	White clay, (seen only at a distance)	

He says No. 2 is the source of the boulders scattered generally over the region west of the Missouri. No. 9 has frequently been burned, producing heat enough to bake the adjoining strata. In such cases the appearance is like that of old brick yards.

THE EQUIVALENTS OF THE LARAMIE.

These beds when first studied by Dr. Hayden were called Tertiary, partly because they seemed to fill the gap between the Fox Hills and the White River Beds, which are Miocene, and partly because the plant remains found in them are closely allied to the Tertiary. He very naturally assumed that these Laramie Beds represent the Eocene. The character of the vertebrate life, however, belongs to the Cretaceous. Bones of Dinosaurs were found in some of the beds and these had no where else been found later than Mesozoic time. The dispute is not yet settled, though not so hotly contested as formerly. The trend of opinion seems to be to favor a compromise of the rival claims by calling the formation Post-Cretaceous or Transitional.

THE ORIGIN OF THE LARAMIE.

This is a fresh water formation, at least for the most part. Dr. White, in his Correlation paper upon the Cretaceous (p, 263) says:

"The Laramie sea is understood to have occupied a very large portion of the area, which in the immediately preceding epoch was occupied by the marine waters, in which the Montana formation was deposited, and that at its close the waters of the Laramie area became more or less completely surrounded by land resulting from an elevation of sea bottom above water level. Its waters, consequently, became partly freshened by the surrounding surface drainage producing the habitat in which it was impossible for true marine forms to live but which was a congenial one for those whose remains we find there. Thus was recorded a great physical, as well as great biological, event in the geological history of the continent. Our estimate of the importance is enhanced, when we remember how great was the geographical area over which it occurred.

"It is reasonable to assume that the habitat of many of the vertebrate and other land animals, which existed within and around that area before the event referred to occurred, was not made uncongenial by its occurrence. But be that as it may, the strata, which physically constitute such geological horizons as I have defined in this case, are the result of sedimentation in great bodies of water, and physical changes which alter the condition relating to those bodies of water and materially affected the character of their denizens, were leading events in geological history."

Elsewhere he remarks: (p. 152.)

"That by some persons the opinion has been held that during the Laramie epoch proper, open sea waters made occasional incursions at different places upon the area occupied by the non-marine waters, whose fauna characterizes the Laramie formation, but although the frequent alternation strata-bearing brackish water fossils with those bearing only fresh water forms show that within certain districts brackish water alternated with fresh, I have, in my extensive examination of this formation, never detected any evidence of the incursion of open sea waters. Because it is my present belief that all true marine waters were withdrawn from the interior portion of this continent at the beginning of the Laramie epoch, no true marine strata are in this memoir recognized as belonging to the Laramie formation.

"While I am not prepared to admit that the open ocean made incursions upon the great Laramie inland sea after it had become established as such at the close of the Montana epoch, it is reasonable to infer that it had somewhere a more or less restricted outlet to oceanic waters, until all the area which it had occupied became in part dry land and in part a bed of the great fresh water Tertiary lake or lakes, which immediately succeeded it. What we now know of the various epeirogenic (continent building) movements, which resulted in the production of the present continent, leads me to believe that such an outlet, if one existed, was at the southern end, and this suggestion is supported by certain paleontological conditions which have been observed in the Laramie strata in the Texan and north Mexico regions. That is, certain fossil forms have been observed in this strata which seem to indicate a greater saltness of the water in which they were deposited than prevailed elsewhere in the Laramie sea; but these observations are too incomplete to be confidently relied upon in an inquiry of this kind."

CHAPTER VII.

THE CENOZOIC FORMATIONS.

Cenozoic means pertaining to recent or new life, and these formations are so called, because the fossil forms found in them resemble quite closely those still in existence. This is particularly true of lower forms; the higher forms of that time long since became extinct. The Cenozoic Eon is divided into the Tertiary and Quarternary Ages, though the tendency of late has been to make the latter a subdivision of lower rank.

THE TERTIARY FORMATIONS.

The Tertiary is divided into: Eocene, Miocene, Pliocene, or "Early Recent," "Less Recent" and "More Recent." Some include the upper part of the Eocene and lower part of the Miocene in another group which they call Oligocene, which means "slightly recent." On the other hand the Miocene and the Pliocene taken together are sometimes called Neocene or "newer recent."

The Tertiary Formations in our own State are now generally referred to the Miocene. Dr. Hayden, who has studied the region more carefully than others, although his work was published several years since, may still be considered the principal authority on these formations. Hence before entering upon a detailed discussion we will give a synopsis presented by him, which he published in the Transactions of the American Philosophical Society. (Vol. XII, Pt. 1, p. 105.) This is presented in stratigraphical order and is given in his own words.

Pliocene.—Bed F.—1st. Dark gray or brown sand, loose, incoherent, with remains of mastodon, elephant, etc. 2nd. Sand and gravel, incoherent. 3rd. Yellow, white grit, with many calcareous, arenaceous concretions. 4th. Gray sand, with greenish tinge, contains a great part of organic remains. 5th. Deep yellowish red, arenaceous marl. 6th. Yellowish gray grit, sometimes quite calcareous, with numerous layers of concretionary limestone from two to six inches in thickness, containing fresh water and land shells: Succinea, Limnea, Paludina, Helix, etc., perhaps all identical with living species; also much wood of coniferous character.

Covers large areas on the Loup Fork in Nebraska, also in the Platte Valley. Most fully developed on the Niobrara river, extending from the mouth of Turtle river 300 miles up the Niobrara; also on Bijou Hills and Madicine Hills, (S. D.). Thinly represented in the valley of the White river, in isolated patches over large portions of Dakota Territory, west of the Coteau des Prairies. Thickness 300 to 400 feet. (Less in South Dakota.)

Miocene. Bed E.—Usually a coarse-grained sandstone, sometimes heavy beded and compact; sometimes loose and incoherent; varies much in different localities. Forms immense masses of conglomerate; also contains layers of tabular limestone, with indistinct organic remains; very few mammalian remains detected, and those in a fragmentary condition, passes gradually into the bed below. Most fully developed along the upper portion of the Niobrara river and in the region around Fort Laramie. Seen also on White river and on Grindstone Hills, (S. D.) Thickness 180 to 300 feet.

Bed D.—A dull reddish brown indurated grit with many layers of silico-calcareous concretions, sometimes forming a heavy-bedded fine-grained sandstone; contains comparatively few organic remains. Niobrara and Platte riversand in the region of Fort Laramie, also in the valley of the Whiteriver. Conspiciuous and composing the main part of the dividing ridge between White and Niobrara rivers. 350 to 400 feet.

Bed C.—Very fine yellow calcareous sand, not differing materially from bed D, with numerous layers of concretions and rarely organic remains; passing down into a variegated bed, consisting of alternate layers of dark brown clay and light gray calcareous grit, forming bands, of which I counted 27 at one locality, varying from 1 inch to 2 feet in thickness.

White River, Bear Creek, Ash Grove Spring, head of Cheyenne River. Most conspicuous near White River and near the east base of the Black Hills. Thickness 50 to 80 feet.

Bed B.—A deep flesh colored argillo-calcareous indurated grit. The outside when weathered has the appearance of a plastic clay. Passes down into a gray clay with layers of sandstone underlaid by a flesh colored argillo-calcareous stratum, containing a profusion of mammalian and chelonian (turtle) remains. Turtle and Oreodon Beds.

Old Woman's Creek, a fork of the Cheyenne; at the head of the South Fork of the Cheyenne; most conspicuous on Sage Creek and Bear Creek and at Ash Grove Spring. Well developed in numerous localities in the Valley of the White River. Thickness, 80 to 100 feet.

Bed A.—Light gray fine sand with more or less calcareous matter passing down into an ash-colored plastic clay with large quantities of quartz grains disseminated through it, sometimes forming aggregate masses like quartzose sandstone cemented with plastic clay; then ash-colored clay with a greenish tinge, underlaid at base by a light gray and ferrugineous silicious sand and gravel, with pinkish bands. Great quantities of silica in the form of seams, all through the beds. Titanotherium Beds.

Old Woman's Creek, also in many localities along the valley of South Fork of the Cheyenne. Best developement on Sage and Bear Creeks. Seen at several localities in the Valley of the White River. Thickness 80 to 100 feet.

This synopsis includes all of the Tertiary Formations, except a few doubtfully referred to the Pliocene, mentioned further on.

Hayden at first considered the lower beds as belonging to the Eocene, but later he classified them as stated above. He grouped the first four beds, which he called White River, and placed the last bed in one which he called Loup Fork Group. The latter he called Pliocene. Prof. Cope, who, perhaps, stands first in authority because of his study of the vertebrate remains, considers that all of the beds mentioned above are Miocene. On the other hand, Prof. Scott, who has also spent much time in the study of vertebrate remains, maintains that the forms of life in the White River formation resemble those of the lower Oligocene of Europe.

THE WHITE RIVER BEDS.

These are the formations which occupy the noted Bad Lands, or "Manvaises Terres," between the White River and Cheyenne, southeast of the Black Hills. They have long attracted the attention of travelers, and have a world-wide notoriety. The surface of these Bad lands are almost entirely barren of vegetation over extensive areas. This is due in part to the rapid erosion and partly to the nature of the clay and absence of soil. One approaching the Bad Lands may gradually ascend a rolling, grassy surface, until he suddenly comes to a crest of ridge and finds himself gazing from a height of 200 to 400 feet upon a labyrinth of winding ravines and narrow ridges, which, in some places, widen into broad buttes capped with tables formed by harder strata, or surmounted with slender pinnacles, reminding one of the spires of a cathedral. At other points the harder beds stand out as cornices and buttresses around the more prominent buttes. While this may appear near by, further away he may see graceful, rounded domes and ridges, which remind one of hay-stacks or railroad embankments, where they continue as narrow ridges, with their tops extending upon the same level for some distance. The prevalent color is of an ashy gray, and in certain beds this is crossed by horizontal bands of a pinkish color. As stated by Dr. Hayen, these vary in thickness from a few inches to a few feet. From a distance they give one the impression of beds of stone of alternate colors, but on nearer approach the color seems not to indicate any difference in hardness, which shows it is not the difference in erosion, but only in the color. The stack-like buttes, which may attain a height of 50 to 100 feet, are often surrounded with very flat, smooth surfaces, some of them bare and level as a floor, others covered with a fair growth of grass, interspersed with cactus. That which surprises an observer is the occurrence of these perfectly barren knobs amid the grassy flats, and again, the sudden change from a grassy flat to a surface wholly occupied by deep ravines and sharp ridges.

The explanation of the strange phenomena just stated, seems clearly traceable to the rapidity of erosion which results, from the clayey character of the formations and the frequent changes of drainage. The clay prevents the imbibition of the water which during rains expends its whole force in erosion, and consequently the region during the dry season is unable to sustain vegetation. The sudden change from grassy surfaces to barren, can be explained by the former having been formed when the base level of drainage was at higher altitude so as to prevent the easy escape of sediments. The clay is largely of a plastic character and yet examples of landslides are strangely rare. Moreover the slopes of eroded surfaces are usually very abrupt. These features may perhaps be accounted for by the massive character of the clay and the general absence of joints and seams which would lead the water into the interior of the mass. Besides the steep slopes and ravines not only carry away the water rapidly, so as to prevent seepage, but also quickly remove the debris of the superficial slide, when it takes place. In this way the interior of the mass is kept dry, and, as a result, the buttes stand like rock. Another peculiar influence may also tend in the same direction. The clay, when wet, swells and blisters up on the surface, like slacking lime. When rain comes upon such a surface, instead of running over the outer surface, it makes its way through the pores, produced in the way described, and small streams and springs, already in vigorous motion, come out at the base of the buttes. From the general impenetrability of the clay, the water runs from the base of the abrupt slopes within a few minutes after the rain has begun. This causes the base to erode backward more rapidly than the upper part of the slope, and prevents the usual gentle slope which is found in ordinary loamy formations elsewhere. On the western side of the Bad Lands, in the southern part of Ziebach county, there is found what is commonly called the Great Wall, which extends from north to south for a distance of sixty miles. Its eastern side is generally abrupt, while the western slopes away gently toward the valley of the Cheyenne. Only one pass, suitable for wagon road, is found between the White river and the Cheyenne. The thickness of the formation of the Great Basin is from 250 to 500 feet, and next to White river, near the southeast corner of Ziebach county, the valley is cut down nearly or quite through the White River formation to the underlying the Cretaceous.

As stated by Dr. Hayden, the lower beds of the White river group have a different color, usually purple or yellow. They also abound in concretionary deposits of silica, which often resemble clusters of coral of a white or delicate blue or brown tinge. In other cases the silica is deposited in vertical seams which are from $\frac{1}{8}$ of an inch to 1 inch in thickness. These are the source of the thin fragments of chalcedony, which are scattered far and wide over the great western plains. In some cases these concretions are of spheroidal forms reminding one of hail stones.

Professors Newton and Jenney record the occurrence of a bed of conglomerate at the base of the Tertiary, (Geol. Black Hills, pp. 30, 185, 298.) It was observed at Old Woman, Butte and near Spring creek. It varies in thickness from 6 to 20 feet. As I found it absent in buttes south of Rapid creek; it is probably local in development. Jenney says "the conglomerate is made up of small boulders, round and water-worn, of granite, trachyte, slate, quartzite and quartz, with chert nodules from the Carboniferous."

The White river beds, though noted for their remarkable and abundant vertebrate fossils are remarkably barren over wide areas. The eye roams over thousands of square yards of gray and pink clays without the slightest trace of bones, shell or pebble, which if present, would be easily recognized at a distance of many rods, because of the break it would make in the symmetrical contour of the slopes. As has been indicated by Dr. Hayden, in his synopsis, in the upper portions of the Tertiary there are extensive beds of conglomerate which are not often of great thickness. Their distribution and oblique stratification suggests their marking the former channels of rivers and currents in the lake. Lower down there are layers of fine sandstone and sandy marl which are filled with worm borings, and at their levels there are thin layers of sand or conglomerate sandstone in which pebbles of clay are abundant. On exposed surfaces these pebbles have dissolved and washed out so that the strata resembles thin layers of scoria, the rounded openings suggesting that origin.

FOSSILS OF THE BAD LANDS.

At other levels in restricted areas skeletons of vertebrates, large and small, are very abundant. They are so numerous as to suggest their having perished in droves, which may have resulted either from some severe storm, causing them to perish from the cold, or more likely from their having been caught upon some exposed point in the ancient lake and overwhelmed by the rise of water attending such a storm. The bones are rarely in a state of good preservation. They are not only broken by the pressure of the superincumbent clay, crushing them, and by its creeping motion separating them, but often the silica deposited in the smaller cracks seems to have split them into fragments. This seems especially common in the teeth and harder bones, so that although nearly all parts of the skeleton may be found within a square rod or two, there are usually but few pieces more than six inches in length. This is especially true of the Titanotherium. In the Oreodon and Turtle beds firmer deposits more frequently occur, and bones are found imbedded in the stone much as in the case of older rocks. In some cases they seem to have served as nuclei for concretions. Besides the bones of animals which evidently roamed upon the plains, there are also traces of squirrel-like animals which may have been counterparts of the prairie dogs and ground squirrels of the present time.

Of the animals whose remains are found in the White river formation, and for the knowledge of whose character we are indebted to the labors of Profs. Cope, Marsh and others, are the following: A small horse having three toes on each foot; the *Oreodon*, which is sometimes described as the animal combining the characteristics of the deer, hog and sheep, not exceeding the last in size. There were also found traces of hyena-like animals; those resembling the hyrax or cony and some species of edentates; then the *Titanotherium* or as some of its forms have been called, the *Brontotherium*, which resembles the tapir in general habit and structure, although its size approaches the hippopotamus; also species of rhinoceros and forms nearly identical with the oppossum. With these are also found rodents and a few lemur-like animals.

SAND DIKES.

At varions points in the Bad Lands the White river marls and clays are traversed with thin dikes of sand. They may be seen keeping one direction for many rods and dividing hard and soft beds alike from the top of the highest pinnacle to the bottom of the lowest ravine. One of the best illustrations of this phenomenon was found in the highest point of the Great Wall, just north of Sage Creek Pass, near the west side of township 1, south range 16 east. Here were two dikes crossing one another at a small angle running nearly east and west. Across them were two others nearly north and south. These seems to be examples of sandstone dikes, such as are described by Prof. Robert Hay in the proceedings of the Geological Society of America, for 1891, p. 50, as occurring in northwestern Nebraska, near Chadron. On the Great Wall these dikes were from 6 to 8 inches in width. The structure consist of thin lamina on the outer portion of the dike, running parallel with its sides. About the middle half was of columnar structure, divided by joints running perpendicular to the walls of the dike. The lamina in the outer portion were frequently fluted vertically and showed other signs of upward motion of the mass. Nothing was found forbidding the theory of Prof. Hay who suggests that they are formed by earthquakes which produced fissures reaching down into the underlying water-bearing stratum. It seems not improbable that these fissures may have extended through the Tertiary and upper Cretaceous beds to the Dakota.

These dikes were evidently formed soon after the deposition of the White River Beds, perhaps at the time of certain eruptions of igneous rocks in the Black Hills. Similar dikes less prominently developed were noticed not far from Black, in south Ziebach county, on White river.

ABSENCE OF ALKALI.

The white color of the beds and of the water found in portions of the Bad Lands readily suggest to a traveller who has been acquainted with alkali basins elsewhere, that the Bad Lands abound in soluble minerals usually known as alkali. Such, however, seems not to be the case. In the Tertiary formation the white appearance of the formation is due to the color of the clay, and the water, although white and milky, often resembling curd in consistency, has no alkaline taste and seems to be mostly a mixture of very fine clay with rain water. Indeed, the presence of soluble salts would doubtless assist in the floculation and precipitation of the clays. The water in the Bad Lands receives its clays immediately after the falling from the clouds; and water will stand for weeks without its settling. In fact, as the water evaporates, the mixture increases in tenacity until it becomes thoroughly dried. In the spring of the year the clay is so thoroughly saturated with water and softened that roads are entirely impassible, Even later in the season the subsoil may be soft and yielding, while the surface is dry and hard. Serious accidents have sometimes occurred from animals and travellers falling into these treacherous pitfalls,

THE ORIGIN OF THE WHITE RIVER BEDS.

All students of this formation agree that it is mainly a Lacustrine formation. As we have sketched the geological history of the region preceding the Tertiary, it will be remembered that the sea had retired from the region at the end of the Fox Hills Epoch; that the Laramie formation was of fresh water origin, either of local lake, or delta deposits of streams. During the Eocene, large areas west west of the Rocky mountains were occupied by great fresh water lakes and marshes. Toward the end of the Eocene the mountain region rose and this water seems to have shifted, partly to the east and partly to the west, forming in eastern Nevada and northern California a great lake; and a still larger one over the region of the great plains from Kansas northward, perhaps beyond the Canadian line. This lake has been named, by Prof. King, "Sioux Lake." The partial elevation of the Rocky mountains quickened the action of the streams and extensive areas covered with mud flats of dry Cretaceous seas contributed their masses of mud and sand to the building up of the White river formation. The picturesque representation of this in the Bad Lands is but a skeleton of its original mass. At first the formation doubtless extended over the valley of the Cheyenne river, and the abundant erosion produced by that rivei has since carried away scores of square miles of the full thickness of these beds. The portion under consideration was toward the northern side of the lake, which has its greatest depth in western Nebraska and Wyoming. We may picture to ourselves the shores of this lake as surrounded with mud flats, for the accumulation of material doubtless went on rapidly. This is indicated by the general absence of vegetable remains and of fresh water shells. That vegetation was abundant on higher areas further back seems certain, from the abundance of vertebrate life which was sustained in the neighborhood. We have already referred to the possible explanation of the wholesale destruction of various animals and their preservation in the strata of this formation. It seems not impossible that storms may have swept the region as at the present time, although the climate was doubtless much warmer. These storms would have had a tendency to drive the hordes of roaming animals over the region, often into the lake. Besides, many of them would be attracted to it both for drinking and cooling themselves. We find few traces of water animals, the turtle being almost the only kind. It is not unlikely that the water of the lake was very muddy, and this may have been unfavorable to the water breathing animals. Some of the beds of sand and grit, which have a local development, may possibly mark the course of the streams flowing from the Black Hills into the lake, and extending their deposits as the shores became more restricted by the deposition of sediments.

THE CHARACTER OF THE LOUP FORK BEDS.

These are not so prominently developed in South Dakota as in northern Nebraska in the basin of the Loup Fork. In general this formation includes the upper Tertiary beds, such as are described collectively as "Bed F." in Hayden's section. The present surface is made up of sandhills alternating with areas of clay or loam. The sand presents the usual appearance of dunes. The division between this and the White river formation is not clearly marked. The bed of conglomerate mentioned by Hayden in his "Bed E." may be considered as the most convenient horizon for distinction. This appears conspicuously on top of certain buttes of the Bad Lands; and while it has not been the privilege of the writer to visit some of the buttes between the Hills and the Missouri river, it seems from reports to be the same which is conspicuous in Grindstone Butte and in other prominent buttes in that region west of the Missouri.

Dr. Hayden refers to the Bijou Hills as containing beds of the Loup Fork formation. We have not been able to obtain his section of these hills and therefore are not sure of its interpretation. The Bijou Hills are capped by a formation of greenish and grayish conglomerate, 15 to 20 feet in thickness. This conglomerate is of very irregular structure, showing frequent traces of oblique lamination, contains pebbles of considerable size and calcareous concretions. Perhaps the most conspicuous feature in it is the solidification of some of its layers into translucent, fine grained quartzite of a greenish tinge. This rock is characteristic and is found also upon Medicine Butte, near Medicine creek in Presho county, also capping a number of buttes south of White river, west of the Bijou Hills. It seems also to form the base of the table land extending south and west from the Missouri in Gregory county. It seems not impossible that this quartzite conglomerate may be an extension of the conglomerate capping the buttes in the Bad Lands between the White river and Cheyenne.

FOSSILS IN THE LOUP FORK.

The vertebrate remains of this formation present very different characters from the White river. The Brontotherium, Oreodons and Coneys have passed away and instead we have animals more closely resembling those still in existence, in many cases belonging to the same genera. In this formation we have the remains of Mastodons, Mammoths, Camels, Lions, and of horses equal in size and similar in form to those of the present.

THE ORIGIN OF THE LOUP FORK.

It is universally recognized as a fresh water formation, deposited largely, if not entirely in a great lake similar to that forming the White river formation and probably a continuation of it. From a movement of the earth's crust it was shifted more to the east and south so that it extended no farther north than the White river but much farther south into central Texas. King named this lake, "Lake Cheyenne." The elevation of the Rocky Mountains had so continued that the streams from the west into the lake was much quickened and hence brought more sandy material, or we may suppose the erosion had so far removed the softer Cretaceous beds that it began to extensively carry away the edges of the Dakota sandstone. At any rate coarser material abounded and sand flats took the place largely of mud flats. These under the action of the winds were shifted into sand ridges and dunes, which probably easily developed themselves over the dried portions of the former lake bed. The plains gradually increased in area from the foot of the mountains eastward and became the home of the herds which in kind resembled those of Africa or southern Asia of the present time.

THE EXTENT OF TERTIARY BEDS.

We have indicated upon the map in a general way the extent of the White River and Loup Fork formations without attempting to distinguish them by a difference in color. In brief, the Tertiary occupies the whole valley of the White river to the divides between it and the Cheyenne and Bad river; also the country south of the Nebraska line. The margins of this area have been much cut away by the prominent streams leaving numerous detached outliers which usually are considerably elevated above the surrounding country. Patches of these are found extending 30 miles west of the Cheyenne between Rapid creek and French creek. So also north of Bad river the Tertiary extends around the head waters and doubtless had numerous points between the tributaries on the north side of that stream. Near the Missouri river the Tertiary beds are known to occur in the Bijou Hills and in similar hills continuing the range west of the Missouri; also in Medicine Butte. The Tertiary quartzite has also been observed a few miles west of Choteau creek on the 43d parallel, and probably forms the core of the high range of hills between Lake Andes and the Missouri. The same strata are known to occur just south of our State a few miles west of Niobrara, and less than 10 miles southwest of Yankton. In the Wessington Hills a bed of sandstone resembling that in the Bijou Hills is found, about 100 feet below the summit, near Wessington Springs. Beds have been found in the Ree Hills which have furnished numerous species of fresh water fishes, which have been described by Prof. Cope. These may belong to later epoch of the Tertiary than the White river, but it seems not improbable that the same formation occurs in Medicine Knoll, near Blunt. Various conspicuous buttes west of the Missouri to the north and east of the continuous Tertiary beds doubtless contain the same formation and have been so reppresented upon the map.

THE PLIOCENE FORMATION.

More careful study may possibly prove the absence of this age in our State, but some small areas have been marked upon the map provisionally to call attention to certain beds of clay and sand that underlie the glacial drifts in the vicinity of the Big Sioux River. After the Loup Fork Epoch there seems to have been a change in the drainage of the region or at least a time of much erosion in the northern part of the area previously occupied by Lake Cheyenne. In the valleys of the streams we should expect to find river, or possibly a lacustrine, deposits lower down and of more recent origin than the well marked beds of the Miocene. It will be rememberd that Dr. Hayden applied the term Pliocene to the Loup Fork beds but more recently it has been applied to the formation overlying or filling the depressions of the Loup Fork formation. In western Nebraska and Kansas such have been called *Equus Beds* because of the frequent occurrence of teeth and bones of horses.

Along the valley of the Big Sioux, outside of the outer Moraine, where the ice of the Glacial Epoch seems not to have been so energetic in its action, beds of clay and sand are found which are clearly preglacial and yet more recent than the surrounding Cretaceous beds. From their stratigraphic and topographic position they are thought to be contemporaneous origin with similar clays and sand in southwestern Iowa, from which a *Megalonyx* claw and teeth of horses have been obtained.

Three or four miles northwest of Sioux City, near the railroad crossing of the Big Sioux, beds of fine sand, overlaid with gray and yellowish clays with very few pebbles, and these apparently not of northern origin, are found overlying the Cretaceous beds at a height of 150 to 175 feet above the river. Beds of Loess lie above them. All these beds of sand resemble others similarly situated 40 to 50 miles west in northern Nebraska. In the sand, bones of mammals have occasionally been found but as yet have not been fully studied. Mr. H. F. Bain of the Iowa Geological Survey informs me, that some teeth obtained from these beds have been pronounced *Equus major* by Prof. Cope, who therefore considers them Pleistocene.

It seems not improbable that a small area of the same formation may exist underneath the Loess north of Richland in Union county. A hypothetical Pliocene area has been marked upon the map. Ascending the Big Sioux river beds of clay have been reported on the Iowa side near Hawarden, which have been referred by the Iowa Geological Survey to the Fort Pierre Epoch of the Cretaceous and this may be their real age. North of Eden, on the Dakota side is an abrupt bluff where an exposure of gray clay is found 50 to 60 feet above the stream, and above it under the drift is a bed of sand 5 to 6 feet in thickness. The clay may be of the Pierre formation; the sand of the lower portion of the glacial drift, but it possibly corresponds to the sand beds before mentioned near Sioux City. About a mile west of Fairview, opposite the sharp bend in the Big Sioux, is an abrupt bluff showing an exposure facing the stream. The following is the section taken at this point:

SECTION NEAR FAIRVIEW—

8.	Slope covered with bouldery clay	50 to 100 feet
7,	Drab, pebbleless clay	14 feet
6.	Unexposed	4 feet
5.	Drab clay, thinly laminated, without fossils and without pebbles	17 feet
4.	Fine, gray sand, horizontally stratified, about...12 to	15 feet
3.	Slope	40 feet
2.	Dark lead-colored or blackish clay, with broken bits of shells	5 feet
1.	Shale, with large calceaceous concretions: The level of the stream	2 feet

On the Iowa side of the Big Sioux, east of Canton, there are beds of lead-colored clay and sand exposed in the lower railroad cuts. On the slopes of the hills upon that side south of the railroad, and also in the steep bluffs northeast of Fairview, S. D., a change in slope, attended with springs seems to mark a continuation of these beds at nearly equal height above the stream. The age of this pebbleless clay, as before suggested, may be of the Fort Pierre Epoch, but nothing requires that explanation, and against it there is the serious difficulty, that in some places there is a layer of sand, unconsolidated, between it and the clays, which are clearly of Cretaceous age. The presence of this sand would strongly lead us to the concluson that the clay, as well as the sand, is of post-Cretacious origin, while the occasional occurrence of northern pebbles in the overlying clay, makes the conclusion more reasonable that both are either Pliocene or the very earliest portion of the Pleistocene.

THE QUATERNARY OR PLEISTOCENE FORMATIONS.

The Quaternary Age, or as it is sometimes called, the Post-Tertiary or Pleistocene (more recently), is the shortest of the geological ages, and, perhaps, should not be ranked as a separate age. Many of the forms of vertebrate life now living began with this age, while certain larger mammals, like the mammoth and mastodon, have long since become extinct.

The most characteristic feature of the age seems to have been the inclement weather, and the consequent extension of a great ice sheet over the northeastern portion of North America; hence, it is often called the Ice Age, or Glacial Period. South Dakota illustrates well the different kinds of work done by nature's forces at that time. The eastern half of the State was covered with the ice sheet, while the western half was subject to unusual floods of water, which flowed in great volume down the valleys of all the principal streams.

It is difficult to classify the deposits of this age according to the chronological order of their formation. It seems rash to attempt it, except in a general way. The characters of the different deposits, however, are quite distinctly marked and are generally easily recognized. We may classify them as (1) Glacial Formations or Drift; (2) Fluvial Formations including Lacustrine, and (3) Eolian and Residual Formations.

GLACIAL FORMATIONS OR DRIFT.

One of the most clearly defined formations of the Quaternary is the Glacial Drift, which is usually easily recognized by its containing boulders or pebbles of foreign origin, that is, unlike rocks found in ledges in the region over which they lie. These boulders, moreover, often show traces of grinding and scratching, in such a manner as is rarely, if ever, produced by other natural agents than ice; either in the form of glaciers, or in the form of floating ice, such as icebergs and river ice. The drift may be conveniently divided into: First, Drift Sheets, where the formation is of broad extent and comparatively uniform thickness and even surface; and second, Drift Hills, where the drift formation is associated with more or less abrupt elevation, such as ridges, knobs, etc. The sheet form of drift may be divided into Till or Boulder Clay, which is unstratified, and Stratified Drift. The drift hills may be divided into Moraines, Osars and Butte Ridges.

TILL.—This formation is unique in that it presents often times great thickness without lamination or stratification. It consists of a mixture of sand and clay with more or less of boulders and pebbles variously scattered throughout the mass. Its color is usually a rusty yellow above in portions that have been permeated by surface waters; while the lower portion and the more compact are usually of a dark drab or blue. The clay is usually very hard and compact, requiring a pick to dig it. This is particularly true of the lower portions. Sometimes it contains much calcareous matter and has been more or less consolidated. It is usually traversed with joints and cracks running in all directions, and hence the name "joint clay," which it is often called. It covers more or less completely all portions of the State east of the Missouri river. Its thickness varies from a few feet to perhaps 200 feet, averaging 50 to 60 feet. It becomes less continuous, and broken into patches, as it approaches that stream, and more particularly the line drawn upon the map as marking the western border of the drift. The Till is generally believed to have been formed underneath an ice sheet, resembling the great glacier which now covers Greenland. Some portions, however, may ultimately be shown to have been the work of floating ice in connection with lakes or flooded rivers.

THE STRATIFIED DRIFT.—This is found locally, particularly in valleys and near streams, and usually overlies the Till. It is found prominent along certain ancient water courses and near the present streams. It consists of beds of pebbly clay sometimes interstratified with sand. The pebbles and boulders in it are usually water-worn, although they sometimes show traces of striation, indicating their former subglacial condition. This formation is attributed to the action of waters flooding the valleys during the occupation of the country by the land ice, and especially the passage of waters resulting from its rapid melting at the time of its disappearance.

MORAINES.—These may be defined as elongated ridges, or systems of ridges and knobs, which run continuously in long winding lines across the surface of the country. They seem to be confined to no particular elevation, but vary very much in their height, width and abruptness.

They are believed to mark the position of the edge of the ice sheet at the time when it remained stationary for some time.

In other words, when the ice sheet had a slow motion from the center toward the circumference, particularly toward the south, it was rapidly melted away by the sun and the warm winds. Sometimes the motion of the ice exceeded the rate of melting; in such a case the ice would advance. At other times the melting would go on more rapidly than the ice was supplied from its source; in such a case the ice sheet would withdraw. The moraines were formed when these forces were nearly in equilibrium. The moraines are sometimes in form of low ridges with gently sloping sides, especially toward the north. At other times the material carried by the ice, which would otherwise have been accumulated, seems to have been carried away by the streams issuing from the ice, or carried away by bergs floating away from the ice sheet. In other cases the surface of the moraine was roughened with knobs, sometimes rising to the height of 40 or 50 feet above the surrounding country, and among the knobs are often pond-holes and lake-basins of all sizes and shapes. These were formed in some unknown way during the process of the building of the moraines. As follows from this explanation, there are several moraines marking different stationary stages of the ice during the time of the withdrawal from the country.

The general position of the moraines may be more clearly understood if we say that it seems clear that previous to the occupation of the region by the ice sheet, the Missouri river probably left its present course near Fort Stevenson, and passed eastward into the present James River Valley, which it followed southward, and that the various tributaries from the west flowed east to that valley. The Grand and Moreau rivers probably passed to the vicinity of Aberdeen; the Cheyenne and Bad rivers, to the vicinity of Huron, and the White river, by Red and White Lakes, to Mitchell.

We may suppose that the ice came into our State from the Red River valley and overflowed the divide between it and the ancient Missouri and cut down its narrow portion north of the Head of the Coteau in Marshall county; filled the present James River valley, (then belonging to the Missouri) nearly to the southern boundary of our State; also extending up the valleys of the western tributaries, before mentioned, west nearly to the present course of the Missouri river. The ice at that time covered nearly the whole surface of our State east of the Missouri. Probably a portion of the east Coteau, the highest position of the Wessington Hills and Ree Hills, and the highland northwest of Leola and about Bowdle and southward to Gettysburg were uncovered. This probably marked nearly the maximum extent of the ice and as it retreated it would naturally form successive moraines approximately parallel with each other.

The First, or *Outer Moraine,* which is also the highest, enters the State over a small area northwest of Leola, in McPherson county, thence it passed beyond our borders northwest and westward entering again east of LaGrace in Campbell county. It continues southward through the west townships of that county to the vicinity of Walworth; thence southeast, being for a distance feebly developed, to Swan Lake creek, south of Bangor, where it turns eastward snd northeastward, becoming a conspicuous ridge crossed by several old drainage gaps, one being about 7 miles east of Bangor, another 2 or 3 miles north of that place. Then it turns abruptly eastward and then southward, passing east of Bowdle; then southeast of Hoven and Lebanon to a high point east of Gettysburg. There it turns abruptly westward and seems to have been quite feebly developed, being marked only with detached ridges which may be traced north of Gettysburg, east of Forest City, including the Artichoke Buttes, Sully Buttes and Snake Butte, north of Pierre, where it turns rather abruptly eastward and north to Medicine Knoll, near Blunt, which is the head of a re-entrant angle of the moraine. Then it turns south and seems to have been carried away between Medicine creek and Chapelle creek either by the escaping waters, or by a tongue of ice extending to the Missouri river. It appears prominent again north of Chapelle creek near the east side of Hughes county, and extends in an easterly direction to the Ree Hills, where it agains turns sharply southward and is found developed along the east bank of Box Elder creek to the vicinity of Gann Valley, in Buffalo county; thence by a very complex systems of loops to the highest point of the Wessington Hills about 3 miles north of Wessington Springs, where it is magnificently developed, rising about 500 feet above the valley east. It may then be traced southwest, passing south of Crow Lake, west of White Lake to Kimball, and from there southwest forming a bend toward Red Lake. Then, feebly developed, it runs southward past the east end of the Bijou Hills and west of Castalia to a cluster of hills about 6 miles north of Wheeler. It then becomes more conspicuous and is easily traced as a high ridge lying east of the Missouri, passing south of Lake Andes, nearly to the junction of the two branches of Choteau creek. Another re-entrant fold or ridge constitutes the Choteau Creek hills. Continuation of the moraine includes a cluster of bouldery hills north of Niobrara; then comes a wide gap between that point and the highlands east of Bon Homme. We find it developing another double fold or re-entrant east of Lesterville, and another east of Clay creek which constitutes Turkey ridge. The southern point of the latter fold extends down to and includes, Spirit Mound about 7 miles north of Vermillion. Then comes a gap between Vermillion river and Brule creek, probably caused by a narrow ice lobe. The moraine extends along

Brule creek northward to Beresford and on to a high point south of Canton. It is then feebly developed, or entirely absent, from that point to the west side of the Big Sioux opposite the northwest corner of Iowa. There it forms a ridge running west, south of the great bend of the Big Sioux near Sioux Falls and westward to the East Vermillion river. It is developed as a high ridge east of that stream northward to the north line of Lake county where it turns abruptly eastward and forms a sweep in the northern part of that county, leaving it near its northeast corner. It passes west of Volga and west of Watertown, east of Waubay and north to a point about 18 miles west of Brown's Valley thence it turns sharply southward passing along the east crest of the Coteau des Prairies passing Summit station on the "Milwaukee," and Altamont on the Chicago and Northwestern, in Duel county, and leaves the State in the southwestern corner of that county. Prof. Chamberlain calls it the Altamont Moraine from the station last mentioned.

The Second Moraine:—This lies closely in contact with the first, near the prominent re-entrant angles of that moraine. It nearly coincides with it northwest of Leola, where it enters the State, turns southward into the second tier of townships in McPherson county, runs westward north of Eureka, then into Campbell county, where it turns abruptly southward and is very much scattered over the surface of the country; then it turns southeast to the hills north of Bowdle, where it joins the first moraine again. It lies as a lower range of hills parallel with that moraine, till it reaches the line of the Chicago and Northwestern, west of Seneca. There it turns eastward and forms a sharp ridge, pointing northeastward. From that point it makes a curve to the south, southeast and east, till it rises in conspicuous hills again, about two miles south of Faulkton. After this prominent development it becomes less conspicuous and returns along the north branch of Medicine Creek to the northwest corner of Hyde county, where it turns southward and forms a rude curve around to the vicinity of Highmore, where it crosses the railroad, and skirts the Ree Hills to their eastern end, southwest of Miller. From this point, owing to the irregular form of the first moraine, it has not been satisfactorily traced, until it again appears in the form of prominent knobs, south of Wessington station, and at other points along Sand Hill creek to the north line of Jerauld county, where it is represented by scattered hills lying east of the north branch of Fire Steel creek. It includes the prominent line of knolls west and south of Woonsocket. Then it sinks into the level plains surrounding, a few miles further south, and we see no more of it until south of Fire Steel Creek, west of Mitchell. One of the most conspicuous portions of this moraine is known as the Enemy Creek Hills, south of Mitchell. Here it is running nearly east, curving toward a prominent knob east of the James river, east of Mitchell. From that point the moraine follows down the east side of the James river to the vicinity of Menno. There it turns abruptly northeast, passing around the north end of Turkey Ridge, and leaving it south of Marion Junction. It passes west of Parker and constitutes the divide between the East and West Vermillions, passing a few miles west of Montrose, between Winfred and Howard, west of De Smet, along the west slope of the Coteau, west of Clark, Bristol and Fort Sisseton, to a prominent knob, known as "Head of the Coteau," located where the west line of the old Sisseton Indian Reservation crosses the north line of the State. From there the moraine lies on the slope of the east Coteau, passes the "Milwaukee" railroad in the vicinity of Marvin, to the "Northwestern" railroad at Gary, on the east line of the State. Prof. Chamberlin calls it the Gary Moraine.

The Third Moraine:—This moraine was formed apparently by the remains of the ice sheet after it had been restricted to the level land of the James River valley. It is, in general, feebly developed and the hills are less continuous than those of the Second Moraine. It frequently shows small semi-circular loops. It enters the State west of Maple river in in northwestern Brown county and runs southwest, east of Leola to Ipswich, then south quite directly between the branches of Snake Creek, about 10 miles east of Falkton, to 8 or 10 miles northeast of Miller where it turns eastward and then northeast on the east side of Turtle Creek to the vicinity of Redfield where it is conspicuously developed, and thence eastward south of the peculiar bend on the James River. It does not cross that stream but turns again suddenly west of south, past Crandon, and west of Hitchcock, to the vicinity of Wolsey. Then it forms a semicircular loop towards the south, crossing the "Northwestern" railroad again east of Cavour. It then turns north and lies approximately parallel with the second moraine approaching it gradually toward the north. It may be traced in a low system of foot hills around the foot of the East Coteau, passing for a short distance out of the State. It lies south of Skunk Lake and from there forms a curve toward the northeast where it forms a conspicuous cluster of hills known as "Lightning's Nest;" then it turns abruptly south along the 97th meridian to the Minnesota river, which it follows for a distance and keeps the southeast direction past Wilmot and east of Milbank to a knob on the Yellow Banks known as Mount Tom. In the Minnesota Valley it is known as the Antelope Hills.

The Fourth Moraine:—This is a small loop formed by the last trace of the ice sheet entering the State, in the northwest corner of Brown county it describes a rude semi-circle passing Amherst, and south of Britton, and leaving the State at the foot of the Head of the Coteau, with the third moraine.

This moraine, though so short, is interesting as being the main barrier which prevents the waters on the upper James river flowing eastward into the Red River of the North. The moraine near Heckla consists largely of sand and the region east of the moraine is lower than the water in the James, on the west side of the Loup near that stream, so that there seems to be sometimes a seepage of water through the moraine eastward. This was observed at a point little north of our boundary, when the James was very high.

OSARS.

These are peculiar bouldery ridges which consist largely of stratified material, but of more regular order than the moraines. They may sometimes be traced for miles in nearly continuous lines. They are largely in the bottom of valleys or old water courses. They frequently branch like a stream. They are usually much more bouldery than the surrounding country. We have only a few in our State, but they are of a very interesting character. Several of them may be found north and east of Bowdle crossing and lying on the outer slope of the first moraine. A very interesting example, about two miles in length, was found southeast of Copp in the northwest corner of Hyde county. It lies in the bottom of an old drainage channel crossing the second moraine toward the northwest. Some imperfect examples of this formation may be found north of Waterbury in western Jerauld county. A very regular one, but not prominently developed, is found south and southeast of Crow Lake in Jerauld county crossing the first moraine toward the northwest.

Another, quite conspicuous in structure is found northeast of Montrose leading along the north side of a lake in an old drainage channel of the first moraine leading to Skunk Creek. Other interesting examples were found west of Sioux Falls near Wall Lake. Less perfect examples are found in many other drainage channels, as for example the channel south of Lake Andes and the one at Pratt creek.

These Osars are of problematic origin. It is not unlikely that different forms closely resembling one another are due to quite different conditions. Some within the moraine have been quite clearly shown to be the work of streams flowing upon or underneath the ice sheet. Those on the outer slope of the principal moraine may have been formed like the bouldery ridges described by Lyell as occurring in the lower St. Lawrence, which he ascribes to the work of floating ice and to ground ice.

BUTTE RIDGES.

These, perhaps, should not be grouped with the drift deposits, for they are supposed to be in part of lacustrine origin. But, since they are prominently strewn with glacial drift, it seems fitting to mention them in this connection. Besides, we may consider their origin not certainly determined. The most conspicuous examples of this formation are found west of the Missouri river on the north slope of the Fox Hills. They are observed about 7 miles south of the Moreau and 15 or 20 miles west of the Missouri, in the vicinity of Virgin Buttes. They may be described as a series of flat-topped ridges 10 to 50 feet in height above the surrounding country, having a breadth of from 2 to 6 rods. These ridges lie in a nearly continuous line, their summits are flat and thickly strewn with granite and limestone boulders. The top of the whole series lies on almost exactly the same level. A series was traced from 10 to 15 miles running in an east and west direction. According to reports, a ridge resembling these crosses the Moreau river about 20 miles from its mouth and turns northward, running approximately parallel with the Missouri river. The ridges mark the limit of the Glacial Drift, and therefore correspond to the line on the map indicating the limit of that deposit. The explanation which seems most satisfactory is that these boulders were dropped by the floating ice upon the shore of a temporary lake occupying the region outside of the first moraine north of the Fox Hills. This lake was probably formed by the Ice Sheet damming the Missouri river and its western tributaries by entering their ancient valleys on the east. The water would rise until it overflowed the low places in the divide, which, previous to the Ice Age, separated the Moreau and the Cheyenne rivers. This ancient and bouldery beach has become a line of ridges by the rapid erosion of the Cretaceous on either side.

FLUVIATILE FORMATIONS.

We have already referred to the strong contrasts in topography of our State. It therefore follows that the action of streams has been unusually marked. The Missouri and Cheyenne with their tributaries have been particularly active in the recent work of erosion, while some of the streams in the eastern part of the State have during and since the glacial epoch, deposited much material. There are many examples, especially about the Black Hills, of the effect of Ferrell's law, which is a result of the earth's rotation, upon the erosion of streams and consequently upon the resulting topography. The streams have quite persistently shifted to the right, and as a result the streams lie nearer their right hand divide, and on that side the terraces are less frequent and the slope generally much more abrupt. This is beautifully illustrated in the streams radiating from the Black Hills as also in the Cheyenne which receives them.

We would include under this head all deposits or formations produced by flowing waters; and even those of lakes which are commonly expansions of streams. We except of course those directly influenced by land ice.

Here we should place, (1) sheet-like accumulations of streams on a plain to which we may apply the term Aqueous Drift, including delta and "alluvial fan" deposits; (2) Loess; (3) River Terraces and (4) Fluvio-Lacustrine deposits.

AQUEOUS DRIFT.

Under this head we would include an extensive deposit of boulders and gravel overspreading quite generally the country around the Black Hills for a distance of from 100 to 150 miles. It seems to have been nearly continuous at first over the whole country. It is found usually capping the high pinnacles of the Bad Lands between the Cheyenne and White rivers. It is found far north to the Head waters of the Morean river. That the material has been derived from the Black Hills seems evident not only from the nature of the rocks, but by the gradual diminution in size of the pebbles and in thickness of the deposit according to distances from the Hills. Favorable opportunities for examining the internal structure have not been found; but it seems clear that the boulders and pebbles are mixed with finer material in a very indiscriminate way rarely showing distinct stratification. This may be partly due to the changes that have since been wrought in it by action of frost, by washing on inclined surfaces and the work of burrowing animals. In the bottom of watercourses in the Bad Lands limited deposits of apparently unstratified pebbly clay were observed. These seem to be clearly the work of streams. In like manner it seems probable that the Aqueous Drift upon the uplands may have been formed and been partly unstratified in many places.

The thickness of the deposit has not been determined at many points. On some buttes in the Bad Lands it was found 3 to 4 feet in thickness. Nearer the Hills it appears much thicker.

There are probably few areas which represent the upper surface of the original deposit, yet such are believed to occur at points where erosion has not been active, as for example, on the divides between the streams flowing from the Hills eastward, as the Elk, Rapid, and French creeks, and also between the Cheyenne and the Head Waters of Bad and White rivers. The elevation of these comparatively level surfaces, in localities named, gently declines away from the Hills. Northeast of Rapid City, according to the topographic map of the United States Geological Survey, the altitude of this plain is about 3,400 feet; east of the Cheyenne river, in its northerly course, it is estimated to be about 3,000. The superficial appearance of the drift as it lies upon the upland frequently reminds one of the Glacial Drift, already described; the bowlders, however, are never striated. This Aqueous Drift has been referred by Prof. Jenney to the action of ice floating in a fresh water lake around the Hills. Prof. Crosby concludes that it has been left as a residuum after the removal of the softer portions of the Tertiary beds, which he conceives at one time covered the whole region where the drift is found on the upland. So far as has yet been found there are no traces of glacial action in the Black Hills. Therefore, the suggestion of Prof. Jenney cannot be accepted. If Prof. Crosby is right the transmitting power which first distributed them must have been wave action. When we consider the slope of the surface which appears to have been covered by the drift, and note that it corresponds with the terrace-like formation inside the outer rim of the Hills, it seems reasonable to suppose that the general distribution of the drift was accomplished by the various streams flowing from the Hills over the plain surrounding, at a time when the slope was slight, the water abundant, and the deposition of material rapid. This may be referred to a time preceding the excavation of the present valleys. In other words, this drift may be considered as a kind of delta deposit formed by streams shifting to and fro upon a plain of deposition. Such a condition of affairs seems probable at an earlier time when the ice was occupying the eastern half of the State.

The Cheyenne river is the main stream draining the Hills, and has, therefore, formed more numerous and conspicuous terraces. These correspond, at least some of them, to prominent terraces along the Missouri, which have already been mentioned.

Distinctions Between the Eastern and Western Drift:—From what has already been said, one would expect a mingling of the erratics from the Black Hills with those brought by the ice sheet from the north. Such is found to be the case, not only in the terraces along the Missouri river, but even in the outer moraine itself. It is often a perplexing question when examining the drift to determine whether a specimen has come from the north or the west. Many, as granite, hornblendic and mica-schists, and greenstone seem indistinguishable often times, though they have come from the different sources. The northern drift, however, alone contains boulders of red quarzite, such as is found at Sioux Falls, and boulders of the white, fine-grained magnesian limestone, which is supposed to have been derived from the beds of the upper Silurian or Devonian in the Red River valley of the north. The western drift never contains these. On the other hand, it abounds in flat pieces of chalcedony, which have come from the veins in the Tertiary beds, and coarse-granite or feldspar pebbles derived from the granite masses about Harney Peak. Also pebbles of trachyte and porphyry, which, after once being seen will be quite easily recognized as distinct from corresponding rocks coming from the north.

LOESS.

This term is derived from a German name for a similar deposit found on the banks of the Rhine and Danube rivers. It may be described as a yellowish loam, very homogeneous in structure, showing little or no trace of stratification, and with a tendency to form joints running vertically. It has been called Bluff Deposits by the geologists of Missouri because it is so prominently developed along the bluffs of the Missouri river, in Iowa and Nebraska and northern Missouri. This deposit is supposed by many to have been formed in lakes or flooded rivers from a fine mud, which had accumulated in the ice sheet, partly from the dust blown upon its surface and partly from the grinding of the rocks underneath. Others suppose that while it derived much material from this source, it may have received as much, if not more, from the washing of the Tertiary beds on the western plains. It is developed in our State only in a very narrow region, although it overlies all of eastern Nebraska and western Iowa. It is most deeply and typically developed in Lincoln and Union counties between the outer moraine and the Big Sioux river, where it is found from 50 to 150 feet in thickness. It is also found outside the first moraine around Sioux Falls, covering much of Minnehaha and Moody counties. It gradually thins out toward the north, and Minnesota geologists have found in their State adjacent, that it is limited by a contour line of 1,550 feet above the sea. It forms a most valuable subsoil because of its under-drainage in wet seasons and by capillary action supplying moisture to plants in dry seasons. It was probably formed either shortly before, or during, the occupation of the first moraine by the ice sheet.

Though what we have just described is most properly called the Loess, similar formations are found of much later origin covering the various terraces of the Missouri and other streams. Along the Missouri particularly, the high terraces, as about Pierre, are occupied sometimes with 30 to 50 feet of the buff-colored loam, indistinguishable from the Loess. Beyond the limits of our State, as around Sioux City, and more distinctly further south, there is a high terrace arising about 100 or 150 feet above the Missouri river, which is mainly composed of Loess-like material. This has often been confused with the higher Loess, which, we believe, has a much older origin.

RIVER TERRACES.

Very striking examples of this feature are found along the Missouri river and the Cheyenne and in less striking degree along White, Grand and Big Sioux rivers, while some streams scarcely exhibit them at all. We will not attempt a complete classification or description of these river terraces, but will briefly mention a few typical cases which we have observed. On the Missouri, near the mouth of Moreau river the following terraces were noted: The lower bottom about 10 feet about the river and a higher one about 30 feet and other terraces at 63, 105, 144, and 210 to 240. At Fort Bennett the terrace at from 260 to 300 feet, is wide and covered quite thickly with loess-like loam, with a thick deposit of clay and northern boulders underneath. At Oahe, above Pierre, terraces were noted at heights of 10, 62, 118, 172, and 310 feet above the river. At Pierre a similar number of terraces is found. Near the mouth of Platte creek, in Charles Mix county, there is a remarkable development of bouldery terraces, one from from 300 to 350 feet above the Missouri and another 90 to 120 feet. Be-Below Wheeler the two higher bouldery terraces, which have been traced above, seem to come together on the level of the lower and this continues down the river at altitudes as follows: Yankton Agency, 130 to 240; Running Water, 200; Yankton, 120 to 145; and Vermillion, 80 to 140, where it presents features of glaciation instead of being purely a river terrace. This terrace probably corresponds with the high terrace south of Sioux City which is composed mainly of loess and also with the terrace at Blair in Nebraska of similar composition. Further notes by the writer on these terraces will be found in Proceedings A. A. A. S., 1888, Vol. XXXVII., p. 203.

On the Cheyenne river, about 20 miles above its mouth there is found a very high terrace, composed in its upper portion largely of boulders, apparently from the Black Hills. This terrace is at an altitude of about 200 feet above the stream. Another one clearly defined lies 370 feet, while a narrow bouldery ridge, which appears to be a remnant of a terrace lies 432 feet above the river. On the Cheyenne near its junction with Elk creek the following terraces were noted: Upon the west side one about 27 feet; another, wide and showing on both sides of the river, cutting across the present bends of the stream, 240 to 245 feet; and another being a continuation of the highest terrace which is well developed along Elk creek, 335 feet. Upon the east side of the stream a very regular devlopement of high terrace was found as follows: 190 to 200; 240, 285, 335; while the summit of the upland further east which showed frequent lake beds, was 550 feet. This latter surface is believed to be part of the original plain upon which the "aqueous drift" was deposited. These terraces are of level surfaces of uniform width and gentle slope. Further up on the Cheyenne these terraces are less numerous, but two are quite distinctly traced as far south as the mouth of Fall river. These two abound in boulders in their upper portions and probably correspond to those 336 and 240 feet above the stream at the mouth of Elk creek. Along Elk and Rapid creeks, and probably all of the streams of the Black

Hills there are two high broadly developed terraces traceable. This appears not only outside of the foot-hill range but in the Red Valley, at least this is true of the highest one.

It was observed above Rapid City, and near Beaver creek, inside of Buffalo Gap, also at Hot Springs. At both these localities the boulders are very abundant and have been consolidated into a conglomerate by the action of the calcareous waters of the streams. At this point they lie 40 or 50 feet higher than the present streams. Outside of the gaps the streams rapidly descend while the terraces continue more nearly upon a level, hence the terraces which are more than 100 feet above Rapid creek at Rapid City are more than 200 feet above it at its mouth, while the terrace which is but 20 or 30 feet above the stream near the Gap is about 100 feet higher than the stream at its mouth.

THE ALLUVIAL FORMATIONS.

Under this head we include the broad bottom lands along the Missouri and other prominent streams. The term is partly applicable to the lower land or flood plain which lies from 10 to 30 feet above the water. This has a subsoil of sand or gumbo. The latter having been formed in quiet water, the former having been deposited by the current as it has shifted to and fro. Minor terraces may be seen along the banks of the streams; but they mark temporary floods or local variation of level rather than any continuous cutting down of the stream. These alluvial deposits rarely contain coarse material. At a height varying from 10 to 25 or 30 feet there are frequently second bottoms, as they are called, which have similar composition to that already described. These are really not of a different class of formations from the higher terraces, but they are composed of finer material. They usually have very rich soil. In terraces higher than 100 feet above the present stream the boulders of the glacial drift generally occur and probably indicate that the ice had not completely withdrawn from the region at the time of their formation.

LACUSTRINE FORMATIONS.

Under this head we have thin deposits locally developed in the various small basins which abound on the drift, with a few very shallow ones west of the Missouri beyond the influence of the formation; and the quite extensive beds which fill the basin of ancient Lake Dakota, in the James River Valley. A few others less important of the same class.

The former are very numerous, and together constitute an important part of our area. They are often filled several feet with fine material, and often contain rich soil, with more moisture than the surrounding country. On the other hand, in wet seasons they may be flooded. This difficulty, however, may usually be remedied by drainage.

An interesting feature of these lake-beds is the common occurrence of a heavy deposit of boulders like a tumble-down stone fence, surrounding much of the margin. This is the work of ice, with fluctuations of water-level and waves.

Lake Dakota was a body of water 5 to 25 miles wide and over 120 miles long, when the Ice Sheet occupied the Fourth Moraine. It is now represented by the remarkably low level plain stretching from Oakes, N. D., to Huron. It is now filled to the depth of 25 or 30 feet with a fine silt, resembling loess. It is throughout about 1,300 feet above the sea. An earlier stage it extended to Mitchell, but the deposits in that extension are more stony. Very even and generally level areas, probably due to still older lakes, occupy extensive portions of Aurora, Hutchison, Brule and other counties. Some of these grade imperceptibly into true glacial drift.

EOLIAN OR RESIDUAL LOAM.

Some authors have referred the Loess largely to the transporting power of the wind, and it seems probable that much of the Loess has been shaped more or less by the action of winds. We would include, however, under this head not the Loess or any portion of it, but rather a very shallow loamy material lying over the surface of both the glacial drift, where it perhaps cannot be distinguished from the glacial deposits, and also over driftless portions of the State. The Cretaceous and Tertiary clays seem to contain a considerable larger proportion of silicious material near the surface in the form of almost inpalpable sandgrains than deeper down. This is more apt to be true of flat areas which have not been exposed to erosion. These in part may be considered of residuary origin, the fine sand having been left behind in the erosion of the upper portion of the clay. But while this subject has not been studied sufficiently to arrive at a definite conclusion, it seems not improbable that the silicious material near the surface has been mainly derived through the action of the winds from the sandy areas surrounding.

LIFE IN THE QUATERNARY.

Many would, at first thought, not expect much development of life in the vicinity of the great glaciers of the Ice Age. But recent explorations of Alaska, (Thirteenth Annual Report United States Geol. Survey) have revealed dense forests, not only near the glacier, but *upon its surface,* over many square miles of its stagnant portions.

The Boulder Clay of our State not infrequently contains fragments of wood sometimes of considerable size. The Loess, further south, quite frequently contains many specimens of land snails with a few fresh water shells, but few, if any, have been observed in the true Loess, in or near our borders. The loess-like loam capping the river terraces has been found to contain many of them in places, as at Pierre.

Much more interesting are the remains of mammoths and mastodons, which are not very rare outside the First or Outer Moraine. Two large tusks, teeth and fragments of large bones belonging to a mammoth, *Elephas Americanus,* have been recently unearthed at Sioux Falls. A fact significant of their comparative recency, is that they lay in loamy sand capping a high terrace about 60 feet above the Big Sioux river above the falls, and only 5 or 6 feet below the original flat surface of the terrace. The bones were not perceptibly worn nor much scattered. All seems to indicate that the monster perished on the spot when that was a flood plain of the Big Sioux, which is believed to have been when the ice sheet occupied the First Moraine. The tusks were over six inches through at the base and the portion remaining was over seven feet long and much curved. Other bones which from reports, appear to have been of a mastodon, have also been dug up near Sioux Falls.

Inside the Moraine and therefore more recent, have been found old muck beds with tamarack logs and fresh water shells in old lake beds. I examined one twenty feet below the surface north of Grand View, Douglas county. It was above the Boulder Clay.

CHAPTER VIII.

ERUPTIVE ROCKS.

We have completed in the foregoing chapters our consideration of the sedimentary rocks. Under the head of eruptive rocks we include all that have been deposited in their present position, while in a molten or plastic condition. We have already alluded to the granite in our discussion of the Archean because its eruptive origin has not been conceded by all.

Eruptive rocks are found in various forms and conditions. They occur in dikes, sheets, lenticular masses and laccolites, which have been already defined on page 20. They have also sometimes been forced upward with sufficient energy to reach the surface and overflow in broad streams, as in the case of modern volcanoes. As a general rule, molten eruptive rocks have a finer crystalline surface, according to the rapidity with which they have cooled. Where they have cooled slowly deep below the surface they are usually coarse-grained. In large overflow masses there may be a glassy or slag-like structure near the surface, because of its sudden cooling, while below the surface the appearance is more like that of ordinary stone, the grains being, perhaps, large enough to be easily seen.

The eruptive rocks in our State cannot be classified easily according to their age, because the time at which they have been intruded or deposited has not been made out with sufficient definiteness. We may, however, classify them with reference to their composition, and will also give, as definitely as present knowledge will permit, the probable time of their outflow. They represent the different kinds, called Diorite, Diabase, Granite, Rhyolite, Trachyte and Phonolite.

DIORITES.

Under this head we include, not only the massive rock which is composed of hornblende and plagioclase or triclinic feldspar, but also hornblendic schists, for more recently the latter have been found to be really sometimes of eruptive origin. The Diorite of the Black Hills seems to have been strangely overlooked by Newton. Boulders of this rock are found frequently over the region east of the Hills. He may have considered them portions of the schist or slate series and therefore of fragmental origin, but as has been pointed more recently by Prof. Van Hise, from a microscopic study of them, corroborated by further field study, they are distinctly eruptive and are probably the oldest eruptive rocks in the Hills. Prof. Carpenter discovered a dike of diorite, sometimes more than 1,000 feet in width, traversing completely the slates, or eastern series of Archean rocks. The distribution of these rocks has been briefly treated by writers upon the subject. They are believed to have but little or no economic value.

DIABASE.

This is a formation of igneous rocks composed of augite and various species of feldspar with sometimes other ingredients. Under this head comes the eruptive rock already referred to as occurring northeast of Sioux Falls along the Split Rock. Prof. Hobbs, who has studied it, pronounced it an Olivine Diabase.

The dike of diabase runs in a north and south direction. Where first observed it was very much weathered. Where it has been covered by overlying clays it shows the tough compact rock which occurs in the boulders of the drift. An interesting feature of this dike is the compact slates which bound it on either side. The country rock is the Sioux Quartzite.

It may be in place here to mention briefly the recent discovery of quartz porphyry not far from our borders. This was found in the bottom of a deep well at Hull, Iowa. From its character it is inferred that it was formed as an overflow upon the crystalline rocks, probably the Sioux Quartzite, previous to the deposition of later formations.

GRANITE.

This well defined group, composed of quartz, feldspar, and mica, with occasional other minerals, has already been treated much at length under the Archean, and we need not speak further about it.

RHYOLITE, TRACHYTE, AND PHONOLITE.

These three formations of igneous rock will be conveniently treated together, both because of their gradation into one another and their probable eruption at about the same time. They are often called porphyry. These constitute a very conspicuous feature of the Hills. The most symmetrical and picturesque peaks are composed of them. They vary in coarseness of structure, from a distinct crystalline character with quite large crystals to formations in which separate grains are scarcely visible. They all present a particularly homogenous though fine grained mass of a pale green, pinkish or grayish color, within which are crystals, usually transparent, which are quartz, or a kind of feldspar, called sanidin.

The Rhyolite contains more quartz than feldspar, both in the fine grained masses and in coarser grains. It usually also has a lighter color and is harder.

Trachyte contains little or no quartz, and the larger grains are almost entirely sanidin.

The Phonolite is usually finer grained and derives its name from its fragments ringing like metal. All these rocks break with comparatively smooth and even joints and separate into angular pieces. The more prominent peaks formed by these rocks are Custer Peak, Terry Peak, which is the highest of the kind in the Black Hills, Crow Peak, Black Butte and Bear Butte. There are also many others of smaller size in the northern portion of the Hills. Custer Peak is based on the Archean slates. Terry Peak has Carboniferous and Potsdam strata high up upon its eastern slope. Crow Peak is thrust up through the purple limestone of the Red Beds. Bear Butte, outside the outer rim of the Black Hills, has been thrust up through the Cretaceous rocks. The Dakota Formation rises in a ring-like ridge nearly surrounding it. The Benton clays lie nearly horizontal about it. Therefore Prof. Winchell supposed that they had been deposited since its elevation. There are also outflows near Tilford, north of the Elk Creek Canyon. At that point the rock has a fine grained, light green color, containing crystals of white feldspar. It occurs in dikes and laccolite masses in the Carboniferous limestone.

The contact between the porphyry and the limestone was clearly traced at one point and exhibited an irregularly arched form. The limestone was altered for only a few inches from the line of contact. The igneous rock showed columnar structure for several feet from the exterior, the columns being at right angles with the surface of contact.

A large number of the peaks of this, lie beyond our borders. One being the Inyan Kara, and another the very singular tower-like Mato Tepee, or Devils Tower.

All observers who have studied these peaks agree that no clear traces have been found of a volcanic overflow of lava. It is known to be a fact that all igneous rocks yet found in the Black Hills have no characters which indicate that they were cooled at the surface. Moreover no clear case of their overlying a weathered surface has been found. Newton reports one doubtful case which he afterwards concluded was due to intrusion and not to surface overflow. Newton supposes that the igneous rocks were deposited in and underneath the Cretaceous strata. Prof. Carpenter considers that they are all laccolitic formations. The strangely columnar form of Mato Tepee has been explained by supposing that the present peak is the cooled core of a volcanic cone; that the lava filled the chimney or throat of the volcano and cooled while the volcanic tufa and

and other soft rocks which constituted the cone were surrounding it. This is indicated by the long vertical columns running perpendicular for 500 or 600 feet, for it is a law of the cooling of the volcanic rocks that the columns formed by the shrinking or the rocks in their cooling run perpendicular to the exposed or cooling surface. Bear Butte seems to be of somewhat similar form, the igneous rock constituting a core of larger diameter.

From this it may be inferred that volcanic outflows occurred and that erosion since that time has carried away the surface rocks of igneous character with the soft clays upon which they lay. A fact which may slightly corroborate this view is found in the occurrence of pebbles of pitchstone in the conglomerate in the Loup Fork beds.

THE TIMES OF THE OUTFLOWS.

There were at least three times of eruption of igneous rocks, one of the Diorites, one of the Granites and one of the Trachytes, Rhyolites and Phonolites. The age of the Diabase very likely may correspond with that of the Granite or Diorites. From the fact that they occur in a different portion of the State their relative ages cannot be clearly determined.

The Diorite outflows necessarily were formed later than than the deposition of the material of the slates in fragmental form. Prof. Van Hise suggests that the eruption of the Diorites took place contemporaneously with the formation of the slaty cleavage which is most manifest in the eastern portion of the Archean area. The irruption of diorite and the metamorphism of the slates must have taken place at a greater depth below the surface and the pressure attending the movement of the molten rock below is supposed to have generated the slaty cleavage in the surrounding fragmental rocks which took place at the time of their change to a crystalline state.

The age of the granite we have already discussed. Its occurrence in lenticular masses, lying approximately parallel with the planes of slaty cleavage, suggests its occurrence later than the diorite is strongly indicated by the entire absence of granite in the diorite. The eruption of the granite, according to Prof. Van Hise, probably attended the development of the schistose structure which is most perfectly developed in the vicinity, and in different planes from the slaty.

Prof. Crosby came to the conclusion that the Harney Peak granite is older than the newer series of schist, which are overlaid by the Potsdam beds, traversed by large intrusive dikes and sheets of porphyry. These porphyries contain not only fragments of the schist and slates, but also occasional fragments of granite which he supposes must have been brought up from lower down. We fail to see that this proves more than that the porphyries were erupted later than the Potsdam.

THE AGE OF THE PORPHYRY ERUPTION.

We here use the term porphyry to include the three varieties, before spoken of as rhyolite, trachyte and phonolite Newton concludes that the time of the porphyry outflow was later than the Fort Benton Cretaceous and earlier than the Miocene. This he infers from the fact that the intrusion of the porphry distorted/the beds as late as the Fort Benton, and because Mr. Jenney found in the conglomerate at the base of the White River formation, not only pebbles of granite and feldspar, but the pebbles also of trachyte. Prof. Carpenter judges that the eruption took place at the close of the Cretaceous, from the fact that the Fort Benton lies undisturbed at the base of the Bear Butte. He reasons that the later Cretaceous formations overlay it and constituted the surrounding walls which limited the porphyry core now constituting this peak. He agrees with Newton in concluding that the eruption must have occurred before the Miocene, because of the pebbles found in the beds of that formation. As before stated, Prof. N. H. Winchell inferred from the horizontal position of the Fort Benton clays at the base of Bear Butte that they were deposited subsequent to the upheaval. According to his view, the eruption probably took place during the Jura Trias. He would attribute the position of the Dakota at the base of Bear Butte to its deposition on abrupt slope. He would probably attribute the relative height at which the volcanic rock stands above this later formation, to the former existence of the tufa, which may have removed previous to the Cretaceous. It seems that Prof. Carpenter's conclusion has this in its favor, that from the heights of the present peaks above the Benton, as seen in the case of Bear Butte and Bear Lodge, there must have been several hundred feet of sedimentary deposits which gave shape to the present porphyritic rocks. We can scarcely attribute that effect to volcanic tufa which might have been built upon the Benton or Dakota. For, if such had been the case, we cannot conceive of the entire removal of all such formations from that region. If, on the contrary, as he supposed, the eruption took place after the deposition of the Pierre or even the Fox Hills, the removal of these beds would very naturally carry away the loose volcanic tufa with it, and so account for the absence of sub-aerial surface of volcanic rocks from the region. Moreover the tufa and the comparatively impervious character of the clays may have had something to do with the concentration of the lava to small circular vents, especially where the outcrop was remote from the older rocks and therefore the greater of the clays. It will be remembered that there is a gap in the deposits about the Hills from the Fox Hills to the Miocene. This may be accounted for by the upheaval preceding and attending the volcanic disturbance. While the the accumulation of water subsequently in the great Miocene lakes, surrounding the area, may perhaps be traced to the subsequent subsidence resulting from the escape of molten rocks from below and the secular cooling of the region.

Rhyolite and trachyte sometimes form vicid lavas, which are capable of rising and standing in dome-like masses without walls to limit them. Examples of these are found in the Isle of Bourbon, where they are known as "mamelons." If the prominent peaks already described were of this nature, it is unnecessary to assume that crataceous formations formerly existed around them. The eruptions may, therefore, have taken place at an earlier stage. Were this the case, however, we see no escape from the reason why there should not be evidence of the occurrence of fragments of volcanic rocks scattered in the Cretaceous formations in that vicinity.

Over much of Nebraska and even close to our southern border there are quite deep deposits of volcanic "ashes" or dust, such as is carried in the air sometimes hundreds of miles. The substance is a pulverized glass as fine and white as flour. The deposit is in Pleistocene deposits and proves that some great volcanic outburst occurred at that time. The location of the eruption has uot yet been discovered.

CHAPTER IX.

GEOLOGICAL HISTORY OF SOUTH DAKOTA.

Having finished our review of the various geological formations found in our State, it will be both helpful and interesting to give an interpretation, making only brief references to that of others, wherever there may be variances. The record is, at various points, so imperfect and the principles of interpretation so change from time to time, that no two of the students of the subject have agreed on every point, and in some places their conclusions are diametrically opposed.

It is generaly believed that at an early stage the earth was a sphere composed of, or at least covered with, molten rocks and the oceanic waters and other volatile substances were suspended in a gassy state above its surface. As the heat was radiated into surrounding space, a crust formed over the molten surface, and in time the waters suspended in the atmosphere took their place as the ocean, which was at first doubtless shoreless. The first dry land is supposed to have been the result of further cooling and the consequent crumpling of the earth's crust by the shrinking of the whole mass within, to such an extent that a portion of the crust was thrust out above the water. We have no evidence of there being any portion of this first crust now exposed in our State. In fact, it is very doubtful whether such is found anywhere on the earth's surface.

The *schists and slates of the Black Hills* were probably first formed as clay and muddy sand in the primeval ocean. The material was derived probably from ancient land to the west or possibly northeast of that locality. They were composed, as we have seen, of unknown thickness. The early crust of the earth, because of its thinness and the probable greater activity of the disturbing forces, is everywhere found very much folded and crumpled, and the rocks are mingled in a confused mass with molten material, which apparently rose from below and in some cases not only penetrated but overflowed. So in the Black Hills the slaty cleavage seems to have been formed in harmony with, and probably attending, the outflow of the Diorite which has been described. At the same time particles of the slates and schists were changed from their fragmentary character of clay, sandstone and limestone into the crystalline condition of schists, slates, quartzite, and marble. These folds were probably at first relatively much higher than now. We have only the stumps as it were of the original sharp folds. There may have been lava outflows spreading over the surface but they have long since been carried away.

Later the granite was similarly erupted. It was no doubt cooled far below the surface and under pressure. The coarse structure indicates that it cooled very slowly as it would under such conditions. The material of the granite may have been derived from the melting and incorporating into itself portions of the schists and perhaps other rocks underlying them. The exposure of the granite indicates that several thousand feet of rock have been carried away by erosion which formerly lay above it. It now rises 7,000 feet above the sea. In those early ages it may have been 6,000 or 10,000 feet lower with reference to the sea level. That the granite succeeded the outflow of the diorite is indicated by the diorite never cutting through the granite veins while the opposite is true of the granite.

Toward the end of Archean time, the Black Hills stood as a high rugged Island, probably considerably higher, relatively, than at present, in a shallow sea in which there was no life. Away to the northeast was a similar and larger land-mass occupying central Minnesota and extending eastward to Labrador, also north and northwest from that point past the Lake of the Woods to the Arctic Ocean. Several more or less continuous ridges probably at the same time occupied the Rocky Mountain region. The ocean surrounded all and lay over the eastern part of our State extending into southwestern Minnesota. In it gradually accummulated, from the adjacent Minnesota land, through the action of waves and tidal currents, extensive beds of sand and sandstone, at least a few thousand feet in thickness. As is commonly the case under such conditions, the increase of the burden weighed down the comparatively thin crust of the earth underneath, so as to receive these thousands of feet of sediment without appreciably filling the surrounding sea. The western end of the State not only suffered great erosion meanwhile, but gradually began to subside while the eastern end held its own and perhaps began to rise.

In the Potsdam Period, the subsidence of the Bleak Hills region went on steadily while the waves cut down its shore and spread the material over the surrounding sea-bottom. In this was deposited the Potsdam sandstone which near the Hills is from 200 to 300 feet in thickness. It seems not to have entirely covered the Archean nucleus until the end of that epoch. The Minnesota land had at some time thrust out a peninsula toward the southwest into our territory so that we find no Potsdam sandstone exposed at that end of the State. During the Potsdam, abundance of low forms of life were found in the sea and fragments of their remains are very abundant in some strata in the Hills.

This phase of the seesaw movement between the two ends of our State seems to have continued through the Silurian and Devonian. The few feet of Trenton limestone of the clays which lies above and below seems to mark the time when the Black Hills were so low below the sea that the action of waves and currents failed to deposit any considerable amount of material. It is an interesting problem not yet investigated, whether there are not in the 25 or 30 feet of greenish clay between the Trenton limestone and Carboniferous traces of a deep sea formation similar to that discovered and described by the explorers of the Challenger Expedition in the abysmal depths of the Atlantic and Pacific. It seems not necessary to suppose that great depth existed, nor that the area was very remote from any land, but rather that it was not in the path of ocean currents nor much affected by tidal action. The latter consideration must probably be given great importance for the area could not have been more than 200 miles from land toward the east and possibly not toward the west or northwest. But it may have been so related to the shores what currents did not transport much material to that locality. It may have had some such relations as the "Bottomless Pit," in the Bay of Bengal.

After remaining in this condition through the Silurian and Devonian a change of oscillation brought it near enough to the surface *in the early Carboniferous* for the flourishing of invertebrate life from which were built the several limestone beds of the Black Hills. At that time the relation may have been like that of areas in the Pacific ocean, where coral islands abound, although remote from extensive land. Toward the end of the Carboniferous the sea had evidently become so shallow that the action of the waves and the possible approach of the shore produced extensive beds of sand.

The eastern half of the State, meanwhile, was dry land with perhaps slight extension farther west. The east shore line must have crossed our state near the middle from north to south. A very interesting corollary follows from this conclusion. Namely, that considerable beds of Carboniferous coal may occur within our borders. For on general principles and from analogy with similar conditions elsewhere, we should expect that along the shore, which we have every reason to think was sloping very gently westward, there were likely to be formed marshy areas similar to those which produced the coal beds, so well known in the eastern part of the Mississippi Valley. Certainly the climate and the character of the vegetation and extent must have been nearly identical with those farther east. That there were no rapid changes going on may be inferred from the facts already mentioned in connection with the Black Hills region.

Therefore everything seems to have been favorable for the growth of luxuriant Carboniferous plants and we see no reason why they should not have formed beds of coal. There is however one *apparently insuperable obstacle* to their being utilized, namely, that they lie below the copious flood of artesian waters. Should it be found that there are local disturbances in the region south of White river within our border we may expect that portions of Carboniferous strata, including coal, may be discovered at no great depth below the surface. In favor of this view may be mentioned the fact that several distinctly Carboniferous fossils are said to have been collected near Gordon, in Nebraska.

Toward the close of the Carboniferous the action of the waves and currents was felt again, indicating that the sea was shallow. We do not find clear evidence that any portion of the Black Hills appeared above the sea in that age. The curve of the upper Carboniferous strata would carry them nearly if not quite over the summit of Harney Peak and other Archean rocks. The principal considerations pointing to the opposite view is the difficulty of accounting for the abundant material which was deposited during that epoch, over the Black Hills. Further study may reveal the fact that there was sufficient elevation to raise the lower Carboniferous and possibly Archean rocks higher than those now in existence above the sea, or to such a height that they furnished abundant material for the later beds.

During the Triassic the whole western end of the State, with the whole region of the eastern slope of the Rocky Mountains, seems to have been shallow sea and barren of life. This may have been the result as before noted, of either the separation of the inland sea from the ocean by a barrier in the southern part of the Mississippi valley, or as Dr. Carpenter suggests, the abundant igneous outflows into this wide basin were sufficient to so poison the waters that they were hostile to life. The difficulty with the latter supposition is twofold: First, there is no clear evidence of extensive igneous outflows within the basin; second, that from the comparison with seas surrounding volcanic regions as in the East Indies, there seems to be no markedly injurious effect upon the animal life, at least not to such a degree as to render it entirely extinct. We therefore favor the former support supposition although there is no clear evidence of its correctness. During this time, the eastern shore of the sea lay probably far west of the Missouri through our State, Nebraska and other States farther south. At the time of the Purple Limestone it seems to have been so condensed that it deposited carbonate of lime as a precipitate. Both before and after it probably deposited together with the clay, much rock-salt and gypsum, as we have elsewhere argued.

At the beginning of the Jurassic there seems to have been a connection with the outer ocean and influx of forms of vertebrate life. The sea was shallow as is shown by the ripple marks and the nature of the deposit. It will be remembered that vertebrate life had attained great development of reptilian forms, the most gigantic lizards that the world has ever seen, (Atlantosaurus) having flourished at that time. Its thigh bone was six feet long and the estimated length of the animal was 80 feet. This change indicates a disturbance in the earth's crust. By reference to our chart of geological formations at the end of this volume, it will be seen that no trace of Early Cretaceous rocks are yet to be found in our State. The Black Hills were at that time dry land, the shores of which were so remote from their center that any formation then produced has been entirely covered up by the easily recognized formation at the base of the Later Cretaceous, namely, the Dakota sandstone. With the *Later Cretaceous* there seems to have been an advance of the sea quite rapidly toward the east and also around the Black Hills caused by a general subsidence, so that before the close of the Dakota period the whole of our State was covered by the waters of the ocean. In the earlier quiescent stages of this advance there seems to have been in the shallow basin south of the Archean peninsula extensive marshy areas in which beds of lignite were formed such as we have mentioned in the vicinity of Centerville and at Ponca, Nebraska. At nearly the sametime, deposits of the same sort were forming around the Black Hills. The layers of lignite near Rapid City and in the southern part of the Hills also indicate this. On Newton's map attending the geology of the Black Hills, "coal" is marked in the Dakota area at the north end of the Hills, although no reference is made to it in the descriptive text. The deposits of coal at Cambria and Newcastle, Wyoming, on the west side of the Hills have been found to be in the early Dakota. It is probable that the western slope of the Black Hills uplift was more gentle and therefore favorable for the formation of marshes; yet we know no reason why it should be more so than on the north and south of the Black Hills. Attending this advance the action of waves and currents formed the extensive beds of sand now constituting the Dakota sandstone and during the quiescent stages of the advance, which was of an oscillatory character, extensive sheets of clay were also deposited alternating with the sand.

In the Black Hills region the dome-shaped uplift became more marked and began to be attended with slow subsidence in the surrounding vicinity. According to Newton, the Hills were covered by the sea and the successive formations of the Upper Cretaceous were formed over the whole area as late as the Fox Hills epoch, but here again we are met with the difficulty of accounting for the source of material. Both for this reason and from the character of the Dakota sandstone, which contains pebbles of Archean rocks, we judge that the Black Hills uplift was an island in the sea. Meanwhile, as before hinted, the rest of the State was slowly subsiding, possibly with local folds, so that the portions of Dakota sandstone were elevated above the sea at one time and again submerged.

In this way we may perhaps account for the occurrence of Niobrara "chalkstone" on the same level with the Dakota sandstone, as in the vicinity of Mitchell. The eastern shore line of the sea at that time was probably far east of our State. The Benton and Pierre clays are such as might have been deposited in a shallow sea far from land, the shores of which were the scenes of active erosion. The Niobrara "chalkstone" was probably formed about the time of the maximum extent of the inland sea, when the central portions would be farthest from land and at the time when the products of erosion were less abundant and therefore the waters more clear. This would be favorable for the formation of extensive Foraminifera beds in the deeper areas, and of oyster-like Inoceramus beds near the shore. The sea was retiring, doubtless, during the *Pierre epoch,* mainly toward the north, and the *Fox Hills stage,* probably marks the time when its waters had become so shallow that waves and currents assorted the material and removed the finer portions. At the close of the Fox Hill, the sea retired from our borders toward the north, never to return.

In the Laramie epoch, as would result from this change, the slope of the newly formed land area would be gently toward the north, and extensive fresh water delta-like formations accumulated over the northwestern quarter of the State, while the deeper beds of the time were formed north and west in Montana. That was an age of extensive marshes and abundant growth of vegetation, both of pines, deciduous trees and palms, from which have been formed the numerous, extensive, and often times thick beds of lignite, which occur in North Dakota, Montana, Wyoming, etc. Over the extensive marshes there roamed strange reptiles, creeping, swimming and flying, with a few marsupials, foreshadowing mammals of later ages. During this time occurred the extraordinary volcanic outbursts, which affected principally the north end of the Black Hills, and as a result of which we have the high and picturesque peaks that we have already described. It is not improbable that the disturbance at the eastern end of the State may have occurred at about the same time. This disturbance is but one manifestation of many similar eruptions which took place in other parts of the earth about the same time.

Following this was the *Eocene epoch* when we may suppose that our State was clothed with luxuriant vegetation, supplied with abundant moisture and peopled with strange gigantic mammals. Of this we have little or no record within our borders. We simply know that the Black

Hills were relatively quite prominent and streams of considerable size radiated from them, as at the present time. Instead, however, of excavating narrow and deep valleys, they flowed with gentle currents and broad channels out across the plains and deposited considerable areas of gravel from the Black Hills. The record of life of these times is lost from our State, because, as is well understood, remains of life, either vegetable or animal, are not preserved except by being buried, either by aqueous or igneous deposits. The history of this time is well recorded in the Eocene beds about the Uinta Mountains. It may be that more careful examination will reveal some valuable pages in this history of life, within our own border.

At the beginninq of the Miocene, we find that a change has taken place, affecting particularly the Rocky Mountain region by which the area around the Black Hills, particularly toward the south and east, became occupied by a vast shallow fresh water lake. We have seen how these lakes have supplied wonderful, and wonderfully abundant, remains of strange vertebrate animals. It is not improbable, as we have already suggested on a previous page, that it was a time of storms, earthquakes and possibly of volcanic outbursts and eruptions. The Black Hills, sharing with the same movement which affected the whole Rocky Mountain system, kept on steadily rising; the lake shifted more to the east and eventually seems to have drained away towards the south. The streams were quickened in their action, the moisture probably increased about the Black Hills because of their greater elevation and the increase of evaporation over the plains. As a result there was a great erosion of the Miocene beds over their whole area particnlarly near the hills and along the channels of the principal streams. As the slope of the streams was slight, compared with the present, their valleys, except toward the east, were probably not deeply excavated.

Then followed a gradual upheaval as is indicated by various buried channels and the accumulation of ice in the northeastern portion of our continent. This advance during the later stages of the Tertiary deepened the valleys of the streams in the eastern part of our State. Toward the close of the Pliocene, the streams like the Grand, Cheyenne and White rivers had cut down 100 to 200 feet below the general level of the surrounding upland, and at that time more than that amount above their present beds. The Missouri (or James river) had cut fully down to the present level of the James, and the Big Sioux, probably as deeply, if not lower

Thus far we have seen nature preparing the foundation for our land; the separation of the ores for the miner; the storing of coal for fuel; the distribution of various ingredients valuable to agriculture, and also recording more or less completely the wonderful advance and multiplication of forms of life. We now come to a time when the finishing touches were put upon the earth to prepare it for the abode of nature's highest workmanship, intelligent man.

The work so far as our State is concerned began with the increase of inclement weather, cold and moist. This was the result of the elevation of the region northeast, and accumulation of ice, already mentioned.

As we have briefly described, *the ice made its entrance* from the northeast by way of the Red River Valley over and through the narrow divide into the James River Valley, then occupied as we believe, by the Missouri river. As a result of this displacement of the Missouri, there was formed for a short time a great fresh water lake, which we have called for convenience, Lake Arickaree. This was formed north of the extension of the Fox hills eastward and which has since been cut through so as to form the present channel of the Missouri, near Forest City. In a similar way a large fresh water lake, which we may call Red lake, was formed north of the Bijou hills; and also in a similar way the divide between the White river and Niobrara was cut through west of the Bijou hills, and for a time a steep rapid was formed a little farther south, near Platte creek, where the waters probably entered a tributary of the Niobrara. The ice mainly filled the valley now occupied by the James river and pushed its sluggish mass, as we have described on a previous page, to the vicinity of the Missouri river, at several points; namely, Walworth, Pierre, Lake Andes, Running Water and Vermillion. It seems probable also that toward the south it may have gone beyond the present location of the Missouri for a short time; so also in the east it may for a time have covered the East Coteau.

Then came as is believed a melting of the ice and the formation of the Loess deposit in the lake-like streams flowing from the southern edge of the ice sheet. The melting, however, was shortly arrested and the ice flowed steadily bringing its debris from the northern rocks, over which it passed, and built along its edge the First Moraine whose location has already been given.

The peculiar bend in the Big Sioux river by which it was thrown over the quartzite at the Falls is to be referred to the presence of the ice sheet immediately south at this stage. Sioux Falls and the region north and east was frequented by mammoths, and possibly a timbered region, while Canton was covered several hundred feet deep with ice.

It is supposed that this melting ice and recession was partly the result of the subsidence of the highland from which the ice streams radiated. We need not dwell upon the different stages of recession and the temporary advance and formation of the successive moraines which we have already located and described on preceding pages.

The beautiful and wonderful planning, and scoring of the red quartzite at many points in Minnehaha county are to be referred to the action of the ice before the moraine was formed, but similar work southwest of Bridgewater, west of Salem and at Rockport, was finished much later.

When the ice occupied the fourth moraine there was formed in the James River Valley from the fourth moraine southward to the vicinity of Redfield, and possibly as far as Mitchell, a long shallow fresh water lake, Lake Dakota, which became filled with loess-like silt forming the remarkable level plain now occupying that region.

Meanwhile the Black Hills were the recipients of great rains as would appear from the continued transfer of gravel and boulders from the Hills over the surrounding region, particularly along the valleys of the Cheyenne and its tributaries. This was the time of the formation of those great terraces along the valleys of the Cheyenne and Missouri rivers, which we have already described. It is probable that the plains were occupied by numerous mammoths and mastodon, possibly herds of buffalo and antelope, wolves, horses, etc., during the epoch of the Ice Age. Traces have been found of more abundant vegetable growth. Several cases of buried trees have been reported from Douglas and Charles Mix counties. In a well near Andes creek two or three miles north of Grand View at a depth of 20 feet from the surface, a layer of peat nearly a foot in thickness was found. Numerous fresh water shells and a log with cones resembling, if not identical, with those of the tamarack, were mingled with it. The character of the deposit above, with the surrounding topography indicate, that there had been a marshy basin in the Drift in which the tamarack had grown for many years, when by some change of the climate, and possibly a change of the course of Andes creek near by, filled it with fine silt and clay to the depth already stated.

Some of the benefits of the Ice Age may be briefly enumerated as follows: It gave a beautifully varied and yet even topography which is found in the eastern part of our State; it mingled the various ingredients of the rocks over which it passed and produced the uniform and rich soil which is characteristic of the whole region east of the Missouri. It produced at many localities beautiful lakes, not only for the ornamentation of the landscape, but for the storing of moisture in our region. Several of these have become known as summer resorts. By the same influence the picturesque terraces were formed along our streams which are found so admirable both in appearance and healthfulness for the location of towns and cities. The convenient storing of subterranean waters, also, has been in many cases perfected by the work of the ice.

As the ice receded and the Rocky mountain system gained somewhat greater altitude, the humidity of the region diminished and the climate became more like that of the present. At the same time the vegetable and animal life gradually changed from forms, which we have briefly mentioned as then existing, to such as are now natives of our State.

CHAPTER X.

ECONOMIC GEOLOGY.

It is difficult to say what portion of Geology may not have an economic bearing. Although many investigations have been pursued in the pure love of knowledge they have often unexpectedly led to economic results of great value. Even a study of fossil forms, which may have been begun with a spirit of curiosity or love of acquisition of rare forms, has been of invaluable aid in determining the existence or absence of coal and other mineral products. In this chapter, however, we shall confine ourselves to the presentation of such facts as are clearly seen to have economic bearings. We naturally take up the various products in the order of the geological formations in which they are mainly found. This will also lead us to consider first the mineral ores and later building materials, cements, etc.

MINERAL ORES.

Gold:—Gold stands at the head of the precious metals, not only in value but in the amount produced in our State. Prof. W. P. Jenney enumerates the methods of occurrence of gold in the Black Hills, as follows:

"1. In veins of ferruginous quartz traversing the Archean schists and slates.

"2. In strata of slate mineralized and altered by the action of waters depositing silica and iron pyrites.

"3. In conglomerates forming the lower layer of the Potsdam sandstone, resulting in this case from the denudation of ledges in the Archean rocks.

"4. In trachyte and porphyry.

"5. In deposits of slates and sedimentary rocks, produced by the intrusion of the trachyte and porphyry.

"6. In placer gravels, resulting from the decomposition and erosion of the above formations in the Tertiary and recent times." (Geol. Black Hills, p. 225.)

In enlarging upon these different forms of occurrence we are chiefly indebted to Prof. F. R. Carpenter, who has made a more recent and careful study of them. His results were published in his "Report of the Geology and Mineral Resources of the Black Hills," already mentioned.

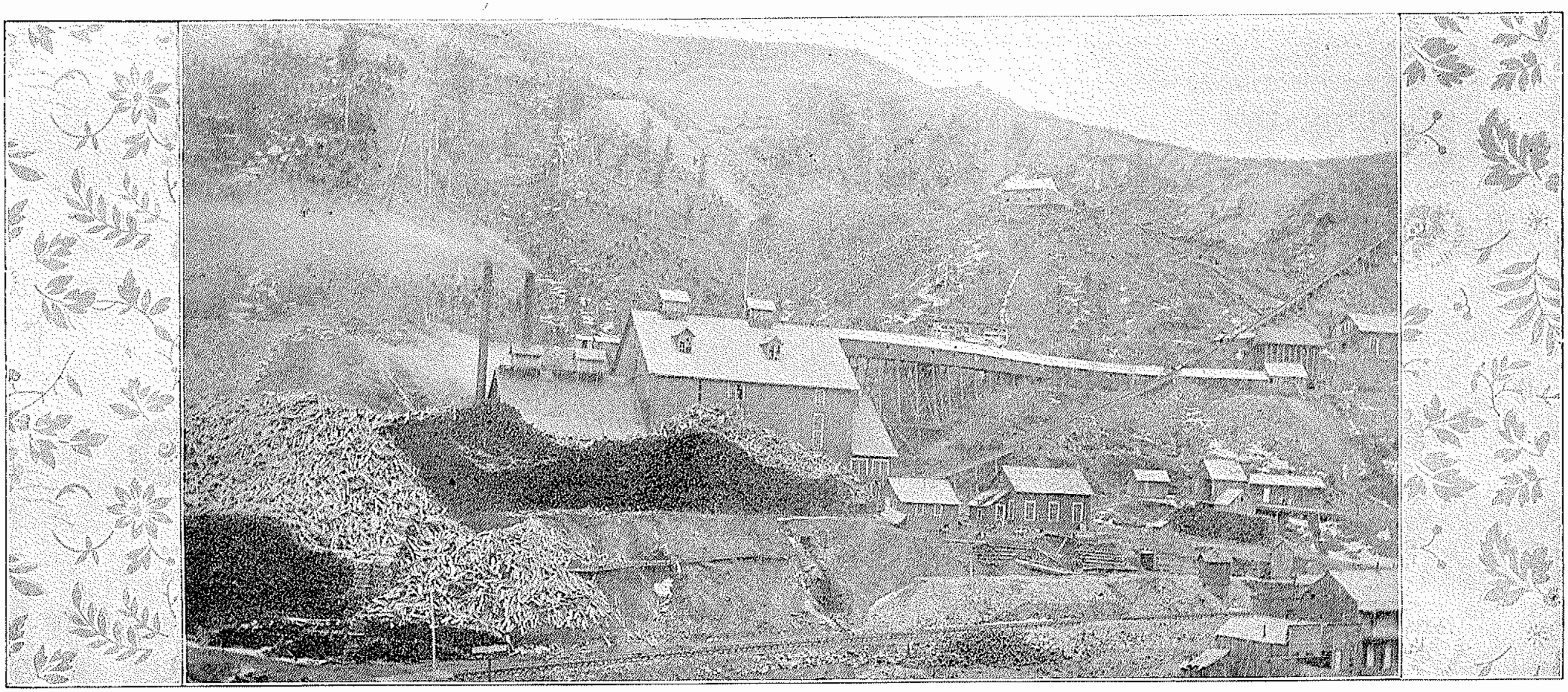


PLATE IV.—THE HOMESTAKE MINE AND MILLS, LEAD CITY.

First. Of the gold in quartz veins he says: "It is accompanied by little or no sulphur but occurs free in the vitreous quartz, often in quite large pieces." (Geol. and Min. Res., Black Hills, p. 121.) As has been stated elsewhere these veins occur more or less throughout the whole Archean area, and not only cut across the bedding, but perhaps in the majority of cases lie parallel with the schistose and slaty structure. They are often times very rich.

Second. Of the second class a more notable example, as he considers, is the Homestake vein which is sometimes spoken of as the "Belt." This feature comprises a 'section 6,000 feet long by 2,000 feet broad upon which several mills are located." (Geol. and Min. Res., Black Hills, p. 113.) He says further, 'The 'ore' is not continuous throughout this distance, (6,000 feet) but occurs in shoots or vast "pipes," lenticular shaped in cross section. The beds of argillites, phyllites and amphibole schists, in which shoots occur, have a strike of nearly 37¾ degrees west, which is also correctly the strike of the plane of the ore channel in which these shoots occur. The dip of the beds, as a whole, is toward the east. The shoots dip east also, upon but athwart this plane, at an angle of about 45 degrees. The ore and in closing rocks have indifferently the same general cleavage structure.

"In the Homestake proper, in the south end of the Belt there are numerous sheets of porphyry, or more properly, of felsite, sometimes cutting across the stratification, but usually parallel to it. In the northern half—that is, the Deadwood-Terra and De Smet end—no porphyry is found in the vein, but the section was once overlain by a felsite, which yet remains as a capping to the ridge between Gold Run and Bobtail Gulch and between Bobtail Gulch and Deadwood Creek. This porphyry was injected between the slate and the Potsdam, raising the latter and other overlying rocks after the manner of laccolite, though they have since been removed in the immediate area. The vent through which this sheet was injected had probably no connection with the small dikes found in the Homestake but was intruded from the southwest and most likely was connected with the igneous mass forming Terry's Peak.

"The percentage of pyrites impregnating the slates and schists and forming the "ore" is never large. The yield upon concentration is seldom 20 per cent. The average is not more than 7 per cent. There are no solid bodies of pyrite.

"The influence of the porphyry upon the lode, seems to be good, but whether in produce an enrichment of the bed, or whether it rendered it by some action of oxidation, or otherwise, more free-milling has not yet been determined definitely. The fact, however, is that the Homestake yield per ton is much greater than that returned by the Deadwood-Terra and other claims, where the igneous intrusion do not occur, the former, from the best attainable data, being $3.87 per ton, while the latter lies between $2.03 and $2.82. The sheets of igneous rocks in the Homestake are porous and much decomposed. Careful assays showed no gold. The sheets east of this, near the pump shaft, are pyritiferous and assay from $1 to $2 per ton. From what we have stated, I am led to the conclusion that the porphyry is of two-fold benefit.

First. It renders the ore more free milling.

Second. It has, in the neighborhood, produced either enrichment of the deposit, or a further concentration of what gold originally existed in it."

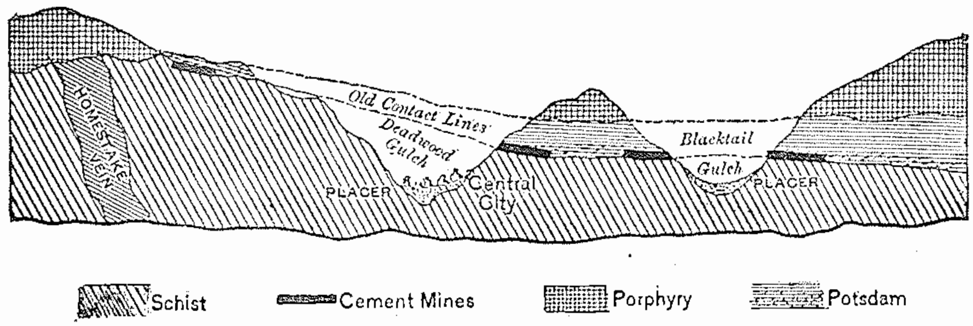
"That it was gold bearing before the injection of these dikes is proven from the fact, that remote from their influence it is gold bearing, and that all similar beds through other parts of the Hills, where no igneous rocks occur, are also gold bearing, as well as from the evidence furnished elsewhere from the study of the Potsdam conglomerate, which as has been stated was laid down prior to their injunction. At the surface the ore has always appeared in shoots, as I have described, but I am credibly informed that in the deeper works of the Homestake end this is no longer the case, the bed being now continuously of the ore bearing for many hundred feet. These ore bodies are said to have exceeded 300 feet in thickness. Careful measurements of the big open cut upon the Golden Star claim gave as the cross-section of that body, 150 by 350 feet, while the Terra cut gave 150 by 250. These figures are probably correct, so far as the width is concerned, but the shoots may be longer."

Prof. Carpenter considers that the Homestake was originally laid down as a stratified or bedded deposit and that it appears to have been subsequently modified by infiltration and that the latter change also occurred in Archean times.

Prof. Crosby in speaking of the deposits of gold attending the porphyry outflows elsewhere, remark: (p. 515.)

"Whether the gold of the Homestake and other mines, situated in the ferruginous slates and schists of the newer Archean series, is derived from the associated porphyry dikes is an entirely independent question. Prof. Carpenter has answered it in the negative; and he is certainly justified, in the main, by the fact that similar ferruginous strata are distinctly auriferous outside the volcanic area. Still, after studying the Ruby Basin, it seems impossible to resist the conclusion that the porphyry is the actual source of some of the gold in the Homestake district; although its chief favorable influence has probably been to render the gold originally present more available."

Third. The third class of deposits, namely, in the Potsdam sandstone, are considered by all who have studied them to be really ancient placers, formed by the action of waves. These mines are known as "cement mines" because of the consolidation of the conglomerate by the cementing material. The gold in these cement beds is mined, stamped and amalgamated as other free milling gold ore. The cut presented, taken from W. P. Devereaux's paper "On the Occurrence of Gold in the Black Hills" (Proc. Am. Inst. Mining Engineers, Vol. IX, p. 465; quoted by Carpenter) shows well the relation of these Potsdam placers to the adjacent formations. The Archean schists lie below and their uneven surfaces show much erosion. The porphry, while sometimes capping the Potsdam is elsewhere injected underneath or within it; at other points it lies between it and the Carboniferous rocks above.



Approximate Geological Sketch from Homestake Vein, Eastward.

FIGURE 2.

"The drawing represents the section taken perpendicular to the Homestake, and extends about 1½ mile to the east. The lower contact line is the ancient Potsdam beach. The later placers occupying the gulches beneath derive their gold mainly from the disintegration of the overlying Potsdam; and while Deadwood Gulch has received additional gold directly from the Homestake deposit, Black Tail Gulch lying at the base with Deadwood creek, between it and the Homestake contains no gold that comes directly from this deposit. What it contains has come through the medium of the Potsdam." (Geol. and Min. Res. Black Hills, p. 112.)

Mr. Devereaux, who had the management of some of these cement mines noticed that the gold in these conglomerates, is finer than the gold of the Homestake, whence it is derived. Since it was set free, it has been subjected to various chemical agencies which have dissolved out a part of its silver alloy. This solution of the silver, having been confined to the surfaces of the pieces of placer gold, has given them a corrugated appearance, and this being true, it follows that the smaller the pieces are, the finer gold. The average of Mr. Devereaux's assays gives the following fineness: Gold, .904; silver, .096; while from assays made by Mr. George Hewitt, the different ores from the Homstake yield gold as follows: (Geol. and Min. Res., Black Hills, p. 112.)

	Homestake.	Highland.	Terra.	Deadwood.	De Smet.
Gold	.820	.830	.825	.850	.820
Silver	.170	.155	.160	.140	.170

4. Concerning the existence of gold in the porphyry the evidence is less distinct. We have already noted the statement of Prof. Carpenter that gold was found in the porphyry attending the Homestake lead. Prof. Jenney in his report, says that as gold has been found in the trachytes of the Bear Lodge range, he considers its occurrence in the igneous rocks of the region of Terry Peak extremely probable. Because the origin of the present mineral deposits has been traced to hot waters attending the igneous outflows, it is not improbable that siliceous precipitates may be

contained in the igneous rocks, as well as in the metamorphic rocks adjacent.

5. Deposits of the fifth class are found in the Paleozoic rock in Ruby Basin and Bald Mountain, at Galena and Carbonate. Of these Prof. Carpenter says: (Page 124.)

"The former are mainly gold bearing while the latter yields silver and lead. They cover a large area, larger as I shall presently indicate than is generally supposed, and must soon become important ore producers. The ore-bodies are not continuous, but occur in shoots. In the first mentioned districts, the shoots have great linear extent and are usually from 40 to 60 feet wide, and while some are less than this, others again are greater. They vary in thickness from a few inches to 10 feet or more. Many hundreds of claims showing minerals have been staked and recorded. The value of the ore varies. Some of the ore-bodies will not average $15, while others exceed $60 per ton. From $20 to $25 may be taken as a fair mean." * *

"At Galena the ore bodies are of equal promise but of a different character, being silver-lead instead of gold. * *

"These ores are found only in connection with the igneous intrusions. The gold ores are found in the vicinity of Terry's Peak and Bald Mountain, where outliers of Potsdam rocks yet remain. Inference is fair that the rocks once connecting these outliers were also mineral-bearing, and that, in the Potsdam beneath the unremoved Carboniferous beds, will be found ores also, at least so far as igneous intrusion continues. * *

"At Galena the miner sees only the outcrops of these ores. They dip eastward with the inclosing rocks at an angle of 16 degrees from the horizon. After leaving Bear Butte creek no other stream cut through to the level of the mineralized portions. * *

"North and south of Bear Butte creek there is an area of nearly 50 square miles, where the igneous rocks occur in exactly the same relation to the Potsdam, as at Galen.a The streams of this area sometimes cut through to the igneous rocks between the Potsdam rocks enabling one to see this relation, while vertical dikes rise in many places to the surface. I believe that shafts, sunk to the Potsdam anywhere in this section, would be likely to intercept ore. West of Terry's Peak and Bald Mountain, the same condition occurs, throughout a much larger area, extending to the Wyoming side of the Hills, where similar ores are known to exist. After a thorough examination I am convinced that not a tenth of the area in which these ores occur has yet been located."

He remarks further with reference to the method of formation: (p. 127.)

"These occur principally along the bedding planes of these rocks, but deposits are also found occupying the vertical joint planes as well as impregnating the quartzite by replacing the cementing material of the original sandstone. They are found in such close relation with the igneous rocks that the conclusion is irresistible that they owe their origin to these rocks."

"At Ruby Basin and Bald Mountain they usually occur as impregnating distinct zones of the quartzite, and occur at different levels in the rock.

The most favorable position seems to be upon or in, the upper part of the quartzite, forming the basal member of the group. Owing to the removal of overlying rocks, many of the ore-bodies are so thinly covered, that the original pyrite has been oxidized. That this oxide, now forming from 10 to 20 per cent of the ore-body was derived from the pyrite there seems to be no doubt. In the deeper workings a peculiar bluish quartzite constitutes the ore. Under the microscope this is seen to be composed of rounded grains of silica, imbedded in the silicious paste, which carries a very finely divided iron pyrite. This silicious paste with the pyrite clearly occupies the spaces between the grains of quartz, which composed the original sandstone and was deposited metasomatically, replacing the former calcareous cement. That is, particle by particle as the original cement was dissolved out, it was replaced by the silica-pyrite cement. The solutions which wrought this change brought also the gold and silver. From the description I have given it will be seen that these deposits did not, in the ordinary sense, fill pre-existing cavities."

"These ore are, in some sections, almost exclusively gold bearing, in others partly gold and partly silver, and again in other places the silver predominates. They fill not only the places between the quartz and grains, but occur in large bodies, replacing the beds of lime shales sometimes occuring in the Potsdam. This last is the mode in which the deposits at Galena occur. It would seem as though the porphyry at Bald Mountain brought mainly gold; at Ruby Basin, a few miles distant, gold and silver in equal quantities, while at Galena, 12 miles distant, silver-lead predominates. In the same section the proportion of gold is greater in the lower contact while in the upper it gives place to silver. That is, briefly speaking, gold predominates in the quartzite, but gives place to silver as we approach the more calcareous portions, forming the upper part of Potsdam; while in the massive limestone such ore bodies as are found, like the Iron Hill, are exclusively lead and silver, notwithstanding that the porphyry is in all instances the same."

Sixth. The recent placers occur, of course, in the gravels of the present streams, both in those of the present flood plains, and those occupying terraces of older origin. These in the Black Hills, as in most other gold bearing regions, were the first discovered deposits of gold. Much of Prof. Jenney's report on the Geology of the Black Hills, treats of the placers as they were found in nearly all streams of the Hills.

The first discovery of gold by white man was on French creek early in August, 1874. Placer mining has nearly passed by, and most of the gold of the present time is derived from the large, though comparatively lean mineral deposits, like the Homestake lead. Occasionally very rich deposits of gold ore in quartz veins are being continually found. The production of gold in the Black Hills for 1892 was $3,700,000; in 1893, $4,-000,000.

Gold elsewhere in the State. From the history after the glacial deposits it is not very improbable, that slight traces of gold may be found in the glacial drift. A few years since such finds were reported upon the East

Coteau. The recent discoveries of gold near the Lake of the Woods and near Redwood Falls, in Minnesota readily explain such occurrence. The finding of a few grains however should not arouse great hopes of valuable placers.

SILVER.

Ores of this metal occur either in connection with gold or lead, and as reference has already been made to its ores in connection with the gold, we need not repeat at this point. The amount of silver produced in South Dakota in 1892, was $75,119; in 1893, $181,527.

COPPER.

Of this metal Prof. Carpenter says: (p. 122.)

"The copper deposits are numerous and extensive, but undeveloped. They are found in both the eastern and western portions of the Archean rocks, the richer being apparently in the latter. They show a copper-stained gossan, from 50 to 500 feet in width. Where the outcrops, or backs of these ores disappear beneath the Potsdam, it also, is copper-bearing, clearly deriving this metal as a secondary deposition from the beds below.

"At the Blue Lead there is a great quantity of these gossan ores. In sinking through them the miners reach a leached, decomposed portion of the bed, but no one has yet gone far enough to tell what lies below this. Doubtless they are identical with the famous Ducktown deposit. (p. 122.)

"There is enough of this surface copper, which consists of malachite, red oxide, native copper and copper glance to justify the erection of a water-jacket smelter at some convenient point. The average per cent of these ores as assayed by the School of Mines, is about 35 per cent copper, equal to 700 pounds of metal copper per ton, worth at present rates, $112."

LEAD.

Around Galena, as has already been stated, silver-bearing galena is found in paying quantities. About Carbonate the ore is principally carbonate of lead and silver.

IRON.

The iron ores found in the Black Hills have not been developed. Prof. Winchell, in his course down Box Elder creek (Black Hills of Dakota, Ludlow, pp. 52 and 53), records the occurrence of extensive deposits of a silicious iron ore in the Archean rocks. In some cases, it apparently attains a thickness of over 50 feet. There were hills of it. Newton calls attention to beds of a similar sort on Rapid creek. Should easy access be eventually obtained to these beds and abundant fuel be obtainable from the lignite of areas of the Laramie, these deposits may eventually prove a valuable source of wealth to our State.

MANGANESE.

Ores of this metal have been discovered at several points in the Black Hills. In 1892, 19 tons were shipped from Custer county. Assays of the ores made at the School of Mines have showed 46 per cent of manganese. (Mineral Resources of U. S., 1892.)

NICKEL.

In the pyrrhotite found on Spring creek, 1½ to 8 per cent of Nickel has been found. Similar deposits doubtless occur at various other points in the Hills. (Carpenter, p. 123.)

TIN.

The universal ore of tin, cassiterite, occurs very generally in the granite rocks about Harney Peak, and in the northwestern part of the Hills, known as the Nigger Hill district. The existence of tin in the Black Hills has been known since 1877, when it was recognized by Prof. Richard Pearce, of Denver. Previous to that time it had been considered a troblesome black sand, which interfered with the easy separation of gold in placer mining. Quantities of "stream-tin" are found in the streams leading from the granite areas, already mentioned. The discovey of tin in the native rocks was at the Etta Mine, east of Harney Peak. The granite rocks seem to contain the tin wherever they are found, but it is concentrated in certain localities which appear to have a vein structure. As Prof Carpenter says: (p. 135.)

"These veins have been classed by Newton, Jenney, Blake and others as igneous or intrusive granites, but they seem to be true veins of a type known as segregated veins, differing from the true fissure veins in that they are parallel to the plain of bedding. Usually they are distinctly lens-shaped.

"Many of them, however, are of the true vein or tabular form and can be traced for thousands of feet. The Margaret lode can be traced with few interruptions from Battle creek to Iron creek, a distance of over 6,000 feet.

"The amount of cassiterite present varies. It is never evenly distributed throughout the veins from wall to wall but lies in zones or sheets. With the exception of being usually parallel to the bedding and not cutting across, these veins have all the characteristics of true fissure veins and occasionally these features are not wanting, two having been observed which cut across the stratification.

"The veins vary very much, not only among themselves but even in the different portions of the same vein. Very often, indeed nearly always when tin is present, one of the constituents of granite is wanting and the vein matter is composed of quartz and mica alone, that is *greisen*, or it consists of feldspar and mica which for want of a better name has been called *albitic greisen*. At other times the veins consists almost entirely of the massive pinkish feldspar and again not infrequently of quartz alone.

"The Etta vein is columar, so to speak, in form, it has a cross section roughly oval of 150 to 200 feet. The arrangement of the minerals is somewhat concentric. The central portion of the vein is quartzite and feldspar around which is a zone of albite and mica carrying tin stones in quite large quantities. Thence comes a zone surrounding these noted for its large and perfectly formed crystals of spodumene 10, 20 and even 30 feet in length. The interstices between these crystals are filled with an aggregation of albite, also carrying tin stone (cassiterite), but in a more massive form than the zone just within. Between the spodumene zone and the inclosing mica-schist, there is a micaceous aggregate composed of both muscovite and biotite but barren of cassiterite."

With the tin there is often found more or less of columbite, sometimes in large quantities. In one locality a mass of a ton's weight was found. This mineral because of its resemblance to cassiterite is sometimes mistaken for it.

Prof. Carpenter remarks concerning the percentage of "black tin" or cassiterite in the rock as follows: (p. 142.)

"If all the stuff broken at the mine were sent to the mill the percentage of tin would be low, if it were closely assorted it could be made very high, depending entirely upon the extent to which the lower grades of ore are rejected. Assays signify nothing. Hand samples containing from 25 to 50 per cent black tin, (cassiterite) can be readily selected at any mine. Prof. W. P. Blake suggests, that it will be probably found advisable to send to the mill for treatment all rock carrying 10 pounds per ton of cassiterite and upwards. If this is done, I estimate two per cent cassiterite as a probable average of the tin ores in the Hills."

According to analyses made at the School of Mines by Prof. W. P. Headden the tin ore from veins contains 74.5 to 76.7 per cent tin, which is higher than that from other prominent localities. The analysis of the Cornish black tin, ready for the market, is about 72.3 per cent. Dr. Headden's assays of the stream tin, both from Nigger hill and the southern hills, gives the percentage 72.84 to 73.21 per cent tin. (p. 141.)

The tin ore cassiterite has never been found with free crystaline surfaces and is always embedded in the rock. Associated with it are several minerals of considerable interest. "Great quantities of phosphatic minerals are found in these veins, including apatite, heterosite, triphllite and autunite." (p. 137.)

Graphite is quite a common mineral in the veins, beryls occur often of large size. Garnets have been found in all mines as far as worked. Ilmenite, zircons and corundum have been reported.

GRAPHITE.

As already stated specimens of this are found in connection with the tin ore, but usually not in sufficient quantities to be worked.

I have been reliably informed that a deposit of considerable extent has recently been found near Hill City. Analysis at the School of Mines shows that it contains about forty per cent graphite, the remainder being of argillaceons and micaceous impurities. It may be found valuable as a lubricant.

MICA.

The granite of the Black Hills in places has its ingredients so large and coarse that mica of merchantable size is found. Sheets 15 inches in length are occasionally found and considerable quantities have been sent to the market. It was in connection with the mica mine that the tin ore was first found, near Harney Peak, at the Etta mine. Another locality is found near Custer City.

BUILDING STONES.

Although the Colorado deposits cover much of the State and are largely free from building stone, important deposits of excellent stone are found both in the Black Hills, and in the eastern part of the State, in Minnehaha, McCook and Hanson counties. Besides, stone for rougher work may be obtained in limited quantities from the Laramie, Tertiary and Drift formations.

GRANITE.

As has already been said the granite of the Black Hills, because of its coarse grain is more subject to disintegration by weathering. It has not been used extensively for building and no quarries have been worked. It is not improbable, however, that the finer varieties of the rock may prove a valuable building stone. Immense quantities of it are exposed.

QUARTZITE.

The red quartzite, commonly known as the Sioux Falls Granite or Jasper, is found very extensively in the eastern portion of the State. It is a most durable rock, and although very hard, natural jointing of the rock makes it possible to excavate it with comparative ease. It is composed almost exclusively of quartz, and is usually intensely compact and hard. Several varieties are found distinguished by different shades of color, varying from a light pink to a dark Indian red, with shades of purple. In hardness it varies from the extreme already mentioned, which is most common, to qualities which have the structure of soft sandstone. The bedding of the rock is such in certain localities that it is most suitable for paving stone, but with little difficulty strata furnishing rock of any size may be found. Extensive quarries have been opened about Sioux Falls and Dell Rapids. The output for 1892 was valued at $50,000 and that for 1893, $27,828; which shows a decline probably due to hard times. From specimens at the World's Fair, the report of the

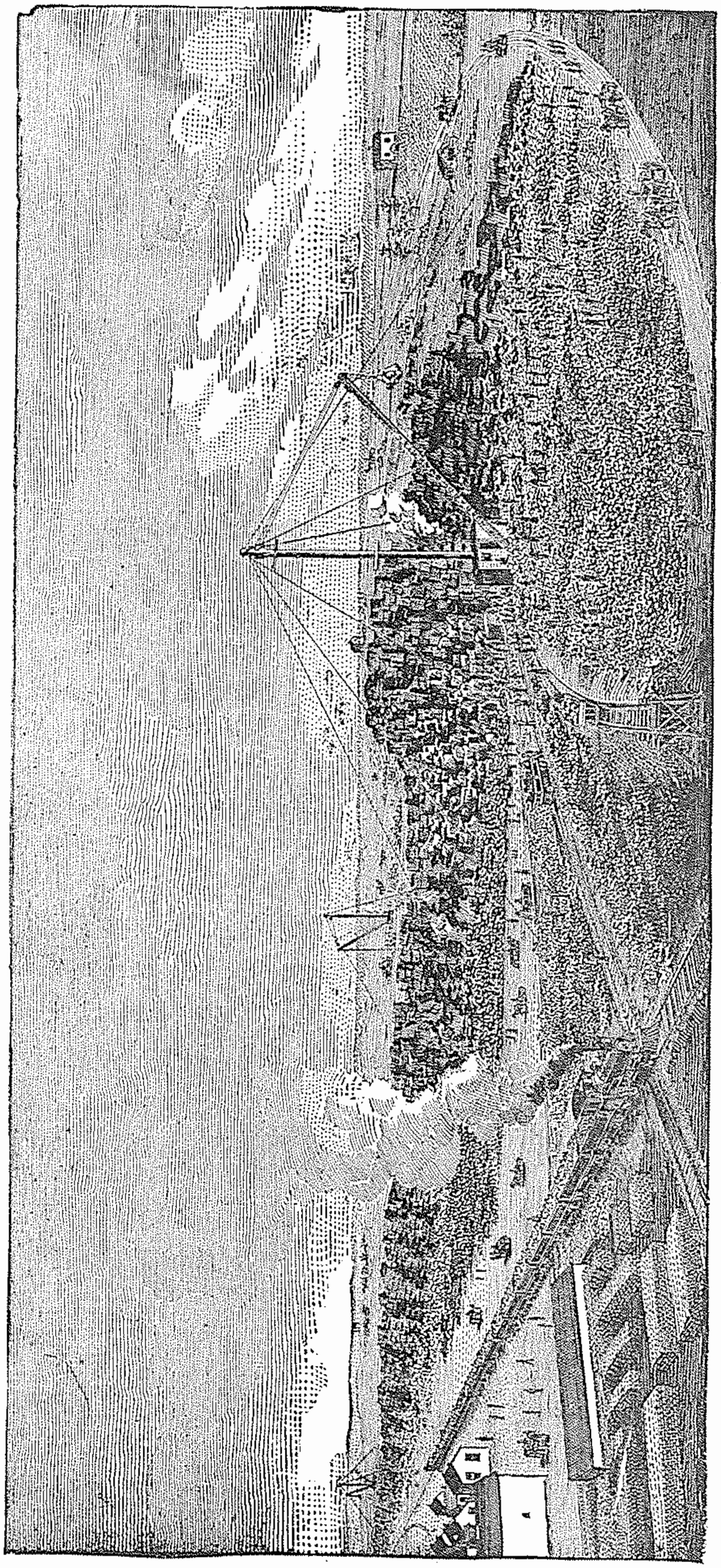


PLATE V.—EAST SIOUX FALLS QUARRY.

Geological Survey and Mineral Resources of the United States referring to polished samples of this rock, says: "This stone shows occasional small knots which will not take polish, but this will not seriously interfere with its beauty. The stone, although beautiful enough for ornamental work, is at present quarried for paving purposes. The blocks being used in Chicago where they give satisfaction. The stone splits easily into paving blocks and it is claimed that it can be worked for this purpose more cheaply than granite. The crushing strength gave about 22,000 pounds to the square inch. The quarrying of this stone has been going on for ten years and it is becoming fairly well known to the country at large as well as to such of the western States as have had practical experience with it."

It is a favorite stone for building, the medium varieties being used for the main walls while the darker and lighter are used for trimming. It is practically indestructible, although in case of fire it is cracked more by changes of temperature than granite.

Specimens of this rock found in Minnesota were tested among others from that State at Fort Wadsworth, Staten Island, under the direction of Gen. Q. A. Gilmore. For this purpose the rock was dressed into cubes two inches each way and were subjected to pressure between steel plates, one direction being perpendicular to the planes of bedding or stratification and another parallel with the same. The strength shown in the first case was 27,750 pounds per square inch; in the second, 27,000. This exceeds that of any other rock from that State, with the exception of the fine grained syenite from St. Cloud, which stood a pressure of 28,000 pounds.

This rock is found not only widely about Sioux Falls but is exposed favorably for quarrying in all the northern townships of Hanson county, where the streams have cut through the drift, and in the valley of Pierre creek, east of Alexandria. Extensive deposits are found southwest of Bridgewater and near Rockport on the James river. Less favorable exposures are found on Enemy creek southeast of Mitchell and two miles east of Parker on the Vermillion.

Extensive deposits of a somewhat similar rock are found in the Archean area of the Black Hills. These have been locally used for various purposes, but have not been shipped away.

SANDSTONE.

Beds of sandstone are rarely found in the eastern portion of the State. The most prominent one is three or four miles north of Milltown, on the James river. It is of a comparatively poor quality, but has been found serviceable not only for foundation walls, but for the rougher forms of building.

Thin strata of a rough greenish-gray sandstone, sometimes hardening to a quartzite, are found generally in the buttes along the Missouri and between that stream and the Black Hills. As has already been mentioned, a deposit of this rock is found capping the Bijou Hills, Medicine Butte and others, near White river. The rock in Grindstone Butte is probably of a similar character. In the western part of the State sandstone beds of the Fox Hills are quite frequently found, but their quality has not been tested.

In the Black Hills there are inexhaustible supplies of sandstone of almost any quality or color. The Potsdam furnishes extensive deposits of the dark brown sandstone of a somewhat different tint, but resembling the brown stone so popular in the Connecticut Valley.

The Jurassic and the Dakota formation of the Cretaceous are largely composed of sandstone, as we have already observed. At almost any point strata may be found of suitable texture either of dressed stone for building for rougher work, or for fine ornamental carving. At the World's Fair specimens were presented from the vicinity of Hot Springs, which showed a remarkable uniform structure, free from blemish. From these statues and ornamental figures of various forms were cut. The prevalent color was a bright red or pink. Certain varieties showed a beautiful veining of red and white, sometimes in the form of ripple marks, in other cases of fragments that have been recemented. These were probably from the Jurassic, and perhaps would not be found most durable for work exposed to the weather.

The sandstone from the Dakota Formation is usually of a gray or reddish cast, and, with little care, would probably rival the famous Berea stone of northern Ohio. Quite extensive quarries have been opened, such as the Evans' quarry near Hot Springs, and near Rapid City. Its use has thus far been mainly local, but should there be a demand created inexhaustible supplies are readily accessible. The samples of the stone from the Black Hills, presented at the World's Fair, were tested by the United States Ordnance Department at the Watertown Arsenal, in Massachusetts. The test was made by covering the compressed surface with a facing of plaster of Paris to secure an even bearing in the testing machine. The blocks were in cubes of 4 inches each way. The principal results are given in the folllowing:

TABLE.

ROCK AND LOCALITY.	Crushing Pressure Per Square Inch.
Sample 1, from the Black Hills Quarry Company, pink color	10,532 pounds
Sample 2, " " " " buff color	8,401 pounds
Sample 3, " " " " light drab color	5,937 pounds
Sample Mount Lookout Quarry	4,516 pounds
Sample from Evans' Quarry	6,305 pounds
Sample 1, of Lem Creek Quarry Co.	5,582 pounds
Sample 2, " "	4,520 pounds
Sample 3, " " wet, after 20 hours' immersion in water	791 pounds.
Sample from Evans' Quarry (best)	7,491 pounds

A comparison of these figures with similar ones from corresponding rocks elsewhere will be instructive. A sandstone from Hinkley, Minn., stood a pressure of 19,000 pounds per square inch, perpendicular to the bedding and on edge 17,500. The Berea sandstone in Ohio, perpendicular to the bedding, 10,000 pounds per square inch; on edge, 6,750.

The Niagara limestone of Stone City, Ia., stood, perpendicular to the bedding, a pressure of 11,250, and on edge, 9,750. The Niagara limestone of Lemont, Ill., stands a pressure, perpendicular to the bedding, 27,000 per square inch, and on edge, 26,250.

From this it will be seen that the samples from the Black Hills Quarry Co. and from the Evan's Quarry Co. are nearly equal to the Berea stone of Ohio.

LIMESTONE.

No limestone is found in the eastern part of the State except the so-called chalkstone which has been quarried and used for building at Mitchell, Scotland, Springfield and Brandon. When carefully selected it stands weather well; some buildings show little imperfections after a dozen years. The stone is very easily worked being so soft that it may be cut with a knife. It is the same stone as that which is more extensively used in Kansas, where it is known as the "magnesian limestone." Its composition is really argillaceous chalk. The difficulty of selecting suitable blocks and the uncertainty of obtaining that which is durable prevents its being used extensively. Moreover it is not widely exposed except at a few points along the bluffs of the Missouri, between Yankton and Chamberlain.

Sometimes quite large blocks of a hard compact magnesian limestone, of a snow-white or light yellow color are found in the drift east of the Missouri, but they are not abundant enough for extensive use.

In the Black Hills, extensive deposits of a gray limestone are found in the Carboniferous. These have not been carefully examined, although with little care almost any quality of limestone would probably be found Some beds are quite silicious and therefore difficult to work. Dr. Carpenter says: "The upper part of the Carboniferous limestone affords a fairly good marble, nearly pure white."

The purple limestone of the Triassic is of remarkable fine grain and pure composition and is susceptible of fine polish, which may make it valuable for ornamental work. It resembles the varigated marble from Tennessee.

PORPHYRY.

The igneous rocks found in the northern part of the Black Hills have not yet been used for economic purposes but may eventually prove to be valuable as building stone. Much difference will probably be found between the different varieties, namely: Trachyte, rhyolite and phonolite. The green porphyry which is extensively exposed near Tilford seems likely to prove a stone equal to granite in durability and more easily worked. I am not aware whether attempts have been made to polish it but presume that it will be found susceptible of polish. The polish may not stand exposure to weather, but for indoor work it may compare favorably with marble. The strength of porphry, as has been tested in Minnesota, is nearly equal to granite. A variety of trap rock from Taylor's Falls, Chicago county, Minnesota, stood a pressure of 26,350 pounds. A sample from near Duluth was of the same strength. It seems not improbable that the samples from the Black Hills, although not tested, may prove considerable stronger than the sandstone already tested from that region.

CEMENTS, CLAYS, SANDS, ETC.

GYPSUM.

The Red Beds of the Triassic have inexhaustible supplies of an excellent quality of gypsum. Mills for the preparation of plaster of Paris and stucco have been erected at Hot Springs and Sturgis. The report of the Mineral Resources of the United States for 1893 gives the following statement concerning South Dakota: "The product in 1891 of the crude gypsum of the amount ground into land plaster, 1,560 short tons, valued at $4,680. The amount of tons burned for plaster of Paris, 2,055, valued at $4,938, total output for 1891. $9,618. For 1893 only 50 tons were ground into plaster while 5,100 were burned into plaster of Paris, having a value of $5,112. Total product, 7,014 tons, valued at $24,359."

Dr. Carpenter gives the analysis of the gypsum as follows: "Lime, 34.60; sulphuric acid, 45.17; water, 20.15; silica, 0.03; total, 99.95, and remarks that a purer quality is not found anywhere.

LIME.

In the eastern portion of the State limited quantities for local use have been prepared by burning white limestone boulders in the drift. Small quantities have also been made from the harder layers of the Niobrara chalkstone. In the region of the Black Hills excellent lime has been made from the purple limestone, for which purpose it is peculiarly fitted by its unusual purity. It consists of 98.75 per cent of calcium carbonate.

Prof. Orton in his Economic Geology of Ohio recognizes two classes of lime. One the magnesian or *dolomitic*, and the other the calcareous or *calcitic* lime. The lime derived from the purple limestone belongs to the latter class and would be classed as a hot, strong, rich quick-slacking and quick-setting lime. It is purer than the best Ohio limes. Prof. Carpenter remarks:

"I have not had an opportunity to study the Carboniferous or 'big white, limestone' from an economic point of view, and can state but little as to its value. The upper part is shaly, the lower part silicious. About 200 feet, composing the central portion, is of a gray or whitish color and appears to be uniformly fine. It has been used somewhat as a flux and is used for building purposes west of Hermosa and probably at other points. The lime produced is pure white, without gray, and is probably magnesian."

PORTLAND CEMENT.

So far as has yet been discovered there is no hydraulic limetone in our State, but deposits admirably fitted for the production of Portland cement abound in several localities. The only point at which the industry is developed is two or three miles west of Yankton on the bluffs of the Missouri river. At that point extensive beds of chalkstone are easy of access, and above them 15 or 20 feet of the dark plastic clays of the Pierre formation. The cement is prepared by the grinding of the chalkstone and the clay and mixing them in the proper proportion, with the assistance of water, then, after drying the mud and burning it, it is ground into cement. This has been found to be of the most excellent quality; in fact, the materials are so easily worked that any proportion of carbonate of lime and silicate of alumina may be quite accurately obtained.

The manufacture of Portland cement seems to be growing in favor and importance throughout the country. The output of our State for 1892 was 3,400 barrels, at a value of $68,000.00; in 1993, 33,739, at a value of $69,502.00. This indicates an increase in the reputation of the cement. It was used very successfully at the Worlds Fair, and is used very extensively in various parts of the west for sidewalks and other outdoor work, as well as for other uses to which it is commonly put. The Niobrara chalkstone and the overlying Pierre clay may doubtless be found in close relation to one another at many points along the banks of the Missouri from Yankton to Chamberlain.

POTTER'S CLAY.

At Sioux City extensive deposits of potter's clay have been found in the lower portion of Fort Benton, or the upper part of the Dakota. No exposure has been found of this deposit upon the Dakota side and perhaps it may not exist at the eastern end of the State. Yet, at the western and corresponding strata of the Dakota are extensively exposed around the Black Hills, and doubtless afford favorable localities for manufacture. It is likely also that at many points clays of the Fort Pierre and the Fort Benton may be found well adapted for this purpose.

FIRE CLAY.

This exists in the lower layers of the Dakota formation around the Black Hills. Tests made of the deposits of fire clay near Rapid City showed it to be of fine quality. Two layers of it, several feet in thickness, are extensively exposed on the south side of the gap at that place.

BRICK CLAYS.

The Loess commonly affords an excellent quality of brick clays; sometimes, however, it is so filled with limy concretions that it is greatly injured for this purpose. This deposit, it will be remembered, abounds in the extreme southeastern corner of the State. The silt capping of the high terraces along the Missouri and other streams also frequently affords loamy clay well adapted for this purpose.

At other localities where these supplies are wanting, the loamy portions of the alluvial deposits on the flood plain of the large streams furnishes suitable brick clay. Sometimes the clay may be made by the mixture of the alluvial deposit, or fine sand, with the finer qualities of the Cretaceous clays that are usually near at hand.

SAND AND GRAVEL.

Deposits of sand and gravel abound along the streams near the Black Hills, not only in the channel but often times in larger deposits along the tops of the high terraces. In the eastern portion of the State similar deposits are found along the upper streams and the old channels that were occupied by streams during the glacial period. In the deposits that have been opened, prominent gravel beds are found near Hudson on the Big Sioux and near Sioux Falls. Most of the State where covered with the Cretaceous clays may not furnish supplies of sand sufficient for local needs, but upon the Tertiary and Lignitic areas little trouble will be felt in this respect.

FUELS.

The obtaining of fuels is one of the most urgent demands of our State. Most of our Territory is without trees and even hay is not sufficiently abundant for burning, although it was used for that purpose in earlier years.

In the Black Hills and in the immediate vicinity of the larger streams wood is found in abundant quantities.

COAL OR LIGNITE.

There are three horizons more or less exposed in our State in which mineral fuel may be hopefully looked for. Namely: The Carboniferous, the Dakota and the Laramie or Lignitic.

The first, though extensively exposed in the Black Hills, seems clearly to have been deposited under circumstances decidedly unfavorable to the formation of coal in that locality. We have on a previous page referred to the probability of coal having been formed at this age in the region between the Black Hills and the eastern part of the State and have also called attention to the impossibility of its being obtained unless there has been some disturbance of the strata which has not yet been discovered.

We have already alluded also to the occurrence of lignite in the upper part of the Dakota formation about Centerville and the extreme southeastern corner of the State. Traces of similar deposits have been found also as far east as Peterson, Iowa, on the Little Sioux river. In all cases the abundance of water and absence of roof will probably render the small deposits at that horizon entirely inaccessible at the eastern end of State. Wherever this horizon is exposed about the Black Hills we may look hopefully for beds of lignite, possibly of sufficient thickness and sufficient excellence to reward the labor of mining it. The mines at Newcastle, over the line in Wyoming belong to this horizon and in Utah and Colorado there are valuable mines found in a similar geological position. It would seem from the marking of coal on Newton's map at the north end of the Hills that traces of this mineral were there found in this formation.

We have already in our description of the Laramie formation called attention to the fact that Prof. N. H. Winchell, while in connection with the Ludlow expedition to the Black Hills in 1874, reports beds of lignite 5 to 6 and even 8 feet in thickness, in the Cave Hills in Ewing county. There were also found beds of lignite 2 to 3 feet in thickness, as far east as Reinhart county, between the Moreau and Grand rivers. The fact that valuable beds occur not far away in North Dakota and west in Wyoming call for a careful examination of this region to determine, if possible, whether workable beds of similar value can be found within our own borders.

PEAT.

This is mentioned to call attention to the possibility of finding deposits of this material upon the East and West Coteaus outside of the First Moraine. It is not improbable that the recurrence of droughts and the burning of prairies has prevented the formation of extensive deposits of this kind or the destruction of them where they have been formed. Yet it is conceivable that in the lakes and marshes in these localities which have been long exposed to circumstances favorable to the formation of peat and similarly situated to localities in Iowa and Minnesota, where peat is found, that valuable deposits may yet be found. The occurrence of numerous glacial lakes and in many localities of perennial waters, with a high altitude and cooler climate, are all favorable to this result.

WATERS.

The State of South Dakota extends from the belt of sufficient rains on the east across the semi-arid and arid belts to the Black Hills on the west, which are also supplied with sufficient rains. The clayey character of the soil together with the lack of rainfall renders the central portion of the State too arid for agricultural purposes especially upon the uplands.

RAINFALL.

The average rainfall of the State, according to published reports of the Signal Service is about 22 inches. On the east of a line passing a little west of Milbank, Watertown, Alexandria and Scotland the average rainfall is 30 to 40 inches. West of that line to a line passing near Fort Sisseton, Faulkton, Miller, Chamberlain and also in the Black Hills, the average is 20 to 30 inches. Over the rest of the State it is from 15 to 20.

RIVERS.

We mention this but briefly here and would simply say that the main streams are pre-ennial, yet fluctuating greatly in volume at different seasons of the year.

Careful measurements have not been made of the amount of water carried by these streams. Those which flow throughout their whole course are the Missouri, Grand, Moreau, Cheyenne, Bad River, White, James and Big Sioux. The other streams like the Maple, Elm, Turtle, Vermillion, Beaver, which are found east of the Missouri in the drift region, have a peculiar characteristic of expanding here and there into deep winding basins while between they cease to flow in mid-summer, except through the underlying gravel. Something of the same feature is also found in the smaller streams west of the Missouri but not so remarkably developed. It seems to be due to the inability of the streams to carry away the coarser material and hence it is accumlated in gravel bars. Not infrequently in the Black Hills and in the vicinity of broken country the streams may flow for some distance at their heads though they are dried up in their lower courses. This is true of most of the smaller streams issuing from the Black Hills and many of the tributaries of the White river from the south.

SPRINGS.

In general we may say that springs are scarce in South Dakota. This is due in part to the slight rain-fall and in part to the impervious clay near the surface underlying most of the State. Also to the fact that where porous strata are locally developed, as under the drift, the clay overlying from its plastic character slips down and seals up their exposures near streams. In the extreme southeastern corner of the State sorings of great durability, but not very copious issue from underneath the Loess where streams have cut through it to the underlying drift. Several springs of this class are found in Union and Lincoln counties. Where the surface is rather abrupt in the drift area, as about Wessington Hills, and various points on the east and west Coteaus, gravel deposits in the old valleys of former glacial drainage sometimes become subterranean watercourses which bring water to the surface. Notable examples occur along the east slope of the Wessington Hills, including the well known Wessington Springs.

These old watercourses also bring water to the surface under quite different circumstances, in perhaps a score of cases along the moraines west of the Missouri. It may be laid down as a rule, that wherever an "alkali" lake-bed occurs a fresh water spring may be found by its side, where the old channel enters it. The explanation of this striking phenomenon is simple. These alkali basins occur in the deepest portions or ends of the old channels and the accumulation of alkali is mainly due to their continued flow and the constant evaporation of their waters.

A few large springs are reported along the Missouri in the vicinity of Yankton and Running Water, which are supposed, by Prof. G. E. Culver (Report on Irrigation, U. S. Dept. Agriculture, 1893), to issue from the deep artesian supply of the Dakota formation. In the broken country of the Tertiary area south of White river, and also in perhaps less degree in the area occupied by the Fox Hills and Laramie formations springs may be found when drouths have not been too severe. About the Black Hills springs are numerous, as is commonly the case in mountainous regions. Some of the most copious springs that may be found anywhere escape from underneath the purple limestone, near Tilford and Hot Springs, and also from the gravel deposits in the valleys of the larger streams. Examples of the latter class are the Cleghorn springs on Rapid creek and the large springs on Amphibious or Beaver creek, near Buffalo Gap. Many others might be named.

LAKES.

In the drift region east of the Missouri, especially in the belts formed by the moraines, numerous lakes, from the size of ponds to those of ten or fifteen miles in length, abound after a number of rainy seasons. Continued drouths, which sometime occur in this region, dry up the smaller of these lakes one after another.

A few of the most important, which are pleasure resorts on account of their beauty and groves surrounding them, are as follows: On the East Coteau—Lakes Buffalo, Waubay, Kampeska, Poinsett, Albert, Thompson, Herman, and Madison. Upon the West Coteau there are none so lasting, although in favorable seasons Crow lake, White lake and Red lake are attractive points, while Lake Andes, at a considerable lower level and yet 200 feet above the Missouri, is perhaps the most lasting of them all. Upon the upland west of the Missouri, on the summits of the divide, shallow lake-beds are found and the larger ones are rarely without water.

WELLS.

In the drift-covered areas water may be obtained near the surface in the bottom of watercourses and lake basins of various sizes, such as abound in glaciated areas. These are derived quite directly from the rainfall, and are limited. This is particularly noticeable in the wells sunk in basins, for the smaller the basin the sooner will the supply become exhausted, which often occurs in dry seasons. Separating the waters near the surface from those connected with the older formations below, lies a blanket of boulder clay, which has been described in a previous chapter. Underneath it there usually occurs a stratum of sand and gravel several feet in thickness. This also contains water, especially in its lower portions, for it lies in an uneven position. When it is struck in the bottom of valleys the water not infrequently rises several feet, sometimes to the surface, as near Artesian City, in Sanborn county. Sometimes this stratum of sand is found intervening between the drift clay and the underlying Cretaceous clays; in that case there is little hope of finding water without going down perhaps several hundred feet to the Dakota sandstone. Concerning the region west of the Missouri and about the Black Hills no such general statement can be made. A fuller explanation of our water supply in wells will be found in the Report of the State Engineer of Irrigation for this year.

ARTESIAN WELLS.

We will simply say here that the Dakota sandstone, which underlies nearly the whole State, wherever struck, except in rim of Black Hills, abounds in water. The pressure is sufficient to bring it to the surface in most parts of the James Valley, and the valley of the Missouri and its western tributaries. The most western point at which this has been demonstrated is at Belle Fourche, in Butte county. Wells of this sort have not been tried in the Valley of the Cheyenne and White Rivers, but their success is not very doubtful. The higher lands of the East Coteau and the highlands west of the James and Missouri are probably above the "hydraulic gradient" of this water supply. By hydraulic gradient we mean the sloping plane to which the pressure at different points will raise the water.

From a comparison of the pressures in the different wells we find that they vary quite regularly as follows: At Jamestown it is 1,619 feet above the sea and this pressure continues southward with little variation to Huron. There it begins to decline quite rapidly to Mitchell where it is about 1,310. South and east from that point it rises to Tyndall where it is 1,505 and then declines to southeast being 1,325 at Yankton and 1,185 at Vermillion. West from this line, so far as has been fully tested the hydraulic gradient rises quite rapidly. Taking the latitude of Huron, we find that it increases at the rate of about 4.3 feet per mile, being 1,950 feet at Highmore, the highest yet found in the State. In the latitude of Mitchell it increases westward at nearly the rate of 10 feet to the mile showing a pressure of about 1,800 feet at Kimball. The Pierre and Chamberlain wells probably do not penetrate to the stratum of the highest pressure. Upon the map will be found a line indicating the eastern limit of the area in which the pressure from the Dakota sandstone will bring water to the surface. From the north line of the State to the vicinity of Salem the area is limited by the East Coteau rising above the hydraulic gradient. From a point near the northeastern corner of Hanson county into Hutchinson county the limit is caused by the absence or slight development of the water-bearing stratum. In the southern part of the State the limit is mainly due to the hydraulic gradient falling below the general upland level of the country. The cause of this remarkable slope has not been definitely determined, but it is probably due to leakage along the exposures of the Dakota formation in the eastern part of Nebraska and about the quartzite area in our State.

Besides the artesian wells derived from the Dakota Formation there are a few small areas supplied from the sands underneeth the Drift. These occur about Artesian City in Hanson county, in the southern part of

Miner county and at two or three points in Turner and Clay counties. Probably other areas will be discovered as the country becomes more known.

The water appearing in artesian wells doubtless enters the Dakota sandstone on the foothills of the Rocky Mountains, the Black Hills and other ranges in Montana. From a study of geological data, which are far from complete, it had been estimated that 326,805,600,000 cubic feet enters annually which may be utilized mainly in our State. If much of the Dakota in Montana lies above 1,300 feet above the sea, as is not improbable, there is an important stored supply available besides. A fuller discussion of the probable adequacy of this artesian supply and other interesting points connected with this subject will be found in the Report of the State Engineer of Irrigation, already referred to.

MINERAL WATERS.

The waters of both springs and wells are quite frequently charged with various soluable salts. Common ingredients from the wells found in the glacial drift are carbonates and sulphates of iron and lime magnesia and soda. The source of these seems to be the clays of the upper Cretaceous. In cases where the water from the sand stratum containing it, is at first sweet and palatable, when it stands in contact with the boulder clay it becomes contaminated, more or less with these salts. Moreover in wells which pass through the drift and penetrate the shales of the Pierre the contamination is still more marked. Sometimes a saline taste is so prominent as to make it particularly attractive to animals. The waters of the deep artesian wells contain nearly the same ingredients. These are sometimes so prominent as to seriously interfere with its desirability for drinking purposes, but as a rule the water is considered to be both palatable and healthful. Some of the springs which we have mentioned on a previous page distinctly contain free hydrogen sulphid. The composition of the water at Hot Springs resembles that of many artesian wells. As yet none of these springs reported, are utilized for medicinal purposes, except those in the vicinity of Hot Springs.

ALKALI.

This term of popular use includes the salts already mentioned as they are found in areas where the moisture has evaporated and left them in perceptible quantities. A white effloresence, called by this name, is frequently found in low places after the water has dried away, so also in basins at all localities in the State in which drainage has accumulated them. As before stated, there are a few large basins, where the concentration of these salts is so great that vegetation is entirely absent. When water is abundant the salt seems not to be deleterious to plants, but in the dry part of the season the alkali in the soil quite frequently becomes so concentrated as to kill the grass and other plants. This appears not only in the basins and along dry water courses, but in spots here and there over much of the country east of the Missouri.

NATURAL GAS.

Natural gas has been reported from several localities as developed by boring wells. In a few cases, as near Blunt, in the northern part of Hughes and Sully counties, it has been struck in very limited quantities below the drift clay. It probably does not exist in paying quantities at that level. In the boring of the deep artesian wells considerable quantities have been found escaping with the water. Careful investigation of the facts has not yet been made. Cases of this sort have been reported from Miller and Pierre.

MECHANICAL POWER.

Perhaps we transcend the ordinary limits of the geological treatise in touching upon this subject. Yet we naturally place under this head not only the capabilites of ordinary water power which exist in running streams, but also the novel source which, perhaps, at first developed them in our State, namely artesian power.

MILL SITES.

We have already in our second chapter given the slope of our principal streams and a reference to these pages will show that the capabilities for water power within our State are great. The streams around the Black Hills descend very rapidly and the water may be conveniently stored in dams at many points. The difficulties which are felt over perhaps most of our State are the absence of suitable material for building dams, and also the soft materials bounding the channels. One of the finest opportunities for water power is the already noted one at Sioux Falls, where the Big Sioux falls in rapids through a height of 75 to 80 feet over the red quartzite. Sites of smaller capacity are found upon the Split Rock and other streams.

ARTESIAN POWER.

Soon after the discovery of high pressure in artesian wells, invention turned it to the running of machinery. This is done by the use of turbine wheels. We are unable to state the full capacity of the wells, now utilized in this way, but simply name as examples the pioneer Well Mill of Yankton where the pressure of 48 to 56 pounds per square inch and a flow of 1,600 to 2,000 gallons per minute runs a flouring mill of 40 barrels capacity; the Hitchcock mill is run by a well flowing 1,240 gallons per minute and have a pressure of 155 pounds per square inch, having a capacity of 50 barrels per day. Besides running the mill it supplies water to the town, maintains water in an artificial lake and irrigates a farm. At Redfield, Springfield, Chamberlain and other points the artesian wells are used for the running of electric lights, besides supplying the common uses of waterworks. It will be easily seen that the efficiency of a well for water power depends not only upon the pressure of the water but volume of flow.

WIND POWER.

The average velocity of wind in South Dakota as shown by the Signal Service at Huron for a series of nine years is found to be an average velocity of 10 miles per hour. A wind mill 10 feet in diameter with a velocity of eight miles per hour will give litte more than a tenth of a horse power per minute. One sixteen feet in diameter will give nearly half a horse power per minute. From this may be seen the capability of wind for power.

SUN POWER.

The distinguished inventor Ericsson believed that his solar steam engine would eventually prove to be his greatest invention. The sun's energy is enormous. Archimedes more than 2000 years ago used it successfully in setting ships on fire at a distance, what may not be its capabilities with modern improvements?

The chief difficulty with both wind and sun is their fickleness. With an adaptation of cheap storage batteries may we not hope that this in measure may be remedied.

Why may not the force of the wind and sun, through the medium of electricity, some day be utilized for heating and lighting purposes, if not for great power?

In France quick-lime has been successfully used for storing heat on a small scale. May not this also be utilized in place of storage batteries for supplementing these inconstant forces?

GEOLOGY AND SOILS.

The soils of our State have not yet been studied and little need be said here except to make a few general remarks concerning them.

East of the line marking the margin of the drift on the map, the soil is a dark rich loam with a clayey subsoil. The soil is generally deeper outside of the first moraine, and near streams, at the foot of slopes and in basins inside it.

The Colorado, when not covered with the drift, forms what is called a gumbo soil. Its qualities been already discussed.

The Fox Hills, Laramie and Loup fork (Miocene) areas are usually sandy, forming light, warm soils.

The Red Beds have a clayey character, which needs much moisture and are apt to bake.

The Purple Limestone and Granite areas are particularly stony.

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ERRATA.

Most of the typographical errors found in this volume are to be attributed to the imperative haste with which it has been printed. Wherever these do not impair the validity of statement, we let them pass.

On page 22, in the Table of Geological Formations, such confusion appears that the reader is referred to a revised form of the same at the end of the volume, opposite the map.

On page 65 for "*Atlantas aurus*" read "*Atlantosaurus.*"

A TABLE OF SOUTH DAKOTA GEOLOGICAL FORMATIONS.

(ARRANGED STRATIGRAPHICALLY.)

Eons.	Systems.	Groups and Stages.	Deposits.	Thickness.
CENOZOIC.	Quaternary,			
		Pleistocene		Feet.
		Terraces,	Gravel, loam, etc.,	5–10
		Loess,	Buff loam,	5–100
		Drift,	Boulder clay gravel, etc.,	10–150
	Tertiary,			
		Pliocene,		
		Equus Beds (?)	Loam, sand and clay,	5–30
		Miocene,		
		Loup Fork Beds,	Sand, gravel and loam,	25–75
		White River Beds,	White clay, sandstone, grits, etc.	250–400
		Eocene,	Absent.	
MESOZOIC.	Cretaceous,			
		Later,		
		Laramie,	Sandstone, shales and lignite,	1,000–2,000
		Fox Hills,	Sandstone, shales and clays,	100–150
		Colorado,		
		Fort Pierre,	Dark clays and shales,	350–700
		Niobrara,	Chalkstone and shales,	50–200
		Ft. Benton,	Dark clay and shales,	50–200
		Dakota,	Sandstones and clays,	200–500
		Earlier,	Absent.	
	Jurassic,		Sandstones, marls and clays,	200–350
	Triassic,		Red clays and purple limestone.	300–400
PALEOZOIC.	Carboniferous,		Limestones, sandstones and shales.	570–785
	Devonian,		Absent (?)	0–25
	Silurian,			
		Upper,	Absent (?)	
		Lower,		
		Trenton,	Bluff limestone, etc.,	25–50
	Cambrian,			
		Potsdam,	Brown sandstone, etc.,	250–300
		Acadian,	Absent (?)	
ARCHEAN.	Keweenian,		Absent.	
	Huronian,			
		Upper,		
		Sioux Quartzite,	Quartzite, etc.,	1,000–3,000
		Lower,		
		Black Hills Slates,	Schists and granites,	10,000–100,000
	Laurentian,		Absent (?)	

SUPPLEMENTARY NOTES ON THE MAP.

The Drift or Boulder Clay covers all the surface east of the margin marked. It varies from 1
... 200 feet in thickness, and probably averages over 50.
...formations as drawn on the map are less confidently given where they are
... Quartzite and the Dakota, surrounding it, are probably drawn
...ered more with the Colorado.
...e to the main one, related to the Dakota
... which derive their waters from