State of South Dakota

M.Q. Sharpe, Governor

STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 53

GEOLOGY OF THE MISSOURI VALLEY IN SOUTH DAKOTA

by

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Vermillion, South Dakota
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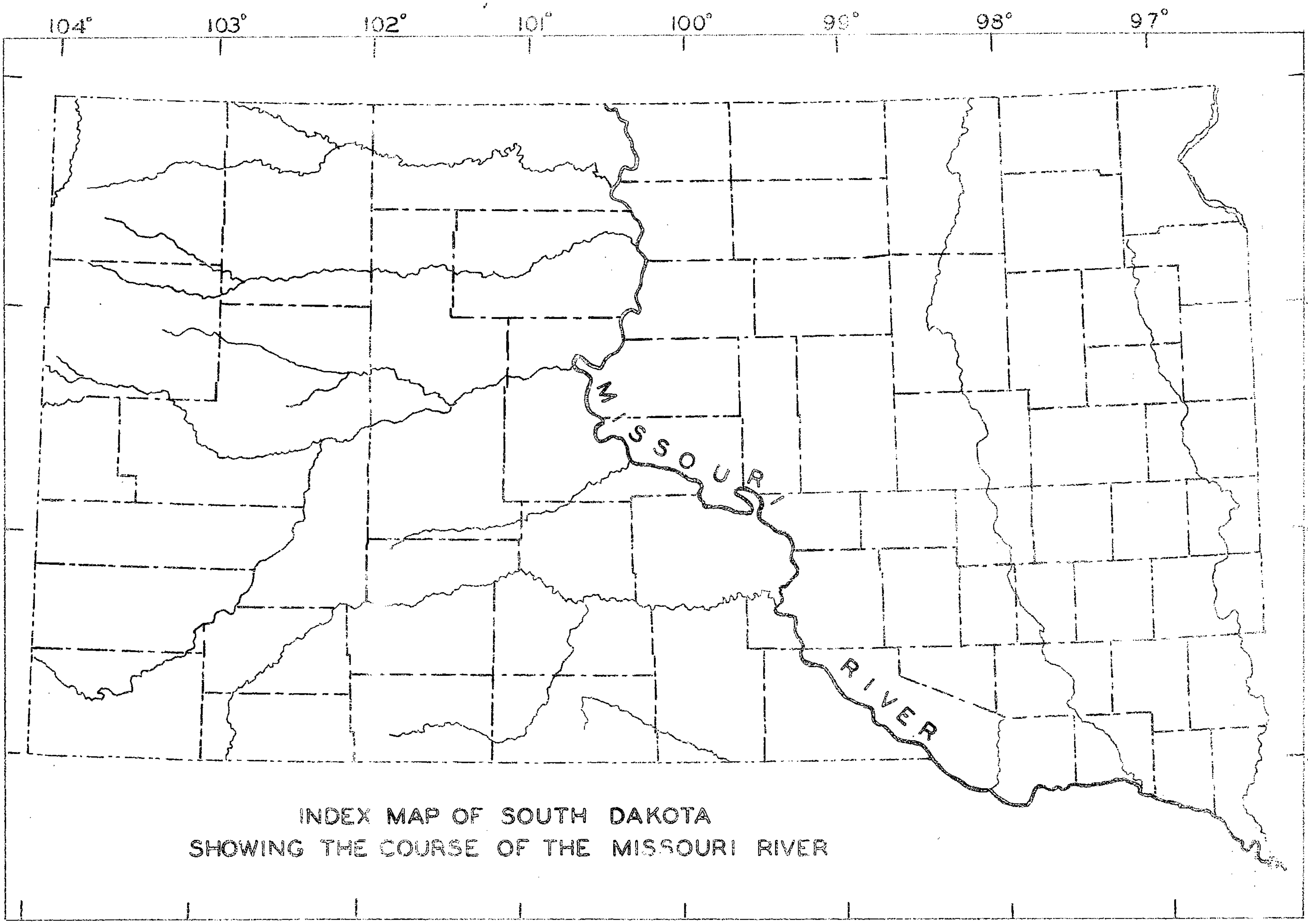

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GEOLOGY OF THE MISSOURI VALLEY
IN SOUTH DAKOTA

by

Bruno C. Petsch

I INTRODUCTION

Location and Area

The Missouri river in South Dakota is 547 miles long as measured along the channel from the mouth of Big Sioux river to the North Dakota state line; the distance was measured by the Missouri River Commission engineers in 1892 and the channel is from one-quarter to one mile wide.

The state of South Dakota is 378 miles long at the 44th degree parallel and 203 miles wide at the 100th degree meridian. The Missouri river enters the state from North Dakota about one-half way between Montana and Minnesota at longitude 100° 30' 30±" and latitude 45° 56' 31±". Its course meanders generally southward to Pierre, a latitude of 107 miles; thence it swings east and south; a departure of 200 miles to Sioux City, Iowa, leaving the state at longitude 96° 28' 30±" and latitude 42° 29'. Figure 1.

Every county in South Dakota is drained by the Missouri river with the exception of the eastern part of Deuel, most of Roberts and Grant, and the eastern half of Marshall, all of which are in the extreme northeastern part of the state.

Although the state of South Dakota contains approximately 80,000 square miles, tributaries leading to the South Dakota portion of the river drain more than 100,000 square miles.

Eight rivers enter the Missouri on its course through South Dakota. They are in order as follows from north to south: Grand, Moreau, Cheyenne, Bad, White, James, Vermillion, and Big Sioux. The Cheyenne is the longest; the James, the second longest; and the Bad River, the shortest.

Purpose of Investigation

The purpose of this investigation is to outline the position of the various geological formations that are in the valley and to fill in gaps that were not covered by other investigations, in order that an areal geologic map of the Missouri valley and adjacent areas could be made.

The State Geological Survey has carried on investigations on different parts of the Missouri river valley and adjacent areas, on problems that were related to the trend of times and on problems that are going to effect future development of the valley.

The Survey has mapped three portions of the valley to show the types of structure that are present and their relation to oil and gas accumulation.[1]

A detailed study of the enormous manganese deposits in the Big Bend-Chamberlain area was made. This investigation consisted of a huge sampling and mapping program which determined the content and extent of the manganese ore.[2]

For many years it was thought impracticable to carry on a mapping program in areas where the Pierre formation was the predominant surface outcrop. For this reason a lithologic study of

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1. Monta E. Wing, A Structural Survey of the Pierre Gas Field, S. Dak., R.I. 29, S. Dak. Geol. Survey, 1938; J.P. Gries, A Structural Survey of Part of the Upper Missouri Valley in S. Dak., R.I. 31, S. Dak. Geol. Survey, 1939; J.P. Gries, A Structural Survey of Northeastern Stanley County, S. Dak., R.I. 34, S. Dak. Geol. Survey, 1940.
2. J.P. Gries and E.P. Rothrock, Manganese Deposits of the Lower Missouri Valley in S. Dak., R.I. 38, S. Dak. Geol. Survey, 1941; E.P. Rothrock, Missouri Valley Manganese Deposits Between Lower Brule and DeGrey, R.I. 46, S. Dak. Geol. Survey, 1943.

the Pierre formation was carried on.[1] It was broken down into recognizable members; later this work was continued and enlarged.

Method of Investigation

This survey was made by a two-man party, consisting of H.R. Fossler as surveyor and the writer as geologist.

The primary aim of the survey was to determine the altitude above sea level of all key beds and contacts of horizons at all points in the valley where one could approach the river, either via automobile or hiking down into the breaks after leaving the vehicle at the edge of the upland or the rim of the valley.

At many places where one could get to the river there was no available bench mark from which an altitude could be taken. In such places the surface of the water in the river was used as a bench--the rise and fall of the water during the season having been corrected from stream gaging records to give a uniform slope to the water surface. Wherever a bench mark was found, an altitude was carried to the water. By this method the gradient of the river was profiled. In other words, the river water was used as an altitude base, substituting for an established bench mark. (See section on relief and elevations.)

The process of putting an altitude on the key beds involved the use of a stadia rod, plane table and alidade. A line of levels was run from the water across the flood plain to the outcrops in the bluffs; here the key beds and contacts were located and their altitudes taken. This profile of the bluffs was made at points along the river from the water to the rim of the valley.

From a composite of these a longitudinal profile of the Missouri valley from North Dakota state line to Sioux City, Iowa, was made which shows the structure of the sedimentary formations forming the bluffs of the valley. (See geologic profile in back of report.)

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1. W.V. Searight, *Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in S. Dak.*, R.I. 27, S. Dak. Geol. Survey, 1937; J.P. Gries, *Economic Possibilities of the Pierre Shale*, R.I. 43, S. Dak. Geol. Survey, 1942.

The various valley profiles were applied in drafting an areal geology map of the valley, so as to show the horizontal position and occurrence of the rock formations in which the valley has been cut.

The altitudes that were taken at the water and the highest elevations of the land surface are also to be used for making a topographic map of the valley from aerial photographs.

Acknowledgments

The writer gratefully acknowledges the opportunity given him by Dr. E.P. Rothrock, State Geologist, to carry on an investigation of this sort.

Appreciation is extended to H.R. Fossler for his careful and painstaking instrument work and mapping; he also assisted in many ways toward the completion of the field work.

Acknowledgment is also made of the help given by residents of the Missouri valley for the many courtesies they showed the party. Their readiness to permit the party to enter fields and pastures in order to get to the river is gratefully appreciated.

The writer has drawn freely from Reports of Investigations published by other members of the State Geological Survey and from data in the Survey files.

II GEOGRAPHY

Missouri Basin

Exceeding in size the combined areas of Germany, France, and Italy, the Missouri basin has 43% of the land in the Mississippi drainage area, but only a little more than 15% of the population. It drains parts of four major physical divisions of the United States: the Ozark Plateau, the Central Lowland, the Great Plains, and the Rocky Mountains. Figure 2.

> "The Missouri valley may be divided into two parts. The upper section runs from the North Dakota line to Yankton and is characterized by its steep rugged bluffs and narrow flood plain. This is known as the gorge of the Missouri. Along most of its length it averages about 400 feet in depth. Toward its southern end, however, the Missouri cuts through a highland where the valley reaches a depth of 700 feet. This is in the vicinity of the Bijou-Iona hills, the Bijou hills being that part of the highland on the east side of the valley and the Iona hills the part on the west. South of these hills the valley becomes less deep until at Yankton it is little more than 300 feet.
>
> "In most of the gorge the valley does not exceed a mile and a half in width. Near Mobridge it averages a mile in width; near Pierre and Chamberlain, a mile and a half. Myriads of small streams cutting back into the bluffs in a labyrinth of gullies form fringes on both sides of the valley locally known as 'breaks' which extend from one to five miles back of the valley proper.
>
> "The mouth of the gorge lies six miles above Yankton and is known as Gavin's Point. Below this point the valley widens rapidly until at Yankton it meets an ancient valley of the Niobrara river which swings into it from the North. From there to Sioux City, Iowa, the lower valley is characterized by very wide flood plains, four miles across at Vermillion and eight miles across at Elk

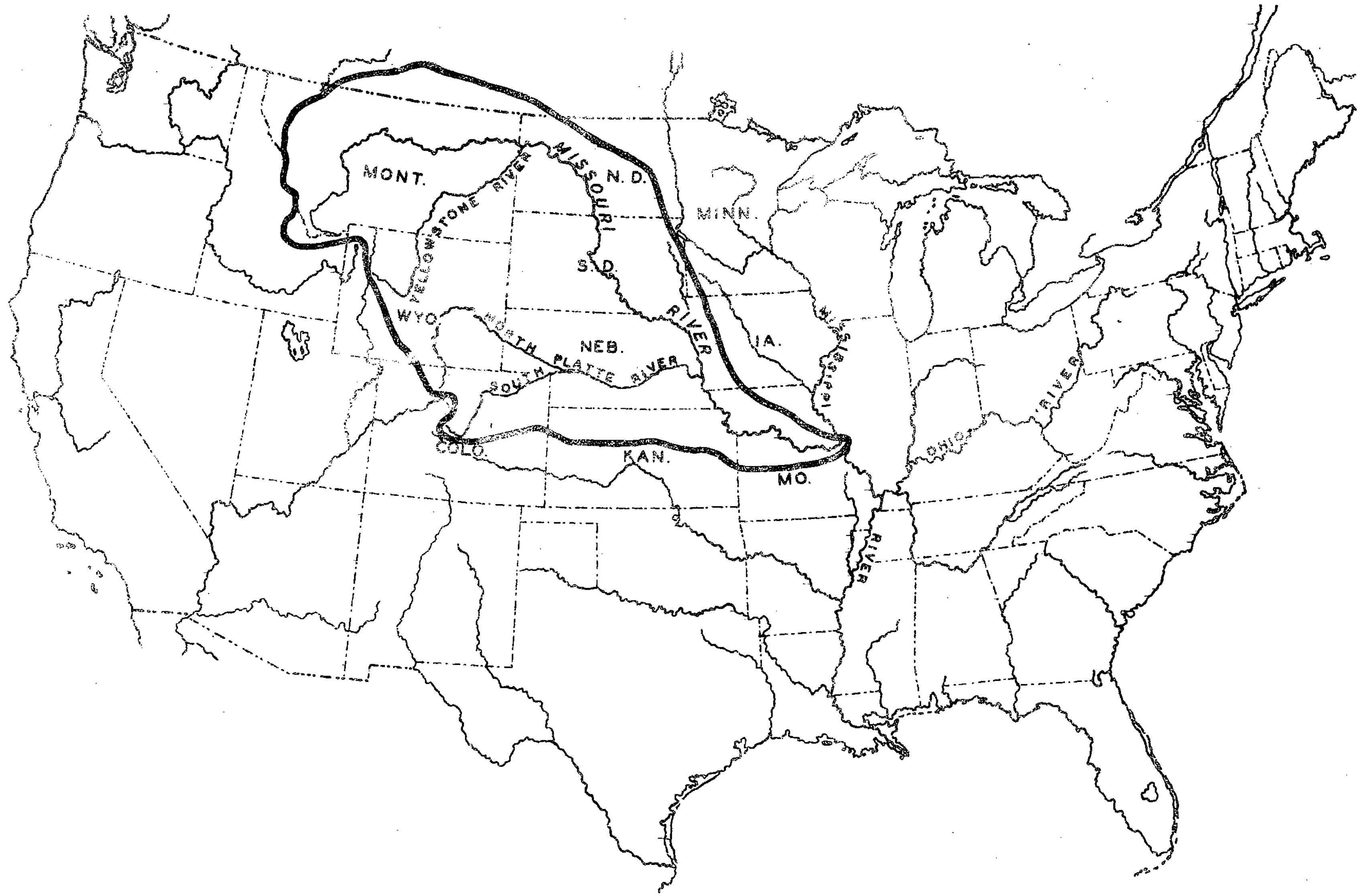

FIGURE 2 MAP SHOWING THE OUTLINE OF THE MISSOURI RIVER BASIN

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> Point. The bluffs are still steep, but breaks such as are known along the gorge of the Missouri are wanting. In this wide flat valley the river loops back and forth changing its course with every big flood. Farm land in this valley, though of excellent quality, is never entirely safe from the river. As much as 160 acres have been taken from a single farm by one spring flood."[1]

The course of the Missouri river seems to have been set by glacial ice which blocked the eastward flowing streams of the Great Plains. There was no Missouri river during pre-glacial times, according to various geologists.[2] From the directions these streams now take, it appears that the Grand, Moreau, and Cheyenne rivers flowed east and north into Hudson Bay. The Bad river joined the Cheyenne somewhere between Pierre and Aberdeen. The White and Niobrara rivers flowed eastward; thence entered a master stream east of Springfield or the present James river, which flowed southward into the Gulf of Mexico. Figure 3.

The gradient of the river water is less than one foot per mile drop with the current. From North Dakota to the Big Bend the drop is .81 of a foot per mile over the Pierre shale bed rock. From the Big Bend to Vermillion it is .94 of a foot over the Niobrara chalk bed rock. The following table shows the gradient of the river in feet per mile where it crosses the various formations of the valley from Montana down stream:[3]

Location	Formation	Feet Per Mile
Mont. & N. Dak.	Fort Union	.77
Mont. & N. Dak.	Lance	.73
N. Dak.	Fox Hills	.63
S. Dak.	Pierre	.81
S. Dak.	Niobrara	.94
	Average	.81

1. E.P. Rothrock, A Geology of South Dakota, Bulletin 13, S. Dak. Geol. Survey, 1943.
2. J.E. Todd, Geol. Soc. of Am., 1902 and 1923; A.G. Leonard, Geol. Soc. of Am., 1916; C.M. Bauer, Journal of Geol., 1915; N.H. Darton, U.S.G.S. Prof. Paper No. 32; E.P. Rothrock, op. cit.
3. R.M. Leggette, Dam Sites on the Missouri River in North Dakota and South Dakota, U.S. Geol. Survey, Corps of Engineers, U.S. Army, February, 1931.

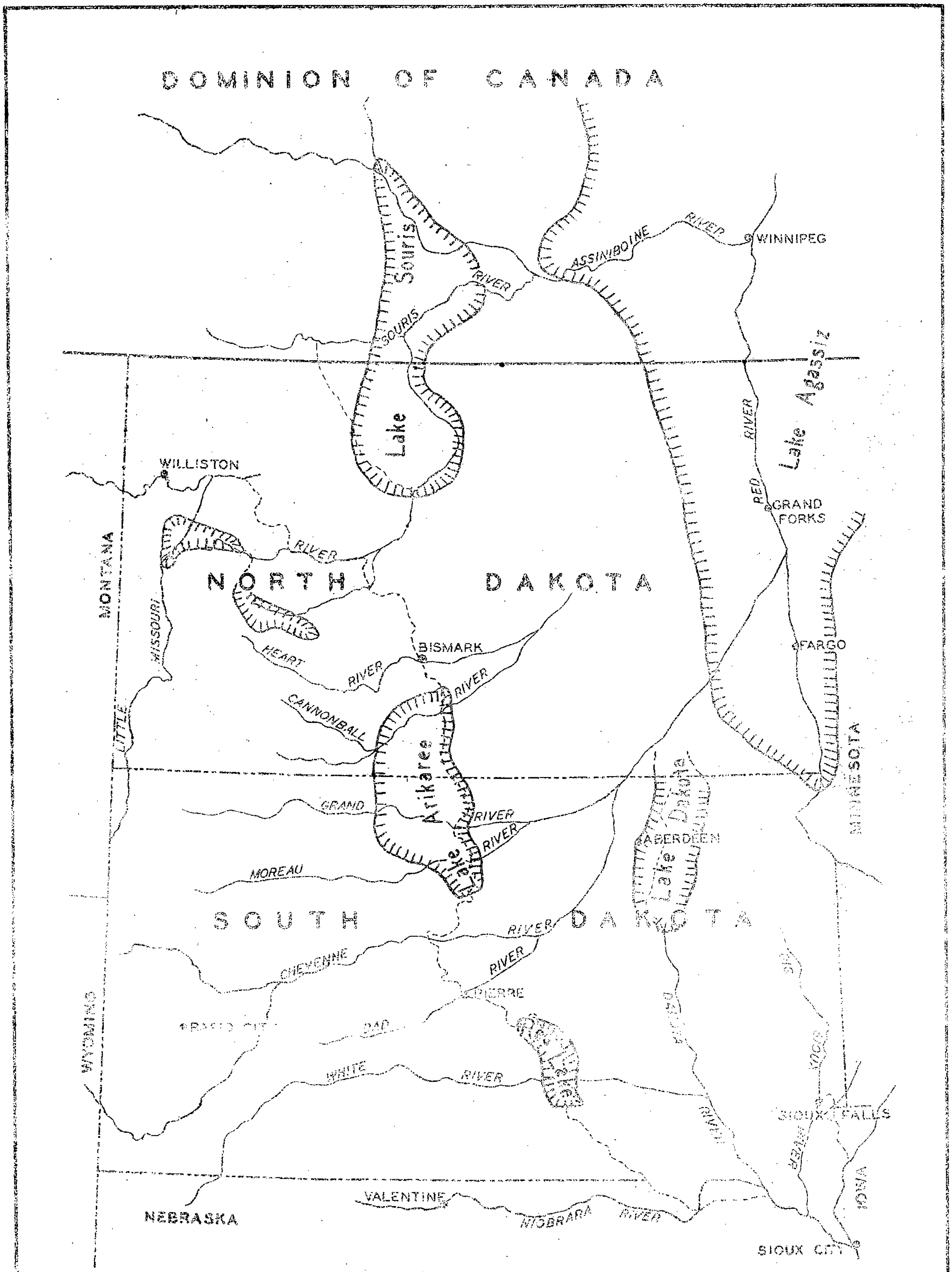

FIGURE 3 PROBABLE PRE-GLACIAL DRAINAGE AND GLACIAL LAKES, ACCORDING TO TODD, UPHAM, DARTON, AND OTHERS

------ PRESENT COURSE OF RIVERS

HCL

The stream flows about eight miles per hour and carries an enormous load of fine clay (bentonite) to silt and fine sand which gives the water a yellow-brown muddy appearance which has given it the well-deserved nickname "The Big Muddy." The word "missouri" is an Indian word meaning muddy water.

The meanders in the rivers are caused both by glaciation and structure of the sedimentary rocks. The eastward trend of the river from the Big Bend to Chamberlain is possibly due to the river flowing around the Medicine Butte anticline. From Chamberlain to Sioux City the river seems to flow around the south side of the Sioux quartzite ridge of Sioux Falls and Parker; thence from Sioux City it flows generally southward.

Relief and Elevations

The Corps of Engineers, U. S. Army, and a federal organization known as the Missouri River Commission conducted a survey of the Missouri river in 1889 from St. Louis to Fort Benton. This survey consisted of both geodetic and plane surveying and included mapping of the shoreline, flood plains, islands, sand bars and topography, leveling and triangulation. The results were published from 1891 to 1895 as a series of charts. These included maps covering the valley from Sioux City, Iowa, to the North Dakota state line.

The topography was originally shown by contours which were later redrafted into hachure maps. Two hundred thirty-two bench marks were permanently established in South Dakota and are used today. County lines and many section corners were located. All creeks and dry washes were shown. Towns, forts, ranches, Indian villages, roads and the water stage were plotted.

The bench marks established on this survey were located with a great deal of forethought and understanding and most of them are as well preserved and as usable today as they were in the 90's. Each bench mark consists of a 4" or 6" iron pipe and a cast iron cover bolted to the pipe. The pipe sets on a rock which is from 2 to 3 feet in the ground and over a cross mark on the rock. At the time the bench mark was "planted" a note was put in the pipe showing the altitude and describing the point. In South Dakota the bench marks are in series starting at McCook in Union county as No. 2/360 and ending as No. 2/208 at the North Dakota line. In the series they are listed as the number 2 or 3 on the left, or east, bank and the number of 1 on the right bank or west side of the river. The bench mark labeled 2 is near the river, and the bench mark labeled 3 is back or away from the river, sometimes as much as ½ mile.

In rugged country along the river there is only one bench mark of the 2 series and where there is flat land or room bordering the river there are two bench marks. In all, the Corps established 232 bench marks spaced 2 to 3 miles apart.

The locations of the bench marks were described with respect to buildings, roads and land forms as they existed then. Today, however, many of the buildings and roads have ceased to exist, making it difficult to find some of the bench marks. Of the 232 that were established, some, of course, have disappeared by vandalism, others by the river's claiming the land that they were on. To find these bench marks it is best to consult some person who is at least 55 years old and who has spent most of his life in the river valley.

Aside from the Corps of Engineers' bench marks, the U.S. Coast and Geodetic Survey has established many bench marks. These are found along all the modern highways that cross the river.

The U.S. Geological Survey has issued several topographic quadrangles covering portions of the valley. These have been designated as follows: the Oahe, Pierre, Canning, Chamberlain, and Elk Point quadrangles. Additional bench marks were established in and about the valley in making these maps.

Roads

There are seven paved highways which cross the Missouri river over bridges, as follows:

U.S. Highway No. 12 through Mobridge (1)
" " " " 212 " Gettysburg (1)(2)
" " " " 14 " Pierre (1)

Figure 4A

U.S. Highway No. 16 through Chamberlain (1)
" " " " 18 " Lake Andes (1)(3)

Figure 4B

U. S. Highway No. 81 through Yankton (4)
" " " " 77 " Sioux City (4)

Figure 4C

(1) Bridges are owned by the State of South Dakota and are toll free.
(2) Whitlock's Crossing or Forest City bridge
(3) Wheeler-Rosebud bridge
(4) Toll bridges

State Highway No. 37 leads to Running Water where the river can be crossed on a toll ferry to points in Nebraska. A toll ferry used to be in operation near the North Dakota-South Dakota border, known as the Kenel-Pollock ferry. This crossing was abandoned during the war because it was not a highway crossing and is located in a very thinly populated part of South Dakota.

There is no continuous road following the entire length of the river on either side; however, many follow the river for short distances. There are many roads and trails that lead to the water's edge. A few are graded primarily for hunting, fishing, and logging. Many lead to ranch and farm homes that are situated in the valley. Good and poor trails on the upland lead to the valley's edge via pastures and fields, but from there to the river is anywhere from 3 miles to less than one-fourth of a mile. All roads that are not surfaced are on gumbo soil and are quite impassable in rainy weather.

Since the State Geological Survey has carried on photogrammetry using aerial photographs of the Missouri river valley, it was found that there are many more trails to the river than had been supposed. Roads and trails of the Missouri valley are shown on the following maps: Figures 4A, 4B, 4C.

The country on the east side of the valley is well sectionized throughout the course of the river; however, section lines can seldom be seen in the breaks. In the early days most roads were graded; in recent years many were graveled through the farm-to-market road program. Many section line roads are graded but not surfaced. Usually where no fence blocks the road, it can be traveled in dry weather, if there is no creek to cross.

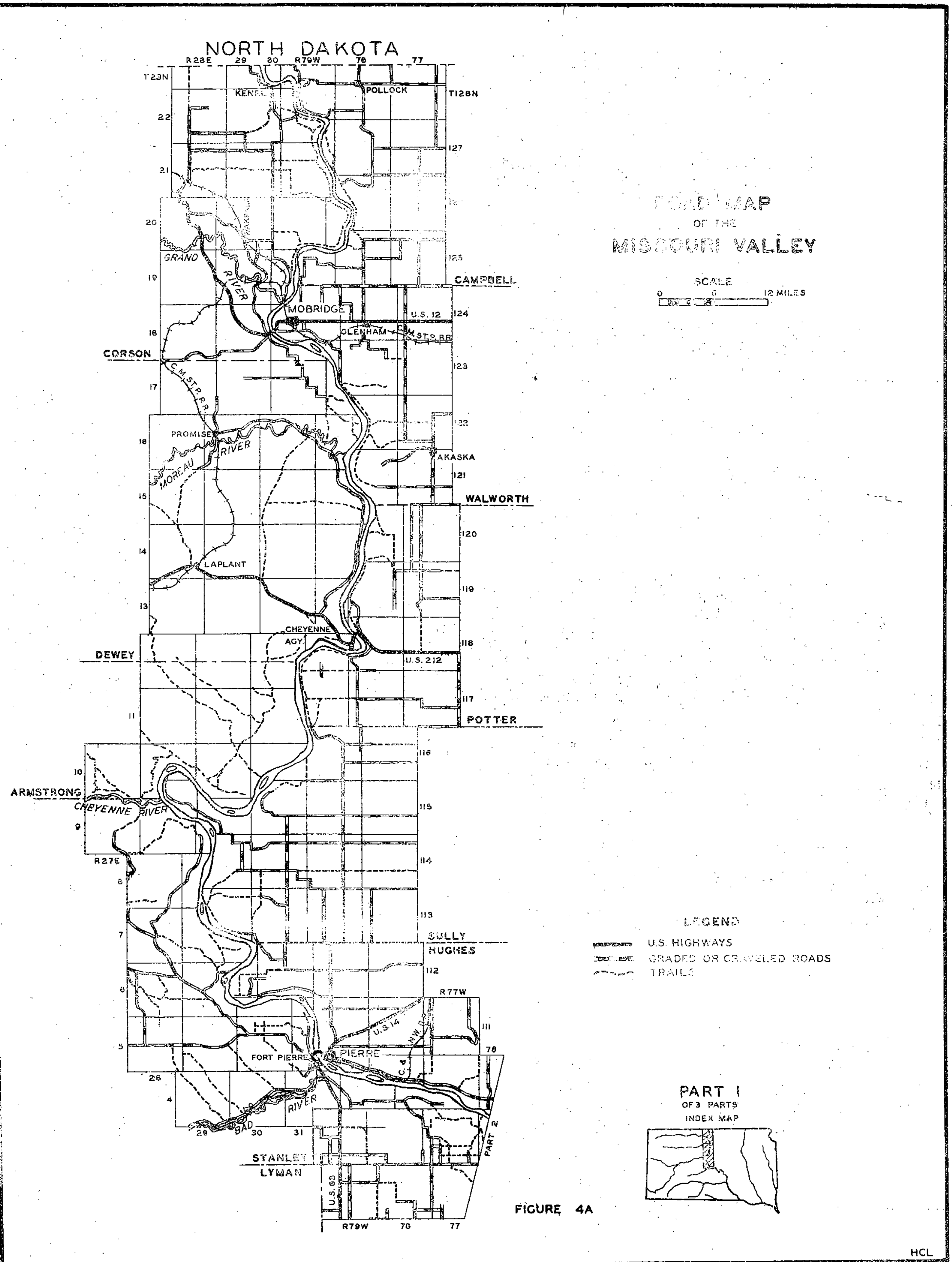
ROAD MAP
OF THE
MISSOURI VALLEY
SCALE
0
12 MILES
NORTH DAKOTA
R28E
29
80
R79W
78
77
T23N
22
21
20
19
18
17
16
15
14
13
11
10
9
8
7
6
5
4
T128N
127
125
124
123
122
121
120
119
118
117
116
115
114
113
112
111
POLLOCK
CAMPBELL
GRAND
RIVER
MOBRIDGE
U.S. 12
GLENHAM
C.M.ST.P.RR.
CORSON
PROMISE
MOREAU
RIVER
AKASKA
WALWORTH
LAPLANT
CHEYENNE
AGY.
DEWEY
U.S. 212
POTTER
ARMSTRONG
CHEYENNE
RIVER
R27E
SULLY
HUGHES
R77W
U.S. 14
FORT PIERRE
PIERRE
C. & N.W.
76
BAD
RIVER
28
30
31
PART 2
STANLEY
LYMAN
U.S. 83
R79W
78
77
LEGEND
U.S. HIGHWAYS
GRADED OR GRAVELED ROADS
TRAILS
PART I
OF 3 PARTS
INDEX MAP
HCL

FIGURE 4A

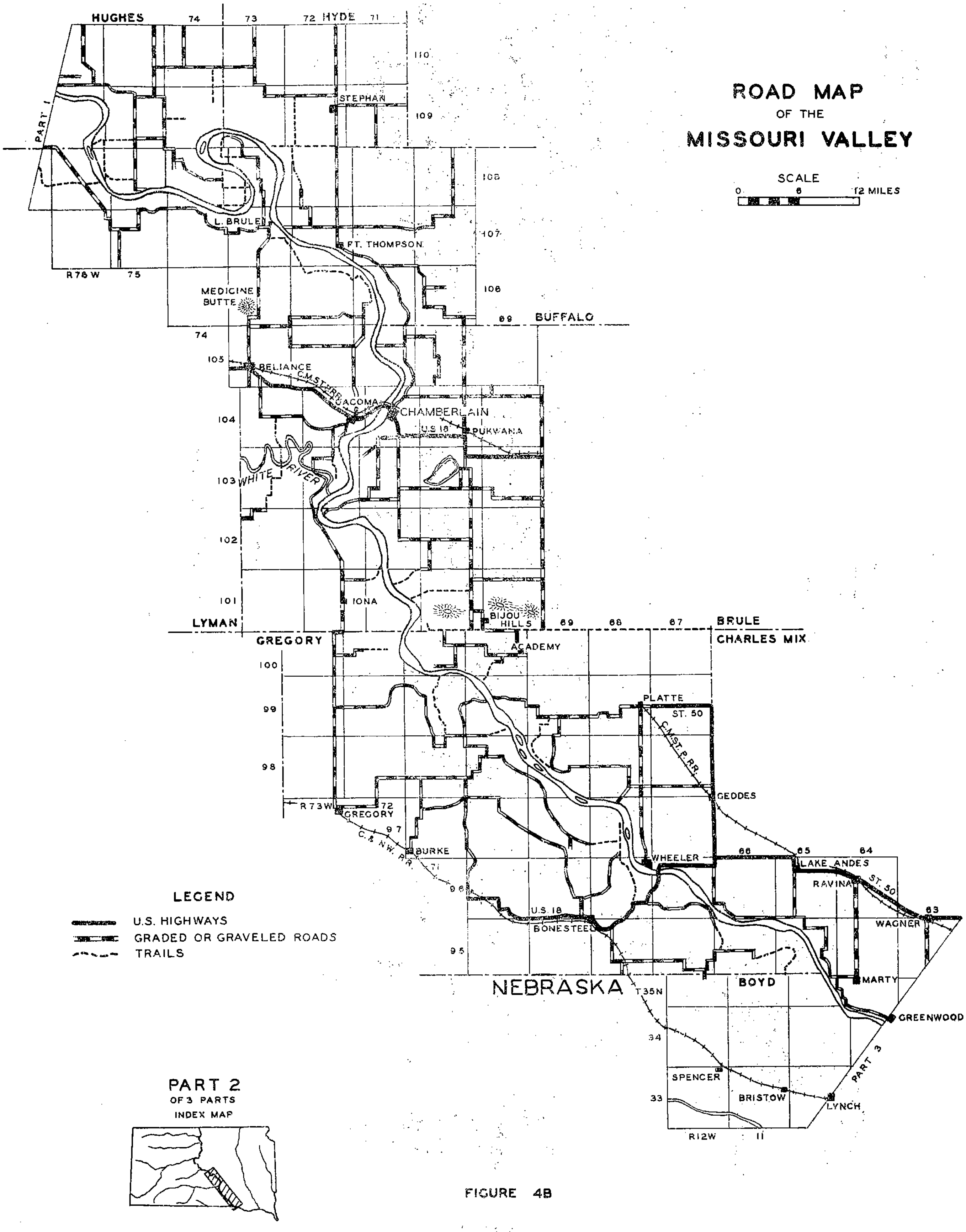

FIGURE 4B

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ROAD MAP
OF THE
MISSOURI VALLEY

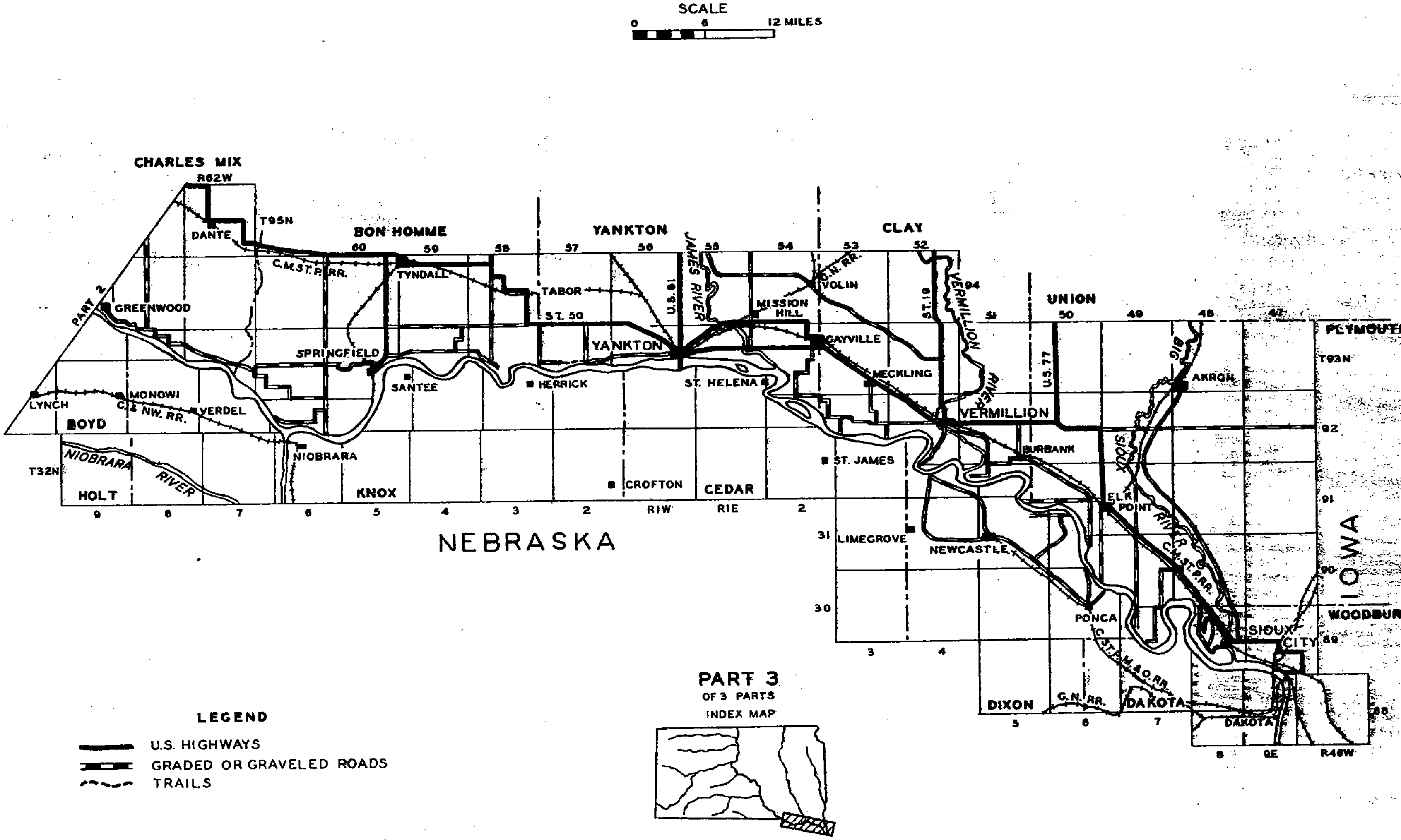

FIGURE 4C

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West of the Missouri valley few roads follow section lines; hence they are cross-country thoroughfares. Graveled or graded roads are scarce, but usually well maintained. At one time during the homestead era many trails were developed. Some of these still remain; many are dim but can be used.

The following maps show three types of roads that are in existence today: first are the hard surfaced all-weather roads which are the U.S. Highway trunk lines; second are the graveled and graded roads which are usually county and state roads; and third are the trails and dim trails which are mainly short cuts to ranches and farms in and about the valley.

III STRATIGRAPHY

The rock formations which are exposed in the Missouri valley belong to three geologic systems: namely, the Quaternary, Tertiary and Cretaceous. Figure 5.

The Quaternary sediments, the youngest in the valley, are of glacial origin, gumbo clay, loess, sand and gravel. They are mostly unconsolidated materials and are primarily located east and north of the river.

The Tertiary sediments, the next older, are ancient stream deposits of stratified clays, sands and quartzite. They are to be found on the highest elevations bordering the valley uplands.

The Cretaceous sediments, the oldest exposed, are all of marine origin, and were deposited in the last great ocean to cross South Dakota. They include shales, chalk rock, with a little sand and limestone, and are divided into two groups. The lower members of the system are in the Colorado group, named for exposures at the east base of the Front Range in Colorado, which is composed in ascending order of the Graneros, Greenhorn, Carlile, and Niobrara formations. The Graneros, Greenhorn, and Carlile are sometimes grouped as the Benton.

The upper members of the Cretaceous system are in the Montana group and include the Pierre and the Fox Hills formations. It was named for extensive development in Montana, especially in the upper Missouri river region.

The Dakota is the oldest formation in the valley. It lies below the Graneros and is exposed only in the lower end of the valley near Sioux City. Its outcrops are limited and it is not exposed on the South Dakota side of the valley. However, it is found on both the Iowa and Nebraska sides.

The geologic maps of the Missouri valley accompanying this report show the position of the formations as they occur in the valley. The outcrop width of the formations is exaggerated on the maps so that they could be clearly shown on a horizontal grid of that size.

TABLE OF FORMATIONS EXPOSED

IN THE MISSOURI VALLEY, SOUTH DAKOTA

Quaternary		Pleistocene formations			Alluvium	
					Loess	
					Glacial Drift	
Tertiary		Arikaree formation				
		White River formation				
Cretaceous	Montana Group	Fox Hills formation	Timber Lake member			
			Trail City member			
		Pierre formation	Elk Butte member			
			Mobridge member		Chalk	
			Virgin Creek member	Upper zone		
				Lower zone		
			Sully member	Verendrye zone		
				Oacoma zone	Upper Mica. Bent.	
					Big Bent. Bed	
					Lower Mica. Bent.	
				Agency zone		
				Crow Creek zone	Chalk	
					Sandstone	
			Gregory member			
			Sharon Springs member		Oil Shale	
	Colo. Gp.	Niobrara formation	Smokey Hill member			
			Fort Hayes member			
		Benton	Carlile formation			
			Greenhorn formation			
			Graneros formation			
	Dakota formation					

Figure 5

During the recent years increased rainfall occurred in South Dakota and as a result the Missouri valley is very much more grassed over than it was in former years. For this reason contacts in many places cannot be found, especially in the upper Pierre section. However, good shale exposures can be found at various places along the valley.

The stratigraphy of the Missouri valley was first studied by F.V. Hayden and F.B. Meek who were employed by Professor James Hall, 1853 to 1857. Their party, equipped with boats and men, left St. Louis on the twenty-first of May and arrived at Fort Pierre the nineteenth of June. In spite of the difficulty of holding the party together, through fear of hostile Indians, they remained in the field for a period of several weeks, returning to Fort Pierre on July 18. They brought with them a large and valuable collection, including mammalian remains which were investigated by Joseph Leidy.

The Cretaceous invertebrate fossils were studied by Hall and Meek and described by them in a memoir published by the American Society of Arts and Sciences of Boston in 1854. This paper was accompanied by a brief vertical section by Meek showing the order of superposition of the Cretaceous. As this is believed to be the first section measured in this region, it is here reproduced in full.[1]

"Section of the Members of the Cretaceous Formation as observed on the Missouri River, and thence westward to the Mauvaises Terres.

	Feet
"Eocene Tertiary Formation:	
"Clays, Sandstones, etc. containing remains of Mammalia. The entire thickness of this formation in the Bad Lands is from	25-250
"Cretaceous Formation:	
5. Arenaceous clay passing into argillo-calcareous sandstone.	80
4. Plastic clay with calcareous concretions containing numerous fossils.	250-350

1. G.P. Merril, The First One Hundred Years of American Geology, Yale University Press, New Haven, 1924.

		Feet
3.	Calcareous marl, containing Ostrea congesta, scales of fishes, etc.	100-150
2.	Clay containing a few fossils.	80
1.	Sandstone and clay.	90

Meek and Hayden"

The present day nomenclature of this early section is: 5. Fox Hills, 4. Pierre, 3. Niobrara, 2. Benton group, 1. Dakota.

Quaternary System

PLEISTOCENE

Alluvium

Alluvial deposits composed of clay, silt, sand and some gravel make up the floor of the Missouri valley on which the river flows and include flood plain deposits, making the so-called "bottoms" covered only in flood times, bars, islands, and other features in the river channel itself. As has been pointed out, the age of the river dates back to the Pleistocene epoch; consequently, a thick deposit of alluvium has been laid down in the valley since that time, which varies from about 70 to 185 feet.[1] The age of the alluvium is both Pleistocene and recent. The lower part was deposited by melt waters from the ice and the upper part, from action of the present streams. This deposit has been called valley fill or flood plain. Level areas of the same material but higher in elevation are bench lands or terraces. The alluvium was deposited by the Missouri river and its tributary streams. The river from time to time reclaims part of its flood plain during periods when the channel changes. Almost every intermittent tributary stream enters the river by way of a deep perpendicular walled gorge or canyon in the alluvium.

The alluvial deposits are generally on the inside of meanders, either on one or both sides of the channel. They are a few

1. G.E. Condra, Missouri River Valley in Northeastern Nebraska, Water Supply Paper, No. 215, U.S.G.S. Pub., 1908.

rods to ten miles wide and range from a few to several thousand acres in area. There are over 200,000 acres of irrigable land in the valley on alluvial soil.

The surface of the alluvial deposits is generally flat, although sometimes the topography is dune-like, such as inside of the Big Bend and southeast of Vermillion, and escarpments, terraces or swamps are common. The islands and sand bars in the river are alluvial deposits. On the whole, the alluvium in the valley supports abundant vegetation and crops.

In aerial photographs of the valley the alluvium is the more obvious of the sediments because the dense vegetation of willows and cottonwood trees which grows on it is black on the photographs. Additions to the flood plains and islands are shown by rows of trees; cutoffs show the tree rows ending abruptly. The recent islands and bars are white or pale gray. No matter how small, they are clear against the water background.

Loess

The loess is a wind-blown deposit of fine clay. It is buff colored wherever it is exposed in the valley. The material is soft and unconsolidated but well packed and settled. Where erosion is acting on it, the outcrops are always quite vertical and the face of the outcrop generally shows a columnar structure. The loess can be nearly 100 feet thick, especially on the Nebraska side of the river. It is only from less than 2 to 10 feet thick on the South Dakota side and can be found from Yankton eastward lying on glacial drift. Its extent up the valley is not known.

Drift

Glacial drift borders the Missouri valley throughout its course in South Dakota. (See geologic maps in back of report.) It can always be found on the left, or east, side of the valley. The Missouri river is not always the western boundary or the limit of the advance of the glaciers which formed the drift; however, glacial boulders can be seen in many places across the valley--for instance, in Lyman, Stanley and Dewey counties. But the valley is the boundary of the drift which can be recognized as such.

The drift is composed of irregular masses of boulder clay and of sand and gravel deposits. It is brown to light buff in color and so can be identified while driving past outcrops. It is usually present at the upper rim of the valley where the flat upland terminated at the valley breaks. The drift is sometimes over 200 feet thick; its thickness is never consistent in any two places. In some localities--at Pierre, for instance--the drift is full of all sizes of boulders and in other places few are present.

The drift covers the Cretaceous shales on the east side of the river and is usually the upland formation. There are places where it has been removed and Cretaceous outcrops are exposed, sometimes many miles from the valley, as at Stephan in southern Hyde county, or south of Lake Andes in Charles Mix county. There are localities where the drift is at the river level such as at the mouth of Platte Creek in Charles Mix county and in southern Bon Homme county.

Tertiary System

There is no doubt that at one time the Tertiary formations covered much of South Dakota, at least as far north as the Big Bend of the Missouri river, because there are remnants of Tertiary on top of Medicine Butte in northern Lyman county.

The Tertiary is also on the top of the Iona-Bijou hills line of high buttes that lies across the valley in southern Brule-Lyman county. In Gregory county the higher elevations that are not composed of Cretaceous formations are overspread with the Tertiary. This condition is also present eastward to at least Santee in Nebraska.

The Tertiary formations are composed of sands and sandy clays, local beds of quartzite and conglomerate, sometimes local beds of volcanic ash.

The Tertiary system is divided as follows:

System	Series	Formation
Tertiary	Miocene	Arikaree[1]
	Oligocene	Brule
		Chadron

1. J.E. Condra, Missouri River Valley in Northeastern Nebraska.

Cretaceous System

FOX HILLS FORMATION

The Fox Hills formation can be observed in two localities along the valley: first in the area of the Wheeler-Rosebud bridge where it forms the upland adjacent to the valley in Gregory county; second, it is present in Dewey and Corson counties west of Mobridge where it also forms the upland. The formation was named for exposures in Fox Ridge, N.W. Armstrong and S.W. Dewey counties, South Dakota.

The Fox Hills is divided into two distinct lithological units: the lower part is the Trail City member and lies on the Pierre shale and the upper part is the Timber Lake member.[1]

TRAIL CITY MEMBER: The Trail City member is a sandy brown to buff clay and brownish sandy shale making a color contrast from the gray to black Pierre shales. It contains three to five layers of very fossiliferous concretions. These layers are locally persistent and in many areas maintain constant intervals for sufficient distances to enable them to be used for structural mapping purposes. The member is from 50 to 90 feet thick.

TIMBER LAKE MEMBER: The Timber Lake member lies on the Trail City member and is usually found on the upland west of the valley. "The lower part is usually a greenish-yellow medium-grained soft or uncemented quartz sand. The upper portion contains thin bands of fine-grained orange to brown well-cemented limonite claystone which also appears as isolated pieces or pebbles. The limonitic claystone occurs most abundantly toward the base of a series of lens-like masses formed by concretionary cementation of otherwise soft sand. The cement is calcite and the concretionary lenses, being relatively hard, weather out as resistant brownish ledges in exposures of the upper Timber Lake member. The soft sand between the concretions is often marked or mottled in a vermicular pattern."

1. R.E. Morgan and B.C. Petsch, A Geological Survey in Dewey and Corson Counties, South Dakota, R.I. 49, S. Dak. Geol. Survey, 1944.

PIERRE FORMATION

The Pierre formation crops out over a great part of the central Great Plains or the Missouri river drainage basin from Canada to Colorado to Kansas, and from the Rocky Mountains to western Minnesota. Figure 6. The formation is made principally of shales and marls in the east and sandstones and shales in the west and ranges from less than 100 feet thick in eastern South Dakota to at least 3000 feet in western Nebraska[1] and 8000 feet in east central Colorado.[2] It was first studied in 1854 by F.B. Meek of the U.S. Geological Survey of the Territories at Fort Pierre, South Dakota, which apparently was the type locality and where the name of the formation was applied. Since that time much work has been done on the formation and as a result it has been divided and subdivided into members which can be traced long distances; hence the original term "Pierre" is almost in disuse. Figure 7. Descriptions of the Pierre formation in various parts of the country can be found in the following publications:

1. United States Geological Survey of the Territories, vol. IX, F.H. Hayden, 1876.

2. Index to the Stratigraphy of North America, U.S.G.S. Professional Paper No. 71, Bailey Willis, 1912.

3. The Geology of Wallace County, Kansas, M.K. Elias, Bulletin 18, State Geol. Survey of Kansas, Lawrence, 1931.

4. The Geological Section of Nebraska, G.E. Condra and E.C. Reed, Bulletin 14, Nebraska State Geol. Survey, Lincoln, 1943.

5. Selenium in Rocks, Soils and Plants, A.L. Moxon, O.E. Olson and W.V. Searight, Agricultural Experiment Station, Brookings, S. Dak., 1939.

6. Missouri River Valley in Northeastern Nebraska, G.E. Condra, U.S.G.S. Water Suppl. Paper No. 215, Washington, 1908.

7. "Upper Cretaceous of the Rocky Mountain Area," John G. Bartram, American Association of Petroleum Geologists, July, 1937.

8. Reports of Investigations, South Dakota State Geological Survey.

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1. G.E. Condra and E.C. Reed, The Geological Section of Nebraska, Bulletin 14, Nebraska State Geol. Survey, 1943.
2. M.K. Elias, The Geology of Wallace County, Kansas, Bulletin 18, State Geol. Survey of Kansas, Lawrence, 1931.

AREA OF PIERRE FORMATION

IN ROCKY MOUNTAINS AND NORTHERN GREAT LAINS

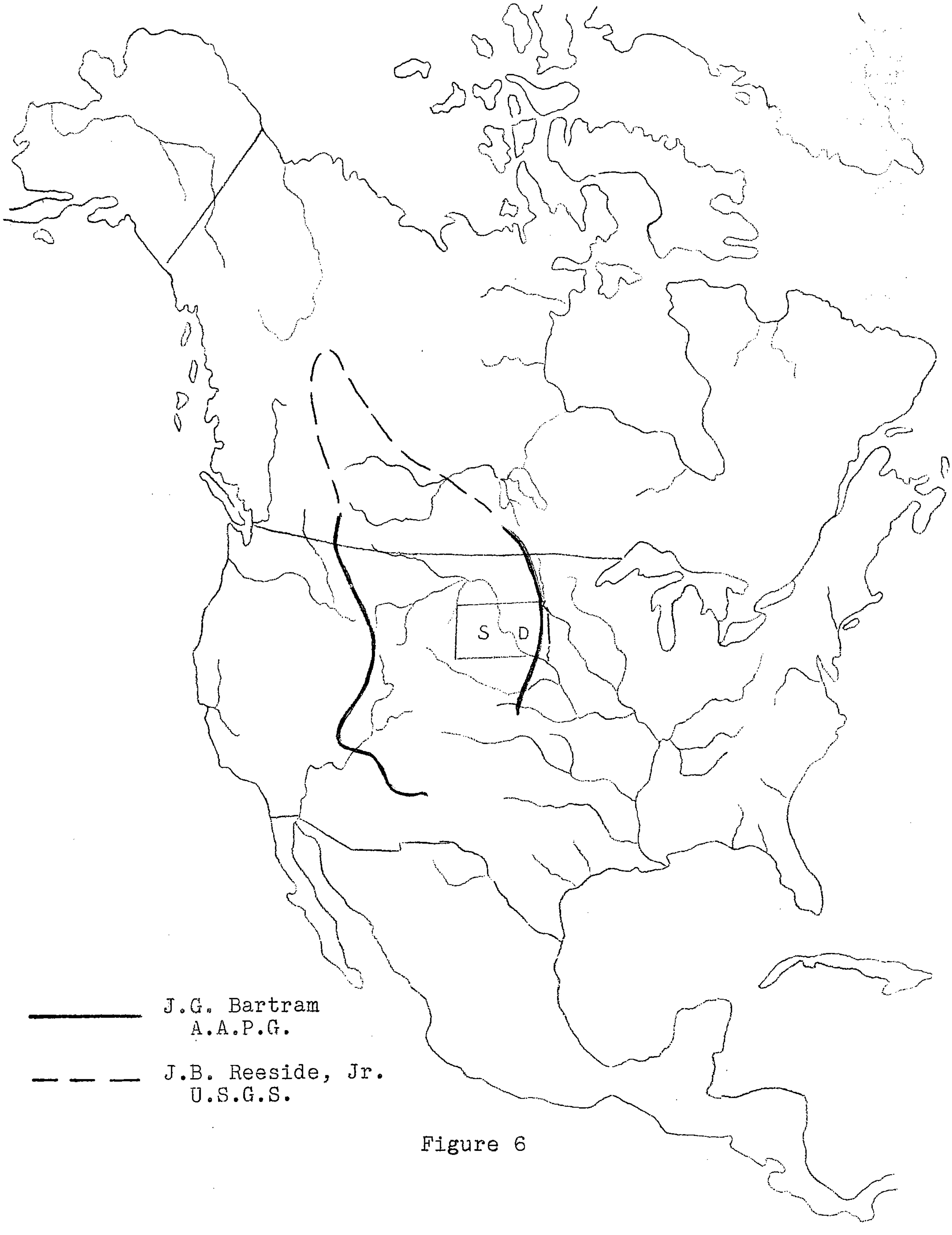

Figure 6

PIERRE SHALE EQUIVALENTS

in

MISSOURI RIVER BASIN

SE. WYOMING[1]	NE. MONTANA[2]	S. ALBERTA[3]	S. DAKOTA[4]	NEBRASKA[5]	KANSAS[6]
	Bearpaw	Bearpaw	Elk Butte		
Lewis					
			Mobridge		
				Undifferentiated	
	Judith River				
Mesaverde			Virgin Creek		Salt Grass
		Belly River			
					Lake Creek
			Sully		
					Weskan
	Claggett				
			Gregory	Gregory	Up. Sharon Springs
Steel					
	Eagle		Sharon Springs	Sharon Springs	Sharon Springs

1. W.H. Holmes, W. Cross and A.C. Spencer, Committee on Geological Names, U.S.G.S.
2. J.B. Hatcher and T.W. Stanton.
3. G.M. Dawson.
4. South Dakota Geological Survey
5. G.E. Condra and E.C. Reed, <u>The Geological Section of Nebraska</u>.
6. M.K. Elias, <u>Geology of Wallace County, Kansas</u>.

Figure 7

In the Missouri valley in South Dakota the Pierre formation has been divided into six members which can easily be recognized and are convenient in geologic field work.[1] These members have been given the following names:

6. Elk Butte
5. Mobridge
4. Virgin Creek
3. Sully
2. Gregory
1. Sharon Springs

The Pierre formation as a whole consists of stratified gray, dark gray to black clays and shales, concretions, marls and chalks, interbedded with many layers of bentonite. Two persistent marls are present and a thick horizon of chalk. Many layers of concretions of various sizes and composed of iron, carbonate limestone and sometimes carrying manganese are present throughout the formation.

Bentonitic clays form the greater portion of the formation. The only true shale in the Pierre is the Sharon Springs member at the base.

The clay, where at or near the surface, expands and pulverizes under the influence of atmosphere and surface moisture and slakes into a fine, powdery dust which is easily blown away or carried away by water moving at the surface; however, when the disintegrated clay is thoroughly moistened by water the particles adhere and form the well-known sticky gumbo. In prolonged periods of dryness, shrinkage cracks form in the surface soil or disintegrated clay, which cracks will close upon the occasion of sufficient moisture. Alternate drying and wetting causes swelling, heaving and contraction which on steeper surface slopes induces creep, slumpage, flowage and many times land sliding. Owing to the impermeability to water ordinarily characteristic of the clays and shales, its content of moisture available to plants is too low to permit the growth of trees and larger shrubs and therefore the chief characteristic vegetation of Pierre outcrops is grasses. However, cedar trees grow in many sheltered places if calcareous soil is present. The calcareous soil comes from the bed rock itself or lime concretions in the bed rock.

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1. W.V. Searight, Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in S. Dak., R.I. 27, S. Dak. Geol. Survey, 1937; J.P. Gries, Economic Possibilities of the Pierre Shale, R.I. 43, S. Dak. Geol. Survey, 1942.

A complete section of the Pierre is exposed along the highway that traverses up the hill from the Rosebud-Wheeler bridge. Going from one road outcrop to the next higher, the entire section can be seen; however, a few of the contacts are not too clear, but upon close examination the section can be measured. Figure 8.

Here the total formation measures 423 feet thick. At the Oahe Dam site and at the mouth of Chantier Creek in Stanley county a composite section both underground and at the surface measures 896 feet thick to the top of the Virgin Creek member. Since outcrops of the complete section of the Mobridge and the Elk Butte members, the remaining upper part of the Pierre, are too far away to afford a practicable measurement, it is inadvisable to complete the full Pierre section in this area. However, the thickness of the Mobridge in its type locality at Mobridge is 150 feet and the Elk Butte is 242 feet thick at Kenel-Pollock ferry crossing. It is therefore apparent that the Pierre thickens northward to about 1400 feet near the North Dakota state line. The Pierre is 1541 feet thick in the Irish Creek Well core S.E. $\frac{1}{4}$, Sec. 17, T. 15 N., R. 20 E., Ziebach county, South Dakota.

Bentonite

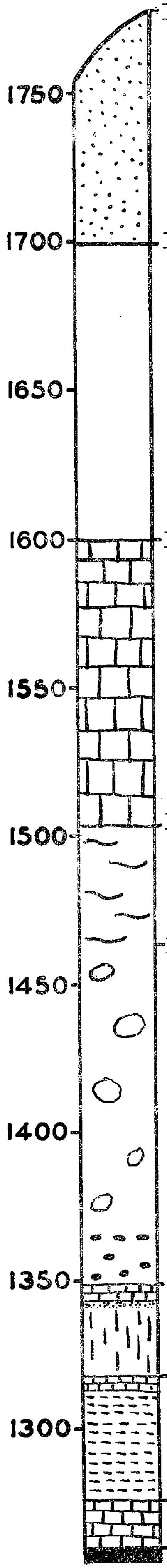
Bentonite is an important factor in the Pierre formation because it can be found most anywhere throughout the formation either in definite layers from 1/8 to 12 inches in thickness, thin laminations or interspersed in the shale itself. It is common to find from 10 to 30 bentonite layers in an outcrop of as many feet in height.

The bentonite is a fine smooth massive material that cuts like cheese, lard, butter or soap. It is usually soft and moist and can be molded in the hand and has a soapy feel and a greasy luster. It is a rock consisting essentially of crystalline, clay-like material, usually the mineral montmorillonite, less commonly, beidellite, which was formed by the devitrification and attendant chemical alteration of glassy igneous material, usually volcanic tuff or ash. (Wentworth--Williams) It was named "bentonite" by W.C. Knight from its occurrence in the Fort Benton formation of Upper Cretaceous age in Wyoming. Layers of it can easily be recognized in fresh exposures because it is so different from the shales with which it is interstratified.

Bentonites in the Missouri valley have various colors caused by impurities as yellow, white, brown, green, olive green and tan. Each color itself ranges from pale to dark. Some of the

SUCCESSION OF BEDS AT WEST END

OF ROSEBUD-WHEELER BRIDGE



1778

FOX HILLS FORMATION

Shale, brownish gray with few brownish concretions.
(Sandstone and sandy shale in the north.)

1699

PIERRE FORMATION

Elk Butte Member

Shale, brownish gray, few concretions or fossils.

1600

Mobridge Member

Chalk, impure, gray, weathers to buff.

1504

Virgin Creek member---Upper

Shale gray, weathers to gumbo.

Lower

Shale gray, weathers to gray flakes with sev. benton.

1464

Sully Member

Verendrye

Shale, dark gray, weathers to gumbo with numerous layers of black, iron manganese concretions.

Shale, light gray, banded, no concretions.

Oacoma-Agency

Sh., gray, with numerous benton. and mangan. iron concretions.

1349 Crow Creek, chalk and sand.

Gregory Member

Shale, gray to brown, limestone concretions.

1318

Sharon Springs Member, oil shale, marl, light gray to buff.

Upper, gray, no fish remains.

Lower, shale, dark gray, fissile, with fish scales and numerous bentonites.

1276

Top Niobrara

1260 Missouri River Water.

Figure 8

IRISH CREEK WELL CORE
SE. ¼, Sec. 17, T. 15 N., R. 20 E.
Ziebach County, Isabel, S.D.

Depth	Thickness	Formation		
0 - 139		Fox Hills[1]		
139 - 335		Pierre[2]		
335 - 670	335		Mobridge	
670 - 959	289		Virgin Creek	
959 - 1017	58		Sully	Verendrye
1042 - 1130	88			Oacoma
1130 - 1372	242			Agency
1377 - 1445	73		Gregory	
1445 - 1680	235		Sharon Springs	
1680 - 1950	270	Niobrara[2]		
1950 - 2334	384	Carlile[2]		
2334 - 2680	346	Greenhorn[2]		

1. W.L. Russell and T.W. Stanton, Well Log in Northern Ziebach County, S.D., Geol. and Natural History Survey, 1925.
2. Alvin L. Moxon, Oscar E. Olson and Walter V. Searight, Selenium in Rocks, Soils and Plants, Tech. Bulletin No. 2, Agricultural Experiment Station, Brookings, S. Dak., 1939.

Figure 9

thicker bentonite layers are characteristically only one color such as the Big Bentonite Bed of the Oacoma zone, which is always yellow. There is generally a distinct contact line both above and below a bentonite layer in the shale.

A few bentonite layers contain abundant flakes of biotite mica ranging up to one millimeter in diameter.

The important bentonite layers such as the Big Bentonite Bed and the micaceous bentonites can be traced long distances and their intervals and positions remain quite constant. Figure 10. The thin layers are difficult to trace individually, but groups of them can be recognized in successive outcrops.

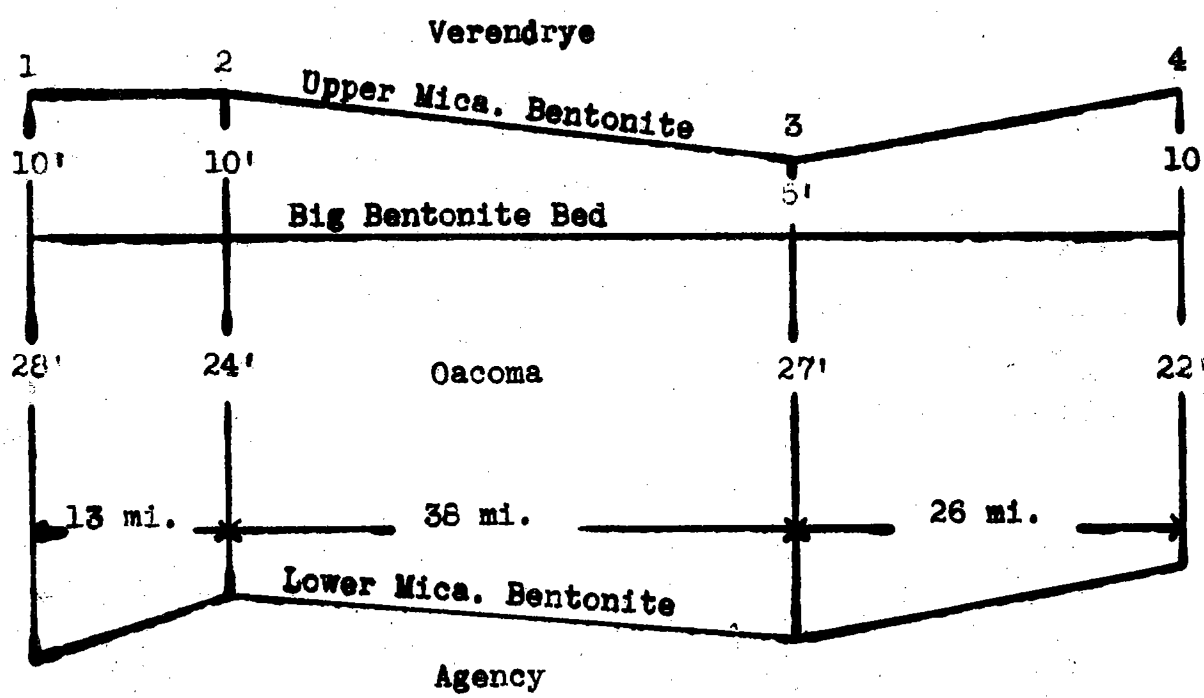
Most outcrops of shale which contain several bentonite layers have a stair-step effect. This is caused by weathering; the bentonite layers make the treads and the shales, the risers. Outcrops of shale in which the bentonite is interspersed or is more or less disseminated are usually rounded and appear as "elephant backs." On these the weathered surface is rough and extremely cracked and spongy. It is usually several inches thick, and by digging into it the chunks obtained are like pop-corn balls.

The bentonite is an alteration product produced largely by the addition of water to fine volcanic dust or glass flakes blown from the vents of explosive volcanoes generally high in the air and thence carried in major amount in the direction of prevailing winds. The finer particles fall to the ground only when they become heavy owing to the condensation of an adhering film of moisture. It settles everywhere on the earth, both land and sea. If it settles on land it may be transported by running water to bodies of still water whereupon it again settles to the bottom. That which falls directly into bodies of water may permanently lodge on the bottom or be carried elsewhere and deposited by the action of currents. Volcanic explosions are seldom continuous but intermittent and therefore layers of pure bentonite will accumulate among those which are impure or consist of other types of sediments. If the volcanic material accumulates on dry land surfaces and is not further transported, such layers are parallel and conformable to the surface relief of the land and in such cases they are useless for structural determination or they may accumulate on a sloping bottom under water and therefore have the form of delta lobes or the bottom slope. This, of course, accounts for their being present in the shales today.

CHART SHOWING CORRELATION

OF BENTONITE KEY BEDS

IN THE OACOMA ZONE



1. North of Kennebec, Sec. 33, T. 108 N., R. 75 W.
2. DeGrey, Sec. 6, T. 109 N., R. 75 W.
3. Giddings Flat, Sec. 33, T. 6 N., R. 30 E.
4. Shack Creek Sec. 29, T. 114 N., R. 81 E.

Figure 10

Occasionally there are beds of unaltered material which is the original volcanic ash; if such deposits are large enough they have commercial value.

The bentonite which is in the water of the Missouri river is probably the main reason why it is muddy, since it is colloidal and therefore settles very slowly. In the continual stirring of river currents, eddies, boils, etc., it may never settle to the stream bed.

ELK BUTTE MEMBER: The Elk Butte is the youngest and topmost member of the Pierre formation. It is present in Gregory county and outliers of it occur on the higher hills south of Lake Andes. It is also present in the north part of the valley west of Mobridge in Dewey and Corson counties.

"The Elk Butte member consists of fine textured, medium gray shale which breaks into thin polygonal chips and ultimately weathers to gumbo. Several types of concretions are found in the member, but none is abundant or typical. Bentonite beds are abundant, particularly in the lower part. These may be seen either in fresh cuts or recognized by the characteristic dark gumbo streaks on weathered slopes."[1]

A number of very thin layers of bentonite are exposed at or near the top of the Elk Butte member. This material is bright yellow on exposures, probably from contained limonite. On weathered surfaces it is formed as yellow nodular limonite pebbles. The top of the member is chosen at a color change from the dark Elk Butte shales to the more sandy shales of a light brown color of the basal Fox Hills. This color change is quite apparent while looking at distant outcrops. But on close examination it is difficult to spot the exact color change contact. The upper part of the member also contains calcareous concretions many of them arranged in nearly horizontal lines and others scattered at random.

"The Elk Butte member has a thickness of from 100 feet in Gregory county and from 202 to 243 feet in Dewey and Corson counties."[1] It lies on the Mobridge chalk member of the Pierre and this basal contact should be chosen at the lowest non-calcareous shale, assuming all beds in the upper Mobridge are calcareous.

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1. J.P. Gries, Economic Possibilities of the Pierre Shale.

The member makes the higher elevation of the upland and is generally grassed over.

<u>MOBRIDGE MEMBER</u>: The Mobridge member lies above the Virgin Creek and below the Elk Butte member of the Pierre formation. The member varies in lithology along the Missouri but is composed mainly of chalk, calcareous clays and shales and some non-calcareous beds and sandstones. Generally, however, the member is calcareous and this is a distinguishing feature that enables one to locate either the top of the base with the acid reaction test. The Mobridge can be spotted by its light buff color and pale blue colored horizons. Many times an outcrop is nearly vertical and high.

The Mobridge member is well described by Gries[1] for various localities along the valley so it is not deemed necessary to repeat the local descriptions in this report.

<u>VIRGIN CREEK MEMBER</u>: The Virgin Creek member of the Pierre formation is possibly the thickest member of the Pierre section, being from 87 feet at Wheeler to 278 feet thick near Promise in Dewey county. The member was first studied and named by Searight[2] from exposures on Virgin Creek in northeastern Dewey county. In 1939 Gries[3] studied the member in detail throughout the Missouri valley.

The Virgin Creek member is divided on the basis of lithology into the Lower and Upper zone. It is a wide outcrop, the lower contact being in the breaks and the upper contact being well back in the upland country, especially on the west side of the valley. The upper contact with the base of the Mobridge is defined as the spot where the acid reaction begins and a color change generally occurs there between the dark non-calcareous Virgin Creek shales below and the yellow or light buff weathering calcareous shales of the Mobridge above. The Virgin Creek lies high up in the breaks of the valley. This is one reason for the lack of outcrops, as erosion does not leave ledges or vertical outcrops. The member is generally moist and springs can be found at the base. Sometimes shale feels spongy under foot due to the moisture within. Small lakes and ponds are present on the upland where the Virgin Creek is the bed rock.

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1. J.P. Gries, <u>Economic Possibilities of the Pierre Shale</u>.
2. W.V. Searight, <u>Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in South Dakota</u>.
3. J.P. Gries, <u>A Structural Survey of Part of the Upper Missouri Valley in South Dakota</u>, R.I. 31, S. Dak. Geol. Survey, 1939; Gries, <u>op. cit</u>.

"The upper Virgin Creek is composed of gray shale which weathers to gumbo. The higher beds frequently consist of alternating calcareous and non-calcareous bands which may be Mobridge. Several types of concretions are characteristic of the upper Virgin Creek. One consists of small gray or buff concretions which weather nearly white and are perforated by many small holes which give them a "worm eaten" appearance. A second type includes small cylindrical concretions, gray or buff in color, with a soft core which weathers out, leaving hollow cylinders often termed "Indian Beads (Serpula? wallacensis, Elias). Somewhat higher, in some localities, small, bluish-gray limestone nodules are found which contain the fossil remains of small crabs. Large septarian limestone concretions, frequently containing yellow calcite, are characteristic of the zone."[1]

SULLY MEMBER: The Sully member is the most important division of the Pierre formation, both stratigraphically and economically in the Missouri valley. The Sully is divided, on the basis of lithology, into the basal Crow Creek, the Agency-Oacoma and the Verendrye zones. The Sully member contains several key beds which can be traced for many miles in the river valley.

The Crow Creek zone is composed of a sandstone about one foot or less in thickness above which is a marl bed of from four to ten feet thick. The Crow Creek zone can be traced from the Rosebud-Wheeler bridge up the valley to DeGrey, a distance of 152 river miles. There it goes under the river. Below the bridge it loses its identity. The zone appears as a light band on any outcrop which can be seen from a distance. Where it is obscure or grassed over it supports the yucca plants. The marl is a smooth, creamy, very calcareous clay. The sandstone is partly unconsolidated in newly dug exposures. In old exposures it is usually on the surface as slabs to paper-like flakes which can always be found. It is an ideal key bed for surface structure mapping.

The Oacoma-Agency zone of the Sully member is an easily identifiable bed. It can first be identified above Rising Hill colony below the Rosebud-Wheeler bridge and can be traced up the valley above the Whitlock bridge in Potter county. Below Rising Hill the zone loses its identity. The Oacoma of this zone is a light gray shale that contains many iron-manganese nodules[2] which make the zone appear as a black band in the breaks of the valley. It carries many thin layers of bentonite and ranges in thickness from 40 feet in Brule county to 8 feet at the Whitlock bridge in

1. J.P. Gries, Economic Possibilities of the Pierre Shale.
2. J.P. Gries and E.P. Rothrock, Manganese Deposits of the Lower Missouri Valley in South Dakota.

Potter county. A layer of bentonite about four inches thick that has much biotite mica flakes in it marks the base of the Oacoma and is called the Lower Micaceous Bentonite (LMB); at the top is also a micaceous bentonite called the Upper Micaceous Bentonite (UMB). About 5 to 10 feet below the Upper Micaceous Bentonite is a thick layer of bentonite known as the Big Bentonite Bed. It is from 4 to 10 inches thick. Below it is a ½ to 1½ inch shale, then another layer of bentonite usually about an inch thick; this sequence--bentonite, shale, bentonite--is the Big Bentonite Bed.

The Upper Micaceous Bentonite, Big Bentonite and the Lower Micaceous Bentonite are key beds of the Oacoma; each can be traced many miles in outcrops. It is seldom that two or all three of the key beds are not present. It is questionable whether or not these bentonites can be used in mapping structure.

From about Elm Creek just north of the Bijou Hills up the river to Medicine Creek at the Big Bend a bed of dark gray shale void of manganese nodules lies between the Lower Micaceous Bentonite and Crow Creek marl. This is the barren zone and becomes the Agency zone northward. Figure 11. The Agency zone is a silicious light gray shale. In fresh exposures it is a blocky jointed shale--weathering breaks it down to thin flakes and chips which do not make gumbo when wet. From the barren zone in the south where it is 18 feet thick, the Agency thickens to 157 feet[1] at the Oahe Dam site north of Pierre; paralleling this the Oacoma thins to 8 feet at the Whitlock bridge in Potter county.

The Oacoma-Agency zone of the Sully member is important economically because it contains an abundance of ferro-manganese carbonate nodules. The nodules occur in layers in the shale; sometimes a layer has enough nodules to form a pavement. There are at least twelve to as many as thirty-one layers of nodules in the zone and their manganese content will average at least 18% Mn. Detailed information on the manganese problem can be found in reports of investigations by the State Geological Survey,[2] U.S. Bureau of Mines,[3] and U.S. Geological Survey.[4]

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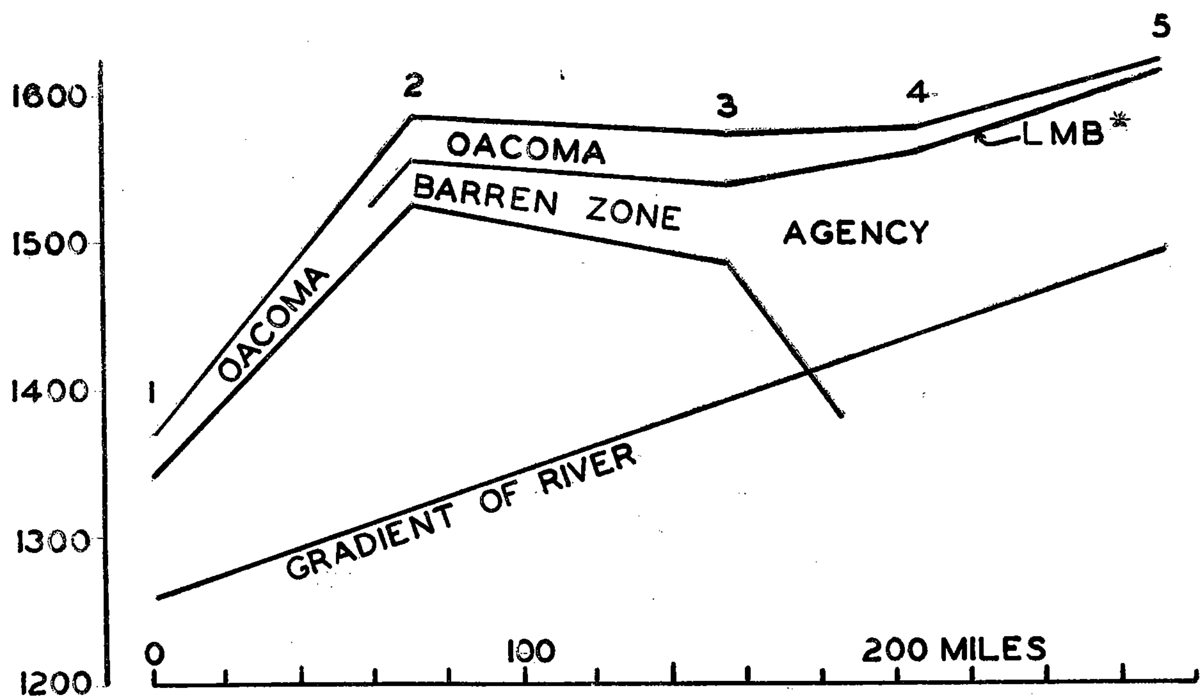
1. G.R. Golder, Geologist, U.S. Army Engineers, Correspondence, January 18, 1946.
2. J.P. Gries and E.P. Rothrock, Manganese Deposits of the Lower Missouri Valley in South Dakota; E.P. Rothrock, Missouri Valley Manganese Deposits Between Lower Brule and DeGrey.
3. L.W. Dupuy, W.A. Calhoun and T.C. Rasmussen, R.I. 3839, Bureau of Mines, February, 1946; F.D. DeVaney, S.M. Shelton and F.D. Lamb, R.I. 3613, U.S. Bureau of Mines, 1946.
4. D.F. Hewitt, Manganese-Iron Carbonate Near Chamberlain, S. Dak., memorandum for the press, U.S. Geol. Survey, February 5, 1930.

CROSS-SECTION SHOWING RELATION

BETWEEN THE OACOMA AND AGENCY ZONES



1. Rosebud-Wheeler Bridge
2. Oacoma
3. DeGrey
4. 12 miles south of Cheyenne River
5. Whitlock Bridge

*LMB - Lower Micaceous Bentonite

Figure 11

The Verendrye zone is the name given the uppermost division of the Sully member.[1] It lies on the Oacoma-Agency zone. It is exposed in the Missouri valley and its tributaries from the Nebraska line northward nearly to Mobridge. The Verendrye is a light to dark shale making an outcrop appear to be banded. It has no calcareous layers but contains many large flat iron-manganese carbonate concretions. The upper part of the Verendrye is dark shale and has layers of rusty concretions that seem to form large steps.

The Verendrye zone does not have traceable key beds. The base of the zone, in contact with the Oacoma-Agency, lies a few feet above the upper Micaceous Bentonite where a color change from the light gray shale of the Oacoma to the darker shales of the Verendrye shale begins. The Virgin Creek-Verendrye contact is not distinct and is usually not exposed. However, on grassed-over slopes an active spring may be present because the Virgin Creek is a moist formation whereas the Verendrye is dry.

Thickness of the Verendrye

Authority	Thickness	Locality
Searight	88 feet	Wheeler
	130	Oacoma
	170	Crow Creek
	170-180	Ft. Pierre
	58	Irish Creek Core
Gries	177-196	Bijou-Iona Hills
	122	Ft. Bennet
	142	Chantier Creek
	100-110	Dewey-Potter Co.

GREGORY MEMBER: The Gregory member of the Pierre formation lies between the Sharon Springs oil shale and the Crow Creek sand zones of the Sully member. The Gregory is the second division upward from the base of the Pierre. The member can be traced from the old cement plant at Yankton to DeGrey, which is west of the Big Bend. It does not have key beds which can be traced; however, at some outcrops, a lense of hard lime sometimes two feet thick is present at the contact of the Sharon Springs. There is one on Elm Creek in Brule county, and two of these limestone lenses at the Rising Hill colony, and one at Iona, Lyman county. These limestone lenses are probably large flat limestone concretions because none was observed that was more

1. W.V. Searight, Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in S. Dak.

than 30 feet long, such as the two at Rising Hill which are about ¼ mile apart.

The Gregory member is made up of alternate light buff to gray shale; the light bands are calcareous. Within the shale are many brown concretions of all sizes and scattered at random. They are not usable as key horizons.

Thickness of Gregory Member

Wheeler-Rosebud Bridge	27?
S.W. of Academy	50
East of Iona	72*
Elm Creek	103
White River	125
Oacoma	119
Bad Hand Bottom	68*
Fort Lookout	65
Crow Creek	84*
Irish Creek Well Core	73**

* J.P. Gries, Economic Possibilities of the Pierre Shale.

** Alvin L. Moxon, Oscar E. Olson and Walter V. Searight, Selenium in Rocks, Soils and Plants.

SHARON SPRINGS MEMBER: The Sharon Springs member is the lowermost horizon of the Pierre formation. It was studied and mapped at and around Sharon Springs, Wallace county, Kansas,[1] where it is 155 feet thick and divided into the lower 90 feet and the upper 65 feet. It has been traced to the Missouri valley[2] where it is exposed from Yankton to the Big Bend. It apparently thins eastward from the Rosebud-Wheeler bridge to Yankton, which is about the easternmost limit of the member.

Thickness of Sharon Springs Member

	Feet
Irish Creek Well Core	235*
Oahe Dam	95**
Mouth of Crow Creek	14***
Five miles north of Chamberlain	25
Two miles south of Oacoma	27
Mouth of White River	22***
Iona	27***
Elm Creek	54
Southwest of Academy	14
Rosebud-Wheeler Bridge	42
Rising Hill Colony	56
Running Water Ferry	9
Verdel, Knox Co., Nebraska	18
Santee, Knox Co., Nebraska	6
Old Cement Plant, Yanton	7

* Alvin L. Moxon, Oscar E. Olson and Walter V. Searight, Selenium in Rocks, Soils and Plants.
** G.R. Golder, Geologist, U.S. Army Engineers. Correspondence, Janualy 18, 1946.
*** J.P. Gries, Economic Possibilities of the Pierre Shale.

The Sharon Springs is predominently an oil shale; it is a brownish-gray fissile shale speckled with fish scales, various twig-like particles and bone splinters, the scales beinga marker. It is very bituminous and will yield $2\frac{1}{2}$ fallons of crude petroleum per ton of shale by distillation.[3]

1. M.K. Elias, The Geology of Wallace County, Kansas, Bulletin 18, Kans. Geol. Survey, 1931.
2. A.L. Moxon, O.E. Olson, W.V. Searight and K.M. Sandals, "The Stratigraphic Distribution of Selenium in the Cretaceous Formations of South Dakota and the Selenium Content of Some Associated Vegetation," Amer. Journ. Botany, vol. 25, No. 10, December, 1938.
3. G.G. Frary, State Chemist, Correspondence.

The member lies on the Niobrara chalk and at the contact is a bed of impure rusty selenite and an inch or so of a red hematite-like material. This bed at the contact is sometimes a foot thick. The lower portion of the Sharon Springs has many bentonite layers that range from less than ½ inch to 1 foot thick. They are separated by dark gray and black shales.

At an outcrop, the member is never grassed over and is usually vertical or canyon-like with deeply grooved buttress forms which seem to hold the outcrop. This tendency of the shale to stand vertical is due to a system of cross joints that are filled with dry yellow bentonite and minute layers of bentonite which seem to give the shale a cross-bedded appearance.

At the south approach of the Rosebud-Wheeler bridge is an 8 foot bed of light grey chalk. It contains tiny shale pebbles and sand grains which can be seen with a lens. This chalk bed has been placed at the base of the Gregory member which lies directly over the Sharon Springs.[1] Above this chalk is an 18-inch bed of oil shale that resembles the oil shale in the Sharon Springs. The chalk loses its identity up the river valley but it can be traced down the river. The sand grains and tiny pebbles persist in the chalk from the Rosebud-Wheeler bridge to the old cement plant at Yankton. However, the 18-inch oil shale above was not observed down the valley.

The base of the member is usually moist and many times springs are present. There are not many good exposures of the Sharon Springs on the north side of the river from Yankton to the Rosebud-Wheeler bridge; from the bridge northward, however, there are good exposures. The base of the member is usually present where the Niobrara has a vertical outcrop.

The farthest outcrop northward is at the mouth of Camel Creek, Lyman county, about 3 miles southeast of Lower Brule. A good outcrop is at the road level of Highway No. 16, about a mile northwest of Cacoma where the highway first starts the upgrade out of the valley.

The member was named at Sharon Springs, Kansas.

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1. J.P. Gries, Economic Possibilities of the Pierre Shale.

NIOBRARA FORMATION

The Niobrara formation is the upper member of the Colorado group in the Cretaceous system. It lies between the Pierre and the Carlile formations. It has been divided into two members: the lower part, the Fort Hayes member[1] and the upper part, the Smoky Hill member.[2]

The Niobrara can be seen at the base of the breaks at the river level almost anywhere from Lower Brule at the Big Bend, southward to Vermillion, and always outcrops as a vertical cliff. Figure 12. The formation is composed of a dark gray chalk; it is a form of soft limestone made partly from shells or tests of micro-organisms and flocculent material. The impurities in the rock are clays, organic matter and a small amount of iron sulphide in the form of pyrite pellets. In the outcrop the chalk is white to yellow. It becomes tan to brown where it has been exposed to weathering for a long time. In subsurface and in fresh exposures it is gray to black. The rock itself is tough and has a rubber-like feel when a pick is driven into it. During weathering and erosion it breaks off the outcrop in semi-dimension chunks--one side is flat.

The Niobrara formation is about 200 feet thick and very extensive and can probably be found anywhere in the Missouri river basin. It was named for exposures along the Missouri river near the mouth of Niobrara river in Knox county, Nebraska.

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1. S.W. Williston, Kansas Acad. Sci. Transactions, 1893, vol. XIII, pp. 108, 109.
2. F.W. Cragin, Colorado College Studies, 1896, vol. VI, p. 51.

TABLE SHOWING POSITION OF THE NIOBRARA FORMATION

ALONG THE MISSOURI RIVER

Miles*	Location	Elev. Top Niobrara	Elev. of River Water	Height of cliff** above water
92	Old Yankton Cement Plant	1330 ft.	1167 ft.	163 ft.***
129	Running Water	1290	1206	84
144	Verdel, Nebraska	1300	1220	80
161	Rising Hill	1317	1237	80
183	Wheeler Bridge	1276	1260	16
209	Snake Creek	1358	1285	73
211	SW. Academy	1340	1286	54
230	Elm Creek	1319	1303	16
245	White River	1354	1316	38
254	2 mi. S. Chamberlain	1382	1327	55
255	S. of Oacoma	1379	1328	51
260	3 mi. N. Chamberlain	1416	1331	85
264	Ft. Lookout	1418	1336	82
280	Camel Creek	1376	1350	26
371	Oahe Dam Site (underground)	1144	1430	

* Miles from Big Sioux river, up the channel of Missouri river.
** Outcrop of Niobrara, generally a vertical cliff.
*** The top of the level flood plain is 37 feet above water.

Figure 12

Benton Group

The Benton group of formations lies beneath the Niobrara chalk and above the Dakota formation. The group includes the Graneros shale at the base, the Greenhorn limestone and the Carlile shale.

The Benton group is exposed along the Missouri river from St. Helena in Cedar county, Nebraska, to Ponca State Park in Nebraska. Exposures are also present in Iowa along the bluffs of the Big Sioux river from Akron to Sioux City and along tributaries to the Big Sioux in Union county, South Dakota. (See geologic map at the back of this report.)

Since the ferries ceased to operate many years ago, the roads to the river have not been well maintained. Hence, it is difficult to reach the river today. To visit some of these outcrops along the base of the bluffs that border the river requires considerable hiking.

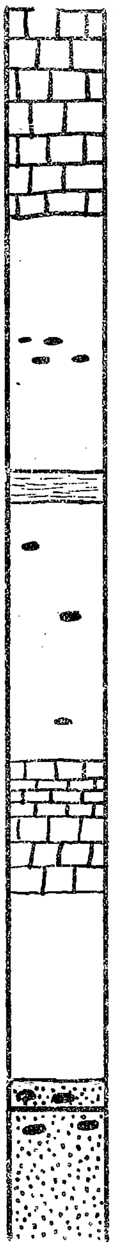
An investigator is assisted by using the Elk Point Quadrangle and Geologic Folio (See Figure 13) and Water Supply Paper 215 of northeastern Nebraska in studying the Benton group.

The formation was named Fort Benton on the Missouri river in Montana, but the stratigraphic limits are based largely on sections along the Missouri in northeastern Nebraska. The word "Fort" has been dropped for many years.

GENERALIZED SECTION OF THE CRETACEOUS ROCKS

IN THE ELK POINT QUADRANGLE

J.E. Todd



Niobrara

White massive chalk rock and calcareous shale.

Carlile

100' Dark shale with concretions at two horizons near center.

15' Hard clay and a layer of white bentonite.

100' Dark calcareous shales with scattered concretions.

Greenhorn

8' Blue chalky limestone.
12' Hard thin bedded limestone.
12' Blue thin bedded chalky limestone.

Graneros

50-75' Dark bluish shale.
5' Dark carbonaceous shale.
25' Dark sandy shale, in places containing thin seams of lignite coal.

Dakota Altitude at top, 1110 feet, Ponca State Park, Neb.

Sandstone with concretions and some lenses of lignite coal.

Figure 13

CARLILE FORMATION

The Carlile shale is the uppermost member of the Benton group. It outcrops along the Missouri river for about 24 miles from a point east of Newcastle, westward to St. Helena in Nebraska.

At the old Meckling ferry landing an enormous landslide occurred in April, 1945, and has destroyed what used to be a good exposure of the Niobrara-Carlile contact.

"The Carlile formation consists mainly of a dark gray and bluish-gray shale and clay. Calcareous concretions are more or less abundant throughout the deposit, occurring mainly at two horizons, 50 and 60 feet below the top of the formation. Near the middle of the formation there is a thin but widespread deposit of white bentonite clay. Considerable pyrite is present in the shale, occurring as crystals arranged in thin bands and concretions. Gypsum is abundant. The formation ranges in thickness from 200 to 215 feet."[1]

The Carlile shale is also exposed in Union county on Brule Creek at the dam in Union County Park northeast of Vermillion on U.S. Highway 77. Outcrops of it are also present between Westfield and Sioux City along the east bluffs of the Big Sioux river in Plymouth and Woodbury counties in Iowa.

The formation was named at Carlile Station west of Pueblo, Colorado.

Section at West End of Vermillion Ferry
Sec. 29, T. 32 N., R. 4 E., Nebraska

	Feet
Quaternary	
Loess	30
Rust colored sand-granite boulders	3
Carlile Shale (upper half)	
Drab shale	12
Irregular, coarse-grained, dark, limestone, conglomerate	1

1. J.E. Todd, Elk Point Folio, No. 156, U.S.G.S., 1908.

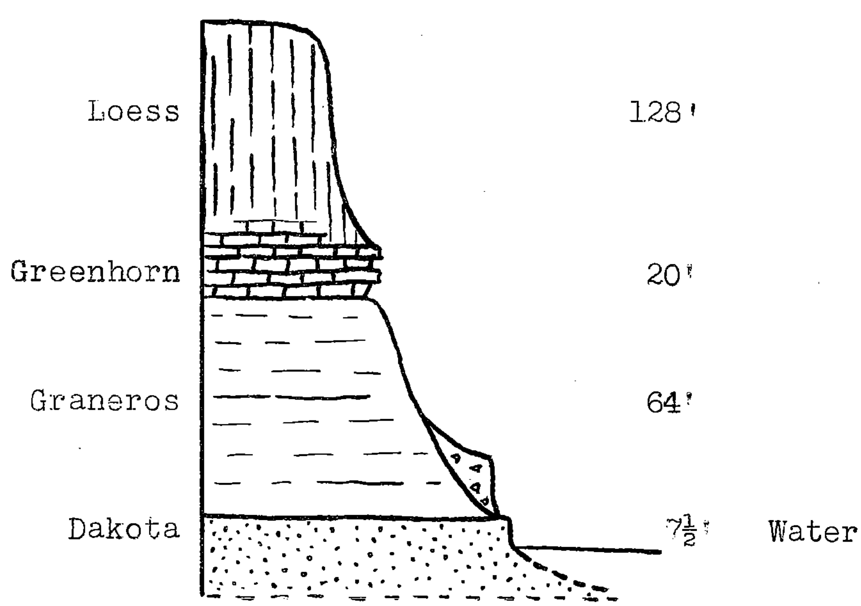
GREENHORN FORMATION

The Greenhorn formation is the middle member of the Benton group and outcrops on the south side of the Missouri river in the bluffs in Nebraska, on the east side of the Big Sioux river north of Sioux City in Iowa and at Richland in Union county, South Dakota

"The formation comprises a thin but very distinctive series of beds of hard impure limestone with a thickness of about 32 feet. It consists of a basal member 8 to 10 feet thick of bluish chalky limestone; a medial member of hard, thin-bedded limestone about 12 feet thick which is well exposed just north of Richland, South Dakota, and containing fossils in great abundance and interstratified with chalky shale; and a top member of bluish limestone 4 to 8 feet thick. The lime commonly occurs in large blocks divided by distinct but irregular joints."[1]

The formation was named at Greenhorn Station south of Pueblo, Colorado.

Section Ponca State Park, Nebraska



1. J.E. Todd, Elk Point Folio.

GRANEROS FORMATION

The Graneros formation lies on the Dakota Sandstone formation and is the lowest formation of the Benton group. The outcrops are confined mainly to the bluffs of the larger streams. It first occurs on the Nebraska side across from Elk Point in the vicinity of Ponca, Nebraska. Outcrops of it are also found in the bluffs along the east side of the Big Sioux river in Iowa between Westfield and Sioux City.

"The Graneros formation consists mainly of fine-grained, dark colored shale which is more or less sandy at the base. Concretions of iron carbonate occur at different horizons and iron pyrite is more or less abundant throughout the shale. In the vicinity of Ponca where the basal member of the formation consists of sandstone there is a thin seam of lignite. The Graneros shale varies considerably within short distances in both character and thickness. It is from 65 to 105 feet thick and weathers into vertical cliffs."[1]

The formation was named for Graneros Creek, Colorado, in the Walsenburg quadrangle, Pueblo county, Colorado.

DAKOTA FORMATION

The Dakota formation is the oldest sedimentary rock exposed in the Missouri valley within the course of the river from northeastern Nebraska to North Dakota.

It is also exposed on the east side of the Big Sioux river in Iowa from Sioux City northward along the base of the bluffs to a point due east of Jefferson, South Dakota.

The Dakota formation is primarily sandstone and is usually referred to as the Dakota sandstone. The sandstone is coarse, sometimes loosely cemented, tan to rusty in color. It is laminated with clay and iron-oxide concretions. Layers of shale are common, especially in the upper part and an occasional lignite bed can be found.

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1. J.E. Todd, Elk Point Folio.

The first outcrop of the Dakota down the valley is at Ponca State Park in Nebraska. There about 7½ feet are exposed above the river water and extend for about 1000 feet along the shore.

The contact with the overlying Graneros shale cannot be seen because a terrace of alluvium 21 feet high above the water is present.

The Dakota sandstone is present in the subsurface beneath the entire Missouri valley and is estimated to be from 50 to 400 feet thick, according to the literature. It is the source of much of the artesian water in central South Dakota.

The formation was named in Dakota county, Nebraska.

IV SUBSURFACE FORMATIONS

The cross-section, Figure 14, shows the general position of the formations in Figure 15 which underlie the Missouri valley as determined by the correlation of well logs.

Two principle structures stand out: the Forest City Basin and the Dakota Basin. They are separated by a Sioux quartzite ridge. The ridge is evident on the surface at Parker to the north and trends southwest through Scotland; thence south through Tyndall, crossing beneath the valley between Yankton and Fort Randall, possibly near Running Water.[1] This ridge is probably related to, or connected to, the Nemaha Ridge of Nebraska and Kansas. In South Dakota it divides the Forest City Basin from the Dakota Basin.

Record of City Well at Yankton

Yellow clay	0- 25
Blue clay	25- 55
Chalk	55-115
Clays, Benton	115-415
Alternations of sandstone and clay, the latter predominating	415-615
Principal water bearing horizon	615-625
Alternations of sandstone and clay	625-898
"Granite"	898-942

Record of Well at Fort Randall

Gumbo and clay	0-100
Soft stone	100-460
Sandstone, 600 gal. flow	460-520
Blue clay	520-576
Very hard rock	576-610

The material recorded in the logs above the "granite" or very hard rock is assumed to belong to Cretaceous formations. The overlap consists of formations from the Dakota group upward to glacial drift. These sediments comprise the bed rock of practically the entire Missouri river basin. It covers the formations of the Lower Mesozoic and Paleozoic systems. The overlapping Cretaceous thickens from 300 feet in northeastern Nebraska to over 2000 feet at the North Dakota state line.

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1. N.H. Darton, Underground Water of South Dakota, Water Supply Paper 227, U.S.G.S., 1909.

CROSS-SECTION OF FORMATIONS UNDERLYING MISSOURI VALLEY
SOUTH DAKOTA

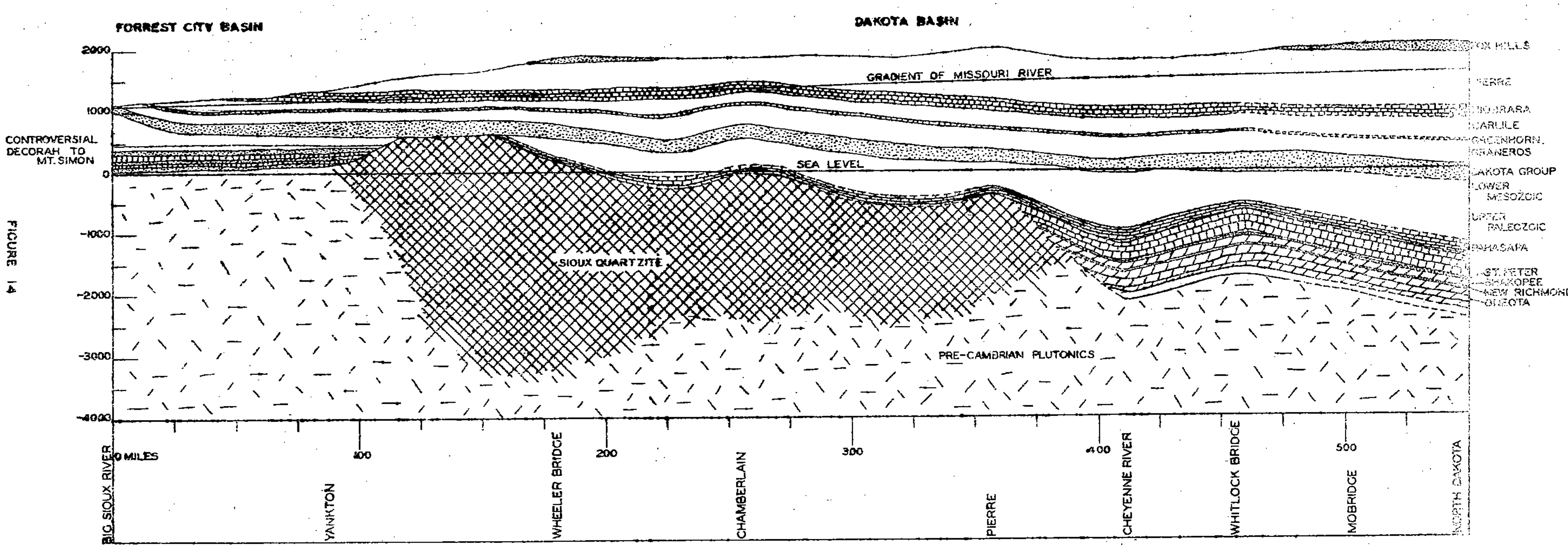


FIGURE 14

TABLE OF FORMATIONS UNDERLYING THE MISSOURI VALLEY

IN SOUTH DAKOTA

Dakota Basin (Lemmon Syncline)

Lower Cretaceous		Fuson Lakota	
Jurassic	Unconformity	Morrison Sundance	
Triassic		Spearfish	
Permian?		Minnekahta Opeche	
Pennsylvanian	Unconformity	Minnelusa	
Lower Mississippian		Charles[1] Pahasapa	
		Strata of uncertain age	
Lower Ordovician[2]	Unconformity	St. Peter-Chazy series[2]	
		Shakopee New Richmond Oneota	Beekmantown series
Upper Cambrian	Unconformity		
Pre-Cambrian		Sioux quartzite, plutonics and basement crystalline complex	

1. E.S. Perry and L.L. Sloss, Dept. of Geology, Montana School of Mines.
2. C.L. Baker, State Geological Survey, Vermillion, S. Dak.

Figure 15

The Forest City Basin contains the following Cambrian and Ordovician formations:

Ordovician	Decorah Platteville St. Peter
Cambrian	Franconia Galesville Eau Claire Mt. Simon

These correlations were made from a study of samples taken from the LaFleur No. 1 in Sec. 18, T. 90 N., R. 48 W., in Union county, by Anthony Folger, geologist, Gulf Oil Corporation.[1] (See log of well on geologic map of Missouri valley, Part 3 of 3 parts.)

The thickness of the Sioux quartzite is unknown as it lies beneath the Missouri valley. It is useless to drill through the formation in search of water; hence it has not been attempted. An oil test in Sec. 15, T. 95 N., R. 65 W., Charles Mix county, is reported to have drilled into it over 3000 feet. The horizontal extent of the formation is also unknown. It crops out in the vicinity of Sioux Falls, Parker and Spencer and is struck in wells as far west as central Stanley county.

The quartzite high shown on the cross-section in the Chamberlain area is purely an inference; however, it is reported that quartzite was struck at Kimball.

The fold in the Cretaceous overlap at Chamberlain as shown on the cross-section is the large Medicine Butte Anticline.[2] From Pierre northward the profile is interpreted from the study of samples from the following wells: Phillips Oil Company, Lang No. 1, Sec. 26, T. 5 N., R. 28 E., Stanley county; Carter Oil Company No. 2, Sec. 12, T. 9 N., R. 27 E., Stanley county; and Carter No. 1, Sec. 34, T. 118 N., R. 78 W., Potter county, which were studied and correlated by C.L. Baker of the South Dakota Geological Survey.

1. Correspondence, December 22, 1939.
2. B.C. Petsch, The Medicine Butte Anticline, R.I. 45, S. Dak. Geol. Survey, 1942.

There is a stratigraphic pinch-out of the Sioux quartzite on the pre-Cambrian plutonics between the Lang No. 1 and the Carter No. 2. Its exact location is not known since the contact of the Sioux quartzite on the plutonic rocks has never been penetrated.

The Paleozoic formations which lie between the Cretaceous overlap and the pre-Cambrian surface in the Dakota Basin have been folded. They are from approximately 200 feet thick in the Lang No. 1 to 1600 feet thick in the Carter No. 2; apparently there exists an enormous stratigraphic pinch-out of Paleozoic formations from the axis of the basin eastward.

The pre-Cambrian plutonic rocks in the basement complex are granite, grano-diorite, quartz monzonite, etc., according to samples from wells which encountered it.

V GEOLOGIC PROFILE OF THE MISSOURI VALLEY

The geologic profile shows the position of the formations of rock with respect to the gradient of the Missouri river in the valley. The diagram is analogous to looking at one wall of a deep ditch but is a composite of sections taken on both sides of the river. (See the profile in back of report.) The distances are taken from the Missouri River Commission and Corps of Engineers U.S.A. charts of the river, as were measured along the channel. On the profile the large meanders and bends are straightened out. The positions of the formations are plotted with respect to altitudes taken in the field on key beds and contact horizons at the outcrops.

The major anomaly that presented itself in this survey is the large anticlinal structure whose flanks are obvious in the Wheeler area to the south and in the Mobridge area to the north. The north dip of the formations was also brought out in a structure survey at Trail City in Dewey county.[1]

The highest elevation observed on the Niobrara chalk is at Fort Lookout north of Chamberlain at an altitude of 1418 feet above sea level, which is on the Medicine Butte Anticline[2] and the lowest altitude is 1276 feet at the Wheeler bridge. The Niobrara chalk rises eastward to 1333 feet near the old cement plant west of Yankton. From this point eastward down the river all formations have west dip so as to expose the older rocks to the Dakota formation. The gradient of the river can be said to flow down the ages. At a glance the valley seems to be in an area of folding.

The Medicine Butte Anticline west of Chamberlain is reflected in the valley. At DeGrey is a structural high on the profile. It is a continuation of the Medicine Butte Anticline northwest-southeast through Medicine Butte and not a separate high as shown. In other words, the river crosses the anticline twice, causing the structure to appear twice on the elongated profile. The profile also shows approximately where each horizon disappears beneath the river level.

1. R.E. Morgan and B.C. Petsch, A Geological Survey in Dewey and Corson Counties, South Dakota.
2. B.C. Petsch, The Medicine Butte Anticline.

It has been known that the Pierre formation thickens to the north and west; this fact is well illustrated on the profile. Although there is a thickening from the Wheeler bridge to the Big Bend, the pronounced increase begins at the Big Bend and northward where the Gregory member and Agency zone add greatly to the thickening of the section.

COLUMNAR SECTIONS

The following sections of outcrops are on a scale of 0.1 inch to 5 feet. Fifty parts to an inch on an engineer's scale was used for plotting the columnar sections. The figures on the right and left sides of the column are altitudes in feet above sea level.

Kenel-Pollock Ferry, Mobridge Section, Corson County

The flood plain of the Missouri river valley is from a mile to three miles wide between Mobridge and the North Dakota state line; there the channel does not strike the shale banks very often in its meanders southward and the breaks are not as pronounced as they are down the river. The valley is well grassed over and at the outside of meander bends are low outcrops.

The only road cuts that have good exposures are at the west end of the highway bridge which crosses the river at Mobridge and the road leading away from the ferry crossing between the towns of Kenel and Pollock.

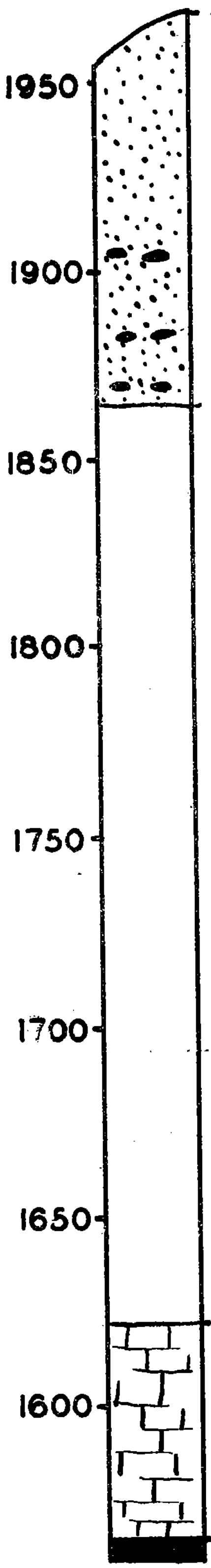
With sea level elevations applied to the contacts of these two sections, they show a decided north dip of the beds. Apparently the base of the Mobridge passes beneath the river about midway between Mobridge and the ferry landing but this point cannot be found due to the lack of outcrops and trails into the valley.

The surface formation on the upland at the ferry is the Fox Hills; its base is at 1864 feet elevation. About eight miles southwest of Mobridge on State Highway 8, the base of the Fox hills is at 2100 feet.[1]

1. R.E. Morgan and B.C. Petsch, A Geological Survey in Dewey and Corson Counties, South Dakota.

SUCCESSION OF BED AT KENEL-POLLOCK FERRY

NE. Corson County



1967 FOX HILLS FORMATION
Sandstone, containing lime concretion layers, heavy layer of flaggy, rusty limestone at top

Sandstone, zone of very fossiliferous limestone concretions at top

Sandstone and sandy shale, more or less slumped; sandy limestone concretions at top

1864 PIERRE FORMATION—Elk Butte Member
Shale, gray, poorly exposed, no bloom

More or less covered interval back from river; shale in blowouts and gullies, gray non-calcareous with ocherous "bloom" in joints

Shale, non-calcareous, yellow-gray blocky; to top of cut bank

1622 Mobridge Member
Shale, gray, calcareous, more or less papery with occasional barite rosette
Bentonite 2"
Shale, blue gray, calcareous, more or less talus covered, some large gray septarian limestone concretions not in place

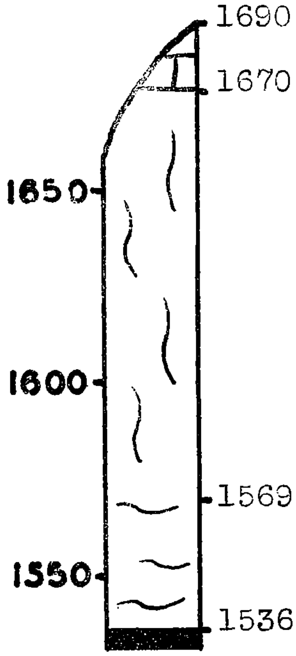
1565
River Water Surface

Succession of beds along traverse running from cut bank north along road to top of hill west of ferry. Measured by Gries and Searight.

Figure 16

SUCCESSION OF BEDS 3 MILES NORTH

OF MOBRIDGE, SEC. 7, T. 124 N., R. 79 W.



Glacial drift
Base of Mobridge
Virgin Creek Member
Upper

Dark gray gumbo soil, grassed over

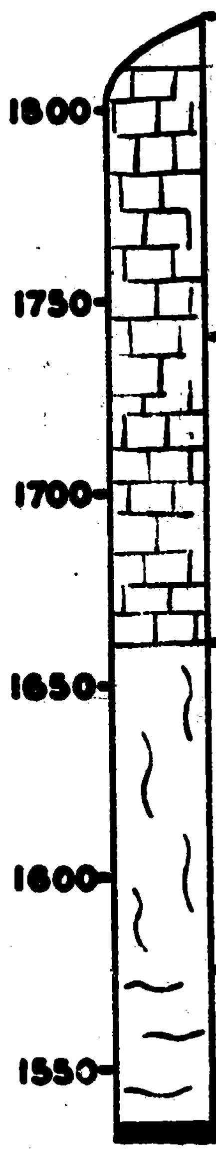
Lower

Dark gray shale exposed in a vertical outcrop, contains several bentonite layers
River water

Figure 17

SUCCESSION OF BEDS AT THE WEST END OF

HIGHWAY BRIDGE, MOBRIDGE, SOUTH DAKOTA



PIERRE FORMATION

Elk Butte Member

1822 Shale, blue gray, non-calcareous with a layer of white non-cal. concretions 30 in. above base capped with buff loess

1811 Mobridge Member

Shale, gray to buff, upper 22 feet more or less cal. and carries a 1 ft. layer of limestone

Lower 45 feet cal. with several layers of large septarian limestone concretions with yellow calcite in cracks

1742 Shale, gray, mostly calcareous with many small rusty concretions and numerous baculites

1661 Upper Virgin Creek Member

Shale, gray, non-calcareous, weathers to gumbo; fossil crabs, serpula, worm-eaten concretions are on adjacent outcrop

1575 Lower Virgin Creek Member

Shale, dark gray to nearly black, several small bentonites exposed in steep outcrops

1535 Surface of River Water

Section measured by Gries and the writer.

Figure 18

Fort Bennett

The area between Fort Bennett and the Whitlock bridge has low outcrops of most of the Sully member, the Oacoma zone being 8 feet thick at the bridge. The three bentonite key beds that are so prominent in the Oacoma zone to the south lose their identity somewhere north of the Little Bend.

Outcrops of shale are numerous between the Little Bend and Fairbanks on the east side of the river, and the valley is well grassed over from Fairbanks northward across Artichoke Creek to Forest City. On the west side of the river, the shales are exposed at river through Armstrong county but are very difficult to reach because the trails are too dim or have disappeared.

The area beginning in the first township south of the bridge and on up to Akaska was mapped for structure during the summer of 1938 by members of the State Geological Survey.[1] The top of the Oacoma zone was used as the key horizon and upon it elevations were taken. The text of the report contains detailed sections of outcrops measured in the area.

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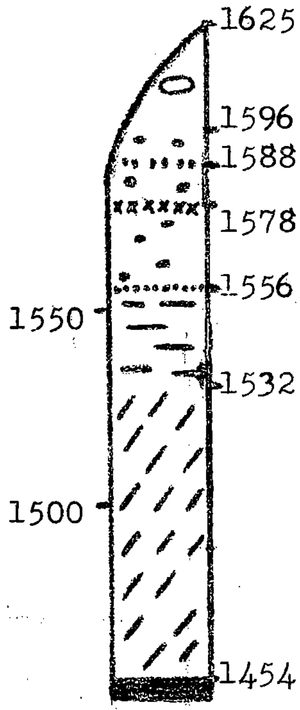
1. J.P. Gries, *A Structural Survey of Part of the Upper Missouri Valley in South Dakota*.

SUCCESSION OF BEDS NEAR MOUTH OF SHACK CREEK
Sec. 29, T. 114 N., R. 81 W., Sully County



PIERRE FORMATION
Sully Member
Verendrye zone
Yellowish gray shale
Oacoma zone
Upper micaceous bentonite
Big bentonite bed
(Light gray shale)
Lower micaceous bentonite
Agency zone
Gray siliceous shale
Base of Outcrop

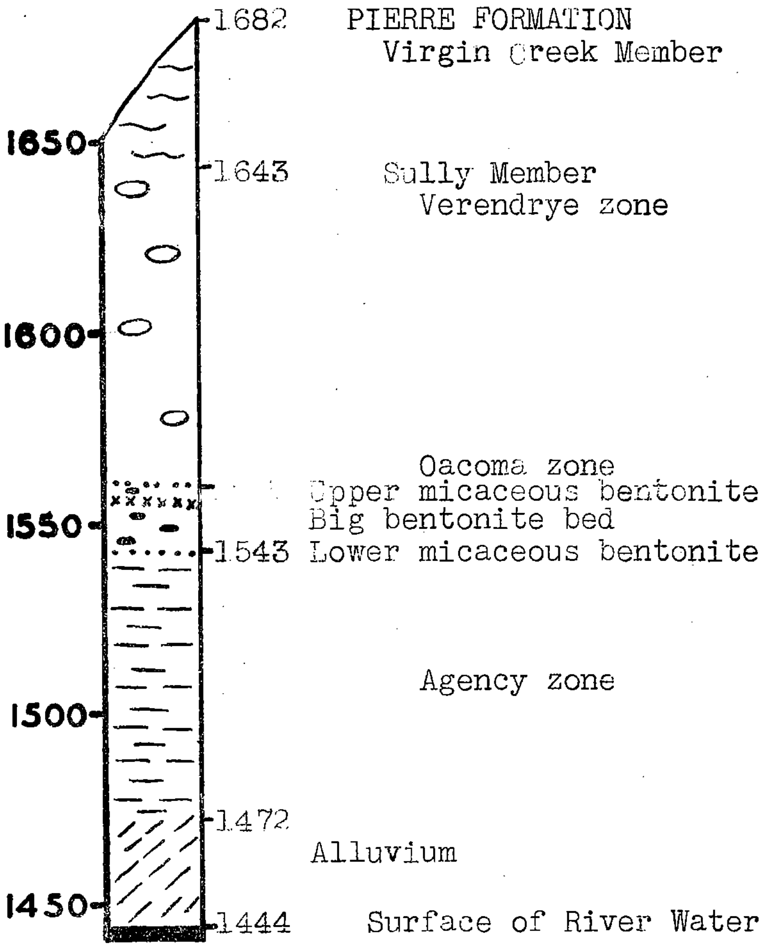
Lower micaceous bentonite:

Olive green bentonite		2"
Rusty	"	$\frac{1}{4}$"
Micaceous (Biotite)	"	$1\frac{1}{4}$"
Yellow bentonite		1"

Alluvium

Surface of River Water

SUCCESSION OF BEDS, 6 MILES NORTH OF CHANTIER CREEK
Sec. 21, T. 7 N., R. 29 E., Stanley County



SUCCESSION OF BEDS INSIDE LITTLE BEND
Sec. 17, T. 115 N., R. 81 W., Stanley County

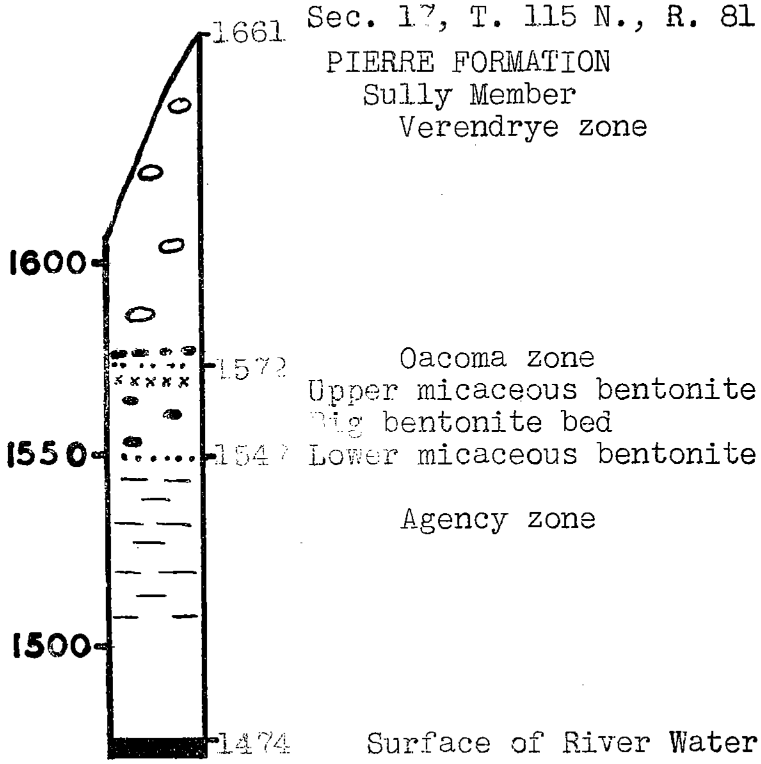


Figure 19

Chantier Creek Section

Chantier Creek enters the Missouri river at the Oahe Bend in Stanley county. In this locality the breaks in the river valley are not much grassed over; hence there are many good exposures of shale. The section is in the NE. $\frac{1}{4}$ of Sec. 27, T. 6 N., R. 29 E., and was measured in detail by Gries. The writer applied sea 1 level elevations to the contacts by running a traverse by plane table from the U.S. Geological Survey bench mark which is located a short distance north of the abandoned site of the Riverview school, on the west side of the county graded road.

There is some question about the top of the Virgin Creek. The buff calcareous shale beds resemble the Mobridge in the upper 71 feet of the section. These beds are conspicuous and can be seen from the road.

About $1\frac{1}{2}$ miles up the county road a side road turns down into the breaks. Along this road most of the section can be examined. It can be followed for several miles through the breaks to within about two miles south of Fort Bennett. However, a better road to the Fort branches off the county road a few miles north from the Chantier Creek road.

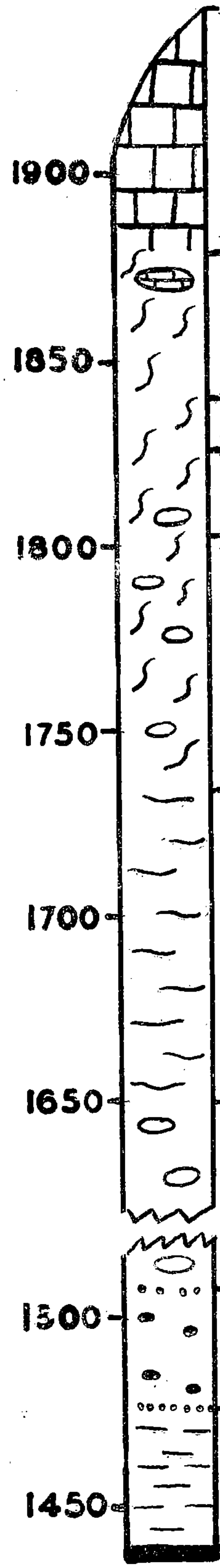
Shales are quite well exposed in the breaks from Fort Bennett along the river southward to Giddings Flat which is across the river from Oahe. The three bentonite key beds in the Oacoma member can be traced with ease along this part of the valley. The Chantier Creek-Oahe Bend area is in a synclinal structure.

The area was mapped in detail for structure by members of the State Geological Survey during the summer of 1939.[1] The Lower Micaceous Bentonite bed was used as the key horizon. The text of the report contains several detailed sections of outcrops which were measured during the survey.

1. J.P. Gries, A Structural Survey of Northeastern Stanley County, South Dakota.

SUCCESSION OF BEDS NEAR MOUTH OF CHANTIER CREEK
NE. 1/4, Sec. 27, T. 6 N., R. 29 E.

Section measured by Gries.



1936 PIERRE FORMATION

Shale, gray, chalky, weathers yellow (Mobridge?). Contains Belemnitella. Base marked by a layer of small, ironstained concretions and baculites

Upper Virgin Creek Member

1877 Shale, gray, calcareous; contains "crab" zone and some white limestone concretions

1839 Shale, gray, non-calcareous, contains several bentonites

1826 Shale, gray, non-calcareous; zone of large white concretions at base, one at top and one between; some bentonite

1803 Shale, gray, non-calcareous, weathers to gumbo; contains worm-eaten concretions and serpula; some bentonites in upper part

1735 Lower Virgin Creek

Shale, gray, flaky, weathers to silvery sheen; many bentonites, especially at base

Sully Member

Verendrye zone

1650 Shale, gray, non-siliceous, bentonitic; weathers to yellow-gray flakes, then to gumbo; iron-manganese concretions abundant

150[illegible] Oacoma zone

Shale, banded, with many bentonites

1476 Agency zone

Shale, slightly siliceous, light gray

1438 Surface of River Water

Figure 20

SUCCESSION OF BEDS BELOW GIDDINGS FLAT

Sec. 29, T. 6 N., R. 30 E., Stanley County

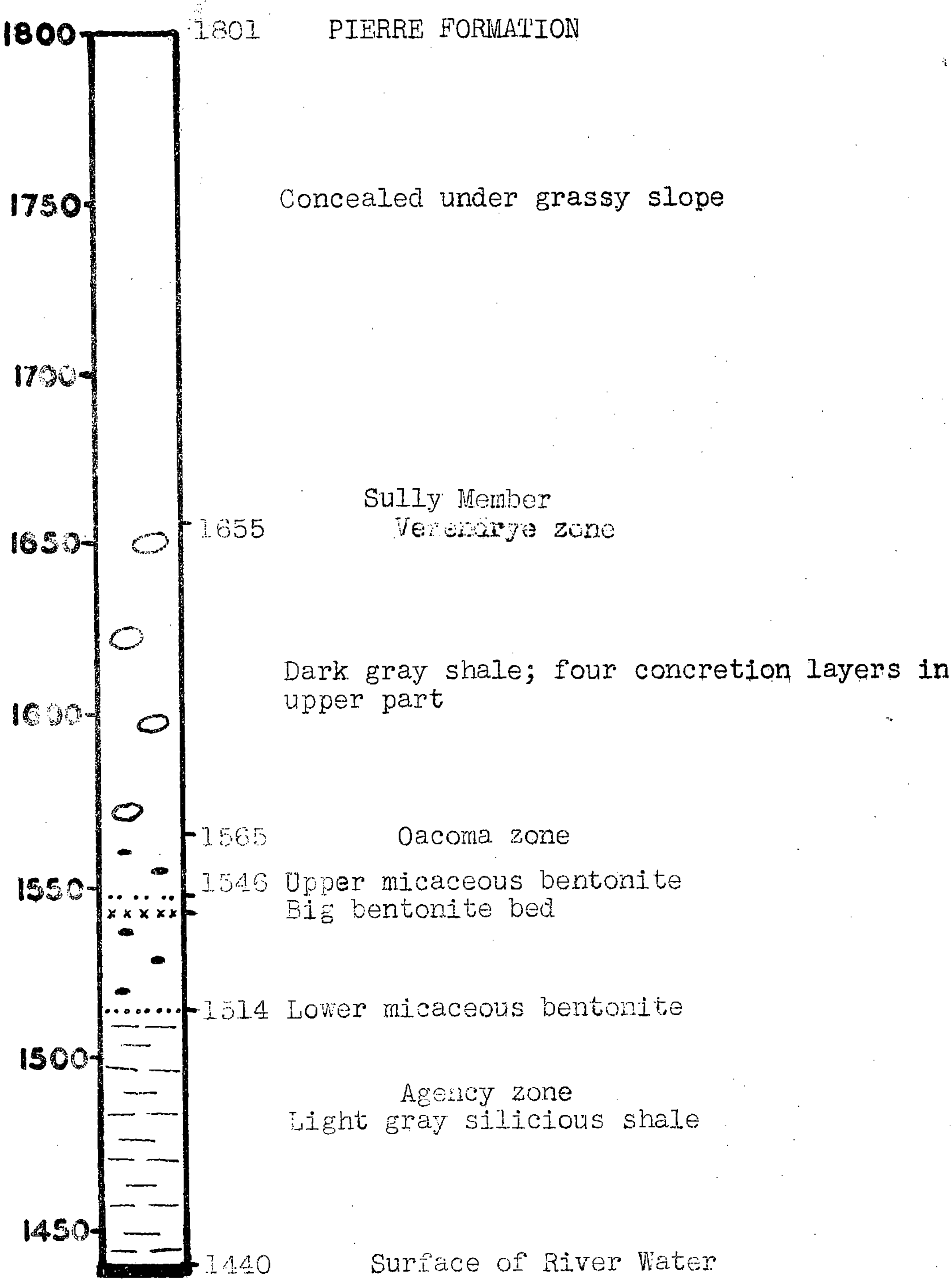


Figure 21

SUCCESSION OF BEDS AT OAHE DAM SITE

Sec. 1, T. 111 N., R. 81 W., Hughes County
Underground date furnished by C.R. Golder, Geologist

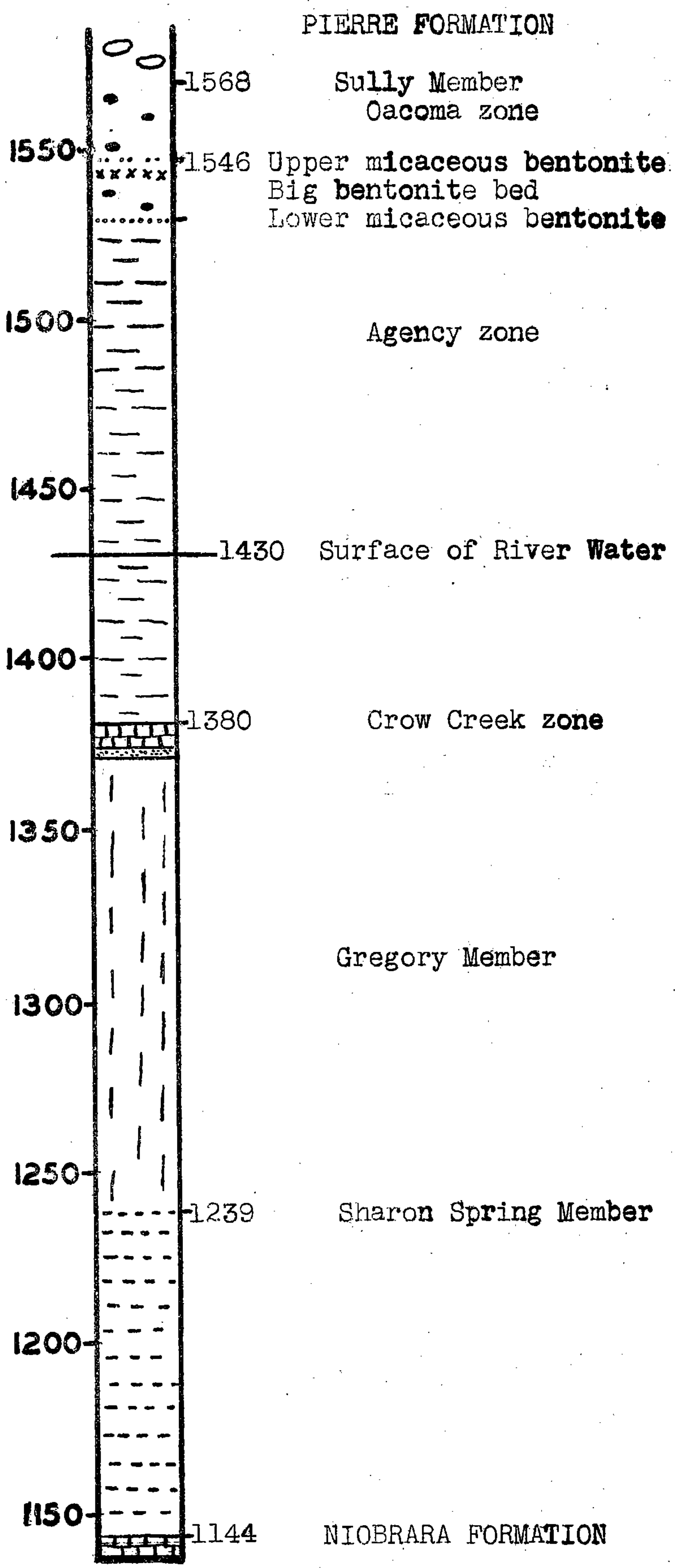


Figure 22

Pierre-DeGrey Section

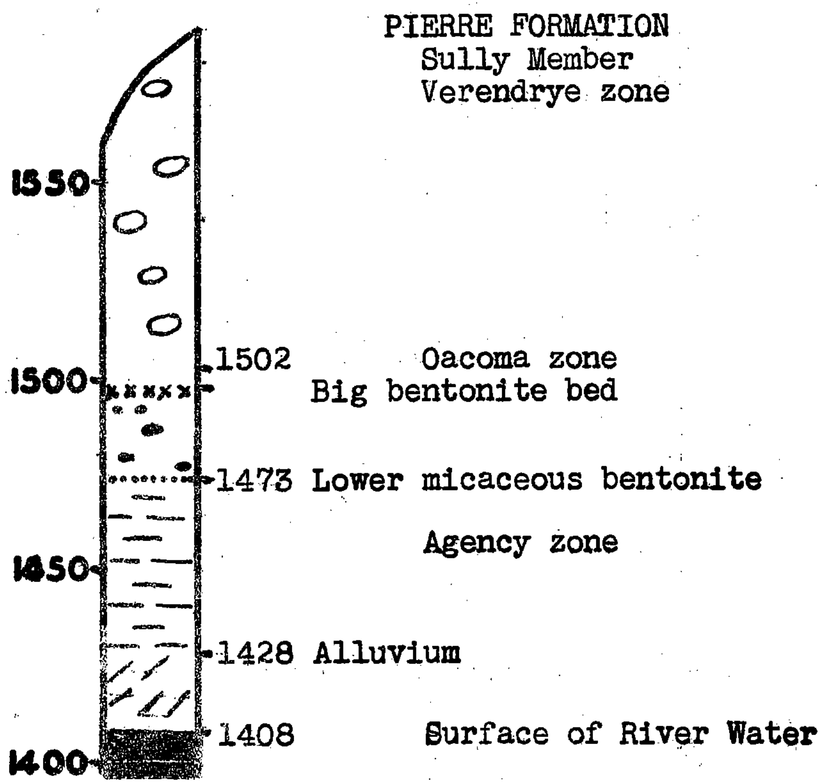
From Pierre eastward toward Rouseau on the north side of the river the valley is glaciated and very much covered with all sizes of glacial boulders and grassed over. Occasionally a small patch of the Sully member is exposed. Toward Rouseau more shale is exposed and the Upper Micaceous Bentonite and the Big Bentonite bed of the Oacoma zone are well developed and can easily be traced. The flood plain covers the lower portion of the Oacoma.

From Rouseau to DeGrey there are no outcrops. The country is rugged, grassed over and boulder strewn. Some shale is exposed in road cuts. Above DeGrey, the country is flat but from Chapelle Creek at DeGrey around the river bend to Dorian Island the country bordering the river is rugged with many outcrops of shale; the upper Gregory and nearly all of the Sully members are present.

Bench marks of the Missouri River Commission, U.S. Geological Survey and the U.S. Coast and Geodetic Survey are numerous along the highway and the river. Three topographic sheets by the U.S. Geological Survey, the Oahe, Pierre and Canning quadrangles, cover the area from Oahe to Rouseau.

On the west side of the river from Giddings Flat to the south Stanley county line, a distance of 55 miles, shales are exposed along the entire length of the valley. The shales of the breaks belong to the Sully member and those of the upland country, to the Virgin Creek member. Somewhere between Rouseau and Pierre the Crow Creek zone of the lower Sully disappears beneath the river. This area is also the northern limit of the concentrates of the manganese nodules of the Oacoma zone.

SUCCESSION OF BEDS AT MOUTH OF ANTELOPE CREEK
Sec. 29, T. 4 N., R. 33 E., **Stanley County**



SUCCESSION OF BEDS 1½ MILES SOUTH OF DEGREY
Sec. 7, T. 109 N., R. 75 W., **Hughes County**

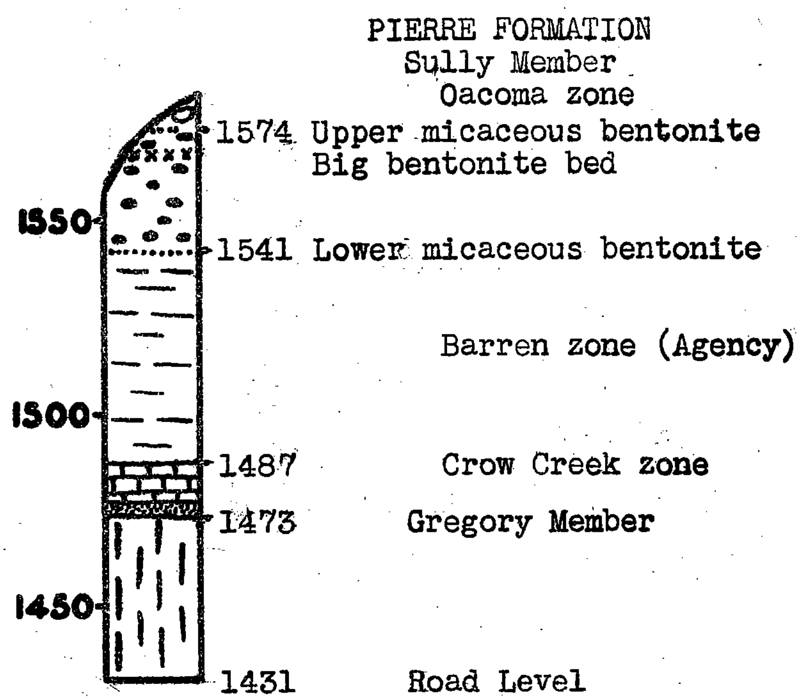


Figure 23

DeGrey to White River

That part of the Missouri valley from DeGrey to the White river which contains the Big Bend of the river is described in detail in previous Reports of Investigations by the State Geological Survey.[1] The purpose of those investigations was a study of the manganese deposits and the structure of the region.

This area has many roads and trails on which the river can be reached. Shales are exposed on both sides of the valley throughout the area and for many miles up the larger creeks. The last outcrops of the Niobrara chalk appear at Fort Thompson and Camel Creek. There are no outcrops of the Pierre shale inside of the Big Bend and north of the river inside of the meander at Joe Creek.

Many key beds to formations and contact horizons can be found in the shale outcrops along this portion of the valley.

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1. J.P. Gries and E.P. Rothrock, Manganese Deposits of the Lower Missouri Valley in South Dakota; Monta E. Wing and J.P. Gries, Stratigraphy and Structure of the Chamberlain Section of the Missouri River Valley, R.I. 39, S. Dak. Geol. Survey, 1949; E.P. Rothrock, Missouri Valley Manganese Deposits between Lower Brule and DeGrey; Bruno C. Petsch, The Medicine Butte Anticline.

SUCCESSION OF BEDS NORTH OF KENNEBEC

Sec. 33, T. 108 N., R. 75 W., Lyman County

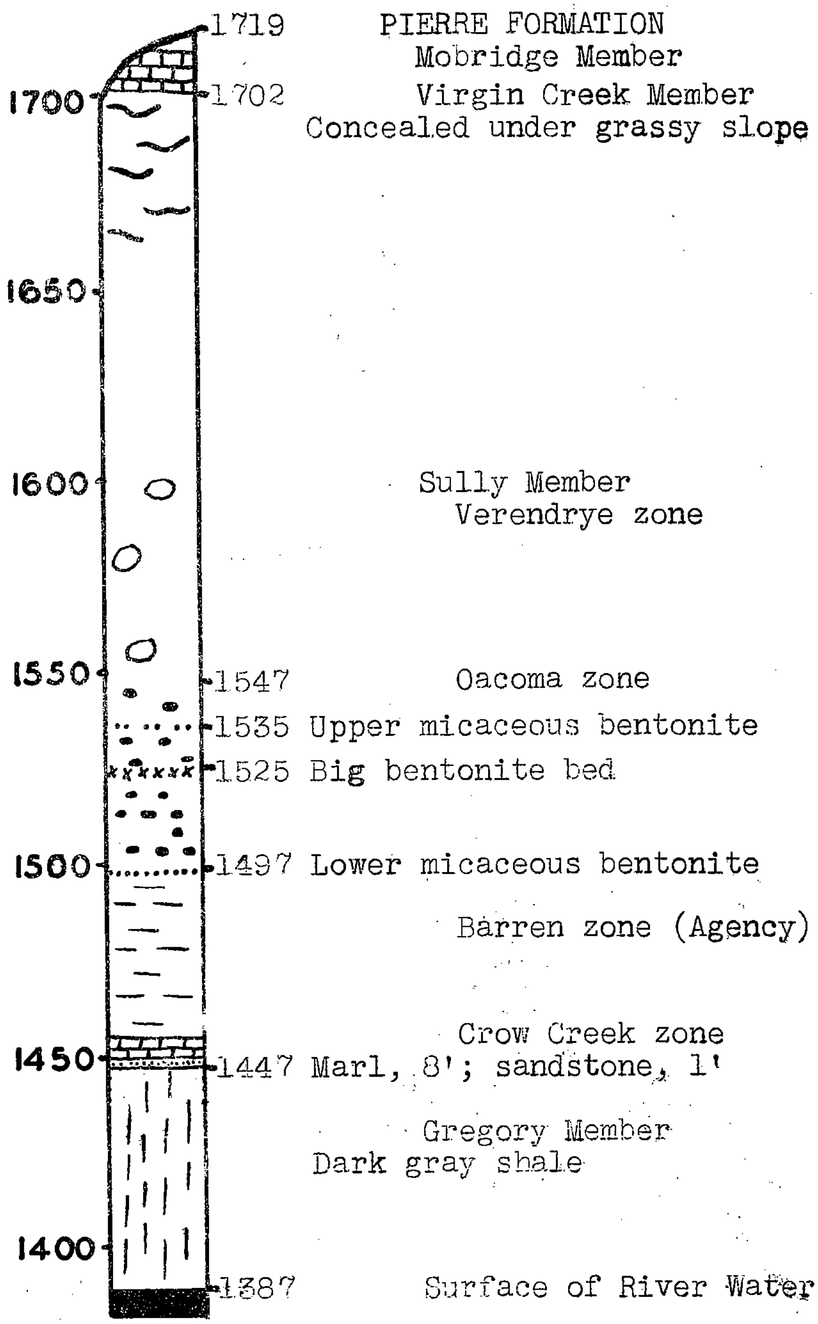


Figure 24

SUCCESSION OF BEDS AT ELM CREEK

Sec. 10, T. 101 N., R. 71 W., Brule County

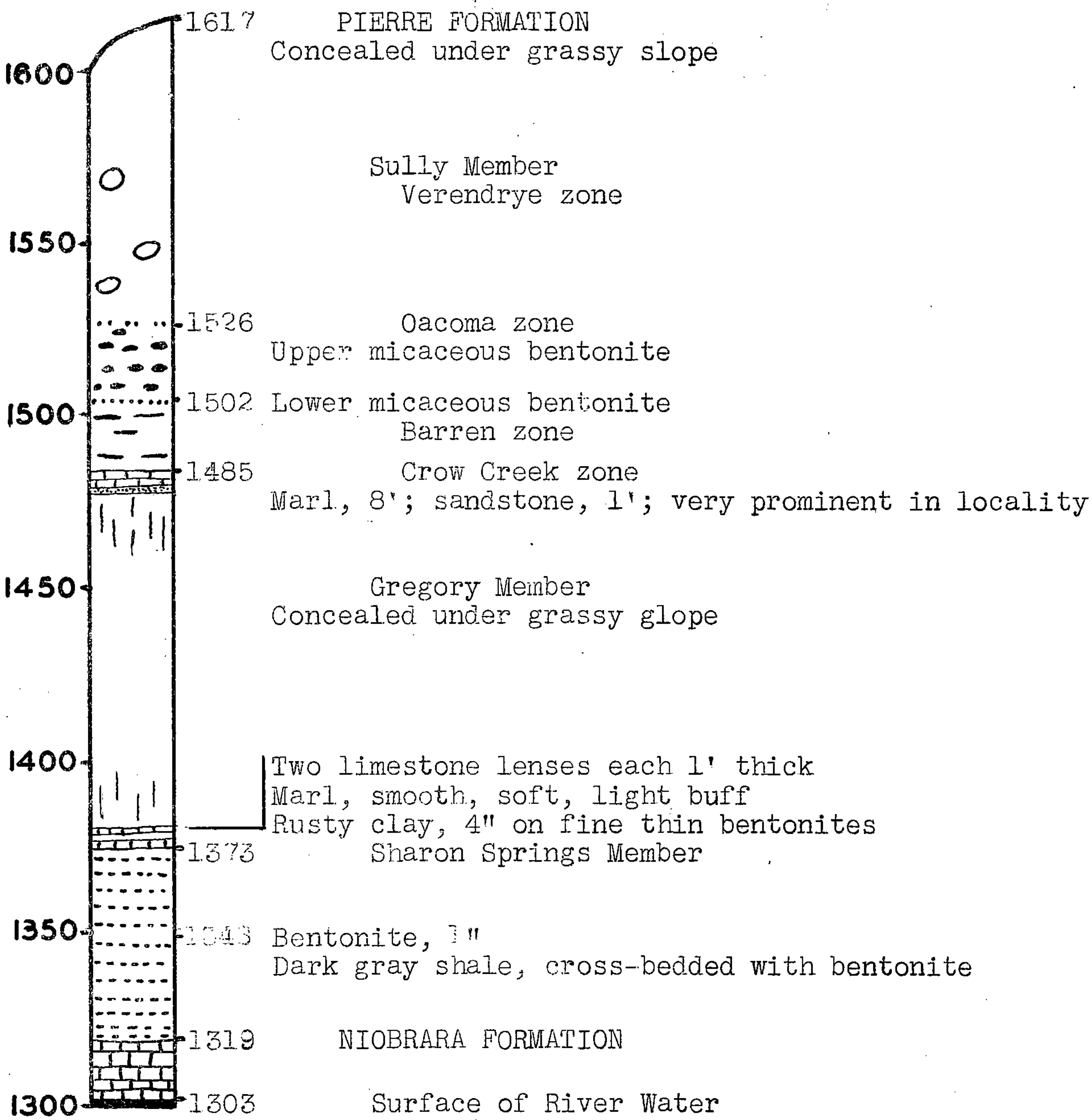


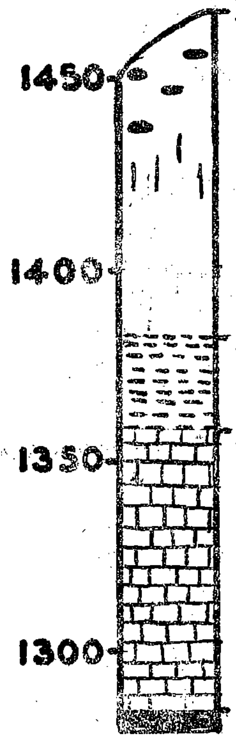
Figure 25

Bijou Hills - Wheeler-Rosebud Bridge - Choteau Creek

The Niobrara chalk formation is the bed rock of the river. Outcrops of it can be seen almost anywhere at the low end of the breaks and at the water where the outcrop is generally a high vertical cliff. The upland country has the Mobridge member but a veneer of glacial drift covers it on the east side of the valley. The rim of the valley usually ends abruptly and the Mobridge is exposed in steep vertical cliffs. Glacial drift is almost down to the flood plain in the locality at the mouth of Platte Creek in Charles Mix county.

In Gregory county the breaks are well grassed over with an occasional outlier of Mobridge exposed. From the Wheeler-Rosebud bridge along the river to Choteau Creek which is the Charles Mix-Bon Homme county line, one can drive on the flood plain except for about seven miles northwest of Rising Hill colony. Once a road existed here. West of Greenwood the Niobrara chalk cliffs are at the water and the road is at the base of the cliff. The flood plain is wide and the outcrops are back from the river. They are grassed over and covered with glacial drift. Niobrara chalk and sometimes Sharon Springs shales are exposed. Glacial drift covers all the sedimentary rocks in the vicinity of Choteau Creek.

SUCCESSION OF BEDS AT MOUTH OF SNAKE CREEK
Sec. 6, T. 99 N., R. [illegible] W., Charles Mix County



1447 PIERRE FORMATION
Sully Member
Gray shale; manganese-iron concretion zone near top

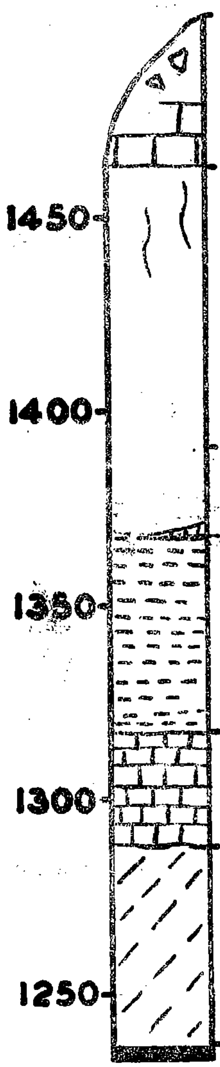
Gregory Member
Concealed under grassy slope

1382 Sharon Springs Member

1358 NIOBRARA FORMATION
Vertical chalk cliff

1285 Surface of River Water

SUCCESSION OF BEDS AT RISING HILL COLONY
Sec. 36, T. 95 N., R. 65 W., Charles Mix County



1503 Pleistocene Glacial Drift

PIERRE FORMATION
Mobridge Member
1463 Virgin Creek Member
Dark gray shale

Concealed under grassy slope

Springs

1366 Sharon Springs Member

1317 NIOBRARA FORMATION
Vertical chalk cliff

1288 Alluvium

1237 Surface of River Water

Figure 26

SECTION OF SHARON SPRINGS MEMBER

6 miles south of Lake Andes
Sec. 5, T. 95 N., R. 65 W.

	Feet	Inches
Glacial Drift to Top of Hill		
Gregory Member		
Trace of yellow to buff marl		
Sharon Springs Member		
Dark gray shale	4	
Yellow bentonite		.2
Dark gray shale	28.3	
Bentonite		1
Dark gray shale, cross-bedded with bentonite		2.3
Bentonite		2
Black cross-bedded shale and bentonite		15
Yellow disseminated bentonite		2
Black shale		7
Yellow bentonite		3
Black shale		3
Bentonite		1
Black shale		3.5
Buff bentonite		1
Black shale		1
Yellow bentonite		1
Black Shale laminated with bentonite		3.3
Yellow bentonite		.5
Black shale		1.2
Brown bentonite		2
Grey chalk		4
Hard iron laminated shale		1
Soft black bentonitic shale, moist		.5
Rusty-yellow bentonite		1.5
NIOBRARA FORMATION		
Black chalky shale and chalk in creek bed		

Figure 27

Choteau Creek - Big Sioux River

The river cannot be reached with a car from Choteau Creek to within about 4 miles above Running Water. A good graveled highway leads to the Running Water ferry landing.

High vertical cliffs of Niobrara chalk border the river in the vicinity of Running Water and occasional exposures of Sharon Springs outcrop below the drift which is the upland formation in the area. From Running Water to Springfield railroad station, which is west of Springfield, the chalk cliffs are over a mile back from the river. A good road leads along the base of the cliffs on the flood plain.

From the railroad station through Springfield and east for several miles are high vertical cliffs of the Niobrara chalk covered with glacial drift. South of Bon Homme townsite through the army bombing range and eastward beyond the Mennonite colony the glacial drift obscures the formation. Three miles west of the Mennonite colony the river has formed a high vertical cliff of the drift. From Gavin's Point to Yankton the Niobrara chalk cliffs are back from the river with a road on the flood plains at the base of the cliffs. Roads on the upland are plentiful. The country on the Nebraska side of the river is very rugged to a point across from Sioux City and has outcrops of the Benton group and the Dakota formation, both along the river and tributary streams.

The country from Yankton to the Big Sioux river on the north is a wide flat flood plain and outcrops are several miles from the Missouri river.

SUCCESSION OF BEDS NORTH OF VERDEL, NEBRASKA

Sec. __, T. 33 N., R. 8 W., Knox County

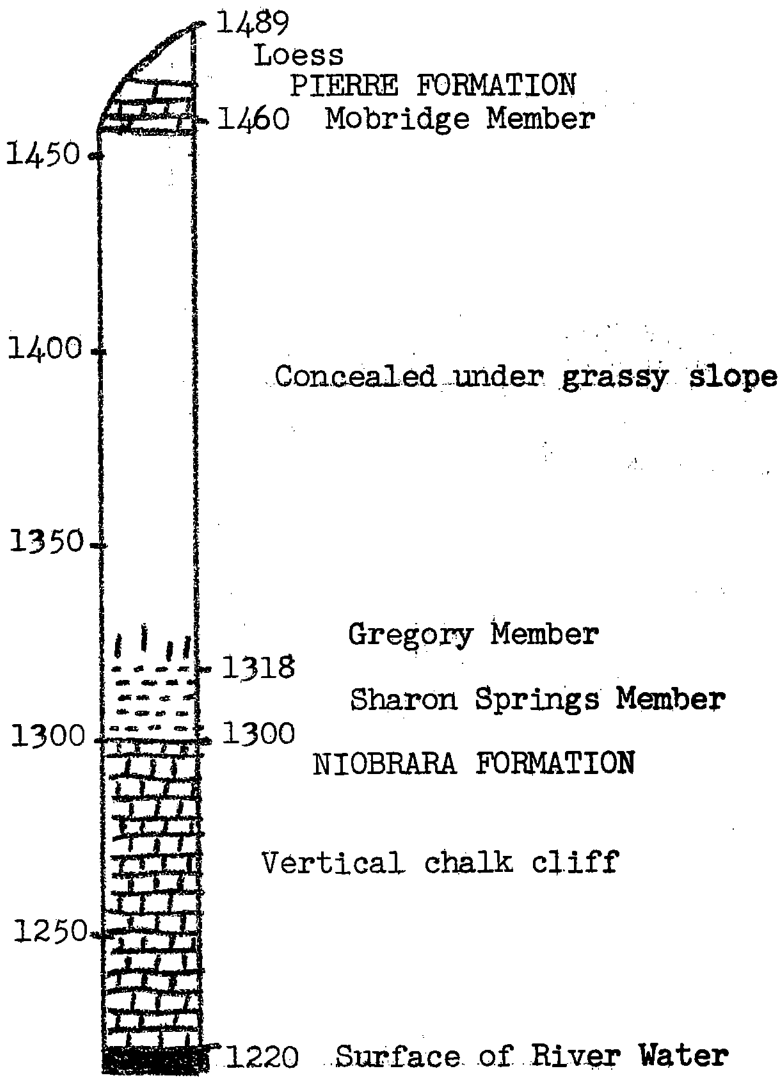


Figure 28

SUCCESSSION OF BEDS WEST OF OLD CEMENT PLANT

Sec. 17, T. 93 N., R. 56 W., Yankton County

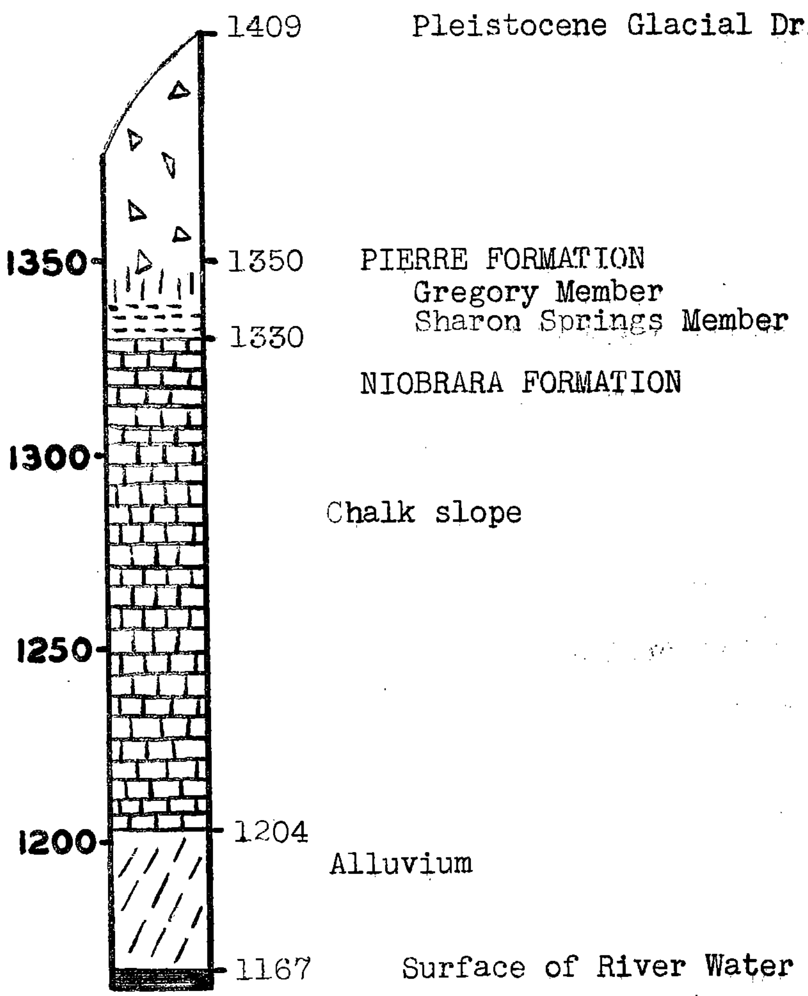


Figure 29

REVIEW OF MINERAL RESOURCES

IN THE

MISSOURI VALLEY

Several minerals are present in the sedimentary rock of the Missouri valley. These minerals occur in vast quantities over large areas and their importance is determined by economic conditions which are caused by the trend of times and by technical improvements.

It is not within the scope of this report to outline or describe in detail each mineral, but they are listed briefly as a review. Some of these minerals have been subject matter in previous reports of the South Dakota State Geological Survey and other agencies.

The mineral products are grouped under the following headings:

- Metals
- Fuels
- Structural Materials
- Clays and Ceramic Products
- Miscellaneous Minerals
- Water Supplies

Product	Mineral	Est. Amount
Manganese	Iron Carbonate Nodules	80,904,000 Tons 15,209,000 Tons Mn
Aluminum	Pierre Shale	Unlimited
Fuel	Natural Gas	Limited
Petroleum	Sharon Springs Oil Shale	123,442 Tons per Acre
Petroleum	Paleozoic Formations	Shows
Structural Material	Sand and Gravel	846,591,000 cu. yds.
Clays	Bentonite	Limited
Pottery Clay	Pierre Shale	Limited
Brick and Tile Clay	Pierre Shale	Unlimited
Refractory Clay	Pierre Shale	Limited
Road Metal	Pierre Shale	Unlimited
Abrasive	Volcanic Ash	Limited
Water Supplies		Unlimited
Whiting and Lime and Rock Wool	Niobrara Chalk	221,314 Tons per Acre

Information on mineral resources of the Missouri valley may be found in the following Reports of Investigations by the State Geological Survey:

R.I. 2 A Preliminary Report on the Chalk of Eastern South Dakota, E.P. Rothrock

R.I. 18 Water Supplies at Fort Thompson, E.P. Rothrock

R.I. 23 The Geology of the Crow Creek Dam Site, E.P. Rothrock

R.I. 26 Artesian Conditions in West-Central South Dakota, E.P. Rothrock and T.W. Robinson

R.I. 27 Lithologic Stratigraphy of the Pierre Formation in the Missouri Valley in South Dakota, W.V. Searight

R.I. 29 A Structural Survey of the Pierre Gas Field, Monta E. Wing, 1938

R.I. 31 A Structural Survey of the Upper Missouri Valley in South Dakota, J.P. Gries, 1939

R.I. 32 Mineral Products and Missouri River Navigation in South Dakota, E.P. Rothrock, 1939

R.I. 34 A Structural Survey of Northeastern Stanley County, South Dakota, J.P. Gries, 1940

R.I. 38 Manganese Deposits of the Lower Missouri Valley, E.P. Rothrock and J.P. Gries, 1941

R.I. 43 Economic Possibilities of the Pierre Shale, J.P. Gries, 1942

R.I. 45 The Medicine Butte Anticline, Bruno C. Petsch, 1942

R.I. 46 Missouri Valley Manganese Deposits Between Lower Brule and DeGrey,. E.P. Rothrock, 1943

R.I. 47 Sand and Gravel Deposits in the Missouri Valley Between Little Bend and White River, E.P. Rothrock, 1944