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CENOZOIC HISTORY OF THE NORTHERN BLACK HILLS

by

LOUISE FILLMAN

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While in the field, courtesies were extended to the writer by many people living in the towns of Hermosa and Whitewood. To each of these the writer wishes to express her thanks and appreciation. Special acknowledgments are made to the staff of the Geology Department of the State University of Iowa, and particularly to Dr. A. C. Trowbridge and Dr. J. J. Runner for valuable advice both in the field and in the office and to the former for general supervision of the work.

CENOZOIC HISTORY OF THE NORTHERN BLACK HILLS

LOUISE FILLMAN

SUMMARY OF THE PREVIOUS WORK ON THE EROSIONAL HISTORY OF WESTERN UNITED STATES

INTRODUCTION

Wide divergence of opinion is disclosed in the literature on the physiography of the western portion of the United States. In many cases the same range or adjacent ranges are assigned notably different histories by different writers. This is perhaps not surprising in the light of the fact that the principles on which interpretation of plural erosion cycles is based have been so recently assembled.[1]

It is the purpose of this chapter to gather together in one place from the literature, the scattered Cenozoic histories assigned to the more important areas of western United States and to give a bibliography. A sketch of the erosional history of the Northern Black Hills, which follows, should serve to clear up in part at least, the bibliographic confusion.

HIGH PLAINS

Johnson[2] in 1900 sketched the history of the Great Plains briefly as follows: A debris sheet washed out from the mountains to the west during the Tertiary was partly eroded during the Pleistocene, after which deposition was again renewed. The Tertiary age of the main deposit and the Pleistocene age of the stream terraces are proven by fossils. Climatic changes are assumed to explain the changes from deposition to erosion and back to deposition.

BIG BADLANDS

The history of the Big Badlands of South Dakota, lying within the Great Plains, has been the subject of frequent controversy

1 Trowbridge, A. C., "Erosional History of the Driftless Area," *Univ. of Iowa Studies in Nat. Hist.*, Vol. IX, No. 3, Pt. 1, 1921.

2 Johnson, W. D., "The High Plains and Their Utilization," *21st Annual Report*, U. S. Geol. Survey, Pt. IV, 1900.

since Dr. Hiram A. Prout[3] of St. Louis in 1874 described a fragment of a lower jaw which he called a Paleotherium.

According to Ward,[4] the section exposed in the Badlands is as follows:

Upper Oligocene	Protoceras beds	Brule formation
Middle Oligocene	Oreodon beds	
Lower Oligocene	Titanotherium beds	Chadron formation
Cretaceous	Interior beds	

After the deposition of the lowermost White River beds, known as the Titanotherium or Chadron formation there was moderate erosion as evidenced by an irregular upper surface. The mid-Oligocene Oreodon beds are composed of coarse sand and silt with a characteristic thinning away from the Black Hills which Ward[5] interprets as suggesting either a change of climate, diastrophic uplift or a combination of both.

After the deposition of the White River beds, the area was subjected to erosion which resulted "in a featureless plain above which were scattering buttes, ridges, and parts of the Black Hills."[6] This is known as the Prairie peneplane. This peneplane was then uplifted introducing another cycle known as the Bench cycle, during which the main streams cut downward 150 feet and then widened. The Bench cycle was interrupted by a southward tilting inaugurating the present cycle, during which the more important erosion forms of to-day were carved.

Wanless[7] working in the Big Badlands believes that the Interior formation owes its origin to the weathering and leaching of the Pierre shale or other younger beds exposed at the surface during the Eocene period. In other words, he believes that a peneplane was developed during the Eocene, upon the surface of which a thick residual soil mantle accumulated and he names this old erosion surface the Interior peneplane. Wanless concludes further that this peneplane was uplifted and deeply eroded prior to the time of deposition of the Oligocene White River formation.

3 Prout, Hiram A., "A Description of a Fossil Maxillary Bone of Paleotherium from near White River," *Am. Jour. Sci., 2nd Ser.*, Vol. 3, pp. 248-250, 1874.

4 Ward, Freeman, "The Geology of a Portion of the Badland," *South Dakota Geological and Natural History Survey*, Bull. No. 11, p. 16, 1922.

5 Op. cit. p. 45.

6 Op. cit. p. 47.

7 Wanless, H. R., "The Lithology of the White River Sediments," *Proc. Am. Phil. Soc.*, Vol. LXI, pp. 197-202, 1922.

In a more recent paper, Wanless[8] discusses to some extent the post-Oligocene history of the Big Badlands. Evidence is given for the development of a high plain of probable Pliocene age. Later terraces were developed either due to uplift or climatic changes.

The Black Hills

The Black Hills must have furnished most of the material for the Oligocene White River sediments of the Badlands and the histories of the two areas should be harmonious. Yet, Darton[9] mentions but briefly the Oligocene history of the Hills. He states that during the Pleistocene period a mantle of gravels and sands which cap the present day divides was deposited by the streams. Further, according to Darton, an uplift accompanied with tilting to the northeast permitted entrenchment, and erosion again became predominant. Two sets of terraces have since been formed along all the main streams, the conditions for which are not determined between climatic change and slight uplifts.

The Rocky Mountains

It is agreed by previous workers that the Black Hills and the Rocky Mountains are similar in structure, in age and in history. To judge from the literature, however, their Tertiary histories were different. In fact, no two investigators agree on the erosional history of the Rocky Mountains.

Dake[10] assigns a history involving three periods of uplift. The first diastrophic movement is assigned to the latest Cretaceous or earliest Eocene, after which and prior to the post-Lance uplift it has been estimated that 6000 feet of material was removed. Following a post-Lance and pre-Fort Union uplift, erosional conditions prevailed until the third orogenic movement took place late in the Eocene. This last uplift was accompanied by much overthrust faulting. No mention is made of later history.

8 Wanless, H. R., "The Stratigraphy of the White River Beds of South Dakota," *Proc. of the Am. Phil. Soc.*, Vol. LXII, p. 260, 1923.

9 Darton, N. H., "Preliminary Description of the Geology and Water Resources of the Southern Black Hills and Adjoining Regions of South Dakota and Wyoming," *21st Ann. Rep., U. S. Geol. Surv.*, Pt. IV, pp. 489-599, 1899-1900.

"Geology and Water Resources of the Northern Black Hills and Adjoining Regions in South Dakota and Wyoming," *U. S. Geol. Surv.*, Prof. paper 65, p. 59, 1909.

10 Dake, C. L., "Episodes in Rocky Mountain Orogeny," *Am. Jour. of Sci.*, 5th Series, Vol. I, pp. 245-254, 1921.

Dawson[11] assigns the Eocene, Oligocene and Miocene as times of stability. By the close of the Miocene a great peneplane had been developed which stood 2000 to 3000 feet lower in relation to the sea than it does now. At the end of the Miocene, differential uplift occurred. During the Pliocene, mature stream valleys were developed and gravels were deposited. This period was closed by a marked elevation in the Cordilleran region. The Pleistocene is noted chiefly for mountain glaciation.

In direct opposition to Dawson, Daly[12] believes in a single cycle history of the Rocky Mountains in the vicinity of the 49th parallel. He presents other theories for the development of the flat interstream areas, which others regard as evidence of more than one cycle of erosion.

Willis[13] working on the erosional history of the Lewis and Livingston ranges in Montana believes in a peneplanation of this section of the Rockies in the Oligocene. To this he gives the name Blackfoot. Folding occurred in the Miocene accompanied by the well known Chief Mountain overthrust. In the Pliocene, erosion was dominant in the higher area with the deposition of the Kennedy high level gravels as alluvial cone deposits. Glacial erosion was predominant in the area during the Pleistocene.

Farther to the south in the Bighorn Mountains, Darton[14] records two periods of uplift. The mountains owe their origin to the Laramide Revolution. At the end of the Oligocene the region was again uplifted. Whether the range had reached a stage of peneplanation previous to the Oligocene is not stated. Stream erosion was the important factor throughout the Miocene, Pliocene and Pleistocene with mountain glaciation important in the later period. During the Pleistocene the more important rivers developed terraces which now stand 200 to 400 feet above the streams.

The history of the Wind River Mountains as given by Blackwelder[15] is briefly sketched as follows: The mountains were up-

11 Dawson, George, "On the Physiographic Geology of the Rocky Mountain Region in Canada," *Trans. Royal Soc. of Canada*, Section II, pp. 1-74, 1890.

12 Daly, R. A., "North America Cordillera," *49th Parallel, Memoir. 38, Canadian Geol. Survey*, pp. 605-641, 1912.

13 Willis, B., "Stratigraphy and Structure of the Lewis and Livingston Ranges, Montana," *Bull. Geol. Soc. Am.*, Vol. 13, pp. 305-352, 1902.

14 Darton, N. H., "Geology of the Bighorn Mountains," *U. S. Geol. Surv.*, Prof. paper 51, 1906.

15 Blackwelder, Eliot, "Mountains of Central Western Wyoming," *Jour. of Geol.*, Vol. XXIII, pp. 193-207, 1915.

lifted at the end of the Cretaceous period. By mid-Eocene time the folds were deeply eroded, with or without reduction to a peneplane, and a change took place which substituted torrential or seasonal alluviation for continuous degradation. In upper Eocene time the Piney conglomerate was deposited. This suggests the work of powerful aggrading streams with constantly shifting channels and a semi-arid climate. By Oligocene time the processes of sedimentation had produced a gently graded plain beneath which were buried the old Eocene hills. In the Miocene, the early sediments of the Tertiary were gently folded and broken along the several scattered normal faults. This folding emphasized the structure produced at the close of the Cretaceous. The Wind River peneplane was then developed. The age of this old erosion surface is not definite but it is tentatively held to be Pliocene. A reconflatness but with subdued mountains and hills with a relief less than 1500 feet near the divides. Early in the Pleistocene rejuvenation due to regional uplift occurred. In this later period, Blackwelder outlines the development of four distinct sets of stream terraces.

Baker[16] gives a very different history for approximately the same area and concludes that the Eocene and Oligocene streams deposited great amounts of material in the intermontane valleys. By mid-Miocene time a peneplane was developed over the entire area. The cycle was closed by regional uplift accompanied by vulcanism. At the base of the mountains and far out on the plains the Wyoming conglomerate was deposited by Pliocene streams. During the Pleistocene two sub cycles have left their records in river terraces.

Blackwelder[17] describes a peneplane of Pliocene age in the Laramie Mountains and calls it the Sherman peneplane. It is represented by a relatively even surface but here and there irregular knobs and piles of exfoliated boulders rise above the general elevation. Rejuvenation occurred during the Pliocene and the streams were predominantly eroding streams during the Pleistocene.

Powell[18] in 1877 outlined the history of the Uinta Mountains. He states that there was a gradual uplift during the Oligocene.

16 Baker, C. L., "Notes on the Cenozoic History of Central Wyoming," *Bull. Geol. Soc. Am.*, Vol. 23, p. 73, 1912.

17 Blackwelder, Eliot, "Cenozoic History of the Laramie Region, Wyoming," *Jour. of Geol.*, Vol. XVII, pp. 429-444, 1909.

18 Powell, J. W., "Reports of the Geology of the Eastern Portion of the Uinta Mountains," *U. S. Geol. and Geog. Surv. Terr.*, 2nd Division, 1877.

In the Miocene denudation took place under humid climatic conditions. During a part of this period the area was a theatre of extended vulcanism. By the close of the Miocene, the streams were at grade and the mesas were becoming smaller and smaller. In the Pliocene and Pleistocene the region was faulted and the streams flowing from the higher areas deposited gravels widely over the adjacent districts.

Rich[19] assigns Pliocene age to an old peneplane in the region reaching from the Uinta Mountains to the northern end of the Leucite Hills in Wyoming. He states that this peneplane may be correlated with that of the high plateau region of Arizona.

A history very similar to the one just outlined is given by R. T. Chamberlin[20] to the Rocky Mountains of Colorado. In the early Eocene, the deposition of the Dawson arkose and the Arapahoe conglomerate records a removal of a total thickness of more than 4000 feet of sediment. Later in the Eocene, an uplift occurred which was accompanied by extensive outbursts of andesite. By Pliocene time a peneplane had developed, with monadnocks rising 200 to 2500 feet above it. The uplift which followed accentuated the height of several of the ranges by warping. In the Pleistocene, the newly uplifted areas were modified by streams and glaciers.

Richardson[21] outlines a history similar to that stated by Chamberlin for the Castle Rock quadrangle in Colorado. A peneplane was developed in Pliocene time which he thinks may be correlated with the Tertiary peneplane of the Sierra Nevada range and the Summit peneplane of the Wind River Mountains. The uplift which ended the cycle was accompanied with tilting to the south and east.

There have been other interpretations of the Tertiary history of the Rocky Mountains of Colorado. One of the most recent papers is that of Lee,[22] who gives evidence of three distinct cycles of erosion in the Rocky Mountain National Park. The remnant of the earliest peneplane may be found on Flattop Mountain, for which the old erosion surface is named. This peneplane was formed

19 Rich, J. L., "Physiography of the Bishop Conglomerate, Southeastern Wyoming," *Jour. of Geol.*, Vol. XVIII, pp. 601-632, 1910.

20 Chamberlin, R. T., "Building of the Colorado Rockies," *Jour. Geol.*, Vol. XXVII, pp. 145-164, 225-251, 1919.

21 Richardson, G. B., "Castle Rock Folio," *U. S. Geol. Surv.*, folio no. 196.

22 Lee, Willis T., "Peneplains of the Front Range and Rocky Mountain National Park, Colorado," *U. S. Geol. Surv.*, Bull. 730A, 1922.

sometime near the middle of the Tertiary. An intermediate cycle followed during which time the Rocky Mountain peneplane was developed. This is dated at Pliocene. The third or Canyon cycle is, as yet, not completed.

Near the southwestern corner of Colorado in the San Juan Mountains, Atwood[23] finds evidence for a Tertiary peneplane both in the mountains proper and on the surrounding plains. The precise age of this old erosion surface is not given.

Colorado Plateau

The theory of plural erosion cycles was first presented by Powell and Dutton[24] in these reports on the Grand Canyon. Dutton's history of the region is outlined as follows:

1. There was a period of erosion lasting until the close of the Miocene.
2. The surface was uplifted, folded, and faulted.
3. The outer gorge was developed during the Pliocene.
4. At the close of the Pliocene faulting occurred and the inner gorge was cut during the Pleistocene and Recent.

Since this time Davis,[25] Huntington, Goldthwait,[26] and others have published on the history of the Grand Canyon district. The most recent paper by Robinson[27] gives the history in much more detail. He believes in the development of a peneplane during the Miocene, another during the Pliocene and a third near the middle of the Quaternary, and in the extreme youth of the inner gorge.

In Idaho, Montana, and Washington lies the plateau area over which a controversy arose concerning the age of a peneplane and its value as a datum plane.[28] This instance illustrates the difficulty

23 Atwood, W. W., "Physiographic Studies in the San Juan District of Colorado," *Jour. Geol.*, Vol. 19, pp. 449-454, 1911.

24 Powell, J. W., "Report on the Arid Region of the United States," *U. S. Geog. and Geol. Surv. of the Rocky Mountain Region*, 2nd Ed., 1878.

Dutton, C. R., "Tertiary History of the Grand Canyon District," *U. S. Geol. Surv.*, Mono. II, 1882.

25 Davis, Wm., (a) "An Excursion to the Grand Canyon of the Colorado," *Bull. Mus. Comp. Zoology* Harvard College, XXXVIII, May 1901. (b) "An Excursion to the Plateau Province of Utah and Arizona," idem. XLII, June, 1903.

26 Huntington, Ellsworth and Goldthwait, J. W., "The Hurricane Fault in the Toquerville District, Utah," *Bull. Mus. Comp. Zoology*, Harvard College, XLII, February, 1904.

27 Robinson, H. H., "New Erosion Cycle in the Grand Canyon District," *Jour. Geol.*, Vol. XVII, pp. 742-763, 1910.

28 (a) Umpleby, J. B., "An Old Erosion Surface in Eastern Idaho: Its Age and Value as a Datum Plain," *Jour. Geol.*, Vol. XX, pp. 139-147, 1912. (b) Blackwelder, Eliot, "A Criticism," *Jour. Geol.* Vol. XX, pp. 410-414, 1912. (c) Atwood, W. W., "Physiographic Conditions at Butte, Montana, and Bingham Canyon, Utah. When the

of dating old erosion surfaces definitely unless conclusive evidence is at hand.

Pacific Coast Mountains

The Pacific Mountains in British Columbia have been described by Spencer,[29] who correlates across all of them an Eocene erosion surface. The warping of this surface allowed the formation of fresh water lakes in the Oligocene. In the Miocene there was local folding accompanied by volcanic flows. The Pliocene marks the uplift of continental character accompanied by warping, flexure, or displacement, raising of tectonic blocks, which have not been effaced by subsequent erosion, and the formation of volcanic cones.

Russell[30] outlines the Cenozoic history of the cascades as follows:

1. Eocene—deposition of freshwater sediments accompanied by volcanic flows.
2. Oligocene—volcanic flows.
3. Miocene—deposition of lacustrine sediments interbedded with lava flows. Miocene closed with folding.
4. Pliocene or early Pleistocene—development of the Cascade peneplane.
   a. Uplift and folding along the older structural lines and dissection of the Cascade peneplane by streams and glaciers.
   b. Volcanic peaks formed.

Several workers[31] in this area give much the same history, but differ on the age of the peneplane. Some date it as early Pliocene and others believe it to be Pleistocene in age.

Diller[32] describes a summit peneplane of Miocene age in the Klamath Mountains and states that numerous oscillations took place along the coast in late Tertiary time.

These studies have emphasized the fact that the correct dating

Copper Ores were Enriched," *Econ. Geol.*, Vol. XI, pp. 697-740, 1916. (d) Blackwelder, Eliot, "Physiographic Conditions and Copper Enrichment," idem. Vol. XII, pp. 541-545, 1917. (e) Rich, J. L., "Dating of Peneplains: An Old Erosion Surface in Idaho, Washington and Montana," idem., pp. 545-547, 1917.

29 Spencer, A. C., "Pacific Mountain System in British Columbia and Alaska," *Bull. Geol. Soc. Am.*, Vol. XIV, pp. 433-464, 1884.

30 Russell, I. C., "A Geological Reconnaissance in Southern Oregon," *4th Ann. Rep. U. S. Geol. Surv.*, pp. 433-434, 1884.

31 (a) Smith, George Otis and Calkins, Frank C., "A Geological Reconnaissance Across the Cascade Range Near the 49th Parallel," *U. S. Geol. Surv.*, Bull. 235, 1904. (b) Smith, George Otis and Willis B., "Geology of Washington," *U. S. Geol. Surv.*, Prof. paper XIX, 1904. (c) Bretz, J. Harlan, "The Satsop Formation of Oregon and Washington," *Jour. Geol.*, Vol. XXV, pp. 446-458, 1917.

32 Diller, J. S., "Topographic Development of the Klamath Mountains," *U. S. Geol. Surv.*, Bull. 196, pp. 367-402, 1902.

of widespread erosion surfaces is of great importance, for such surfaces serve as datum planes for the interpretation of the greater part of the Tertiary history. It is clear that there is lack of agreement among the several investigators. It is not possible, therefore, in the following chapters to fit the erosional history of the northern Black Hills into any general scheme upon which there is any considerable agreement.

THE NORTHERN BLACK HILLS

Introduction

In this report an attempt is made to trace the topographic history of the northern Black Hills in western South Dakota and eastern Wyoming. The Cenozoic history of the range is especially emphasized and the pre-Tertiary conditions are described only briefly.

Location

These mountains lie between the 43d and the 45th parallels and between the 103d and 105th meridians. They occupy an irregular area approximately 120 miles in length and have a width of 40 to 50 miles. (See Plate I). The range is divided into distinct provinces by the differences in the topography. The north central portion of the Black Hills has a topography which has been largely determined by the Tertiary intrusives and subsequent stream erosion. The south central portion of the Black Hills, on the other hand, has had its topography shaped by stream dissection of the pre-Cambrian granite, and other pre-Cambrian formations.

Although separated from the main range of the Rocky Mountains by several hundred miles, the Black Hills are similar to them, both in character and in structure.

> "In the structure of the hills there are many points that make them a miniature representative, compact and wonderfully complete within themselves, of the topography and geology of the great Rocky Mountain system."[33]

Field Work

The field work upon which this study is based was done mostly during the summers of 1922 and 1923, but an additional two weeks were spent in the area during the summer of 1927. In 1922 and 1923 the work was confined mostly to the region of the northern Black Hills, but in the summer of 1927 a correlation with the Big

33 Newton, Henry and Jenney, Walter P., "Report of the Geology and Resources of the Black Hills of Dakota," *U. S. Geog. and Geological Surv.*, 1880.

Badlands west of the Black Hills was attempted. In the first two seasons, the areas within a radius of twenty-five miles in each direction from the towns of Whitewood and Rapid City were studied in detail and other nearby areas were visited. In 1922 the writer was accompanied by Agnes Cozine, in 1923 by Marion Ansel, and in 1927 by Catherine Lucas, Evelyn Garst, and Irene Fillman.

Upland plains, stream terraces, streams and their valleys, and surficial deposits were studied in order to determine the erosional history. The size grade distribution of the gravels was determined for the most part in the field. A set of full height eight inch sieves of 64, 32, 16, 8, 4, and 2 millimeter openings was carried. Samples of about 25 kilograms were collected from the faces of exposures. Samples were weighed with a spring balance, after which they were run through the sieves. The -2 mm. material was put in sacks and brought in for later study in the laboratory. The coarser grades were then studied for composition and source and then weighed.

Laboratory Work

Further studies of collected samples were made in the sedimentation laboratory. Mechanical analyses of the finer grades of the gravels were made. Only small amounts of the field samples were of the -2 mm. size and only the 1, ½, ¼, ⅛, and 1/16 millimeter openings were used. Thus, all the samples were ultimately divided into 64, 32, 16, 8, 4, 2, 1, ½, ¼, ⅛, 1/16 and -1/16 mm. grades. The percentages of the grades were obtained by the use of the slide rule and were then plotted into pyramids.

The pebble counts made in the field were also reduced to percentages and plotted into pyramids. These counts were made, as a rule, in the same locality as the mechanical analyses.

The amount of roundness was obtained by the use of a sheet metal incline of progressively decreasing slope and calibrated by the use of the convexity gauge. This device was designed and is described in detail by Wentworth.[34] In brief, the method is based on the fact that the rounder the pieces the farther they will roll.

Library Work

Note the bibliography on page — of the more important publications relating to the geology of the Black Hills.

These papers were studied carefully and the conclusions reached

[34] Wentworth, C. K., "The Shapes of Pebbles," *U. S. Geol. Surv.*, Bull. 730C, pp. 91-114, 1923.

by the several writers checked with each other and with the conclusions that resulted from the present investigations.

In order that the Cenozoic history and its problems may be clearly understood, the pre-Cambrian, the Paleozoic, and Mesozoic rocks are described briefly and in a general way. The generalized columnar section is as follows:

SYSTEM	FORMATION	KIND OF ROCK	RESISTANCE TO EROSION	Thickness
Pleistocene	Terrace Gravel	Gravels, Conglomerate, Sand, and Clay	Nonresistant	50′±
Oligocene	Chadron	Gravels, Conglomerate, Sand, and Clay	Nonresistant	100′±
Cretaceous	Laramie	Sandstone, Shale, Lignite	Nonresistant	2500′
	Fox Hills	Sandstone, some Shale	" "	250′
	Pierre	Dark Gray Shale	" "	1400′
	Niobrara	Impure Chalk, Calcareous Shale	" "	175′
	Carlile	Gray Shale, with Concretions	" "	700′
	Graneros	Dark Shale, Some Sandstone	" "	1000′
	Dakota	Buff Sandstone with Iron Concretions	Resistant	100′
Comanchean	Fuson	Massive Shale	Nonresistant	50′
	Lakota	Coarse, Cross-Bedded Sandstone	Resistant	200′
Jurassic	Morrison	Massive Greenish Grey Shale	Nonresistant	120′
	Unkpapa	Massive Grey Sandstone	Nonresistant	75′
	Sundance	Gray Shale, Buff Sandstone	Nonresistant	275′
Triassic	Spearfish	Red Sandy Shale, with Gypsum Beds	Nonresistant	600′
Permian	Minnekahta	Gray Limestone	Resistant	40′
	Opeche	Red Sandstone and Sandy Shale	Nonresistant	80′
Pennsylvanian	Minnelusa	Buff and Red Sandstone and Limestone	Resistant	500′
Mississippian	Pahasapa	Massive Grey Limestone	Resistant	500′
	Englewood	Pink Slabby Limestone	Nonresistant	′50′
Ordovician	Whitewood	Massive, Buff Limestone	Nonresistant	80′
Cambrian	Deadwood	Conglomerate Sandstone, Greenish-Gray Shale and Dolomitic Limestone	Nonresistant	400′
Pre-Cambrian		Slate, Schist, Granite, Quartzite, Marble	N.R. as a Rule	Very Great

The general distribution of each of the four groups is shown on Plate II. The pre-Cambrian crops out in the central portion of the Hills, the Paleozoic in a belt around the older core and the Mesozoic formations on the edges of the Hills, dipping under the surrounding plains in all directions. The Cenozoic formations are found to cut across all the older rocks from the central hills to the plains beyond.

Pre-Cambrian Rocks

The outcrops of pre-Cambrian rocks in the central Hills extend approximately sixty miles north and south and twenty-five miles in greatest width east and west, and comprise an area of approximately 850 square miles.

The rocks of this group are composed of great thicknesses of metamorphosed sediments chiefly quartzites, schists and clay slates into which, in pre-Cambrian time, the Harney Peak granite was intruded. All are relatively coarse in texture and contain many lenticular masses of quartz. All of the metamorphic rocks are so closely and complexly folded, that thicknesses of layers vary from a few feet to three or four hundred feet. As a rule, the metamorphic rocks are nonresistant and the region is made up of an extensive system of shallow valleys of thoroughly late mature forms. Some of the more resistant quartzites rise conspicuously above the surrounding country as distinct ridges only a few feet in width.

The Harney Peak granite is confined, in the main, to the central portion of the southern Black Hills. The coarse grained granite is of varying resistance, giving rise in certain areas to a rugged, rough topography; while in other areas valleys in late maturity abound.

Paleozoic Rocks

The Deadwood formation of upper Cambrian age is approximately 400 feet thick in the northern Black Hills. The basal member is quartzite of great resistance to erosion and commonly crops out as a conspicuous ledge. The middle part of the formation is made up of shale, limestone conglomerate, and thin seams of limestone, and the surface in most places is heavily timbered or grass covered. The upper member of the formation is also quartzite and forms conspicuous escarpments.

The Whitewood limestone is generally found as a grass covered slope. It crops out naturally in only a few places.

The Englewood and Pahasapa limestones which are Mississippian in age, are plateau formers. The Pahasapa, as shown in the columnar section above, is both thicker and more resistant than the underlying Englewood.

The Minnelusa sandstone and limestone are also resistant and participate, with the Pahasapa, in the formation of the limestone plateau of the Black Hills. The Permian formations, the Opeche shales and the Minnekahta limestone, have a distinctive topographic expression. The Opeche shales are bright red and non-resistant. The Minnekahta, although less than fifty feet in thickness, forms a prominent hogback ridge, the outer slope of which varies in steepness according to the dip of the formation.

Mesozoic Rocks

The Spearfish formation, which is either Triassic or early Jurassic in age, is composed of red shales, thin layers of sandstone, and some gypsum. The total thickness is approximately 600 feet. This is a nonresistant formation and forms the famous "Red Valley" which encircles the entire Hills.

The Sundance, the Unkpapa and Morrison formations are relatively nonresistant and consequently do not outcrop abundantly.

The crest and inner rim of the hogback encircling the Black Hills area is formed by the coarse, resistant Lakota sandstone. To quote from Darton:[35]

> "Its cliffs surmount rounded slopes of Sundance and Morrison shales and in many portions of the region are of considerable extent and prominence. From Rapid northward for some distance, where the dips are moderately steep, the outcrop is narrow and the sandstone is in the crest of the ridge. In the northwestern portion of the uplift, where the dips are low, the sandstone widens into sloping plateaus of considerable extent, capped to a greater or lesser extent by the Lakota sandstone."

The Fuson formation consists of nonresistant sandstone or shale. In some places the entire formation is concealed by talus from the overlying Dakota sandstone. On the eastern edge of the Hills, the Fuson is indicated by a valley-like depression between the sandstone cliffs of the hogback ridge.

In general, the Dakota sandstone forms distinct cliffs of topographic importance. On the eastern edge of the uplift, especially from Rapid City north almost to Belle Fourche, the sandstone is

35 Darton, N. H., *U. S. Geol. Surv.*, Prof. paper 65, pp. 40-41, 1909.

nonresistant. It crops out along the east foot of the hogback ridge; but in only a few places does it give rise to cliffs or even ridges.

The other Cretaceous formations are nonresistant shales, limestones, and sandstones. In a few places, the more resistant parts of these formations give rise to flat-topped mesas or buttes.

Tertiary Intrusives

Among the most striking geologic features of the northern Black Hills are the Tertiary intrusives. They take the form of laccoliths, both covered and uncovered, which have been discussed in detail by Jaggar[36] and Irving.[37] In this report only the more important ones, from a topographic standpoint, are mentioned. The Bear Lodge Mountains are a true laccolith, which is elongated from northwest to southeast. Warren Peak is the central mass and rises an elevation of 7,160 feet.

Some of the other outstanding igneous masses are Devils Tower, Missouri Buttes, Inyankara Mountain, Black Buttes, Elkhorn Peak, Whitewood Peak, Crook Mountain, Deadman Mountain, Bear Butte and the Terry Peak District, Plate I.

Structure

The Black Hills uplift is an irregularly shaped dome extending from south of Edgemont to north of Alzada, a distance of about 125 miles. Again quoting Darton:[38]

> "It is elongated to the south and northwest, has steep slopes on the sides, is nearly flat on top, and is subordinately fluted. The greatest vertical displacement of the strata, as indicated by the height at which the granite and the schist floor is now found, amounts to 9000 feet."

In the northern Black Hills, the uplift is unsymmetrical. The central western portion is marked by a wide area of gently dipping rocks averaging five to six degrees to the westward. This general dip is broken by a few laccolithic intrusions including Inyankara, Black Buttes, Devils Tower, and Missouri Buttes where locally the dips are higher. North of the town of Sundance, Warren Peak rises abruptly with steep dips to the south and east.

36 Jaggar, T. A. Jr., "Laccoliths of the Black Hills," *U. S. Geol. Survey, 21st Ann. Rep.*, Pt. 3, pp. 163-303, 1901.

37 Irving, J. D., Contribution to the Geology of the Northern Black Hills," *Annals New York Acad. Sci.*, Vol. XII, pp. 187-340, 1899.

38 Darton, N. H., "Geology and Water Resources of the Northern Black Hills," *U. S. Geol. Surv.*, Prof. paper 65, p. 62.

In the central northern area from Spearfish south through Deadwood to Rapid City and north to Belle Fourche, the dips average fifteen to twenty degrees to the northeast, but vary considerably because of the laccoliths. The more important igneous disturbances are Terry Peak, Bald Mountain, Deadman Mountain, Whitewood Peak, Crook Mountain, Elkhorn Peak and Bear Butte.

The general anticlinal structure is reversed in some places by minor anticlines and synclines. One of these anticlines, which extends from north of Deadman Mountain to beyond Belle Fourche has an almost straight north-south axis and is noticeably asymetrical. The dips of the western limb are as high as seventy-five degrees and few of those on the eastern slope exceed twenty degrees. North of Crook Mountain, however, the dips on both sides are lower.

Another anticline east of Spearfish Creek pitches to the north. This is best seen in the Spearfish and Sundance formations. Between the Whitewood anticline and the Spearfish anticline lies a syncline which brings the Graneros formation far up in the foothills area.

Pre-Cenozoic History

The present Black Hills are not the first mountain system within this area. After the deposition of many thousands of feet of sediment during the pre-Cambrian, the ancestral Black Hills arose as evidenced by the profound structural unconformity between the Cambrian and the pre-Cambrian rocks. As to the exact amount of uplift and the extent of this former mountain range, there is little basis for judgment.

From Upper Cambrian time to the close of the Cretaceous period no important diastrophic movements seem to have occurred. Marine sediments record for the most part the conditions of the interval. According to Chamberlin[39] "The Cretaceous period was the long quiet before the storm. At its close the growing stresses within the earth sought relief in folding movements."

The geologic date of the uplift and the Tertiary intrusions may only be stated in general at the present time. A careful study of the sediments of the Laramie series should reveal more precisely the time of uplift, but as yet this has not been done. Since some of

39 Chamberlin, R. T., "The Building of the Colorado Rockies," *Jour. Geol.*, Vol. XXVII, p. 152.

the igneous mass was intruded into the Benton series of Upper Cretaceous age and pebbles of Tertiary porphyries occur in the basal portion of the White River beds, the uplift must have taken place after the deposition of the uppermost Cretaceous and long before the deposition of the White River beds. It is clear that the folding was accompanied by igneous activity as in certain places vulcanism was certainly a competent agent of folding. On the basis of analogy and on geologic evidence the Black Hills were probably uplifted in the Laramide revolution, inaugurating the erosional history at the very beginning of the Cenozoic era.

Topography

Topographically the Black Hills are divided into four major divisions: the interior basin, the limestone plateau, the red valley, and the hogback ridge. They are surrounded by the Great Plains. An idea of the topography may be gained from Plate I.

Interior Basin

The central area of the Black Hills is an elevated basin elongated from north to south. The rim rises conspicuously above the basin in most places. The maximum width is approximately twenty-five miles, and in length it stretches from near the town of Pringle to north of the city of Lead, a distance of fifty-three miles. Rising from the floor of the basin there are ranges of hills made up of the more resistant quartzites, schists and granite. These have, as a rule, an altitude of less than 7000 feet, and Harney Peak, which is the highest point in the Hills, rises to an elevation of 7,216 feet. Due to differential erosion, broad park-like valleys are interspersed with ridges and serrate peaks.

Limestone Plateau

The name limestone plateau was applied by the earliest geologists to the interior highland rim west of the interior basin, above which it rises conspicuously. In its western portion, where the plateau is most extensive, the surface slopes gently to the westward. At the inner edge, the surface is nearly level and is bordered by a line of cliffs, many miles long and in numerous places the tops of the cliffs are 800 feet above the central valleys.

As the plateau extends southward and swings around the eastern edge of the Hills, it narrows to a mere ridge with a steep inner face, broken by the canyons of all the streams which flow to the south or the east.

Red Valley

The Red Valley is a conspicuous depression a mile or more in width, which encircles the entire Black Hills. The inner wall consists of long slopes of the pavement-like Minnekahta limestone, while the outer wall is made up for the most part of the resistant Lakota sandstone standing in precipitous cliffs. The valley proper is made conspicuous by the red soil of the Spearfish formation and also by the absence of trees, for the main forests end on the limestone plateau.

Within this valley, the landscape is monotonous. The valleys contain two sets of terraces, which are covered by coarse gravels, and the present day streams have wide, open valleys. Here and there are red buttes rising fifty to one hundred feet above the general surface, which owe their origin to a capping of resistant gypsum.

Hogback Ridge

The hogback ridge is composed of resistant Lakota and Dakota sandstones and forms the outer rim of the Hills. In most places it constitutes a single ridge which varies in steepness of slope.

> "It nearly everywhere presents a steep face toward the Red Valley, above which its crest line rises several hundred feet, but on the outer side it slopes more or less steeply down to the plains that extend far out from the Black Hills in every direction. The hogback ridge is crossed by numerous valleys or canyons, which divide it into level topped ridges of various lengths. At the southern point of the Hills, the Cheyenne River has cut a tortuous valley through the ridge for several miles, and the Belle Fourche does the same at the north end of the uplift."[40]

The Plains

The area here considered is surrounded by the Great Plains. The rocks dip gently away from the Hills and are essentially horizontal at a short distance. Since the formation for the most part are nonresistant shales and sandstones, their treeless surfaces are essentially flat except for wide, shallow valleys and small buttes capped by more resistant formations.

The topography of the Big Badlands, which lie to the east of the Rapid City area, is much more dissected than the remainder of the Rapid City area, is much more dissected than the remainder of the Great Plains area. The region is in early maturity of regional development. Here the precipitous valley walls owe their char-

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[40] Darton, N. H., "Geology and Water Resources of the Northern Portion of the Black Hills and the Adjoining Regions in South Dakota and Wyoming," *U. S. Geol. Surv.*, Prof. paper 65, p. 11.

acteristics to rocks which are slightly, though unequally resistant. The formations are largely composed of clay beds which alternate with discontinuous layers of sandstone and gravels. The semi-arid climate with a concentration of the precipitation gives rise to a maximum amount of rain-wash and preservation of the steep slopes from season to season.

Relief

The highest elevation is found in the southern part of the Black Hills, where Harney Peak attains an altitude of 7,216 feet. Terry Peak in the northern section reaches an altitude of 7,069 feet. The surrounding plains have an average altitude approximating 3,000 feet. The maximum relief, therefore, is about 4,216 feet.

Drainage

The main streams of the regions are shown on Plate III. All belong to the Missouri River system. The Cheyenne, which is the main stream draining the Hills area, and is the largest tributary of the Missouri in South Dakota, rises in Wyoming and with its two branches almost encircles the Black Hills. In ordinary stages, it is fifty to one hundred feet in width and is choked with sand.

The North Fork of the Cheyenne or the Belle Fourche River encircles the northern and western portions of the Hills. Its chief tributaries are Inyankara Creek, which rises on the western slope of the Bear Lodge uplift and flows in a general northwest direction, Red Water Creek rising on the east flank of the Bear Lodge Mountains, Spearfish Creek which has its origin on the limestone plateau and flows in a deep canyon almost due north to the Belle Fourche, Whitewood Creek which rises in the interior basin and flows northeastward across the plains, and Bear Butte Creek which heads in the interior basin and flows eastward to the plains.

The South Fork of the Cheyenne has its origin on the plains of Wyoming and encircles the southern edge of the Hills. The main tributaries which are important in the Northern Hills are Elk, Boxelder, Rapid, Spring and Battle Creeks, all of which rise in the interior basin and flow eastward, draining the eastern slopes of the Black Hills.

On the northern edge of the uplift the Little Missouri is separated from the Belle Fourche by a few miles only. Ordinarily this stream is very small and is of very little importance when considering the drainage of the Black Hills region.

Topographic History

Mountain Meadow Surface

Introduction

One of the most striking characteristics of the Black Hills area is the pronounced contrast between the gently undulating topography of the greater portion of the interior basin and the deep, almost vertical walled canyons crossing the plateau. The flattish upland surfaces have been correlated on the basis of physiography, as an old erosional surface, and mapped over wide areas in the northern Black Hills. Because this upland surface is typically seen on Mountain Meadow, just a mile and a half east of the town of Deadwood, it shall be called in this paper the Mountain Meadow surface.

General Distribution

The Mountain Meadow surface is widely distributed in the interior basin where the streams have not, as a rule, cut deep canyons but still flow through open parklike valleys. On the western edge of the Hills on the limestone plateau, the Mountain Meadow surface is well preserved. In other areas, such as on the plains portion near the foot-hills district, the flat-topped divides and inter-stream areas are the remnants of the Mountain Meadow surface. (See Plate IV). Farther out on the plains, the Mountain Meadow surface is buried beneath younger rocks.

Between almost any two of the stream valleys on the plains surrounding the Hills, mesas and dendritic ridges occur, which are accordant in level. Some of these are shown on Plate IV. Illustrations are found (1) between Spring creek and Belle Fourche river; (2) just east and south of the town of Belle Fourche; and (3) in an area paralleling the river north and west of Belle Fourche.

Just west of the town of Whitewood, at an elevation of 4,250 feet, there is a prominent, approximately flat summit, capped by an unknown thickness of gravels. On this surface there are several small undrained areas. A few miles to the south of this point, Crook Mountain has only gentle slopes above the 4,250 foot level. The same is true of Elkhorn Peak two miles west of the Whitewood flat. These accordant levels are 400 to 500 feet above the present day streams.

At many points in the Hills there are similar flat-topped divides. Some of the important ones occur (1) on a ridge one mile due south of Rapid City; (2) on the Minnelusa formation above Stagebarn Canyon south of Piedmont; (3) on the Minnelusa formation above Bear Butte canyon; and (4) along Sandy creek, just south of Beulah, where there is a high divide at an elevation of 4,100 feet capped by gravels and conglomerates.

In summary, it may be said, that there are many divides whose summits are noticeably flat; that some of these upland flats are on continuous ridges from the central hills to the plains, although others are isolated mesas or hills; and that the relief of these surfaces is considerably less than that of the present topography. If these summit areas are projected until they meet, a surface is constructed in the northern Hills, which has for its highest points Terry and Warren peaks. The relief within short distances on this plain is as high as 1000 feet but the average relief is less than 400 feet. Here and there are found remnants rising above the general surface.

Relation to Structure

The Mountain Meadow surface bevels all the geologic formations from the pre-Cambrian to the Benton shales, as shown in the following table.

Tabulation of localities showing the Mountain Meadow surface beveling various formations:

1. Pre-Cambrian rocks:
   a. Eastern edge of Lead
   b. North fork of Rapid Creek near Dumont
   c. French Creek at Custer
   d. Spring Creek above Hill City
   e. Slate Creek near Redfern
   f. Castle Creek near Deerfield
   g. North, Middle, and South Boxelder and Hay creeks west and north of Nemo, especially on Mountain Meadows
   h. Elk Creek above the settlement of Elk Creek
   i. Bear Butte Creek 1½ miles south of Moll
   j. Whitewood Creek above Englewood
2. Limestone Plateau—Pahasapa, Minnelusa, and Minnekahta formations:
   a. Spearfish Creek above Hanna
   b. Cold Springs Creek
   c. Head of Sandy Creek
   d. Mountain Meadow east of Deadwood
   e. Shoulder of Elkhorn Peak
   f. Shoulder of Crook Mountain
   g. Anticline east of Crook
   h. Above Stagebarn Canyon near Piedmont

   i. Extensive flat beginning one mile south of Rapid City
   j. Flat above Hayward
   k. 1½ miles south of Beulah above Sandy Creek Canyon
   l. Numerous unnamed valleys on the limestone plateau
3. On the Spearfish formation:
   a. Ridge extending from pre-Cambrian across to the plains area between Battle and Spring creeks
4. On the Sundance formation:
   a. In the Bear Lodge Mountains west of Government valley
5. On the Hogback ridge (Lakota, Fuson, and Dakota formations):
   a. Extensively in the Bear Lodge Mountains
   b. On the divide between the headwaters of Miller and Hewiston creeks
   c. On the divide between the headwaters of Miller and Lytle creeks
   d. North of the town of Whitewood—in Whitewood creek gap
   e. Above Elk Creek on Piedmont butte
   f. Above Rapid Creek where it crosses the hogback ridge
6. On Benton shales:
   a. At the base of the Missouri Buttes
   b. Divide between Poison and Barlow Creeks
   c. Stoneville Flat between Big Bend of the Belle Fourche River, and the town of Alzada, Montana
   d. On the divides among the following streams on the plains—Whitewood, Bear Butte, Elk, Rapid, Spring, Battle and French creeks

Mature Valleys on the Mountain Meadow Surface

Within the interior basin and on the limestone plateau on the western edge of the Hills, there is a perfect network of valleys in a late mature stage of development. These are broad, well graded valleys with gently sloping sides or with indistinct valley walls. All are mature to their heads, even though their streams are intermittent. This type of valley may be seen on Mountain Meadows near Nahant; south of Dumont; and on the limestone plateau above Spearfish canyon. (Plate V, Figs. 1 and 2).

In the Bear Lodge Mountains there are extensive dendritic shaped ridges, from 5,000 to 5,900 feet in elevation, which slope from north to south and are covered by an unknown thickness of gravel. On the west side of these mountains, there is an extensive ridge at the head of the East Fork of Hewiston Creek, at an elevation of 5,800 feet and another ridge paralleling Miller Creek, which has an altitude of 5,300 to 5,800 feet. The last two ridges rise as distinct terraces above the surrounding area. On them may be found mature valleys similar to those of the interior basin.

The late mature valleys are strong evidence of a former cycle of erosion, in which the majority of the streams had developed open park-like valleys. This feature added to the evidence of an accordant summit level which bevels successively younger beds from the central Hills to the surrounding plains, strongly suggest the following history:—(1) The strata were folded forming an elliptical dome with a few anticlinal ridges and synclinal troughs. (2) The surface was eroded until a large part was brought approximately to grade leaving an undulating surface. (3) The area was uplifted causing renewed degradation by the streams.

Surficial Deposits (The Mountain Meadow Formation)

Newton and Jenney[41] describe gravel at the base of the White River beds as

> "piles of loose pebbles, having all the appearance of a gravel beach on the seashore. Indeed it is evidently a shore deposit, the remains of the beach of the old fresh-water lakes, formed before the waters attained their greatest height and while they were sorting over materials brought by the rivers from the neighboring Black Hills."

Later, Crosby[42] reported a gravel deposit resting on the resistant and nonresistant formations of the highest hills as well as on the plains. He believed that these gravels were residual from the base of White River beds, which were deposited in a broad shallow lake, covering the entire Hills area.

Todd[43] states that there is an extensive deposit of boulders and gravels 100 to 150 miles from the Black Hills. The nature of the material, the thinning away from the Hills and the gradual diminution in size of the pebbles indicated to him that the material must have been derived from the Hills. The general distribution of the gravel

> "was accomplished by various streams flowing from the Black Hills over the Plains surrounding, at a time when the slope was slight, the water abundant, and the deposition of the material rapid. This must 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 formed by streams shifting to and fro upon a plain of deposition. Such a condition of affairs seems probable at an earlier time than when the ice was occupying the eastern half of the state."

41 Newton, Henry and Jenney, Walter, "Geology of the Black Hills of Dakota," *U. S. Geol. and Geog. Surv.*, p. 129, 1880.

42 Crosby, W. O., "Geology of the Black Hills of Dakota," *Proc. of the Boston Society of Natural History*, Vol. XXIII, pp. 516-517, 1882.

43 Todd, J. E., "A Preliminary Report on the Geology of South Dakota," *South Dakota Geol. Surv.*, Bull. no. 1, pp. 120-121, 1900.

In 1909, Darton[44] described some Oligocene deposits of gravel near Lead, near Beulah, in the Bear Lodge Mountains, near the Missouri Buttes and south of Rapid City, which he believed to have been deposited by streams or by local lakes of bayous. He named them the Chadron formation from Chadron, Nebraska, from which place these same materials were traced into the Black Hills.

Distribution

At many localities remnants of the Mountain Meadow formation occur on the plain of the same name. They are found on the 4,250 foot flat west of Whitewood; on the shoulders of Crook Mountain and Elkhorn Peak; on Mountain Meadow east of Deadwood; on the anticline east of Crook Mountain; at many points on the limestone plateau on the eastern edge of the Hills; on the divide between Rapid and Spring creeks; in the Bear Lodge Mountains; at the base of Missouri Buttes; and at many other places too numerous to mention. Although they are found most abundantly on the Mountain Meadow surface, they are widely scattered over the surfaces resulting from post-Mountain Meadow erosion.

Thickness

The thickness of the gravel can be accurately obtained only in a few places. On the divide between Spring and Rapid creeks, it has a thickness of 103 feet and on Mountain Meadow east of Deadwood of 97 feet. The average original thickness can not be stated but probably did not exceed 20 or 30 feet.

Stratification

The Mountain Meadow gravel is poorly stratified (Plate VI). Most of the material is of coarse texture with a very low percentage of sandy material. In those parts, which are most perfectly stratified, there are lens-shaped masses of gravels buried in finer gravels and sands. Generally, however, the materials show but slight sorting.

Texture and Lithology

Plate VII gives the locations in the northern Black Hills and the adjacent plains, from which samples of the Mountain Meadow gravels were taken for field and laboratory analysis. Plates VIII

44 Darton, N. H., "Geology and Water Resources of the Northern Portion of the Black Hills," *U. S. Geol. Surv.*, Prof. paper 65, pp. 58-59, 1909.

and IX give in pyramidal form the results of lithological analyses in the second and fourth horizontal columns and of mechanical or textural analyses in the first and third horizontal columns. The numbers on each of the analyses correspond to the locality numbers on Plate VII. These analyses were made as described on pages 22 and 23.

The mechanical analyses (Plates VIII-IX) bring out the fact that a large percentage of the gravel is of pebble size. An exception to this is seen in number 14 in which there is no piece larger than two millimeters in diameter. In some of the pyramids a double maximum occurs. It will be noted that these gravels are practically of the same texture over the entire area.

In order to make more clear the results of these mechanical analyses an average analysis was made. (Plate X). The Mountain Meadow Summary (Mechanical) graph of this plate shows (1) that 15 per cent of the pieces are more than sixty-four millimeters in diameter; (2) that 77 per cent are less than sixty-four millimeters and more than four millimeters in diameter; (4) and that in the fine grade most of them are concentrated in the one-half millimeter grade. This, according to Wentworth's classification[45] would be called a pebble gravel, or if cemented, a pebble conglomerate.

It is made clear from a careful study of the lithological pyramids in the second and fourth horizontal columns of Plates VIII and IX and of the location map, Plate VII, and of the geologic map, Plate II, that the lithology of each sample from within the Hills is determined to a considerable extent by the rock which outcrops at or near the location. For instance, numbers 1, 8, 11, 16, 18 and 23, all of which are located on the Paleozoic limestones and sandstones, contain higher percentages of these same materials than do samples taken from other geologic locations. In other words, a considerable fraction of the materials in the Mountain Meadow formation of the Hills was locally derived. Samples from the plains, however, consist almost entirely of foreign matter from the Hills.

In addition, the analyses and locations show that the percentages of quartz in the formation increases and the percentage of Paleozoic limestone and sandstone decreases with increasing distance from the central Hills. This is doubtless due to the fact that quartz is the most durable material derived from the Hills proper and that

45 Wentworth, C. K., "Grade and Class Terms for Clastic Sediments," *Jour. Geol.*, Vol. XXX, p. 381, 1922.

materials of inferior resistance were worn out in transportation or weathered to pieces.

An averaged Mountain Meadow lithological analysis (Plate X) shows (1) that porphyry is the most abundant material, making up 28.7 per cent; (2) that quartz is next most abundant with an average of 16.4 per cent; (3) and that pre Cambrian quartzite is last with an average of 13.44 per cent. Of these materials, the quartz and pre-Cambrian quartzite—29.91 per cent of the total—were derived from the pre-Cambrian rocks of the central Hills. The fact that so large a percentage of the Mountain Meadow formation was derived from the pre-Cambrian emphasizes the amount of erosion between the Laramide Revolution and the deposition of these gravels. The gravel, even in its lowest beds contains a high percentage of pre-Cambrian rocks which at the close of the Mesozoic era were covered by at least 7,000 feet of sediments. The pre-Cambrian must have been exposed over wide areas by the time these gravels began to be deposited.

It is clear from these analyses and the average mechanical analyses that whatever may have been the depositing agent and however far from the sources these materials may have been deposited the agent or agents of transportation from the sources to the sites of deposition must have had considerable power. It appears also that there must have been about as much power for transportation thirty miles from the Hills as in the central Hills themselves.

Shapes

The shapes of the pebbles and cobbles are variable. One hundred and eight pebbles picked up at random were brought into the laboratory and measured for shape index. These were calibrated as stated on pages — and —. These values are tabulated on page —.

The table shows that the gravels of the mountain Meadow formation are very angular, and as a rule, show very little rounding. This is especially true of local material such as the Minnekahta limestone. It was noticed in the field that the farther from the source of material the rounder the pebbles appeared. No roundness analyses are available to prove this fact in this respect.

Cementation

Locally these sediments are cemented by calcium carbonate into a resistant conglomerate, although for the most part they are largely unconsolidated. South of Rapid City, between Spring and Battle creeks, the topmost eight or ten feet of the formation is firmly cemented.

The causes for this selective cementation have not been definitely determined. There at least two possibilities which have been considered.

In the present day stream valleys calcareous tufa is being deposited where the streams flow across the Minnelusa formation. In Sandy Creek above Beulah, Wyoming, falls four or five feet in height are made by tufa. In Polo Creek, at the base of Elkhorn Peak, gravel is being cemented by tufaceous material. The cause for the deposition of this material by streams unknown. It has been suggested that evaporation causes a saturation of the stream and that with agitation carbon dioxide is lost with a reduction of bicarbonate to carbonate and precipitation occurs because of loss of solubility.

ROUNDNESS ANALYSES OF THE MOUNTAIN MEADOW GRAVELS

Kind of Rock	Number of Pebbles	Radius of Average	Curvature Maximum	Shape Average	Index Maximum
Size of piece 16-32 mm.					
Pre-Cambrian quartzite	24	.0071	.168	.000291	.007
Deadwood quartzite	5	.00	.052	.00	.00216
Quartz	21	.0065	.27	.00277	.112
Porphyry	9	.00	.077	.00	.00320
Size of piece 8-16 mm.					
Pre-Cambrian quartzite	25	.077	.318	.00633	.0265
Deadwood quartzite	7	.0256	.36	.00213	.03
Minnekahata	10	.00	.00	.00	.00
Porphyry	6	.00	.082	.00	.00683

It is also possible that the cementation may have been due to ground water precipitating calcium carbonate in the usual manner. This is suggested by the local irregular areas of cementation.

Fossils

A few fossils have been found in the Mountain Meadow formation,[46] which are identical with those commonly found in the Oligocene White River beds of the Big Badlands forty miles to the east of the central portion of the Black Hills. The fauna consists of:

Oreodon culbertsoni
Poebrotherium wilsoni
Hyracodon nebrascensis
Stylemys nebrascensis
Ischyomys typus

All of these animals were upland form. *Poebrotherium wilsoni* belonged to the camel family and was perhaps the commonest South Dakota species. *Stylemys nebrascensis* was a land form of tortoise. The head, as a rule, is absent. This is due perhaps to the fact that they were land forms and, being carried by the streams, were rolled. The remaining forms *Hyracodon nebrascensis,* and *Ischyromys typus,* an ancestral squirrel, are found occasionally in the Mountain Meadow. The presence of such land forms and the absence of aquatic forms suggests fluviatile rather than lacustrine origin for the Mountain Meadow gravels.

46 Darton, N. H., "Geology of the Southern Portion of the Black Hills of Dakota," *U. S. Geol. Surv., 21st Ann. Rep.*, Pt. 4, p. 543, 1899-1900.

Origin

The lithology, texture, stratification, fossil content, and topographic distribution all point unmistakably to the conclusion that the Mountain Meadow is wholly fluviatile in origin, at least in so far as the region under discussion is concerned. The formation occurs from the central Hills to the Plains, mantling a topographic surface which was developed at the same time. This surface represents a late mature topography with relief locally 1000 to 1500 feet. The gravels are poorly sorted both mechanically and lithologically. The absence of lacustrine fossils points to the fluviatile origin of the formation. All of the fossil remains are of animals which lived either along the stream courses or on the plains.

The Mountain Meadow formation was formed by streams which were depositing over wide areas. No doubt there were other streams on the Mountain Meadow surface which were degrading rather than aggrading. Still other streams were depositing fine material which has either become worked over to become a part of the soil or has been carried away by streams or the wind. The gravels being more resistant and more porous have remained over large portions of the area.

Some of the gravel which occurs on the plains surrounding the Black Hills was undoubtedly deposited on the flood plains of the streams due to decrease in gradients following the post-Mountain Meadow uplift in the Hills proper.

Stream Adjustment and the Mountain Meadow Surface

Introduction

Antecedent streams, as used in this discussion, are those which develop courses independently of rock structure in one erosion cycle and hold those courses after uplift which is accompanied by warping. Streams of this type are the Susquehanna and Potomac of the Appalachian region.

Davis[47] outlined three stages of stream adjustment in regions of folded strata during erosion cycles. In the first stage the slope of the land controls the stream courses and as a result the major streams flow in the synclines parallel to their axes. In stage two, the streams on the flanks of the anticlines have the advantage; while in stage three, the major streams flow on the crest of the anticlines. A fourth stage has been added by Trowbridge,[48] in which the stream which flows the shortest distance to the sea will be the major stream irrespective of the structure of the underlying rocks. If the main streams in any earlier stages of the reduction cycle than extreme old age flow irrespective of structure, it is strong evidence of a former cycle of erosion. Some of the streams of the Black Hills flow in deep gorges across folds in such a way as to appear to have gone to old age in a previous cycle.

Bear Butte Creek

In the northern Black Hills, Bear Butte creek represents a stream in the fourth stage of adjustment, which is not in harmony with the stage of reduction in the present cycle. This stream heads in the interior basin and flows eastward to the plains. It flows down the dip of the rock, in general, until Boulder Park, about two and one-half miles west of Sturgis is reached. At this point, the creek flows eastward although the rocks are tilted as high as 75 degrees to the west. On the axis of the anticline, the stream is deflected to the north parallel to the axis of the anticline. After flowing due north a few hundred yards, it suddenly turns again to the east. Its course

47 Davis, Wm. M., "Rivers and Valleys of Pennsylvania," *Nat. Geog. Mag.*, Vol. I, pp. 183-263,1889.

48 Trowbridge, A. C., "The Erosional History of the Driftless Area," *Univ. of Iowa Studies in Nat. Hist.*, Vol. IX, No. 3, p. 32, 1920.

across the anticline must have been developed in old age of some previous cycle.

Whitewood Creek

Whitewood Creek also has several anomalies which can not be explained on the basis of a single cycle of erosion. It heads in a late mature valley in the interior basin above the town of Englewood and flows, in general, eastward across the pre-Cambrian strata. Below Deadwood it has cut a deep canyon in the resistant limestones. It is deflected sharply to the eastward and remains in the resistant limestone; although a few hundred yards to the north of the point of deflection are the nonresistant red beds. Flowing eastward Whitewood creek has cut through the periphery of Crook Mountain and across the axis of the Whitewood anticline just a quarter of a mile east of the town of Crook. From this last point, the creek follows in general the axis of the anticline.

This lack of harmony between the original slope of the land, rock structure and the present course of Whitewood creek can only be explained on the basis of a previous cycle, in which Whitewood creek flowed across the shoulder of Whitewood Peak, the Boulder Park syncline, across the periphery of Crook Mountain, across Crook valley syncline to the axis of Whitewood anticline irrespective of structure.

Interrupted Profiles with Respect to the Mountain Meadow Surface

In the northern Black Hills, the streams all have high gradients, except where their headward portions are on the Mountain Meadow surface. The slope may change and become less steep on the nonresistant formations but no decided interruption is noticeable. If the observer, however, follows a stream to its head, a decided break is found at the edge of the Mountain Meadow surface. Below the Mountain Meadow surface the streams have high gradients and canyon-shaped valleys in the main, but on the former erosion surface the valleys are park-like and have indistinct valley walls and low gradients. In many cases the interruption is at the edge of the Mountain Meadow surface where the material is of the same resistance above and below the break. Since all the valleys are in late maturity and have relatively low gradients in the interior basins and on the inner edge of the limestone plateau where the resistance is certainly not constant, the interrupted profiles seem to be good evidence of more than one cycle of erosion. It appears that the streams must have had low gradients even to their heads during the closing stages of the Mountain Meadow cycle and that the rejuvenation due to the uplift of the old surface has not as yet become effective there.

Age of the Mountain Meadow Surface

The precise age of this former erosion surface can not be stated from physiographic data. It is younger than the Fox Hills sandstone of uppermost Cretaceous age, for the surface bevels this formation. It is probably older than the Pleistocene for deposits of that age fill valleys which were cut after the uplift of the Mountain Meadow surface.

However, the age of the surface is fixed by the fossils contained in the gravels which lie upon it. There can be no doubt that the fossils are in place in the gravels and the fossils include five typical mid-Oligocene forms. This is, therefore, the date assigned to the Mountain Meadow surface.

Another strong suggestion as to the age of the Mountain Meadow peneplane is found in the Badlands. The author has not found any outcrop of Mountain Meadow gravels from the point on the plains where the Mountain Meadow is covered by younger materials. Ward,[49] in speaking of the formation in the Badlands says, "The Titanotherium is separated from the overlying Oreodon by an unconformity. The contact is well displayed along a large part of the "Wall" as well as on a great number of outlying buttes. Reference to the map (Plate I) will disclose the fact that there are many miles of observed as well as inferred contact. Probably two-thirds of the cases where the contact was seen it was found to be a disconformity. In the remainder of the exposures the unconformity was angular. The angle between the two formations was in almost every case low, one to three degrees, but in one instance was as much as twelve degrees." Wanless[50] also speaks of the unconformity between the Titanotherium and Oreodon formations.

The writer, after visiting the area and studying the unconformity, believes that the Titanotherium-Oredon break, which is so prevalent in the Badlands, marks the Mountain Meadow surface in this area. Wanless[51] in discussing the lithology of the White River beds expresses exactly the belief which the writer holds. The conditions during the Titanotherium time favored degradation in the Hills. "It is quite reasonable to believe that streams may have been distributaries from the points where they left the mountains until their disappearance by absorption and evaporation on the plain." These conditions prevailed until the close of the Titanotherium epoch when differential uplift occurred. Then both the Black Hills and the surrounding plains were subjected to erosion.

49 Ward, Freeman, "The Geology of a Portion of the Badlands," *Bull. Univ. of S. Dak.*, Series XXII, No. 6, pp. 23-24, 1922.

50 Wanless, Harold, "Lithology of the White River Beds," *Am. Phil. Soc.*, Vol. 62, p. 205.

History of the Mountain Meadow Surface

The Mountain Meadow surface with its topographic and structural relations, high level gravels, antecedent streams, and interrupted profiles, is the result of a previous erosion cycle interrupted by uplift during mid-Oligocene times. The Oligocene surface was not a geometrical plane or perhaps even a peneplane, but neither did it have the relief or the ruggedness of the surface of today. Some of the streams were depositing gravel, some were doubtless eroding and others were probably at grade and depositing material finer than gravel. In some localities, as for example, near Terry Peak and Warren Peak, the relief may have reached 1000 feet in short distances.

Amount of Uplift

The amount of uplift at the close of the Mountain Meadow cycle may be at least approximately ascertained on the plains and in the foothills by the difference in elevation between the present day elevation of the Mountain Meadow surface and the present day stream beds. Below is given a tabulated list of different localities.

Location On the Plains	Difference in elevation between Mountain Meadow surface and the stream beds
1. Stoneville Flats	100–300 feet
2. Section 3; T. 8 N.; R. 4 E.	200–240 "
3. East edge of Rapid map T. 5 N.; R. 4 E.	200–300 "
4. Section 21; T. 3 N.; R. 9 E.	200–300 "
5. Ridge east of Rapid City	250–350 "
6. Snake Bench, SE. portion of St. Onge map	180–220 "
7. Divide between Rapid and Spring creeks	235 "

51 Wanless, Harold, *op, cit.*, p. 206.

8. Divide between Spring and Battle creeks	200–400	feet
9. Divide between Battle and French creeks	200–400	”
Average	250	”

In the Foot-Hills

1. Mountain Meadows	500–600	”
2. Above Bear Butte creek, a mile west of Sturgis	500–600	”
3. North shoulder of Crook Mountain	800–900	”
4. Whitewood Flat	600–700	”
5. Shoulder Elkhorn Peak	450–550	”
6. Above Stagebarn canyon	500–600	”
7. Sections 25 and 26; T. 1 N.; R. 6 E.	550–650	”
8. Southwest of Big Bend or Stoneville Flat	600–700	”
9. Section 19; T. 1 N.; R. 7 E.; Southeast of Rapid City	500–600	”
10. Above Hayward on the Hermosa map	500–700	”
11. Center section 18; T. 2 S.; R. 7 E.	400–600	”
12. One and one-half miles Southwest of Beulah	500–600	”
Average	575	”

Judging from the above figures it seems that the average uplift of the plains area was about 250 feet and that of the foothills about 575 feet.

None of the streams are at grade in the central Hills and consequently it is necessary to make certain assumptions in order to arrive at a datum gradient with which to compare the elevation of the Mountain Meadow surface there. The Belle Fourche River for a distance of eighty-five miles is essentially at grade with a gradient of 6.76 feet per mile. Assuming that the tributaries of the Belle Fourche will have a gradient of seven feet per mile when they reach grade in the central Hills it is concluded that the uplift in the central Hills must have been at least 3000 feet. The method used is explained on the accompanying chart. This figure may be stated as a rather high estimate since all the streams are smaller than the Belle Fourche and may have higher gradients than assumed after they reach grade.

According to a second assumption that the streams' gradients will be fourteen feet per mile when grade is established, the chart shows an estimated uplift of 2800 feet in the central Hills.

A third assumption that the gradient of the graded streams will be twenty-eight feet per mile leads to the estimate of 2200 feet of uplift as may be seen by reference to the chart.

These series of assumption and tabulations show that the vertical uplift in the central Hills was between 2000 feet and 3000 feet in

Table Illustrating Amount of Uplift

Name of Stream	Distance	Elevation of some point downstream	Elevation of Mountain Meadow surface	1st Assumption Elevation at head when at grade	1st Assumption Uplift	2nd Assumption Elevation at head when at grade	2nd Assumption Uplift	3rd Assumption Elevation at head when at grade	3rd Assumption Uplift
Iron Creek	31	3100	6500	3530	3180	3530	2970	3970	2530
Spring Creek	51	3100	6500	3450	3050	3800	2700	4500	2000
Castle Rock Branch	55	3000	7000	3390	3160	3770	3230	4540	2460
South Fork of Rapid Creek	44	3000	7000	3320	3680	3620	3380	4230	2770
Boxelder Creek	40	3000	6500	3280	3220	3560	2940	4120	2380
Elk Creek	33	3300	6000	3230	2800	3470	2530	3890	2110
Bear Butte Creek	31	2750	6000	2975	3230	3184	2816	3620	2380
Whitewood Creek	34	2900	6000	3138	2862	3376	2624	3852	2148
Deadwood Creek	30	2900	6000	3100	2900	3320	2680	3740	2260
East Fork of Spearfish Creek	32.5	3200	6000	3430	2570	3655	2345	4100	1890
Spearfish Creek	36	3200	6500	3450	3040	3700	2800	4200	2300
Little Spearfish Creek	32.5	3200	6500	3430	3070	3655	2845	4100	2400
Average uplift in feet					3037		2799		2189

contrast with an uplift not to exceed 235 feet on the plains. It is clear, therefore, that not only during the Laramide Revolution but at the close of the Mountain Meadow Cycle there was marked differential uplift so that the Black Hills were raised far above the surrounding plans.

Summary

In summary, it is concluded that the Mountain Meadow erosion cycle, which began as the surface emerged from the seas during the closing epochs of the Cretaceous period with the Black Hills towering above the surrounding plains, and which resulted in the removal of more than 7000 feet of sediment from the central Hills and the reduction of the surface to a late mature stage of erosion, was interrupted in mid-Oligocene time by a differential uplift amounting to 2000 to 3000 feet in the central Hills, 250 feet in the foothills and 20 to 30 feet in the Badlands, as indicated by the Titanotherium-Oreodon unconformity.

Post-Mountain Meadow History

Introduction

As a result of the mid-Oligocene uplift last mentioned, new valleys were carved out below the Mountain Meadow surface. Before the close of this cycle of reduction the valleys in the Hills had developed almost to their present conditions, while on the Plains the non-resistant formations were eroded to form a peneplane. It is in these valleys and on this erosion surface that stream deposits younger than those of the Mountain Meadow are found, recording later events in the physiographic history of the region.

The Rapid Cycle (High Terrace)

Historical Mention

The first mention of the terrace deposits of this region was made by Newton[52] in 1880, as follows:

> "The Quaternary deposits have had little interest geologically, as they consist merely of certain local deposits of gravel along a portion of the foothills and alluvial deposits of boulders, gravel, sand and clay, forming the bottoms or floors of the valleys of the creeks. . . . The deposits all belong to very recent geologic time, and are the result of wearing and abrading action of existing streams. Of the glacial drift we could find no evidence."

52 Newton, Henry, and Jenney, Walter P., "The Black Hills of Dakota," *U. S. Geol. and Geog. Surv.*, p. 44, 1880.

Todd[53] mentions the presence of two distinct terraces in the valley of Cheyenne River, as follows:

> "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 foothill range but in the Red Valley, at least this is true of the higher one."

The terraces of the northern Black Hills are discussed briefly in Darton's report of 1909.[54]

> "Remnants of old terrace deposits occur at various levels above the present stream bottoms in many portions of the northern Black Hills."

General Description

There are two distinct terraces within the area of the northern Black Hills. These have been called, as previously mentioned, the Upper and the Lower terraces. When the so-called Upper terrace is traced from the Hills proper it is found to cut across the Mountain Meadow surface on the Plains. In this latter area, it forms the most conspicuous feature of the landscape. Ward[55] has called this high surface the Prairie or Upper Prairie.

Since, however, the topographic expression of the Upper terrace of the Hills and the Prairie surface of the Plains is markedly different, and since the Upper terrace is well developed in valley of Rapid Creek in and near Rapid City, the name Rapid is given to the Upper terrace of the Black Hills proper, the materials which cover them and the cycle in which they were formed. The name Prairie may be retained for the flat interstream summits of the Plains.

Topographic Expression

The Rapid cycle is represented by well developed terraces within the Hills from the outer edge of the limestone plateau to the adjacent Plains where they pass over the Mountain Meadow surface. The terraces form conspicuous flats within the main valleys. They are identifiable in part by their height above the streams and in part by tracing their accordant remnants up and down stream from point to point. All rise either abruptly from the lower terrace or

53 Todd, J. E., "A Preliminary Report of the Geology of South Dakota," *South Dakota Geol. Surv.*, Bull. I, pp. 124, 1894.

54 Darton, N. H., "Geology and Water Resources of the Northern Black Hills," *U. S. Geol. Survey*, Prof. paper 65, p. 60, 1909.

55 Ward, Freeman, *op. cit.*, pp. 13-14.

from the stream bed. They are strikingly flat-topped and in places, as two miles east of Belle Fourche, are two to three miles in width. Several miles out from the Hills, the Rapid bench occurs as inter-stream summits. This Rapid level has been traced from Rapid City across the Cheyenne eastward to the Badlands. Gravel accompanies this level either as a thin capping or as a deposit thirty to forty feet in thickness. An idea of the widespread distribution of remnants of the Rapid cycle may be gained from Plate IV. The surface bevels the non-resistant formations of the Red Valley, and the surrounding plain. In the Badlands, this erosional surface is well marked. It cuts across the Pierre shale, the Oreodon and Titanotherium beds, and farther south the Leptauchenia and Rosebud beds, as Wanless[56] describes in his paper on the Badlands.

All students who have worked on the Rapid terrace are impressed with the fact that it is found over wide areas at approximately the same height above the present day streams within the Hills and on the border of the Hills. A table is given below showing the heights of the terraces above the present day valley bottoms in many portions of the region. These heights were obtained in most cases by hand leveling but occasionally an aneroid barometer was used.

Location	Height above valley bottom Rapid Terrace
Belle Fourche River	
½ mile above Hulett	100
Center Section 21; T. 56 N.; R. 64 W.	100
Corner Sections 10, 11, 14, 15; T. 56 N.; R. 64 W.	100
NE. ¼ Section 11; T. 56 N.; R. 64 W.	102
NW. ¼ NW. ¼ Section 35; T. 57 N.; R. 64 W.	104
Center Section 23; T. 57 N.; R. 63 W.	103
Stoneville Flats	100
Section 18; T. 57 N.; R. 62 W.	102
Corner Section 16, 17, 20, 21; T. 57 N.; R. 62 W.	100
Northern portion Section 27; T. 57 N.; R. 62 W.	103
NW. ¼ SW. ¼ Section 35; T. 9 N.; R. 1 E.	100
Terrace which parallels Belle Fourche River northeast of the town of Belle Fourche	103
Just north of town of Belle Fourche	105
Section 1; T. 8 N.; R. 3 E.; Section 6, 7; T. 8 N.; R. 4 E.	102
¾ mile east of Twin Buttes	100
Section 1, 2; T. 8 N.; R. 4 E.	102
Northeast corner of Rapid Quadrangle	106
Whitewood Creek	
Eastern portion Section 27 and southeast portion Section 22; T. 6 N.; R. 4 E.	101
SW. ¼ SW. ¼ Section 21; T. 6 N.; R. 4 E.	100
Center Section 22; T. 6 N.; R. 4 E.	102
SE. ¼ NE. ¼ Section 21; T. 6 N.; R. 4 E.	100
NE. ¼ SE. ¼ Sec. 16; T. 6 N.; R. 4 E.	100
SW. ¼ NE. ¼ Section 16; T. 6 N.; R. 4 E.	101
SE. ¼ SW. ¼ Section 24; NW. ¼ Section 25; NE. ¼ SE. ¼ Section 26; T. 7 N.; R. 5 E.	103
North central, central and south central portions Section 16; T. 7 N.; R. 5 E.	100
SW¼ Section 33; SE. ¼ Section 32; T. 8 N.; R. 5 E.; NE. ¼ Section 5; T. 7 N.; R. 5 E.	100
At mouth of Whitewood Creek	101
Falsebottom Creek	
East portion Section 35; T. 7 N.; R. 3 E.	100
Parallels stream in Section 5, 8, 16; T. 7 N.; R. 3 E.	100
Bear Butte Creek	
2 miles west of Sturgis	100
½ mile west of Sturgis	104
Eastern edge of Sturgis	105
SW. ¼ Section 13; T. 6 N.; R. 7 E.	102
Mouth of Bear Butte Creek	103
Rapid Creek	
North of Rapid City	100
½ mile east of Rapid City	100
1¼ miles east of Rapid City	100
Southern edge of Rapid City	103
Central and southern portions Section 11; T. 1 N.; R. 8 E.	102
West portion Section 15; T. 1 N.; R. 8 E.	102
Mouth of Rapid Creek	104
Battle Creek	
NW. ¼ SE. ¼ Section 2; T. 3 S.	102
½ mile west of Hermosa	100
In the western edge of town of Hermosa	98
SW. ¼ SW. ¼ Sec. 6; T. 3 S.	101
NW. ½ NW. ¼ Section 35; T. 3 S.	99

56 Wanless, Harold R., *op. cit.*, Vol. 62, p. 261.

As is seen in the above tables the Rapid terrace remains at approximately the same height above the present day streams within the region of the Hills. This is of importance in interpreting the history of this valley cycle. It must mean that the streams which formed these terraces had developed valley flats with gradients approximately the same as those of today.

The Rapid Formation

The Rapid formation is composed typically of pebble and cobble gravel. So similar is it with the Mountain Meadow that it is difficult to distinguish the two formations even after an analysis. Porphyry, quartz, and quartzite make up the greater percetnage in both formations and texturally they are notably similar. This similarity is not surprising since both are fluvatile in origin and the same rocks were exposed during both periods of deposition.

The characteristics of the formation as to texture and lithology are presented in Plate XI; the localities of samples being given in Plate VII.

The important features brought out by these charts are (1) the coarseness of the material, 27.95 per cent being more than 64 millimeters in smallest diameter and 63.85 per cent larger than 4 millimeters in largest diameter; (2) the high percentage of porphyry pebbles and cobbles, which constitute 26.12 per cent of all the material; (3) the high percentage of quartz with an average of 24 per cent; (4) and the high percentage of local materials.

The pebbles of the formation are of about the same roundness as those of the Mountain Meadow formation. The quartz, porphyry, and quartzite are usually well worn. Some of the pieces of local origin, such as the limestones, are very angular, some of them having been transported only a fraction of a mile.

The thickness of the Rapid formation can only be obtained in a few places. A maximum thickness of thirty-eight feet was exposed at station 35 (Plate VII) just east of the town of Whitewood. The formation more commonly has a thickness of fifteen to twenty feet. Even on the high surfaces near Scenic—fifty or sixty miles from the Black Hills—there is a covering of gravels and alluvial materials eight to ten feet thick.

In a gravel deposit, such as the Rapid, fossils are ordinarily very scarce. In the three summers work no fossils were found by the writer although hundreds of exposures were visited. It has been reported that a Pleistocene horse tooth has been found in the Rapid terrace gravels of Indian Creek. This creek is one of the tributaries of the Belle Fourche river in the northeastern portion of the area under consideration.

Origin of the Rapid Surface

Any theory for the origin of the Prairie surface must explain (1) the near parallelism of the terraces within the Hills with the present stream beds; (2) the Rapid level on the Plains; (3) the coarse materials found on this surface; and (4) the limitation of the terraces to the outer edge of the limestone plateau and beyond to the badlands area. A complete understanding of these factors can be secured only through a broad study of the Great Plains and the eastern Rocky Mountain region with particular reference to the history of the Missouri river, but some of the events and conditions are clearly indicated in the terraces of the streams of the Black Hills and the erosion surface of the adjacent plains.

Following the differential uplift of the Mountain Meadow surface, the streams began to erode the entire area. The streams in the Black Hills area cut valleys several hundred feet in depth before they reached grade and became depositing streams. On the Plains, due to the smaller amount of post-Mountain Meadow uplift, the streams were soon at grade. A peneplane with little relief was developed on the non-resistant formations of the plains. Streams coming from the foot-hills deposited their materials widespread over the area. Still later erosion was renewed in the area.

Such changes as these from post-Mountain Meadow erosion to Rapid deposition and back to post-Rapid erosion are never easy of explanation. They have usually been ascribed in this region and elsewhere to diastrophism, but the competence of climatic changes to produce these same results have been brought out by Johnson[57] and Davis.[58]

If the rejuvenation of streams such as is indicated by the renewal of erosion following deposition of the Rapid gravel be thought to have resulted from diastrophism, the following history is involved. With the interruption of the Chadron cycle by differential uplift, the streams began cutting downward. They first reached grade on the non-resistant, less elevated, portion of the area. The streams were developing flats and depositing on these flats from the edge of the limestone plateau out to the main drainage line; while they

57 Johnson, W. D., "The Utilization of the High Plains," *U. S. Geol. Surv., 21st Ann. Rept.*, Pt. 4, pp. 630-631, 1900.

58 Davis, Wm. M., "Exploration in Turkestan," *Carnegie Institution Publication*, No. 26, pp. 203-206.

were still degrading in the higher Hills. This valley cycle was then interrupted by a vertical uplift of approximately fifty feet.

Johnson's[59] explanation of climatic control is about as follows: The streams developed wide valleys in the foothills and on the plains as a result of a change from humid to semi-arid conditions. The greatest precipitation would occur then in the elevated portions, thus allowing the streams to degrade in the main portion of the Hills at the same time that they were depositing in the foothills and on the plains where the rainfall would be less than that in the Hills. The streams deposited most of their materials in the semi-arid districts causing wide flood plains. Later the change toward increased rainfall occurred and the streams began again to degrade throughout their entire courses.

If a change from humid to semi-arid back to humid climate be called to explain the deposition and erosion of the Rapid gravel, it does not seem probable that the terraces would parallel so closely the slope of the present day streams. Changes in volumes of the streams should result in changes in stream gradients. It seems more likely, therefore, that the Rapid terraces are not the result of climatic changes. This hypothesis can hardly be ruled out entirely, however, until its principles have been worked out in greater detail.

Perhaps changes involving the distribution rather than the amount of rainfall might later be found to afford an explanation for such histories as these streams seem to have had. Uniform distribution of rainfall gives rise to a high ground water surface and to permanent streams with relatively uniform flow which never have great transporting power. Intermittent precipitation on the other hand increases the total run-off and causes streams to flow with great volume, velocity and transporting power, when they flow at all. Perhaps such intermittent streams might cut into deposits laid by previously permanent streams with permanent though always small carrying power.

It is possible also that changes in temperature might influence stream action in important ways. During prevailing conditions of high temperature, vegetation might have flourished in the valley bottoms causing the streams to deposit there and with decreasing temperatures the vegetation might have loosened its hold on the deposits permitting them to be carried on again. A change from

59 Johnson, Wm. D., *ibid*, pp. 630-631.

humidity to aridity would presumably have about the same indirect effect.

The evidence is clear that the Black Hills were not directly effected by Pleistocene glaciers, but they may have been covered by great névé- and icefields. Even if effected by only such incipient glaciers, it may be that so much material was prepared for transportation in the central Hills and the melting ice gave rise to so much water that the streams carried more sediment to the foothills and plains than could be carried farther resulting in a partial filling of the valleys. After these ice fields had melted away during a following inter-glacial epoch, the streams would not carry so much debris out from the Hills and might erode the previous deposits for the same reason that valley trains are commonly eroded.

As these terrace gravels represent mechanical rather than chemical disruption at their sources, changes from erosion to deposition and back to erosion as recorded might be explained on the basis of temperature changes in the central Hills not involving even incipient glaciation there. With low temperatures in the area of disruption, rocks would not be covered by vegetation, the mechanical processes of exfoliation, crumbling, wedge-work of ice, gravity action, etc., would be effective and much material would be prepared for transportation. Under these conditions much mechanically disrupted debris would be carried to the foothills and deposited. Then if conditions should be altered toward higher temperatures in the Hills, the vegetal covering would thicken there, mechanical disruption would be decreased, and the streams reaching the foothills and plains with decreased loads would pick up some of the materials previously deposited thus turning flood plains into terraces.

Todd[60] has shown that certain terraces in the Missouri valley and its main tributaries are due to glaciation from the north and east. He treats especially the Wisconsin history of the river as follows:

"In the valleys of the Missouri and its principal tributaries, there are many very striking river terraces. These terraces are mainly the result of erosion, the lower part of them being composed of bed-rock and the top composed largely of coarse materials, mainly from glacial drift, the finer silty material being largely washed away . . . . They vary in altitude above the stream from 20 to 450 feet . . . . These terraces are as near level as usual under such circumstances, except several miles below Bihou Hills, where some of the terraces show a much steeper slope down stream. This uniform history of the

60 Todd, J. E., "Is the Channel of the Missouri River through North Dakota of Tertiary Origin?," *Bull. Geol. Soc. Am.*, Vol. 34, pp. 491-493, 1923.

streams in these three states has been unusually uniform. . . . We know no reason why the stream changes were not as numerous and striking in the Nebraskan or Illinoian as we have found them in the Wisconsin.''

The possibility presents itself that the valley terraces of the Black Hills region are genetically related with the glacial terraces farther east and downstream. It is conceivable that as the Missouri River was blocked and deposited materials, the tributaries to it from the west also became aggrading streams, at least in the lower parts of their courses. The gradients in the higher portions of the Black Hills region would remain the same but coarse materials would be deposited in the gentler valleys of the plains. With the retreat of the ice blocking the Missouri, that river would re-excavate permitting all the tributaries to do likewise, thus making terraces in their valleys.

The Rapid terraces in the Hills and the Rapid peneplane on the plains may, therefore, represent the ponding of the Missouri and consequently all of the tributaries during one of the glacial epochs and renewal of erosion during the following interglacial epoch. Although the complete history of the Rapid cycle must await an extensive study of the whole drainage basin, it is thought likely that its explanation may be found in glaciation and deglaciation either directly or indirectly or in other climatic changes less profound.

Drainage Changes During the Rapid Valley Cycle

At Stoneville Flat, located thirty miles north of Belle Fourche, the Rapid terrace is a flat area which was once the bed of the upper portion of the Belle Fourche river,[61] which during the Rapid, flowed into the Little Missouri river. This fact is proven by the flat gravel-covered bench which is valley-like in contour and also by the small ponds which occur on this flat, being the present remains of the deeper parts of the former river. The sharp bend of the Belle Fourche river is also indicative of stream piracy. (Plate IV).

The upper Belle Fourche river during the Rapid cycle was the largest tributary of the Little Missouri river, for it received the run-off of the greater portion of the western slopes of the Black Hills. On the northeastern edge of the Hills during this same cycle was the lower portion of the present Belle Fourche river working

61 Darton, N. H., "Stream Piracy Upon Which the Belle Fourche Irrigation is Based," *Science N. S.*, Vol. 29, pp. 556-557, 1909.

headward. This was a small stream with a high gradient and during the Rapid cycle cut across the narrow divide diverting the Upper Belle Fourche River.

The Sturgis Valley Cycle (low terrace)

General Description

The terrace level, which is found approximately fifty feet below the Rapid terrace, will be called the Sturgis terrace in this paper since in the town of that name, the lower terrace is well developed. Terraces, which are apparently of the same age, since they are found in a similar topographic position have been described by Ward[62] as follows:

''Between the flood plain and the ''Wall'' is a flat to gently rolling prairie. It averages three miles in width ranging from half to twice that amount.''

The Sturgis terraces occur in the main valleys between the present flood plains and the Rapid terraces both horizontally and vertically. The Sturgis terraces are characteristically flat-topped and covered with coarse gravels. They rise abruptly from the present flood plains and are found in all the main streams from the limestone plateau area to the Badlands.

Topographic Expression.

The Sturgis terrace system is similar to the Rapid benches except that they are on a smaller scale. These terraces also parallel the stream gradients of today and remain approximately fifty feet above the present day flood plains over the entire area studied. The following table shows the height of the Rapid terraces above the present stream beds.

Location	Height Sturgis Terrace
Belle Fourche River	
Directly opposite Devil's Tower	53
NW. ¼ Section 1; T. 55 N.; R. 64 W.	52
NW. ¼ Section 31; T. 56 N.; R. 64 W.	52
NE. ¼ Section 29; T. 56 N.; R. 64 W.	50
SE. ¼ NE. ¼ Section 11; T. 56 N.; R. 64 W.	51
Western edge Section 1; T. 56 N.; R. 64 W.	50
NE. ¼ NE. ¼ Section 35; T. 57 N.; R. 64 W.	50
SW. ¼ NW. ¼ Section 25; T. 57 N.; R. 63 W.	51

62 Ward, Freeman, "Geology of a Portion of the Badlands," *Bull. Univ. of S. Dakota*, Series XXII, no. 6, p. 12, 1922.

SW. ¼ NE. ¼ Section 20; T. 57 N.; R. 62 W.	49
NE. ¼ Section 28; T. 57 N.; R. 62 W.	51
SW. ¼ NW. ¼ Section 36; T. 9 N.; R. 1 E.	51
Southern portion Section 31; T. 9 N.; R. 3 E.	51
Southern portion Section 7, 8; T. 8 N.; R. 4 E.	50
Section 15, 16; T. 8 N.; R. 4 E.	51
Corner Section 5, 6; T. 8 N.; R. 5 E.	48
Northeast portion of Rapid quadrangle	51
Whitewood Creek	
SW. ¼ NE. ¼ Section 27; T. 6 N.; R. 4 E.	50
NE. ¼ NW. ¼ Section 27; T. 6 N.; R. 4 E.	52
NW. ¼ NE. ¼ Section 25; T. 7 N.; R. 4 E.	53
SW. ¼ NE. ¼ Section 17; T. 7 N.; R. 5 E.	50
At mouth of Whitewood Creek	54
Polo Creek	
NW. ¼ Section 23; T. 6 N.; R. 3 E.	45
NW. ¼ NW. ¼ Section 14; T. 6 N.; R. 3 E.	50
Rapid Creek	
Mouth of Rapid Creek	51
Battle Creek	
NW. ¼ SE. ¼ Section 2; T. 3 S.	49
½ mile west of Hermosa	52
In western edge of Hermosa	52
SW. ¼ SW. ¼ Section 6; T. 3 S.	48
NW. ½ NE. ¼ Section 35; T. 5 S.	50
Bear Butte Creek	
2 miles west of Sturgis	50
½ mile west of Sturgis	52
Eastern edge of Sturgis	52
SW. ¼ Section 13; T. 6 N.; R. 7 E.	50
Mouth of Bear Butte Creek	49
Rapid Creek	
U. S. Indian School	50
Western edge of Rapid City	51
NW. ¼ NW. ¼ Section 10; T. 1 N.; R. 8 E.	52
Eastern portion Section 15; T. 1 N.; R. 8 E.	50
SW. ¼ Section 24; T. 1 N.; R. 8 E.	52
7 miles east of Rapid City	52

Sturgis Formation

These terraces like the Mountain Meadow and Rapid surfaces, which are developed on bed rock, are covered with gravel. Lithologically and texturally the formation is similar to the older Rapid and

Mountain Meadow gravels. Porphyry, quartz and quartzite are the predominant rocks but in some places the local formations have furnished a large percentage of the material. The Sturgis gravels are locally cemented just as the Mountain Meadow gravels are. On the Sundance road just east of the town of Beulah, Wyoming, a portion of the Sturgis formation is cemented by calcium carbonate into a resistant conglomerate.

On Plate XII separate mechanical and lithological analyses of samples of the Sturgis formation are given. The chart showing the averages, Plate X, summarizes these analyses. The Sturgis formation is made up of 30 per cent of cobble size. The finer material is all locally derived either from the red beds or the non-resistant Upper Cretaceous shales on the plains. Locally, the Minnelusa and Minnekahta formations furnish a high percentage of the material.

The Sturgis gravels reach a maximum thickness of forty-three feet in the terrace along Sandy Creek in the eastern edge of the town of Beulah. More commonly the formation is fifteen to twenty feet thick.

History of the Sturgis Valley Cycle

The records of the Sturgis cycle are similar in all respects to those of the Rapid cycle, suggesting that the history of the Rapid cycle was merely repeated during the Sturgis time. Whenever and however the Rapid terraces are finally explained, the explanation will doubtless fit the Sturgis cycle as well.

Present Day Flood Plains

The streams of the present have developed wide valley flats from the Red Valley out to the Great Plains. On these flood plains there is gravel now in process of deposition. On Plate XII numbers 45 and 46 are mechanical and lithological analyses of these gravels. The average analysis are given on Plate X.

SUMMARY OF THE CENOZOIC EVENTS

The folding and the intrusion of the Black Hills occurred at the close of the Cretaceous period. The movement resulted in a mountain range rising several thousand feet above the surrounding plains.

This post-Cretaceous folding was followed by a long period of erosion, during which time the surface was roughened, and finally by mid-Oligocene time was reduced to an imperfect plain. On this Mountain Meadow surface some, but not all, of the streams were at grade. The general surface of this time had a relief of about 1800 feet.

In about mid-Oligocene time there was a differential uplift, in which the plains were uplifted approximately 100 feet and the central Hills 2500 to 3000 feet.

This uplift started a new cycle of erosion, during which the existing valleys were cut. Later, probably, in some Pleistocene epoch, the streams outside the central Hills were graded, while on the non-resistant formations of the plains a peneplane was formed. Because of diastrophic uplift, climatic change, or the removal of glacial obstructions, erosion was renewed and the Rapid surface was dissected to the Sturgis level. The Sturgis cycle was interrupted, probably because of a repetition of whatever changes brought the Rapid cycle to a close, and the valleys were deepened below the level of the Sturgis flood plains.

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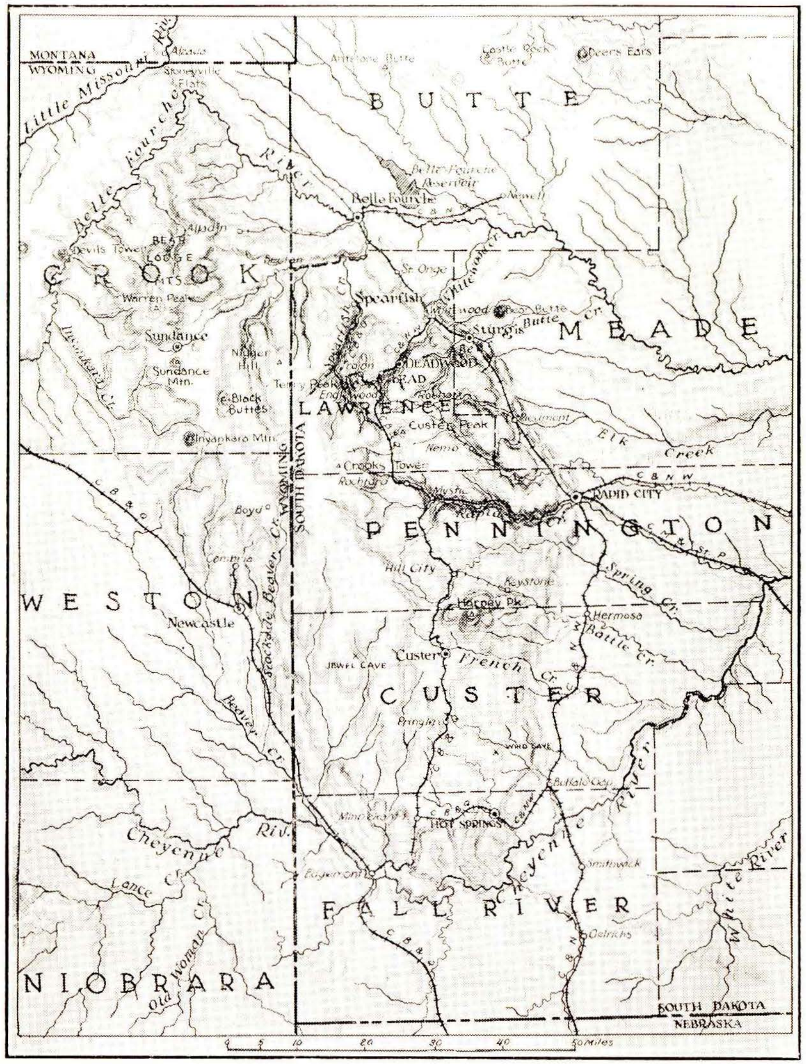
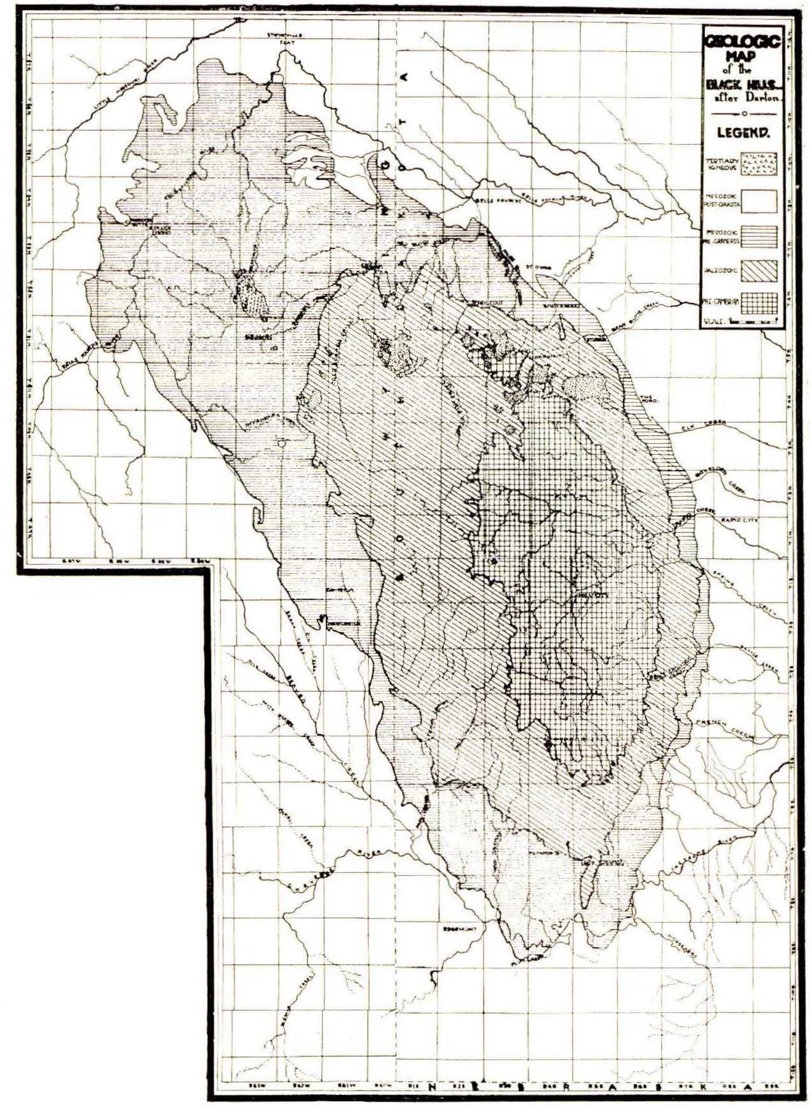
PLATES

PLATE I



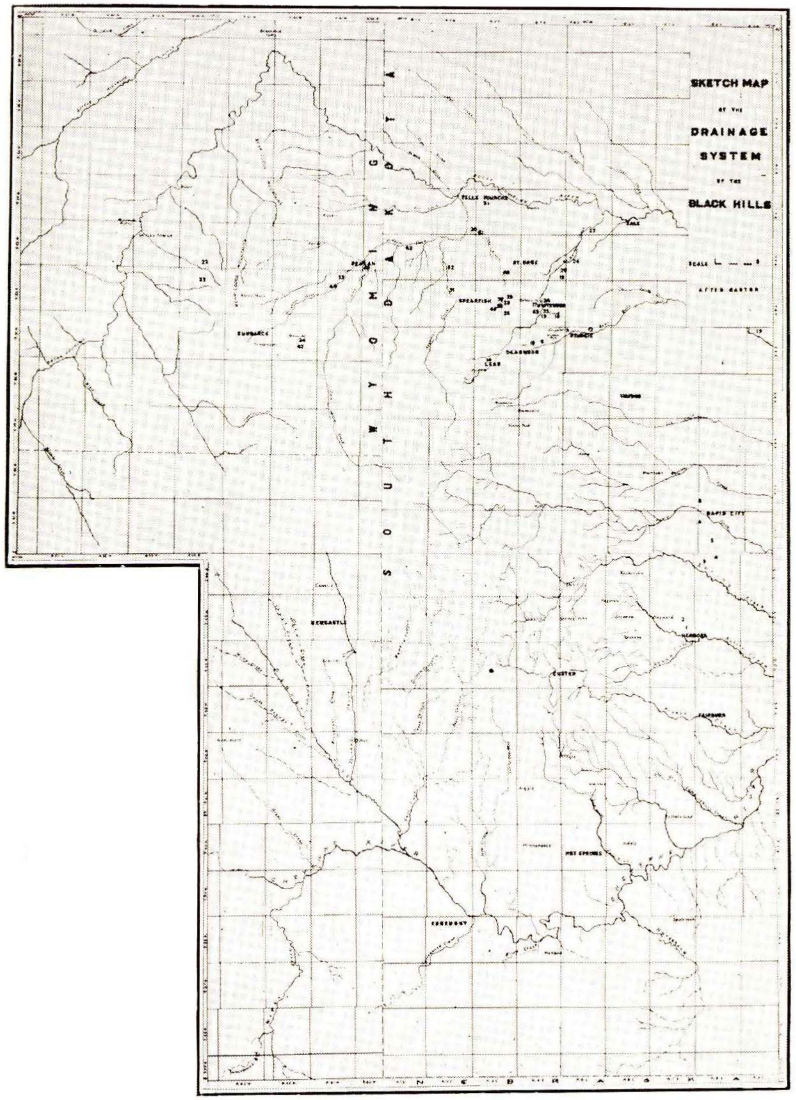
Physiographic Map

PLATE II



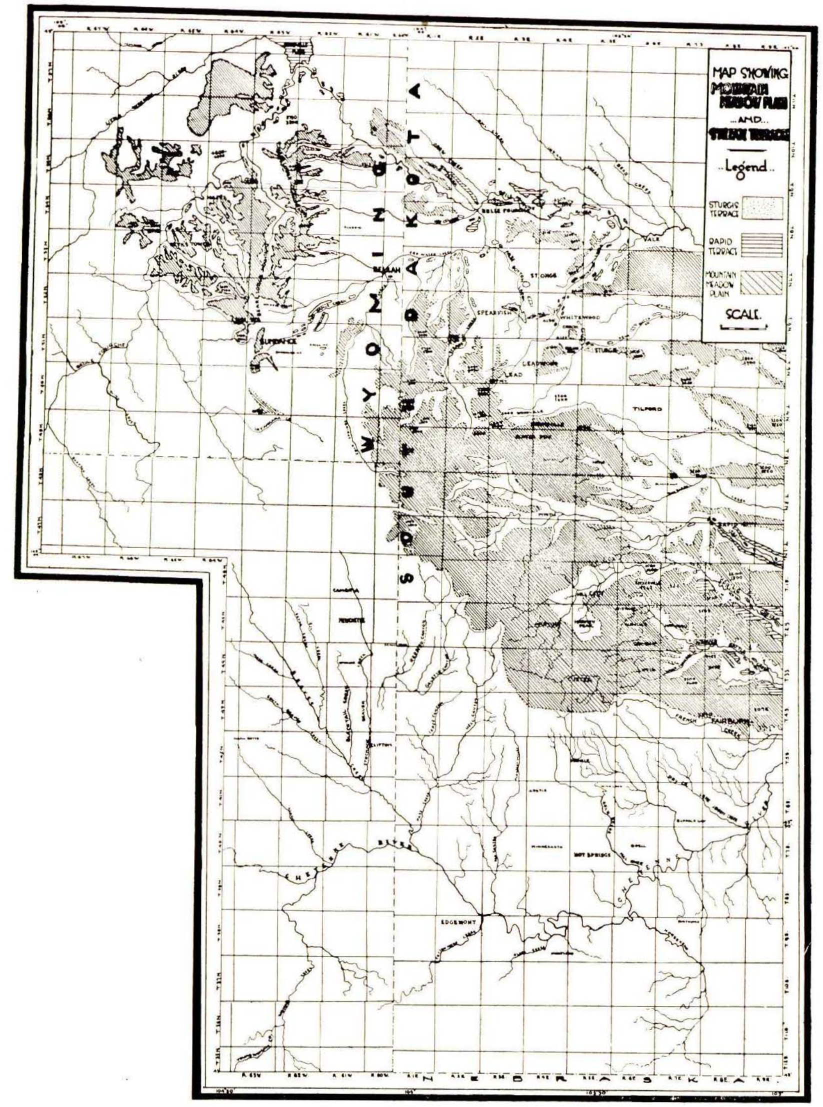
General Geology Map

PLATE III



Drainage System Map

PLATE IV



Mountain Meadow Plain and Stream Terraces

PLATE V

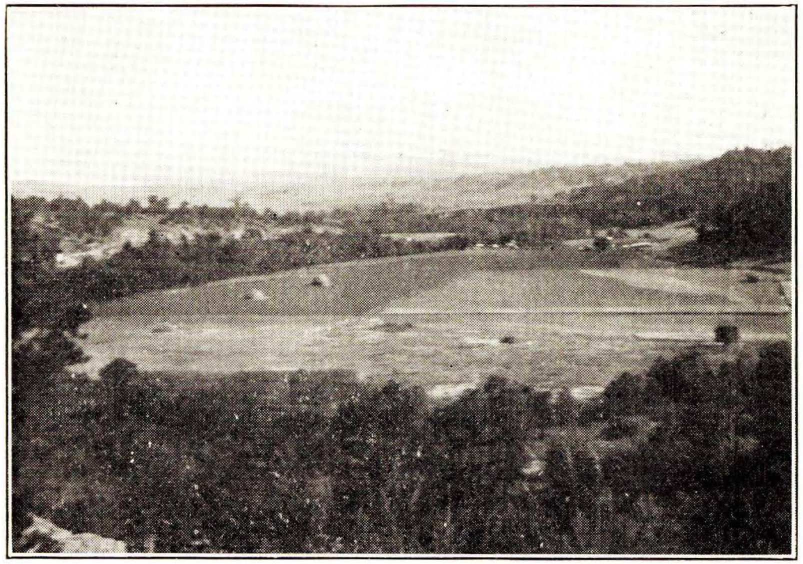


Figure 1. Whitewood Creek above Englewood

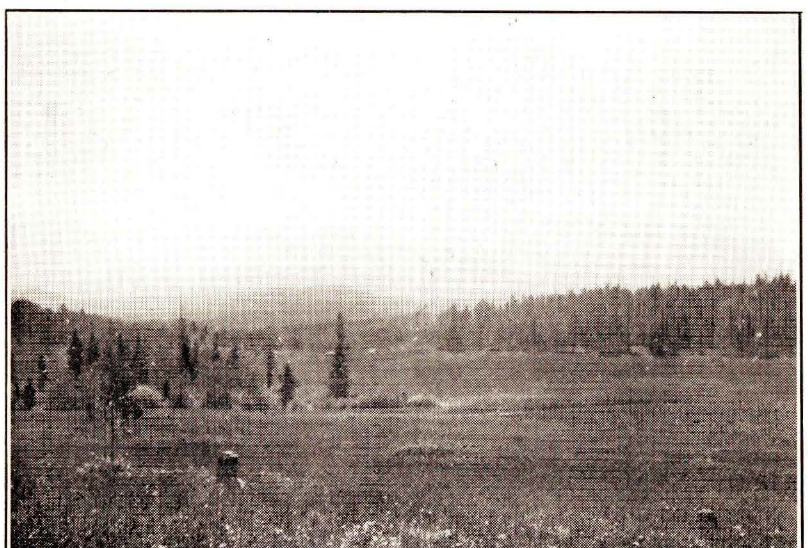


Figure 2. Elk Creek near Nemo

PLATE VI

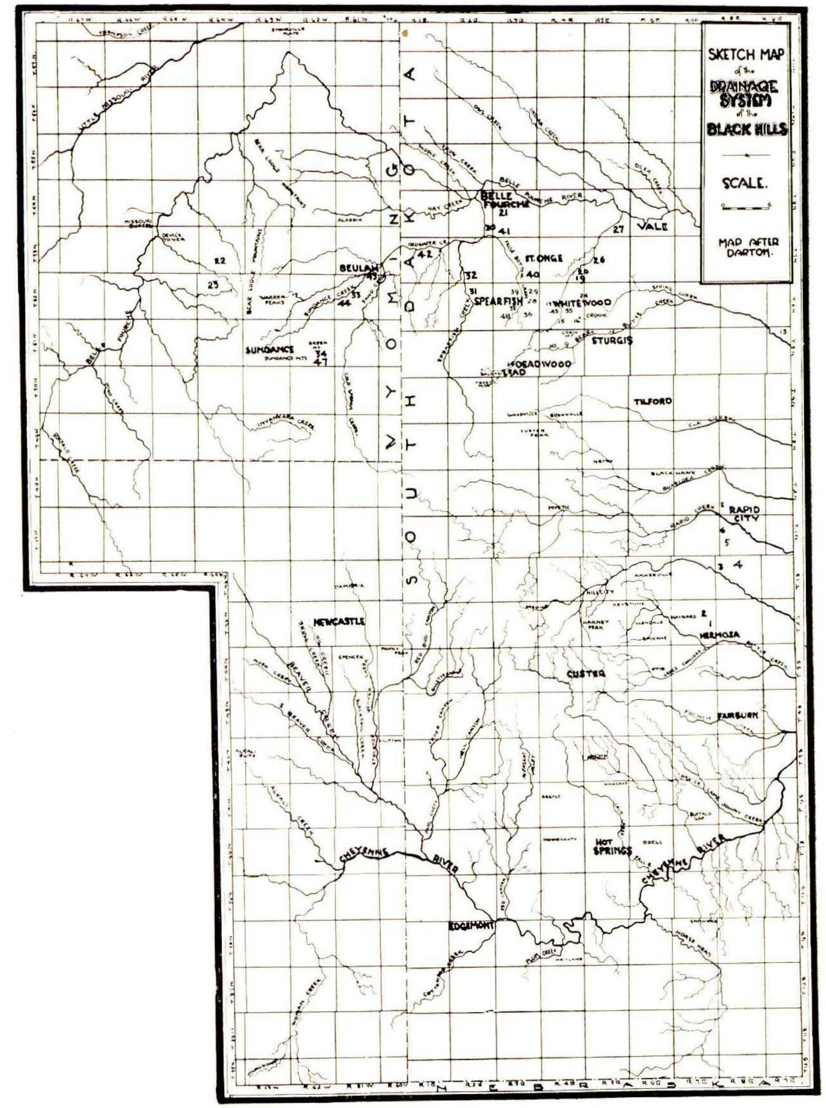
Figure A. Mountain Meadows 1½ miles east of Deadwood

Figure B. Rapid Creek divide 4½ miles south of Rapid City

PLATE VI (Continued)

Figure C. Spring Creek divide 3 miles north of Hermosa

PLATE VII

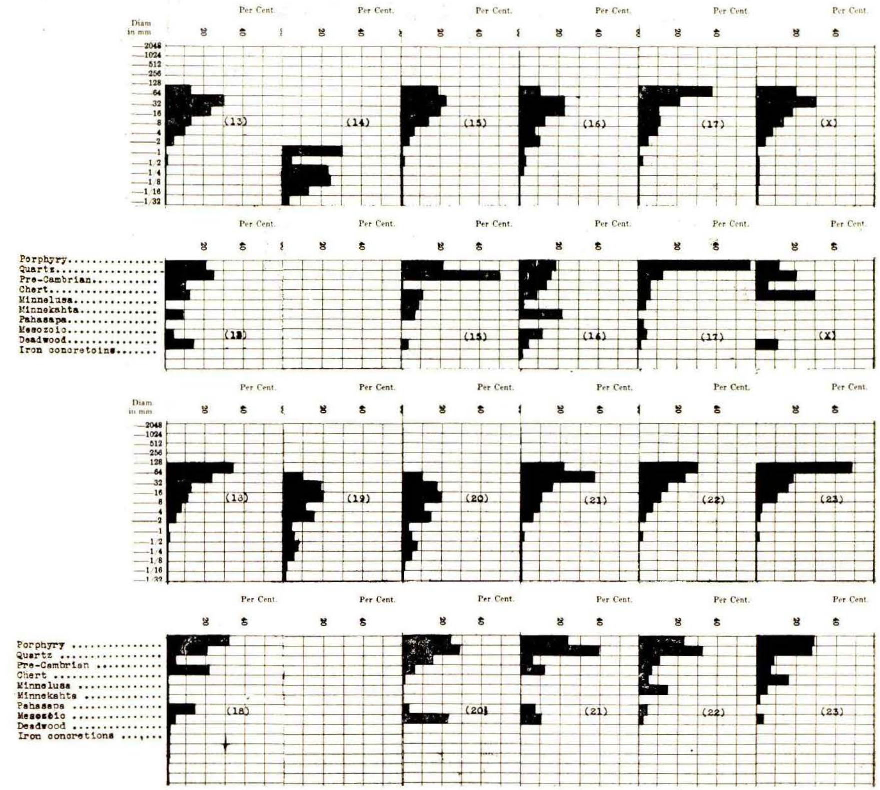


Sample Location Map

PLATE VIII

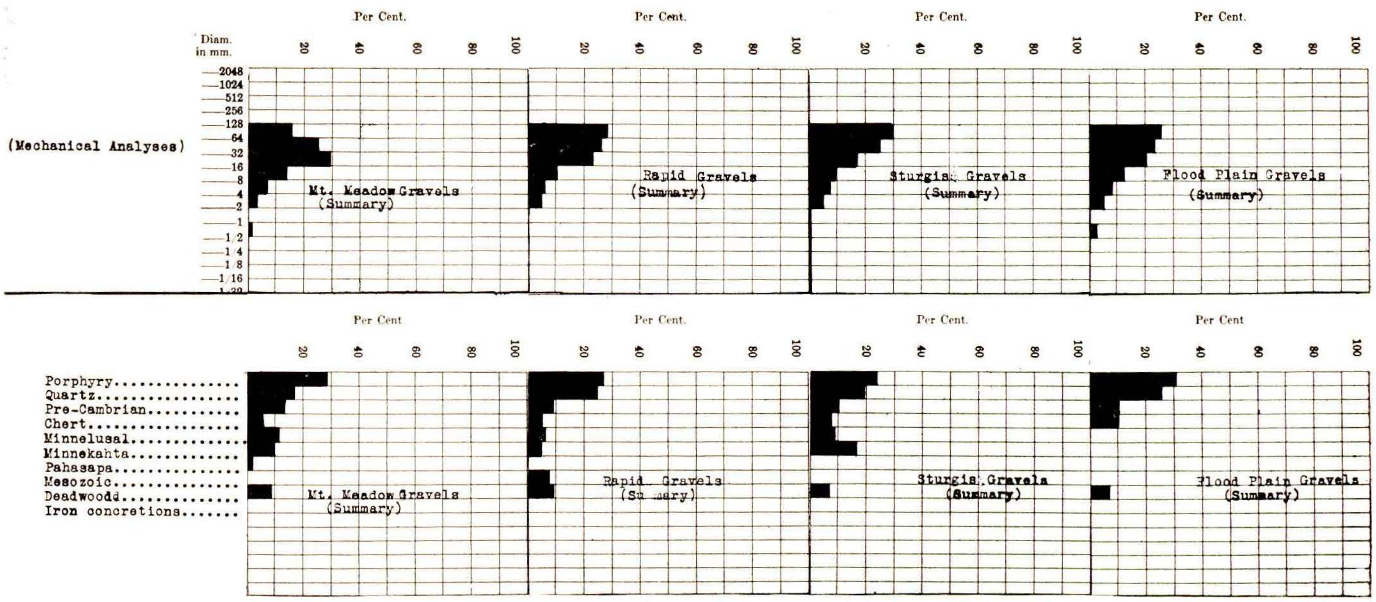
Mechanical and Lithological Analyses

PLATE IX



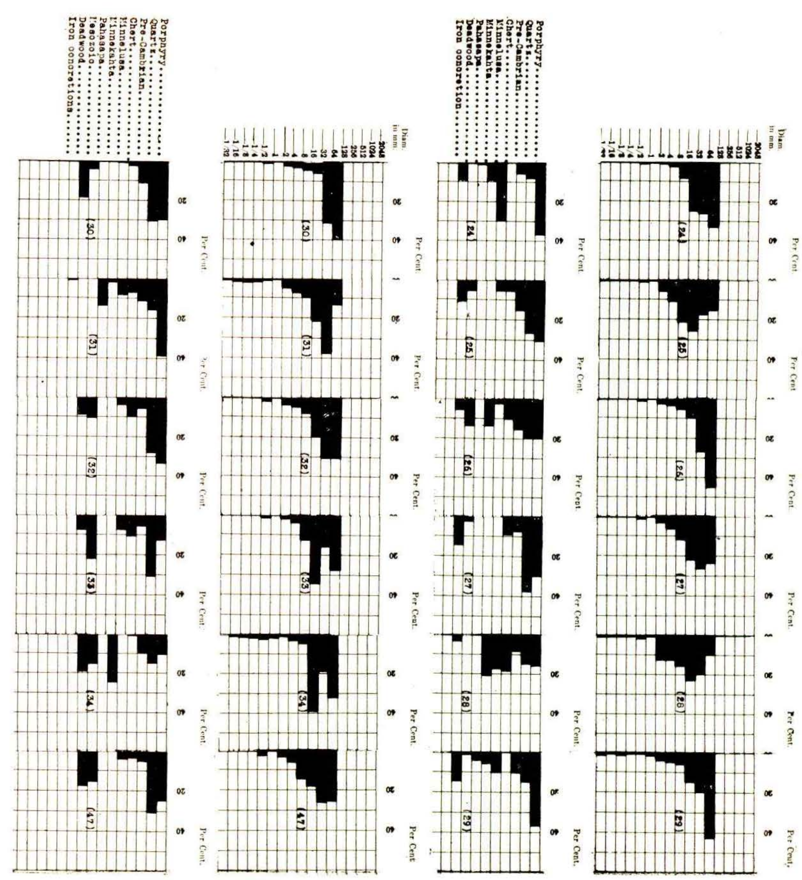
Mechanical and Lithological Analyses

PLATE X



Average Mechanical and Lithological Analyses of the Mountain Meadow, Rapids, Sturgis, and Present Day Gravels

PLATE XI



Mechanical and Lithological Analysis of the Rapids Series

PLATE XII

Mechanical and Lithological Analyses of the Sturgis and Present Day Gravels