* *

STATE OF SOUTH DAKOTA

Harlan J. Bushfield, Governor

STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

NO. 43

ECONOMIC POSSIBILITIES OF THE PIERRE SHALE

by

John Paul Gries

University of South Dakota
Vermillion, S. Dak.
May, 1942

* *

SOUTH DAKOTA

STATE GEOLOGICAL SURVEY

ECONOMIC POSSIBILITIES

OF THE

PIERRE SHALE

by

John Paul Gries
Assistant Professor of Geology
South Dakota State School of Mines

TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
II.	STRATIGRAPHY	
	The Pierre Formation of the Missouri Valley	3
III.	STRATIGRAPHY	
	The Pierre Formation North of the Black Hills	43
IV.	STRATIGRAPHY	
	The Pierre Formation South of the Black Hills	54
V.	ECONOMIC POSSIBILITIES OF THE PIERRE FORMATION	
	Aluminum	63
	Barite	67
	Bentonite	68
	Cement	70
	Chalk	71
	Clay	71
	Gas	72
	Gypsum	72
	Manganese	73
	Oil Shale	77
	Soils	78
	Water	79

LIST OF ILLUSTRATIONS

TABLES

		Page
Table I	Classification of the Pierre Formation......	13
Table II	Aluminum Content of the Pierre Shales.......	66

MAPS AND DIAGRAMS

Figure 1	Map showing distribution of the Pierre Formation..............................	4
Figure 2	Generalized Columnar Section of the Pierre Formation in the Missouri Valley...	6
Figure 3	Cross Section of the Agency-Oacoma Zone.....	21
Figure 4	Correlation of the Missouri Valley Sections of the Pierre Formation...................	30
Figure 4a	Index Map Showing Location of Measured Sections..............................	30a
Figure 5	Columnar Section at the Wheeler Bridge......	32
Figure 6	Generalized Columnar Section of the Pierre Formation in Butte County..........	47
Figure 7	Columnar Section of the Pierre Formation on the Belle Fourche River. (SectionXVI).....	50
Figure 8	Columnar Section of the Pierre exposed on Two Top Peak, Butte Co. (Section XVIII)..	52
Figure 9	Generalized Section of the Pierre Formation South of the Black Hills..................	59
Figure 10	Map Showing Outcrops of Commercial Bentonite in the Pierre Formation..................	69
Figure 11	Map of Outcrops of Manganese bearing portion of the Agency-Oacoma Zone................	74

PHOTOGRAPHS

Plate I	Basal Members of the Pierre Formation.......	34

I. INTRODUCTION

The Pierre formation has been defined as the series of gray shales lying above the Niobrara Chalk and below the Fox Hills Sandstone. It lies at the surface over about 20,000 square miles of the state of South Dakota, and is present under younger deposits in much of the remaining area. Because it is the formation out of which much of the present topography is carved, the thickness is highly variable. It ranges from at least 1700 feet where the sequence is complete, to nothing where it has been entirely removed by erosion.

Purpose of the present study. Because of the widespread occurrence of the Pierre shale, it has seemed advisable to investigate the economic possibilities of the formation. This paper presents the conclusions of such an investigation, conducted by the State Geological Survey during the months of July and August, 1941. The present uses and resources of the Pierre are described, and several potential economic aspects discussed.

Nature and scope of the work. This survey was made by a two man party, consisting of Mr. R. P. Maloney as instrument man, and the writer as geologist. Because instrument work was limited, Mr. Maloney actually served as an assistant geologist much of the time.

The first aim of the investigation was to thoroughly sample the Pierre formation. Because the different members into which the formation may be subdivided have different properties, and because these members themselves vary from place to place, the problem soon resolved itself into a stratigraphic study. That is, it became necessary to recognize these various zones, and to measure their thickness in each locality before sampling could be done on a scientific basis.

The survey was started south of the Rosebud Bridge, and worked up the Missouri River to the North Dakota line. Then, because of limited time, a jump was made to the outcrop area south of the Black Hills, and then to the Pierre outcrops north of the Hills. Along the Missouri River, where the stratigraphy has been well worked out during previous surveys, progress was rapid, but farther west, where the formation has not been so thoroughly studied, progress was of necessity slow.

Method. Each section to be sampled was first carefully studied, then measured with a plane table and telescopic alidade. Outcrops were trenched where details were obscured by weathered material at the surface. Samples of each shale zone were taken from pits or trenches dug sufficiently deep to encounter fresh material. These were put in cloth sacks and forwarded to Vermillion, for subsequent study by the State Geological Survey and State Chemical Laboratory.

II. STRATIGRAPHY

THE PIERRE FORMATION OF THE MISSOURI VALLEY

Introduction

Name and Stratigraphic Relations: The Pierre formation was first described by Hall and Meek in 1855 from exposures along the Missouri River valley in South Dakota.[1] It was described as a lithologic unit, consisting of gray plastic clays lying between what are now called the Niobrara Chalk and the Fox Hills sandstone. In 1861 Meek and Hayden named these beds the Ft. Pierre Group and subdivided the group into four zones on lithologic and paleontologic evidence. In 1876 the same writers outlined the distribution of the Ft. Pierre in the northern great plains states.

Meek and Hayden considered that the Niobrara surface was channeled before the first Pierre shale was deposited, but subsequent studies have indicated that no break in deposition occurred, even though the transition from chalk or chalky marl to black fissile shale is sharp.

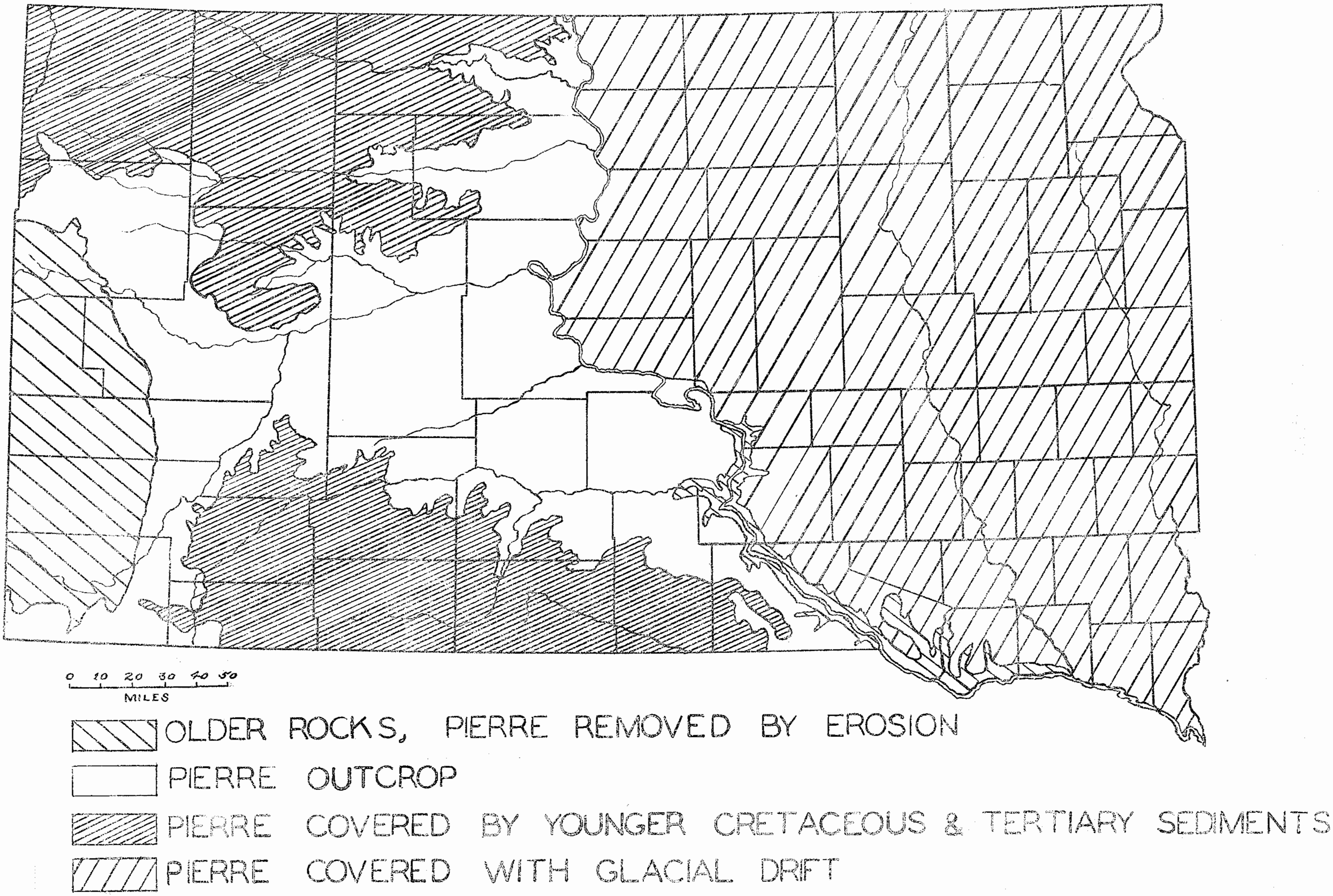
The contact between the Pierre shale and the Fox Hills sandstone is also one of gradation, formed as the muds of the retreating Pierre sea gave way to near shore sand deposits. Because of the slow retreat of the sea to the south, this transition occurred somewhat later in the south than in the north, a point which will be discussed in more detail later.

Previous Work: This has been described in other reports and will be only briefly summarized here. The first comprehensive study of the Pierre shale of the Missouri River area, made for the State Geological Survey by Searight in 1937[2], resulted in the subdivision of the formation into five members, several of which were in turn subdivided. Minor changes in nomenclature were introduced by the same writer

---

1. For a summary of work on the Pierre prior to 1876, see Meek, F.B., and Hayden, F.V., U.S. Geol. Survey of the Territories, Vol. IX, 1876.
2. Searight, W.V., Lithologic Stratigraphy of the Pierre Formation, of the Missouri Valley in South Dakota, Report of Investigations No. 27, S. Dak. State Geol. Survey, 1937.

DISTRIBUTION OF PIERRE FORMATION



in 1938[1] and 1939[2]. A series of detailed stratigraphic and structural studies have been made by the State Geological Survey since 1938.[3] Each has added to the understanding of the stratigraphic details, resulting in some further modifications of the classification and nomenclature as shown in Table I.

The contribution of the present study is primarily integrating this data by investigation of the intervening areas. Several new sections were measured, and some of the earlier sections restudied, or remeasured if the original measurement had been made by aneroid barometer. It is now possible to present a fairly complete and accurate picture of the Pierre formation along the Missouri River within South Dakota.

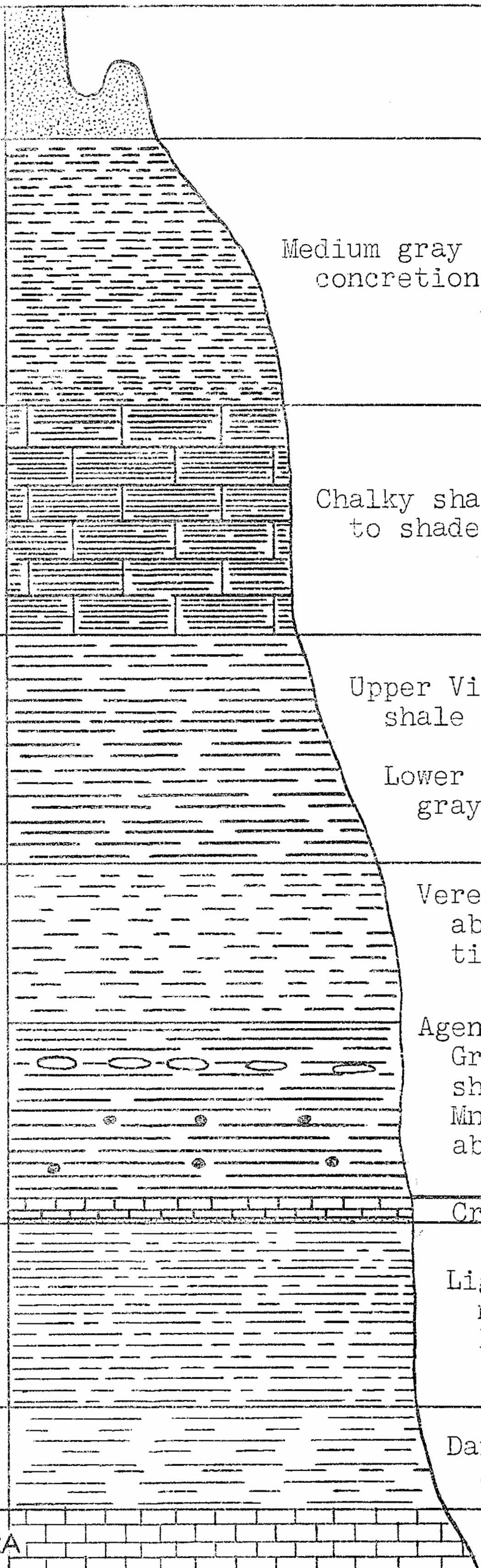
---

1. Moxon, A.L.; Olson, O.E.; Searight, W.V.; and Sandals, K.M.; The Stratigraphic Distribution of Selenium in the Cretaceous Formations of South Dakota and the Selenium Content of Some Associated Vegetation, Amer. Jour. Botany, Vol. 25, No. 10, pp. 794-809, December, 1938.
2. Moxon, A.L.; Olson, O.E.; and Searight, W.V.; Selenium in Rocks, Soils, and Plants, Technical Bull. No. 2., Agr. Exp. Sta., South Dakota State College Agr. and Mech. Arts, May, 1939.
3. See Reports of Investigation, Nos. 29, 31, 34, 38, 39, S. Dak. State Geol. Survey. Also Bibliography.

Note: Subsequent references to any of the above 8 papers will be made by author's name, date, and page number in the text.

GENERALIZED COLUMNAR SECTION
PIERRE FORMATION

Missouri Valley Area
Figure 2



Formation	Member	Description	Thickness
FOX HILLS FORMATION			
PIERRE FORMATION	ELK BUTTE MEMBER	Medium gray shale, flaky, few ferruginous concretions, mostly small.	100-243
	MOBRIDGE MEMBER	Chalky shale and chalk which weathers to shades of buff on outcrop.	90-241
	VIRGIN CREEK MEMBER	Upper Virgin Creek. Yellowish gray shale which weathers to gumbo.	65-142
		Lower Virgin Creek. Shale, bluish-gray with many bentonites.	26-145
	SULLY MEMBER	Verendrye Zone - Gray shale with abundant flat sideritic concretions.	88-180
		Agency-Oacoma Zone Gray, dominantly siliceous shale with many bentonites. Mn-Fe concretions locally abundant.	23-124
		Crow Creek. Chalk and sand.	2-15
	GREGORY MEMBER	Light gray to buff shale with many concretions and calcareous layers.	35-125
	SHARON SPRINGS	Dark bituminous shale with abundant fish scales	7-35
NIOBRARA		Chalk	

Sharon Springs Member

Name and Description: The Sharon Springs, as described in 1931 from the type locality in Kansas, consists of dark gray to black, slightly bituminous shale with abundant fish remains.[1] Similarity of the basal Pierre in Kansas and South Dakota was noted at that time, and Searight (1938) abandoned his term "lower Gregory" in favor of Sharon Springs. (See Table I). The same writer (1939, p.20) subdivided the Sharon Springs of South Dakota into a lower and an upper member on the basis of the lithology, and on the same page states that "In South Dakota all beds above the Niobrara formation and below the Gregory marl are included in the Sharon Springs member." Subsequent work (Gries and Rothrock, 1941, p. 9) has shown that the beds comprising the "upper" member actually lie above the Gregory marl, and are characterized by a general absence of fish remains. For that reason the Sharon Springs formation is now limited to the lower Sharon Springs of Searight, and the "upper" beds are included in the redefined Gregory member. The section at the west end of the Rosebud Bridge, Gregory County, is the type for the original Gregory member of Searight (1937), the restricted Gregory of Searight (1938), and the redefined Gregory of the 1941 report.

Subdivision: As explained below, the shale between the Niobrara chalk and the base of the Gregory formation is divisible south of Oacoma into two zones on the presence or absence of fish remains.

Fish Scale Zone

Description: The lower part of the Sharon Springs consists of a dark gray, fissile, somewhat bituminous shale containing on close examination an abundance of scales and other fragmentary remains of fish.

A bed of impure, rusty-colored selenite, varying from less than an inch to over a foot in thickness, is usually present at the contact with the Niobrara. The top of the fish scale zone is marked by a layer of small, 1 x 2 inch, white concretions which have been found in every exposure examined. Other concretions are typically absent.

---

1. Elias, M. K., The Geology of Wallace County, Kansas State Geological Survey of Kansas, Bull. 18, p. 58, 1931.

On steep slopes, outcrops of the fissile shale stand out in sharp, buttress-like forms which appear nearly black from a distance. Exposures on gentle slopes appear as patches of loose, light gray shale flakes. The surface of all outcrops is characterized by many small fragments of selenite, and a yellow ochrous "bloom" which runs in veinlets through the joint and bedding planes.

Numerous bentonite beds are a conspicuous feature of the outcrops. These are usually thin, though one-foot seams are not unusual. In a 14 foot section near the mouth of Crow Creek, Buffalo County, a total of 44 inches of bentonite has been recorded. In outcrops where the basal bentonites are particularly well developed, it has been noted that the associated shale is earthy in texture, in sharp contrast to the overlying fissile beds.

Small areas of burned shale testify to the bituminous nature of this zone. (See Gries and Rothrock, p. 10) Where burning has occurred, normally gray outcrops have become light pink to brick red, and the individual shale fragments are quite hard and have a harsh feel.

The only fossils seen in this zone are the numerous small fragmentary fish remains, and occasional bones of large marine reptiles.

Thickness: The fish scale zone is 34 feet thick at the Rosebud bridge, 14 feet southwest of Academy (See Section IV), 27 feet near Iona, 28 feet near the mouth of White River, 22 feet 8 miles up that stream, 25 feet 5 miles north of Chamberlain, and 14 feet at the mouth of Crow Creek in Buffalo County. The zone passes beneath the level of the river a few miles above this place. Searight (1937, p. 16) reports 7 feet of bituminous shale overlying the Niobrara at the old cement plant at Yankton, South Dakota.

Upper Shale Zone

Description: Above the fish scale zone lies a thin bed of soft, bluish-gray shale devoid of fish remains. It is characterized by occasional specks of red hematite, the presence of numerous, very fine, tubelike holes, and the almost complete absence of concretions. It lies immediately over the small white concretions at the top of the fish scale zone, and is bounded at the top by the concretionary or calcareous beds of the lower Gregory member. The zone is less resistant to weathering than the underlying fissile shale, and usually presents a gentle flaky slope marked by selenite and yellow ochre "bloom."

Thickness: Only one foot of this shale was observed by the writer at the Rosebud bridge section, but a few feet more may have been concealed by slumping of the Gregory Chalk at the point measured. Nine feet have been noted at Iona, and 14 feet near the mouth of White River. Farther north the upper contact is not conspicuous, and the zone, if present, has been included in the Gregory.

Correlation: This upper shale zone does not fit the description of the Sharon Springs of the type locality. It is tentatively included with that member only because it appears more closely related to the fish scale zone than to the overlying Gregory member.

Gregory Member

Discrepancies in the classification and correlation of this part of the Pierre have arisen because the thin sand and marl zone lying at the base of the manganese zone was overlooked when the Rosebud bridge section was first studied. Investigation in 1940 (Gries and Rothrock, p. 11) showed that the Crow Creek chalk of the Chamberlain area should be correlated with this overlooked sand and marl zone, and not with the conspicuous calcareous zone at the base of the Gregory.

Name: The name Gregory member is now used to include all beds between the base of the Gregory marl or calcareous zone, and the base of the overlying Crow Creek sand and chalk zone. These intervening beds form a distinct lithologic unit in the type locality, and as far north as Hughes County where they pass beneath the river level.

Subdivisions: At the Rosebud bridge, the Gregory member consists of two distinct lithologic units; a lower chalk bed and a thicker shale zone. To the north the chalk loses its identity and the shale increases in thickness.

Chalk Zone

Description: At the type locality this bed consists of about eight feet of impure light gray chalk, with small shale pebbles and scattered sand grains in the lower part. Southeast of Wheeler this contact was seen in only one place, near Rising Hill Colony in southern Charles Mix county. There, above the fissile shale, there appears a 2-3 foot layer of concretionary limestone overlain by a thin calcareous shale. A 5 foot impure chalk overlying the Sharon Springs in the old cement plant quarry west of Yankton has been correlated with this basal Gregory chalk (Searight, 1937, p. 16).

North from Wheeler, a poor exposure southwest of Academy showed 3-4 feet of impure chalk and concretionary limestone at this horizon. In the vicinity of Iona, Lyman County, the base of the Gregory is marked by a one to two foot layer of buff limestone overlain by a similar thickness of very calcareous shale. Near the mouth of White River, this horizon is characterized only by an intermittent zone of large one to two foot concretions, and farther north even this marker is generally absent.

Shale Zone

Description: This shale varies in color from light buff to dark gray when fresh, and from light brown to gray when weathered. Outcrops are typically banded with alternate beds of dark gray, non-calcareous shale containing brown ironstone concretions and light gray to buff calcareous layers.

The latter range from slightly calcareous shale to impure chalk and limestone in composition, and from a few inches to several feet in thickness. Of particular interest is an intermittent chalky bed which occurs a few feet below the top of the member near and opposite the mouth of Crow Creek, in Buffalo and Lyman counties. This bed varies from nothing to six feet or more in thickness over short distances, and is consequently very patchy in its distribution. Where well developed it closely resembles the basal Crow Creek zone of the overlying Sully member.

A conspicuous feature of all exposures of Gregory shale is an abundance of brown, fossiliferous concretions. These range from two to six or more inches in thickness, and may be small and intermittent, or may form nearly continuous ledges. Zones of large, one to two foot, gray limestone concretions are also present in some exposures.

At the type locality the basal 18 inches of the zone contains abundant fish remains, but these have not been observed elsewhere in spite of careful search.

Thickness: The thickness of the Gregory member varies greatly. Thirty-four feet were noted at the Rosebud bridge, 50 feet southwest of Academy (see Section IV), 72 feet east of Iona, 125 feet 8 miles up White River, 77 feet including the upper shale of the Sharon Springs near Bad Hand Bottom north of Chamberlain, 86 feet for the same interval at the mouth of Crow Creek, and about 40 feet still exposed beneath the Crow Creek chalk as far north as DeGrey, Hughes County.

Stratigraphic relation: Searight has suggested the possibility of an unconformity at the base of the present Gregory formation to explain variations in thickness of the underlying Sharon Springs. Further study is needed between Wheeler and Yankton, and also around the Black Hills before the validity of this suggestion can be checked.

Paleontology: The shale zone is relatively fossiliferous. The flat brown concretions contain numerous large specimens of _Inoceramus_ and _Baculites_. In one of the chalky layers north of Chamberlain (Gries and Rothrock, p. 14, and Table VII) an extensive fauna was found, including young specimens of _Pachydiscus complexus_. The fish remains in the basal beds at the type locality have already been noted.

TABLE I

CLASSIFICATION AND NOMENCLATURE OF THE PIERRE FORMATION IN MISSOURI VALLEY

Searight (1937)	Searight (1938)	Searight (1940)	R. I. 39 (1941)	This Report (1942)
Elk Butte	Elk Butte	Elk Butte	Elk Butte	Elk Butte
Mobridge	Mobridge	Interior	Mobridge	Mobridge
Virgin Creek	Virgin Creek	Virgin Creek	Virgin Creek	Virgin Creek
upper	upper	upper	upper	upper
lower	lower	lower	lower	lower
Sully	Sully	Sully	Sully	Sully
Verendrye	Verendrye	Verendrye	Verendrye	Verendrye
Oacoma	Oacoma	Oacoma	Oacoma	
Agency	Agency	Agency	Agency	Agency-Oacoma
	Gregory marl	Gregory	Crow Creek	Crow Creek
Gregory	Sharon Springs	Sharon Springs	Gregory	Gregory
			shale	shale
upper		upper	marl	marl
lower		lower	Sharon Springs	Sharon Springs

Sully Member

Name and Description: The Sully member was named by Searight (1937, p. 21) from typical exposures along the Missouri River in and opposite the western part of Sully County, South Dakota. As originally defined, it included all beds lying above what is now called the Crow Creek marl and below the bentonitic beds of the lower Virgin Creek member. Subsequently (Searight, 1938, p. 796) this sand and marl zone was included as a basal part of the Sully member.

Distribution: This member is exposed continuously along the Missouri and the lower parts of its tributaries from northern Nebraska as far north as Mobridge, Walworth County, South Dakota, where the uppermost zone passes beneath the level of the river.

Subdivisions: The Sully has been divided into four lithologic units, which are, in ascending order, the Crow Creek sand and marl, and the Agency, Oacoma and Verendrye shale zones. It will be suggested in this paper that the Agency and the Oacoma be combined, thus reducing the number of units to three.

Crow Creek Zone

Name and Description: The basal sand and associated chalky beds of the Sully member were originally correlated with the Gregory Chalk of the Rosebud bridge section. Subsequent studies (Gries and Rothrock, 1941, pp. 11,14) showed that this upper chalk was distinct from the Gregory chalk, and the basal Sully marl was then named the Crow Creek zone from characteristic exposures at and south of the mouth of Crow Creek, Buffalo County.

Basal Sandstone: This bed was first observed by Searight (1937, p. 13) who noted its persistence throughout the area of outcrop. In an unweathered condition, the sandstone is probably nearly white, but it appears even in relatively fresh exposures as brown, laminated blocks, and on further weathering these break down into numerous gently curved plates one eighth inch or more in thickness.

This sandstone has been shown to consist of fine sand and silt, cemented by calcium carbonate. Pebbles of the underlying shale were noted in this bed by Searight (1937, p. 13) but have been seen by the present writer only very rarely. The line of demarcation between the sand and the overlying marl is typically sharp, although the contact is apparently one of gradation.

The thickness of the sandstone averages between eight inches and one foot, although thicknesses from four inches to nearly two feet have been recorded. Because of the persistence and uniform thickness of this bed, it makes an excellent key horizon for structural mapping.[1]

Marl Bed: The calcareous phase of the Crow Creek zone may be described as a marl, although in many places it appears more as an impure chalk. This bed, because of its very light gray color, forms a conspicuous horizon throughout its area of outcrop. Where outcrops are steep, it forms a sharp band, but where slopes are gentle, it becomes more ragged because of the tendency of the overlying gumbo to creep down over the exposure. On very gentle, or grassed over slopes, it shows only as a band of yellow soil frequently supporting an abundant growth of wild yucca plants. The thickness of the marl averages between six and eight feet, with a maximum of 14 feet noted southeast of DeGrey, Hughes County, and a minimum of two feet at the Rosebud bridge. The marl is locally absent at the mouth of Medicine Creek in Lyman County.

Distribution: The Crow Creek zone has been identified only in the Missouri valley and its tributaries. It is inconspicuous in Gregory county, but becomes more prominent northward. It has been traced about 12 miles west along White River to the point where it dips beneath the level of the stream. It finally passes beneath the level of the Missouri in the vicinity of Rousseau, about 12 miles east of Pierre. It seems likely that the sandstone might be identified in well cuttings outside the area of outcrops.

Stratigraphic relation: The uniformity of the thin basal sandstone and the evenness of the line of outcrop both indicate that the Crow Creek beds were laid down over a smooth or gently undulating surface. The relation with the underlying Gregory appears to be one of conformity.

---

1. Wing, M.E. and Gries, J.P., Stratigraphy and Structure of the Chamberlain Section of the Missouri River Valley, S. Dak. State Geol. Survey Report of Investigations No. 39, April, 1941.

There is no evidence of a break between the marl and the overlying shale, although the line of contact is quite sharp.

Agency-Oacoma Zone

The Agency shale was originally named by Russell[1] for exposures of hard, light gray, siliceous shale occurring along the Missouri River in the vicinity of Cheyenne Agency, Dewey County, South Dakota. He traced the zone south to beyond the mouth of the Cheyenne, and north to where it passed beneath the level of the Missouri, just south of the junction of the Moreau River. The top of the member is characterized by a zone of large, grayish white limestone concretions; the bottom lies below river level; with an intervening thickness at the type locality of 115-120 feet.

Overlying the Agency in that area, Russell distinguished a 30 foot zone of alternating light and dark shale layers which weathered into stair-like outcrops. He referred to these beds as the LD (light-dark) member.

Searight (1937, p. 22) traced the Agency zone south to the vicinity of Crow Creek, Buffalo County, where he considered it to wedge out and disappear.

The Oacoma zone was named by Searight (1937, p. 23) for exposures along the Missouri River, particularly those in the vicinity of Oacoma, Lyman County. In the type locality the zone consists of gray shale containing an abundance of black iron-manganese carbonate concretions and numerous thin bentonite beds. Because of the alternating hard and soft layers, the outcrops weather with a stair-like effect. Searight considered these manganese bearing beds to lie on the Crow Creek chalk from Crow Creek south to beyond the Wheeler bridge, but north of Crow Creek he considered them to lie on the increasingly thick wedge of siliceous Agency shale. North of the Great Bend the manganese nodules become much less conspicuous. At Cheyenne Agency, the Oacoma of Searight comprised the LD beds of Russell.

In subsequent areal studies made by the State Geological Survey, the term Oacoma zone was limited to the stepped zone containing many bentonites which lay above the siliceous zone containing but few widely separated bentonites.

---

1. Russell, W.L., The Possibilities of Oil and Gas in Western Potter County, S. Dak. Geol. Survey Report of Investigations No. 7, 1930, p. 5.

In Potter and Dewey counties, careful trenching of the stepped zone above the typical Agency showed a persistent zone of 10-13 bentonites within an interval of 5 to 13 feet. This was taken as the Oacoma zone in that area.

Studies in northeastern Stanley County (Gries, 1940) revealed a somewhat thicker section, containing from 17 to 28 bentonites, lying above typical Agency shale. The lowest of these, a 6 inch bed containing abundant mica, and designated the lower micaceous bentonite (LMB), was chosen arbitrarily as the base of the zone and used as a key bed for structural mapping. Measurements within that area indicated that the bentonitic zone thickens to the north and west, from 36 feet at Fort Pierre to 46 feet near the mouth of the Cheyenne River.

An investigation of the manganese possibilities of the concretions in the Oacoma zone in the Chamberlain area was made by the State Geological Survey in 1940. This included detailed measurements of the concretion and bentonite beds of the manganese zone at intervals along the Missouri River from Gregory County to Hughes County. It was recognized that the manganese zone included beds below the lower micaceous bentonite of the Ft. Pierre area, and the suggestion was made that the lower beds of the "Oacoma" zone in the southern part of the Missouri Valley probably grade laterally into the much thicker siliceous Agency beds farther north. During the present survey, the lower micaceous bentonite, which was previously known to extend from Crow Creek to the Cheyenne, was traced northward across Armstrong County and was recognized 72 feet below the top of the Agency shale at Cheyenne Agency. See Plate II.

It is thus shown that the Oacoma zone as defined by Searight included not only the light and dark banded beds of Russell, but also part, if not all, of the Agency zone. The term Oacoma, however, cannot be entirely discarded in favor of the previously defined Agency, because it includes the upper banded beds (LD) which were separated from the Agency by Russell. Inasmuch as it is not possible to draw the line between the true Agency and the banded beds in the type locality of Searight's Oacoma zone, it is here suggested that both terms be retained, and that all beds lying between the Crow Creek chalk and the base of the Verendrye zone be hereafter referred to as the Agency-Oacoma zone.

This would follow Searight's concept of the Agency as a great wedge of siliceous shale, thinning to the south, but would differ in adding that the shale becomes much less siliceous as it thins, and that the zone extends much farther south than previously supposed. The bentonites which are more or less closely spaced through the section in the Oacoma-Chamberlain area become more widely spaced to the north.

The upper contact is not clear cut. It may be chosen as the top of the zone of thin bentonite beds which can be found in all areas. From Dewey county to Stanley county, this lies just a few feet above the zone of large, rusty concretions, and about 15-25 feet below the lowest purple concretion layer in the Verendrye. South of Stanley county, it may be taken as the top of the manganese concretion zone.

Thus delimited stratigraphically, no single lithologic description will fit the entire zone. As noted above, it consists primarily of a wedge of siliceous shale, thinning to the south, and becoming progressively less siliceous in that direction. It contains two types of concretions; one or two zones of large gray limestone concretions a foot or two across and up to a foot in thickness which weather rusty, and the smaller, more numerous iron-manganese concretions which characterize the zone, particularly south of the great bend. Thin bentonite beds are distributed throughout the zone, but where the zone is thick, they are more conspicuous near the top. Some of these, such as the one called the lower micaceous bentonite, may be traced great distances; others cannot be followed from one outcrop to the next. In a few instances, these grade laterally into thick lenses of unaltered volcanic ash. (Gries 1940, p. 27) Small, gray barite rosettes are occasionally found in bentonitic parts of the zone.

Distribution: The Agency-Oacoma zone is known from outcrops to extend along the Missouri and its principal tributaries from south of Wheeler, to a short distance below the mouth of the Moreau river, where it disappears beneath river level.

Thickness: The interval from the top of the Crow Creek marl to the top of the manganese zone measures 23 feet at Wheeler, 32 feet just north of Bijou Hills, 42 feet near Oacoma, 42 feet on Crow Creek, 38 at Lower Brule, 60 on Medicine Creek, 63 feet on Cedar Creek, and near DeGrey, where the Crow Creek is last seen above the river level, 84 feet has been measured. At Cheyenne Agency, in Dewey County, 124 feet has been measured above the level of the river. North of there, the exposed thickness decreases rapidly.

Verendry Zone

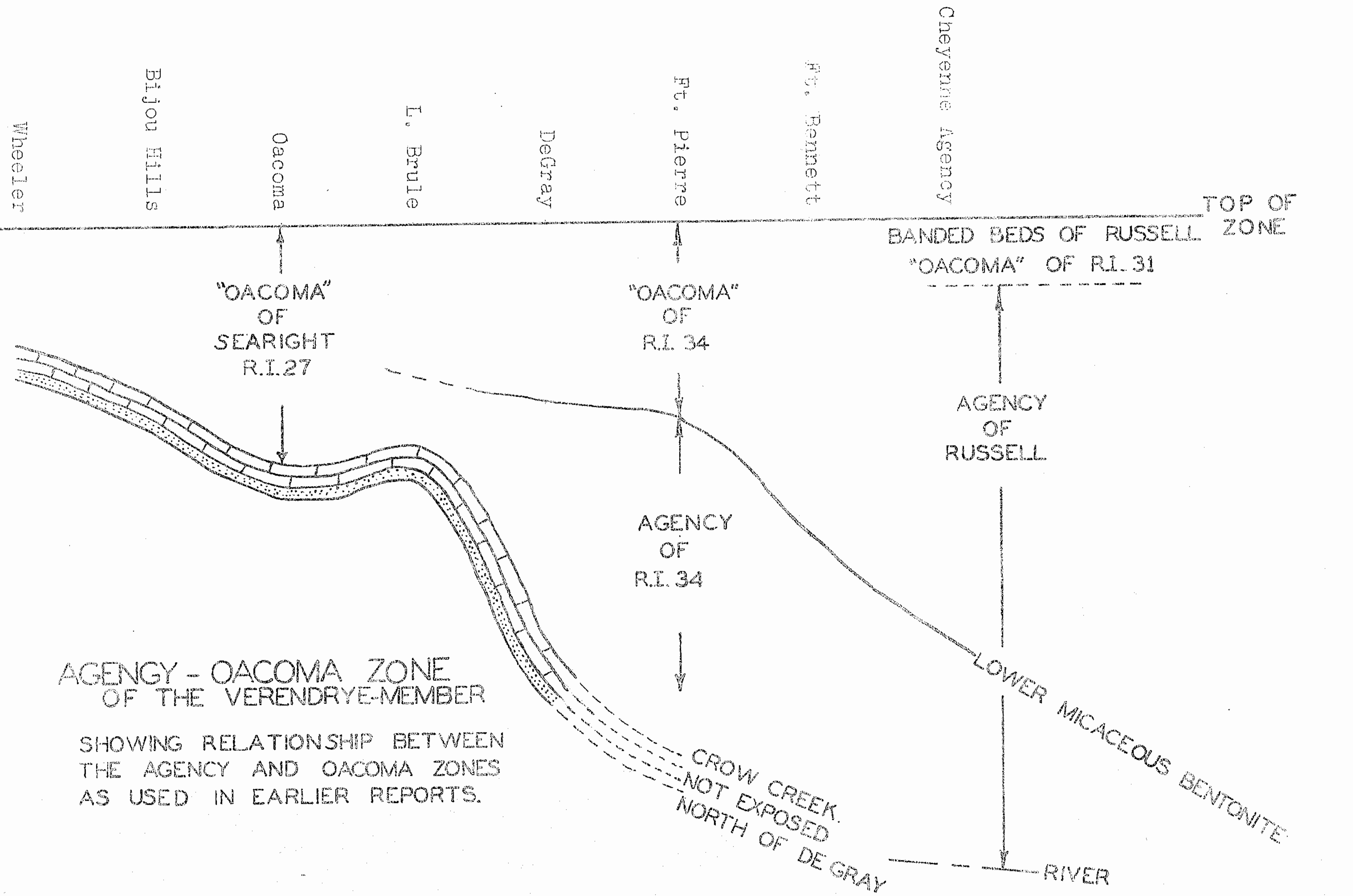
Name and Description: The uppermost subdivision of the Sully member has been called the Verendrye zone by Searight (1937, p. 25) from exposures near the Verendrye monument at Ft. Pierre, Stanley County. It includes all beds between the top of the Agency-Oacoma zone and the base of the bentonitic lower Virgin Creek member.

The Verendrye typically consists of light to medium dark shale which contains large, flat, iron-manganese carbonate concretions in more or less well defined layers. These may reach a diameter of several feet, but are generally six inches or less in thickness. They are usually gray or greenish gray on the interior, but weather to purplish black on the surface. South of the type area, the concretions are much less numerous in the lower third of the Verendrye. This basal, more or less concretion-free phase consists of alternate beds of light gray, somewhat flaky shale, and typical dark gray gummy shale, thus giving rise to the term "banded beds". The only concretions in this phase are zones of large gray to rusty limestone concretions, and occasional scattered buff lime nodules in the lowest few feet. Above the banded beds lies typical gray, gumbo-forming shale studded with large black iron-manganese concretions.

Distribution: The Verendrye zone is exposed along the Missouri River and its tributaries from south of the Nebraska line, north nearly to Mobridge, northwestern Walworth County.

Thickness: The contact of the Verendrye with the overlying Virgin Creek member is frequently difficult to locate, particularly on high areas away from the rivers. For that reason relatively few measurements of the zone have been made, and some of these are subject to error. Searight gives the thickness of the zone as 88 feet at Wheeler, 130 feet at Oacoma; 170 feet on Crow Creek, Buffalo County; 170-180 feet at Ft. Pierre, and 200 feet at Wendt. Subsequent measurements by the writer include 177-196 feet in the vicinity of the Bijou-Iona Hills, 122 feet at Fort Bennett, and 100-110 feet in Dewey and Potter Counties. Measurements of the basal banded beds show an interval of from 11 to 48 feet between the highest Agency-Oacoma beds and the lowest persistent layer of typical Verendrye concretions.

Stratigraphic Relations: There seems to be complete gradation between the Agency-Oacoma and Verendrye zones, so that the contact must be more or less arbitrarily chosen at the top of the concentration of manganese concretions and/or bentonites. The contact between the Verendrye and the Virgin Creek is not usually well exposed. It lies somewhere in the few feet between the highest ironstone concretions in the Verendrye and the lowest bentonites in the Virgin Creek. In a general way, it is marked by springs and the appearance of selenite fragments on the surface. The contact is probably one of gradation from the grayish-brown bentonitic shale of the lower zone to the blue-gray, flaky shale of the upper member. For field purposes the contact is placed at the base of the lowest visible bentonite in the lower Virgin Creek.



AGENCY - OACOMA ZONE
OF THE VERENDRYE-MEMBER

SHOWING RELATIONSHIP BETWEEN THE AGENCY AND OACOMA ZONES AS USED IN EARLIER REPORTS.

Virgin Creek Member

Name and Distribution: The Virgin Creek member was named by Searight (1937, p. 35) from exposures on Virgin Creek, a tributary of the Moreau River, in northeastern Dewey County. It includes all beds lying between the Verendrye zone of the Sully member and the highly calcareous, chalky beds of the overlying Mobridge. The outcrop of the Virgin Creek has wide distribution along the Missouri Valley from Charles Mix and Gregory Counties north nearly to the North Dakota line.

Throughout much of the Missouri Valley area, the Virgin Creek occurs high on the valley sides, and forms the bedrock over much of the adjacent upland. Good outcrops of the entire formation are few, although the complete section is apparently present in many places.

Description: The Virgin Creek member is divisible on the basis of lithology into a lower and an upper zone. Each will be described but briefly here; for details the reader is referred to Searight (1937) and Gries (1939).

The lower Virgin Creek consists of medium hard gray shale which weathers to small silvery flakes, and is characterized by the presence of a large number of thin bentonite beds. Small selenite fragments are common on the outcrop. Very few concretions are present. The zone appears to thin southward from 145 feet in Dewey County to 26 feet or less in Charles Mix County.

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. Several types of concretions are characteristic of this 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 "wormeaten" 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.

Thickness of the upper Virgin Creek is hard to measure because the outcrops weather to gentle slopes which are usually slumped, and cause the contacts to be hard to locate. Searight gives the thickness at the type locality as 100-140 feet. The writer has observed the following: 65 feet at Wheeler, 142 feet in northeastern Stanley county, and 86 feet at Mobridge.

Total thicknesses of the Virgin Creek member have been recorded as follows: 87 feet at Wheeler, 67 feet near the Bijou Hills, 228 feet in Stanley County, and 245-285 feet at the type locality near Promise, Dewey County. About 126 feet is still exposed above the river level at Mobridge.

<u>Stratigraphic relations</u>: The contact between the Verendrye and the Virgin Creek is one of gradation. In the field it is chosen above the highest black concretions of the Verendrye, or at the base of the lowest outcrop of flaky blue-gray, typical lower Virgin Creek shale containing thin bentonites. In a general way, this contact is marked by springs and the presence of selenite flakes on the surface. Recognizable bentonites or concretions which have occurred near the contact in one locality have not been found in adjacent areas.

The upper contact is distinct south of Bijou Hills where there is a sharp line between the gumbo forming beds of the Virgin Creek and the overlying impure chalk of the Mobridge member. In the vicinity of Mobridge, the contact has been taken at the lowest of the abundant rusty concretions which characterize the lower part of the Mobridge member. Between these areas, along the Missouri, considerable difficulty was encountered in choosing a division line. There the contact appears to be gradational, and has been taken above the highest typical septarian concretions, at the top of the gumbo-forming beds, or at the place where the lowest baculite casts are found. These criteria are of local use only.

It is possible that some of the irregularities in thickness of the Verendrye and lower and upper Virgin Creek members may be due to difficulty in picking the same contacts in different areas. During the present study, special point was made to determine the total interval between the top of the Agency-Oacoma and the base of the Mobridge wherever possible. The following intervals are illustrative: Wheeler, 174 feet; southwest of Academy, 192 feet; Bijou Hills, 244 feet; Iona, just across the river from Bijou Hills, 242 feet; Stanley County, 370 feet; and Dewey County (composite), 345-375 feet.

The uniform increase in this total interval, compared with the less regular thicknesses of the individual zones suggests the possibility that slight variations in lithology cause the Verendrye-Virgin Creek contact to be chosen at different stratigraphic horizons in different localities. If this is true, there is some doubt whether this contact should be used to separate the Sully and Virgin Creek members.

Mobridge Member

Name and Distribution: This member of the Pierre shale was named by Searight (p. 44) from beds exposed in Walworth and Corson counties, near the town of Mobridge. As originally defined, the member includes beds of chalk, chalky shale, sandy shale, and perhaps some sandstone beds lying between the Virgin Creek and Elk Butte members.

Searight subsequently suggested that his Mobridge may be correlated with the Interior beds described by Ward[1] from near Interior, Jackson County, and that the name Interior should take precedence over the term Mobridge (Moxon, Olson, Searight, p. 22). Because of the possibility that the Interior beds are the result of weathering of an old erosion surface of Pierre shale before the deposition of the "Badlands",[2] the complete equivalence of all the Interior beds to the Mobridge appears to be in doubt. Pending further work, the term Mobridge is retained by the State Geological Survey, and used as originally defined.

Searight (1937, following p. 43, and 1939, p. 49, fig. 14) shows the Mobridge persistently occupying the high areas adjacent to the Missouri south of the Bijou Hills and north of the Moreau. Between, it occupies high areas back from the river, with only occasional outliers on high buttes near the river.

Description: Because the Mobridge varies so greatly in lithology from place to place, particular effort was made during the course of this investigation to measure detailed sections in the hope of finding some persistent zone which might carry over considerable areas regardless of gradual change in lithology. Following is a brief description of each of the sections studied.

Near the Wheeler Bridge, in Charles Mix and Gregory counties, the formation consists of 90-96 feet of dark gray

---

1. Ward, Freeman, The Geology of a Portion of the Badlands, S. Dak. Geol. Survey Bulletin 11, pp. 17-18, 1922.
2. Wanless, H. R., Lithology of the White River Sediments, Proc. Amer. Philos. Soc., Vol. LXI, No. 3, 1922, pp. 184-269, esp. pp. 194-202.

impure chalk which weathers to various shades of gray and yellow. The contact with the Virgin Creek is marked by a definite change in lithology, and the upper part of the Virgin Creek is non-calcareous. A sharp contact may also be drawn between the calcareous Mobridge and the non-calcareous Elk Butte members.

Southwest of Academy, near the northern edge of Charles Mix County, (see Section IV), 86 feet of gray, impure chalk was measured between the Virgin Creek member and the glacial drift which covers the upland.

Due west of Bijou Hills, (Section VI), 241 feet of gray chalky shale lies between typical Virgin Creek and the Tertiary clay which caps the higher hills. The lower contact is marked by a half inch sand streak, and the underlying shale contains numerous thin bentonites suggestive of the lower Virgin Creek farther north.

Northeast of Iona, (Section V), weathered exposures show about 20 feet of gray calcareous shale overlain by an unmeasured thickness of the yellow, weathered chalky shale which forms the upland surface.

Yellow-weathering shale characteristic of the Mobridge was noted on Medicine Butte, Lyman County, and on Ft. George Butte in eastern Stanley County.

Corresponding beds in northeastern Stanley County have already been described in as much detail as the section would permit. (Gries, 1940, pp. 33-34.) In that area the uppermost Upper Virgin Creek is calcareous, and the contact with the Mobridge tentatively chosen at a layer of rusty brown baculite casts at the base of the yellow weathering calcareous shale which forms the higher parts of the upland surface.

The Mobridge beds change in lithology even more rapidly to the west. A random section measured on Plum Creek, Haakon County, about 40 miles west of the Stanley County exposure is included here with the Missouri River sections. (See Section XII).

The Mobridge does not appear close to the Missouri between Stanley County and the type area in Corson and Walworth counties. At Mobridge, the beds originally defined as the type section may be divided into two units. The lower 82-88 feet is a dominantly calcareous gray shale containing abundant small rusty concretions (up to 2 x 8 inches) and many baculites. Above this section lies about 70 feet of shale containing numerous large gray septarian limestone concretions and some thin discontinuous ledges of limestone. The upper part includes alternating calcareous and non-calcareous beds, so that a contact must be chosen more or less arbitrarily at the place where the non-calcareous beds become dominant.

At Wakpala, east of Elk Butte, 86 feet of gray calcareous shale containing a few gray limestone septaria appears in a cut bank along Elm Creek. These beds are assigned to the upper Mobridge; the overlying beds are dominantly non-calcareous and are considered by the writer to be basal Elk Butte. (see Section x)

Southeast of Kenel, near the North Dakota line, 78 feet of gray, dominantly calcareous shale with septarian concretions is assigned to the upper Mobridge. (See Searight, 1937, p. 48, Table 18, and Section XI of this report.)

From these sections certain generalizations may be drawn concerning the beds assigned to the Mobridge along the Missouri River. South from the Bijou Hills these beds, ranging in thickness from 90 to over 241 feet, consist of chalky shale containing neither abundant fossils nor concretions. In the northern area, the member consists of about 150 feet of gray shale, typically calcareous, but containing many beds which are not calcareous. Small rusty concretions and numerous baculites are characteristic of the lower part in the vicinity of Mobridge; large gray limestone septaria with cracks filled with yellow calcite appear in the upper beds throughout the northern area.

<u>Stratigraphic relations</u>: As already pointed out, the lower and upper contacts of the chalky Mobridge zone are sharp and easily found in the southern part of the state. But to the north, where the underlying Virgin Creek contains numerous calcareous zones, both contacts are hard to locate. The lower contact has been taken at the place where the lowest rusty concretions and abundant baculites appear. The upper contact is not sharp, but has been taken where the septarian concretions disappear and the non-calcareous beds predominate. Details of this phase will be described in connection with the Elk Butte Member.

It is obvious that the limits of the Mobridge member are based primarily upon lithology, and it is quite probable, consequently, that the beds thus limited in one area are not the precise equivalents of those in another region.

Elk Butte Member

Name and Distribution: Searight (1937, p. 50) gave the name Elk Butte to those beds of shale at the top of the Pierre which lie between the calcareous Mobridge beds and the overlying Fox Hills sandstone. The type section lies along U. S. Highway 12 (old route) between Wakpala and Elk Butte, in eastern Corson County. Searight has noted the member in many places within the central part of the state, from Gregory and Charles Mix Counties, north to Corson. Fresh exposures are rare.

Description: 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 nor typical. The present workers found bentonite beds to be 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.

Three complete sections were measured during the present survey; two of these have been previously described, and were remeasured only to correct earlier aneroid figures.

The type area was restudied in an attempt to find a satisfactory division point between the Mobridge and Elk Butte members. There is an apparent zone of transition consisting of an alternating series of calcareous and non-calcareous beds, each ranging from a few inches to several feet in thickness. Even after detailed measurement of several exposures, it was not found possible to correlate these beds. In three widely separated exposures small white nodules were noted within a few inches of the base of the first thick non-calcareous shale bed. If these concretions represent a persistent zone, they may perhaps be useful as a horizon marker, and the base of the non-calcareous shale which encloses them may be arbitrarily chosen as the base of the Elk Butte member.

Somewhere near the top of this alternating series is a thick bentonite (6-18") containing many one-half to three inch gray barite rosettes. Although this bed was seen in numerous places, it was invariably slumped and on a grassed surface, so that its relationship to the banded beds could not be ascertained. Several thinner bentonites, some carrying barite rosettes, occur above the larger one. Some of these may be seen in fresh road cuts along the new route of U. S. Highway 12, extending west from the Sakakawea monument across the river from Mobridge. The big bentonite and all those above it are tentatively placed in the lower part of the Elk Butte.

The upper contact in the type area is taken where the increasingly sandy shale at the top of the member gives way to the sand of the Fox Hills formation. The latter is prone to slump down over the Pierre, so that this contact is hard to find in place, and would consequently not make an ideal horizon for structural mapping.

Along the southern edge of the state, the shale lying above the Mobridge is similar in appearance to the Elk Butte farther north. Searight (1937, p. 50) noted a Fox Hills fauna in the upper part of this shale, and limited the Elk Butte to the shale below the fossiliferous zone, although admitting the inconsistency of choosing contacts on lithology in one area and paleontology in another. The writer agrees that paleontologic divisions must be used if the Missouri River subdivisions of the Pierre are to be correlated with other areas where conditions of sedimentation were different.

Thickness: The true thickness in the type area depends upon the choice of the base of the member, and upon the allowance made for slumping in tying together sections XXa and XXb. The measured thickness may be either 202 feet if only the non-calcareous beds are included, or 243 if the contact is placed at the base of the lowest thick non-calcareous zone. The latter figure appears more logical.

In Gregory County an even 100 feet of shale was measured below the beds correlated as Fox Hills.

CORRELATION OF MISSOURI VALLEY SECTION OF THE PIERRE FORMATION

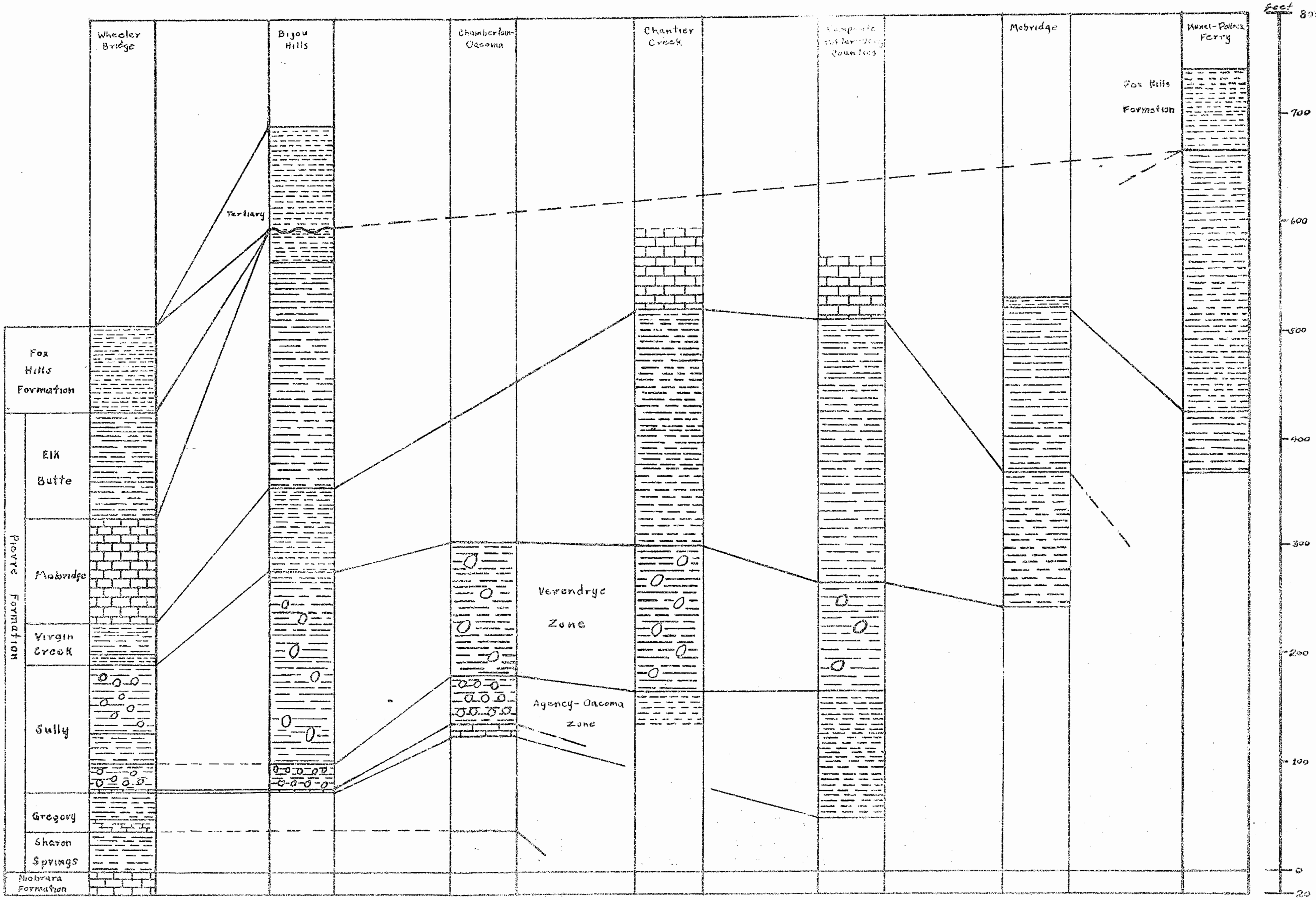
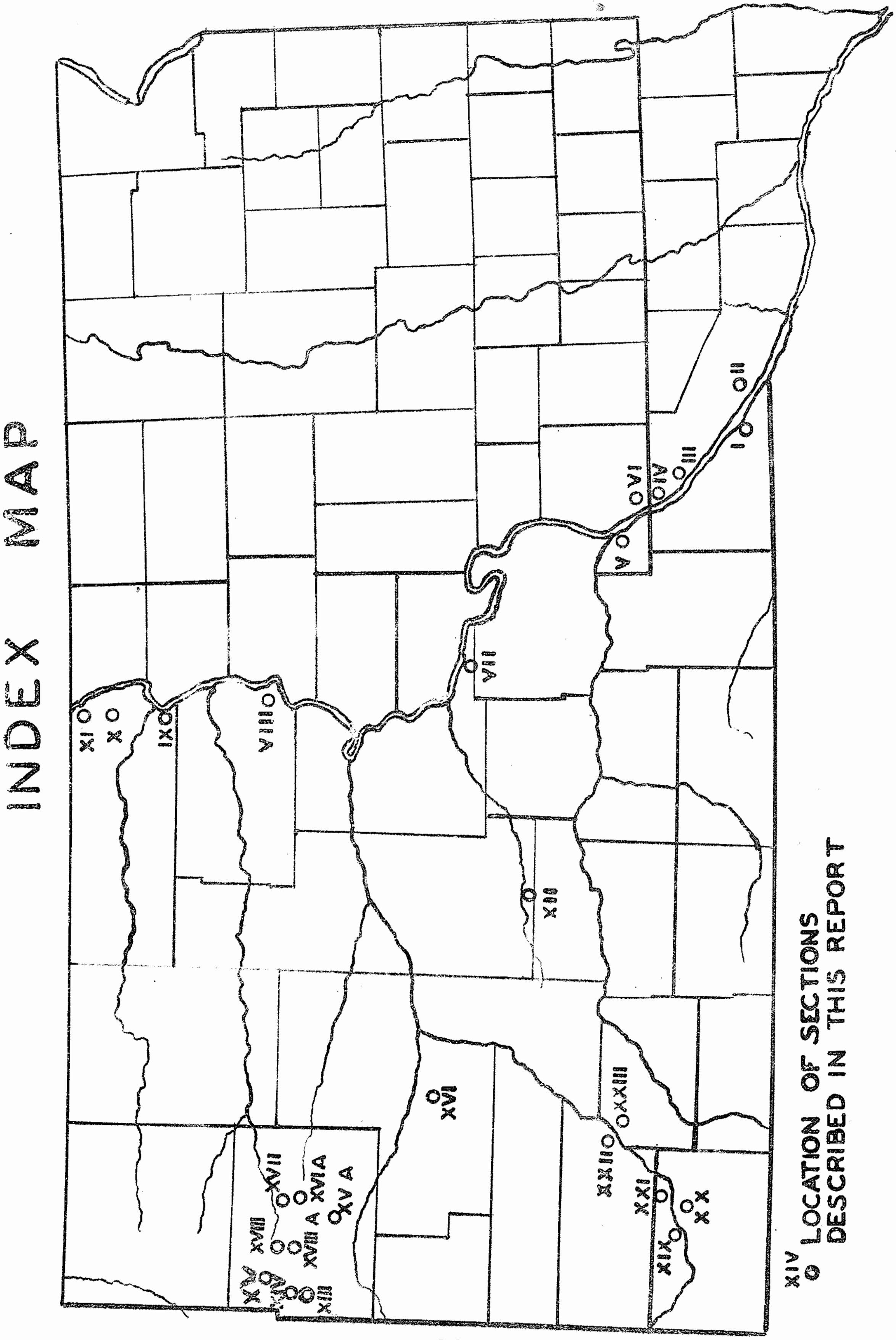


Figure 4

Figure 4a

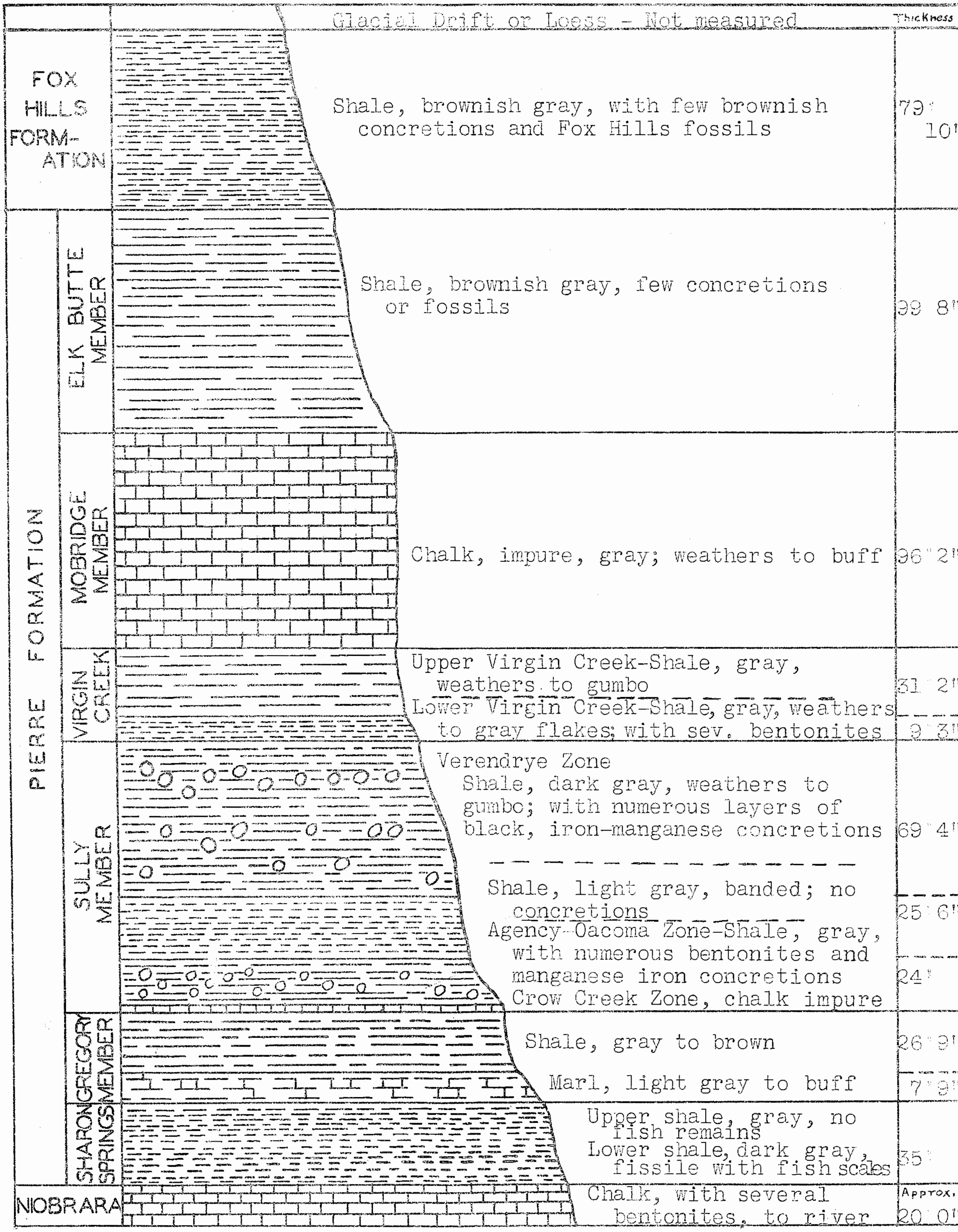

INDEX MAP
LOCATION OF SECTIONS DESCRIBED IN THIS REPORT
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
XV A
XVI
XVI A
XVII
XVIII
XVIII A
XIX
XX
XXI
XXII
XXIII

Section I

Succession of beds along U. S. Highway 18, west of Wheeler Bridge, extending from river's edge to top of Hill. (See also Searight, Table I, 22;and Gries and Rothrock, 1941, Table II). Gregory County, S. Dak.

	Feet	Inches
Fox Hills Formation		
Shale, brownish gray, with few brownish concretions and Fox Hills fossils........	79	10
Pierre Formation		
Elk Butte Member		
Shale, brownish gray, few concretions or fossils..............................	99	8
Mobridge Member		
Chalk, impure, gray; weathers to buff.....	96	2
Virgin Creek Member		
Upper Virgin Creek		
Shale, gray, weathers to gumbo............	31	2
Lower Virgin Creek		
Shale, gray, weathers to gray flakes; with several bentonites.....................	9	3
Sully Member		
Verendrye zone		
Shale, dark gray, weathers to gumbo; with numerous layers of black, iron-manganese concretions..........................	69	4
Shale, light gray, banded; no concretions.	25	6
Agency-Oacoma zone		
Shale, gray, with numerous bentonites and manganese iron concretions..............	23	0
Crow Creek zone		
Chalk, impure...........................	2	0
Gregory Member		
Shale, gray to brown.....................	26	9
Marl, light gray to buff..................	7	9
Sharon Springs Member		
Upper shale, gray, no fish remains.........	1	0
Lower shale, dark gray, fissile, with fish scales and numerous bentonites...........	34	0
Niobrara Formation		
Chalk, with several bentonites, to river, approximately.........................	20	0

Section I Wheeler Bridge



Section II

Succession of beds exposed along U. S. Highway 18, and north of highway in bare hill, at least partly in Sec. 3, T. 96 N., R. 67 W., Charles Mix County, S. Dak. (See also Searight, Tables 16 and 19)

	Feet	Inches
Elk Butte Member		
Shale, rusty brown, weathered, non-calcareous with small zones of iron concretions. Belemnitella on top...........	7	8
Shale, gray to rusty brown, non-calcareous no concretions.........................	8	0
Mobridge Member		
Chalk, shaly, and shale, calcareous, blue-gray................................	90	7
Upper Virgin Creek Member		
Shale, blue-gray, crumbly in fresh exposures, weathers to gumbo............	64	2
Lower Virgin Creek Member		
Shale, gray, weathers to silvery flakes; contains at least 8 bentonites ranging from $\frac{1}{2}$ to 2".............................	22	4
Sully Member		
Verendrye zone		
Shale, dark gray, weathers to gumbo, with numerous zones of large dark iron-manganese concretions.........................	86	8
Agency-Oacoma zone		
Shale, light gray, with many small manganese-iron concretions, and numerous thin bentonites which may contain small gray barite rosettes; not measured.		

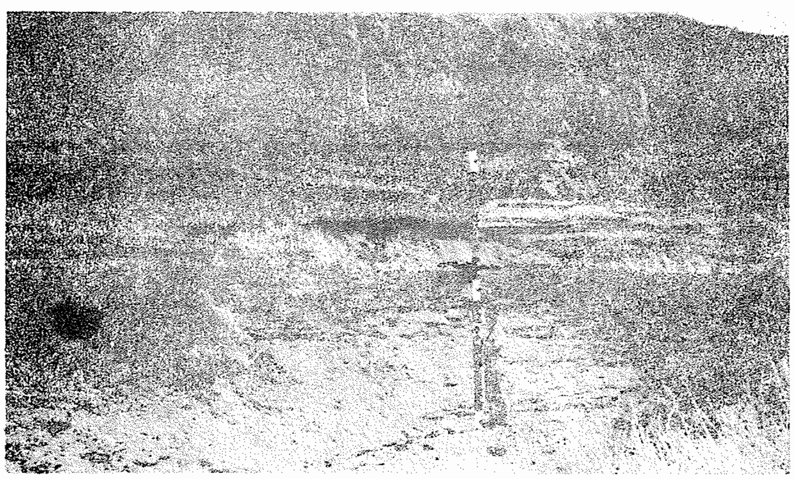
BASE OF PIERRE FORMATION

Gregory Member

Sharon Springs Member

Niobrara Formation

Outcrop on White River (See Table V)
Sec. 31, T. 104 N., R. 72 W. Lyman County



Bentonite Beds (White)
At Pierre-Niobrara Contact
Sec. 9, T.102 N., R.71 W. Brule County

Section III

Succession of beds in Missouri River breaks, due west of Platte, Charles Mix County, South Dakota.

	Feet	Inches
Agency-Oacoma and Gregory		
Shale, manganese-iron concretion zone at top, rest obscured....................	92	6
Sharon Springs		
Shale, dark gray, fissile, with numerous bentonites in lower third...............	24	6
Niobrara Formation		
Chalk, not measured		

Section IV

Succession of beds exposed in river breaks about 2½ miles west and 3 miles south of Academy, Charles Mix County, S. D. South of old Eaton? place.

	Feet	Inches
Glacial Drift		
Boulder clay, not measured, approx.	25 - 30	
Pierre Formation		
Mobridge Member		
Chalk, gray, weathers to buff soil; top eroded.................................	85	10
Virgin Creek and Verendrye		
Shales, not well exposed; bentonites near top.......................................	191	8
Sully Member		
Agency-Oacoma zone		
Shale, gray, with numerous bentonites and manganese-iron concretions.............	41	2
Crow Creek zone		
Chalk, impure, light gray; basal 6 inches rusty and slightly sandy...............	10	2
Gregory Member		
Shale, gray to buff; thin calcareous zone at base.....................................	50	6
Sharon Springs Member		
Shale, dark gray, fissile, with bentonites, and small white nodules near top.......	14	2
Niobrara Formation		
Chalk, gray, not measured, to river's edge		

Section V

Succession of beds, along road descending to Missouri River Bottoms, about 2 miles north, then east, from Iona, Lyman County, S. Dak.

	Feet	Inches
Pierre Formation		
Mobridge Member		
Shale, gray, calcareous, weathers yellow; not measured..........................		
Shale, gray, calcareous, apparently remains gray..........................	20	
Virgin Creek and Verendrye		
Shales, not well exposed.................	242	8
Agency-Oacoma zone		
Shale, gray, with abundant bentonites and manganese-iron concretions;not measured		

Section VI

Succession of beds measured on high butte, due west of Bijou Hills, Brule County. At least part in south $\frac{1}{2}$, Sec. 31, T. 101 N., R 70 W.

	Feet	Inches
Tertiary		
Buff, calcareous sands and clays, overlain by heavy quartzite, to MRC benchmark on top of butte...............	95	6
Pierre Formation		
Mobridge Member		
Shale, blue-gray, chalky, 2 inch bentonite at base................................	30	10
Shale, gray, very calcareous, $\frac{1}{2}$ inch sand at base.............................	210	0
Virgin Creek Member		
Shale, gray, with numerous thin bentonites near top..........................	67	0
Sully Member		
Verendrye zone		
Shale, gray, weathers to gumbo; with zones of large dark iron-manganese concretions, and few baculites near top.....	177	0
Agency-Oacoma zone		
Shale, gray, with numerous bentonites and small black-manganese-iron concretions; not measured..........................		

Section VII

Succession of beds exposed in cut bank on west side of Antelope Creek, near its mouth, Stanley County, South Dakota.

Pierre Formation	Feet	Inches
Sully Member		
Verendrye zone		
Shale, yellowish gray, with large iron-manganese concretions; weathers to gumbo; to top of hill	26	
Bentonite		$1\frac{1}{2}$
Shale, as above	8	0
Bentonite		1
Shale, as above	5	9
Bentonite		1
Shale, as above		6
Bentonite, impure, micaceous at base		4
Shale, as above	8	8
Bentonite		$\frac{1}{4}$
Shale, as above, browner toward base	29	$9\frac{1}{2}$
Agency-Oacoma zone		
Bentonite		$\frac{1}{2}$
Shale, gray, slightly siliceous		6
Bentonite		$\frac{1}{2}$
Shale, as above		6
Bentonite		$\frac{1}{2}$
Shale, as above	1	4
Bentonite		2
Shale, as above	1	11
Bentonite		5
Shale, as above	9	$1\frac{1}{2}$
Bentonite		$\frac{1}{4}$
Shale, as above		8
Bentonite		3/4
Shale, as above		10
Bentonite		$1\frac{1}{2}$
Shale, as above		6
Bentonite		2
Shale, as above	2	6
Bentonite		$1\frac{1}{2}$
Shale, as above		9
Bentonite		3/4
Shale, as above		9
Bentonite		$\frac{1}{4}$
Shale, as above	3	7
Bentonite		3
Shale, as above		0
Bentonite		$\frac{1}{4}$
Shale, as above	5	8

Section VII, cont'd.

	Feet	Inches
Bentonite (lower micaceous bentonite)......		6
Shale, as above, concretions 9 feet below top, manganese concretions above it....	36	8
Bentonite..................................		$\frac{1}{4}$
Shale, to creek level......................	10	0
Total Agency-Oacoma exposed.	78'	$4\frac{1}{2}$"

Section VIII

Succession of beds, type section of Agency shale, west end of Bridge at Whitlock's Crossing, Dewey County, S. Dak.

	Feet	Inches
Pierre Formation		
Sully Member		
Verendrye zone		
Shale, dark gray, weathers to gumbo; with zones of large, black, iron-manganese concretions, not measured................		
Agency-Oacoma zone		
"Oacoma" of R.I. 31, Table III. Shale, more or less siliceous, containing several bentonites; covered with gumbo from above..............................	8	3
Shale, gray, siliceous, typical Agency, with bentonites up to 3 inches...........	69	2
Bentonite (lower micaceous bentonite)......		6
Shale, as above, to river..................	44	1
Total Agency-Oacoma exposed....	122'	0"

Section IX

Succession of beds at west end of highway bridge across Missouri River at Mobridge, in Corson County, S. D. Section beginning at river's edge and extending along highway to Sakakawea Monument at top of hill. (See also Searight, Table 17)

	Feet	Inches
Pierre Formation		
Elk Butte Member		
Covered interval, mostly buff loess?, to base of monument........................	6	0
Shale, blue-gray, non-calcareous, with a layer of white non-calcareous concretions about 30 inches above base..............	5	8
Mobridge Member		
Shale, buff to gray; calcareous above, non-calcareous below.....................	3	7
Shale, more or less calcareous............	7	0
Limestone layer..........................	1	0
Shale, gray, calcareous...................	3	8
Shale, mostly non-calcareous, poorly exposed...................................	8	7
Shale, mostly calcareous, several layers of large septarian limestone concretions with yellow calcite in cracks...........	45	5
Shale, gray, mostly calcareous, with many small rusty concretions and numerous baculites..............................	81	5
Total Mobridge	150	8"
Virgin Creek Member		
Upper Virgin Creek		
Shale, gray, non-calcareous, weathers to gumbo; crab, serpula, worm-eaten concretions on adjacent outcrop...............	86	5
Lower Virgin Creek		
Shale, dark gray to nearly black; fissile; weathers to steep buttresses. Contains several ¼ to 1 inch bentonites; to river	40	0

Section X

Succession of beds extending from cut bank along Elm Creek on northwest edge of Wakpala, along highway (Old U.S. 12, to top of Elk Butte, eastern Corson County. (See also Searight, Table 20.) Type Section of Elk Butte Member.

Traverse from road fork west of town, where CCC-ID road branches off to northwest, on along main highway to top of Butte.

Xa	Feet	Inches
Fox Hills and Tertiary (?)		
15 Sandstone, greenish gray, coherent..........	10	0
14 Buff to white sandstone, and sandy shale, with several types of concretions........	300	0
Pierre Formation		
Elk Butte Member		
13 Shale, gray, blocky, sandy in upper part. Contains some gray limestone concretions near top.............................	94	2
12 Shale, gray, crumbly, some gypsum; rusty to black limestone concretions at top.....	20	0
11 Shale, becoming more silvery and flaky above	52	10
10 Bentonite, with many small gray barite rosettes................................		2
9 Shale, non-calcareous....................	14	2
8 Shale, calcareous, mostly grassed over......	33	2
7 Bentonite, slumped, with numerous barite rosettes up to 2 inches across...........	1	0
Xb. Cut bank at Wakpala		
6 Shale, gray, calcareous-grading into 6 foot calcareous soil zone; to top of bluff..................................	12	2
5 Shale, blue-gray, non-calcareous; yellow blossom and gypsum in joints and bedding planes................................	16	4
4 Bentonite................................		3
3 Shale, blue-gray, non-calcareous, with small white calcareous concretions.......		6
Mobridge Member		
2 Shale, blue-gray, calcareous, with small concretions as above, possibly from above zone..................................	8	5
1 Shale, blue-gray, mostly talus covered. Probably contains more than one zone of gray limestone septarian concretions with yellow calcite near top, to creek...............	69	0

Note: The actual interval between these two sections could not be determined. Bed 7 and those immediately above it are obviously slumped, and actually lie about 18 feet lower than the top of Bed 6. Total interval between Mobridge and upper zones of Elk Butte probably nearly right.

Section XI

Succession of beds along traverse running from cut bank north or Kenel-Pollock ferry, along road to top of hill west of ferry. North Eastern Corson County. (For lower part, see also Searight, Table 18.)

	Feet	Inches
Fox Hills Formation		
Sandstone, to top of hill, not measured		
Sandstone, containing lime concretion layers; heavy layer of flaggy, rusty limestones at top....................	49	7
Sandstone, zone of very fossiliferous limestone concretions at top...........	33	7
Sandstone and sandy shale, more or less slumped, sandy limestone concretions at top...............................	21	0
Total Fox Hills measured	104	2
Pierre Formation		
Elk Butte Member		
Shale, gray, poorly exposed, no bloom...	24	8
More or less covered interval back from river; shale in blowouts and gullies gray, non-calcareous, with ochrous "bloom" in joints......................	193	5
Shale, non-calcareous, yellow-gray, blocky; to top of cut bank............	24	1
Total Elk Butte	242	2
Mobridge Member		
Shale, gray, calcareous, more or less papery, with occasional barite rosette	27	8
Bentonite..............................		2
Shale, blue-gray, calcareous, more or less talus covered. Contains some large gray septarian limestone concretions not seen in place; to river's edge.........	30	0

Section XII

Succession of beds measured near mouth of Plum Creek, Haakon County. The following intervals were picked up along a traverse extending over more than a mile and contain inaccuracies due to rather extensive slumping. They are included here only to show the nature of the beds lying above typical Lower Virgin Creek shale.

		Feet	Inches
Pierre Formation			
10	Shale, gray, calcareous, with thin sandstone at base, to top of outcrop.	24	6
9	Shale, yellowish gray, calcareous.......	14	3
8	Shale, bluish gray above to yellowish gray below; at base is 8 - 10" buff chalky zone overlain by a 2" - 1' sandstone bed.........................	8	3
7	Shale, bluish gray, non-calcareous......	21	0
6	Shale, gray, mostly non-calcareous, with many septarian concretions, largest of which is a 2 x 6' rusty limestone concretion zone at base. Numerous baculites....................	22	0
5	Shale, mostly calcareous, sandy zone at base; some fossils.................	61	6
4	Shale, more or less calcareous, gray to yellowish gray, crumbly; with zone of light limestone concretions near middle and abundant purplish brown concretions in lower part.............	84	6
3	Shale, bluish gray, weathers to crumbly gumbo, fibrous calcite zone at base..	13	0
2	Shale, weathers to gray gumbo...........	20	0
1	Shale, with many typical lower Virgin Creek bentonites, occasional light limestone concretion, and abundant large rusty to purplish brown concretions in lower part - to creek level, approximately.................	60	0
	Approximate length of section...	329'	0"

III. STRATIGRAPHY

THE PIERRE FORMATION NORTH OF THE BLACK HILLS

Two weeks during the present survey were spent in Butte County and adjacent areas, where a tentative subdivision of the Pierre was made and samples taken of the principal members.

Generalized descriptions of the Pierre shale have been published in the several folios of the United States Geological Survey which deal with this area.[1] More recently, Rubey has made a seven fold subdivision of the Pierre formation in adjacent parts of Montana and Wyoming.[2] The writer has not visited the sections described by Rubey, but from the descriptions believes that the members may be recognized in this area.

One of the purposes of the present study was to investigate the possibility of correlating the Black Hills section with that of the Missouri Valley. Exposures in the Butte County area are limited to isolated buttes so that building up a complete section is much more difficult than along the Missouri where the outcrops are essentially continuous. The criteria which have proved valid in the central part of the state were applied to the present area. Available outcrops were measured in detail, the poorly exposed intervals studied along roadcuts, streams, and even on grassed over slopes. A preliminary section built up by tying together the data obtained is given in Table II. The place where each member was measured is indicated by reference to the accompanying detailed sections.

As may be seen, the section is fairly complete except for an estimated 500 foot interval in the middle part of the formation which is apparently without resistant members, so weathers to gentle slopes. The beds in the uppermost part of the section apparently are highly variable, and the exact relationship between the Pierre, Fox Hills and Lance formations is not clear.

---

1. The folios which cover this area include the Belle Fourche (164), Newell (209), Aladdin (128) and Central Black Hills (219).
2. Rubey, W. W., Lithologic Studies of Fine-Grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region, U. S. Geol. Survey, Prof. Paper 165, page 4, 1931.

As compared with the Missouri Valley section, the Pierre north of the Black Hills is characterized by a more uniform lithology. Zone for zone correlation between the two regions appears to be impossible without detailed lithologic and paleontologic studies carried continuously from one area to the other.

Certain similarities and differences may be pointed out without making direct correlations. The basal black fissile shale of the Missouri Valley and southern Hills areas appears to be missing, and the basal beds in the northern area appear similar lithologically to the Gregory member in the central part of the state.

There is a possibility that the Crow Creek sandstone may be an eastward extension of the Groat sandstone, though from the rapidity with which the latter thins in this area it is not considered likely that it would be so persistent in the lower Missouri Valley area.

The calcareous zones of the central section are missing in the western outcrop areas, though they are probably represented by beds of different lithologic character.

The zone of Serpula (?) wallasensis, "wormeaten" concretions, and associated bentonites, conspicuous in Butte and Meade counties probably corresponds to a similar zone in the Virgin Creek member of the Missouri Valley section.

Probably some of the basal "Fox Hills" sandstone of this area is the time equivalent of the Elk Butte and Mobridge members farther east.

Study of the invertebrate fossils collected during the present survey may make some of these relationships clear.

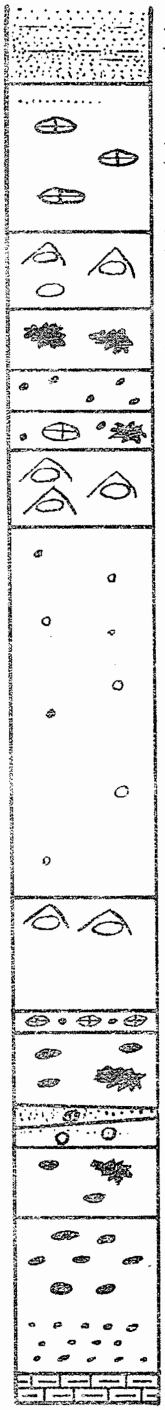
GENERALIZED, COMPOSITE SECTION OF PIERRE FORMATION
BUTTE COUNTY, SOUTH DAKOTA

		Feet
18	Sandstone, slabby at base, loose to massive above. with some zones of sandy shale. Probably in part equivalent of upper Pierre of Missouri Valley section. See Sections XVII and XVIII..........	
17	Shale, gray, with many gray septarian limestone concretions and sandy streaks near top. Some shale gray with much yellow "bloom". See Sections XVII and XVIII........................	200
16	Shale, gray, with gray limestone concretions. Locally, masses of tough porous limestone with fossils in upper part of zone form the upper horizon of tepee buttes. See Sections XVI and XVIa................................	100
15	Bentonite, with much fibrous calcite and gray barite rosettes; rosettes locally may form nearly continuous layers 2 or more inches thick. Bentonite up to 30" thick. This zone is exposed in many places, but may be most easily seen along Highway 85 at Rothford, in Section 19, T. 11 N., R. 6 E. What is believed to be the same bed has been seen along Elm Creek in Meade County, and along The Cheyenne River in Custer and Washington Counties....................................	1
14	Shale, dark gray, contains many large brownish black concretions, some covered with buff cone-in-cone. See Sections XV, XVI, XVIa..........	75
13	Shale, gray, weathers to gumbo. Contains Serpula wallacensis (?), Wormeaten concretions, and at least one thick bentonite containing numerous small barite rosettes. See Sections XV, XVa, and XVI...............................	50
12	Shale, gray, with gray and rusty limestone concretions and some with buff cone-in-cone. See Sections XV and XVa......................	50
11	Shale, gray, containing at different levels, masses of tough, gray limestone with abundant fossils locally, which form the main tepee butte zone. See Sections XV and XVa.....	100
10	Shale, gray, poorly exposed throughout the area..	500
9	Shale, gray, not well exposed, masses of tough gray porous limestone may locally form the lower tepee butte zone. Buttes well exposed in Sections 35 and 36, T. 9 N., R. 6 E., and in Section 2, T. 8 N., R. 6 E..................	150

		Feet
8	Shale, gray, weathers to gumbo, with many heavy purplish concretions with yellow calcite, and many baculite casts. See Section XIVa..........	20
7	Shale, buff to nearly white, possibly largely volcanic ash. Sometimes with large concretions covered with buff cone-in-cone. A conspicuous horizon. See Section XIVa......................	1
6	Shale, gray, with large rusty concretions covered with thick cone-in-cone. Also very abundant baculite casts. With two overlying zones makes low ridges. See Section XIVa..................	100
5	Sand, becoming more shaly toward base. Sand frequently incoherent except for spherical concretions up to 5 feet across. Thins rapidly to east. Apparently the Groat sandstone of Monttana and Wyoming. See Section XIV..............	30
4	Shale, light gray, silty toward top. Contains gray calcareous silty or sandy concretions. See Section XIII................................	25
3	Shale, light gray, silty, non-calcareous, with numerous large rusty concretions, some with buff cone-in-cone coating. See Section XIII...	100
2	Shale, light gray to yellow gray, silty non-calcareous. Contains many yellow to rusty limestone concretions up to 2 inches thick in lower part, larger above. Numerous baculite fragments. Some large concretions with cone-in-cone in upper part. Exposed north of Miller Butte, in Sections 29, 32, T. 9 N., R. 5 E..	200
1	Shale, medium gray, calcareous. Niobrara formation..	
	Total shale exposed between Niobrara formation and the so-called "Fox Hills" sandstone of this area, approximately........................	1700

Table II

DIAGRAMMATIC SECTION PIERRE FORMATION
BUTTE COUNTY, SOUTH DAKOTA



		Feet
18	Sandstone and sandy shale	
17	Shale, gray, with bloom and septarian concretions	200
16	Shale, gray, with tepee butte zone at top	100
15	Bentonite with fib. calcite and barite	1
14	Shale with dark concretions	75
13	Shale, with Serpula and WE concretions	50
12	Shale with dark concretions	50
11	Shale, gray with main tepee buttes	100
10	Shale, gray, poorly exposed	500
9	Shale, with lower tepee butte zone at top	150
8	Shale with septarian concretions	20
7	Shale, white, with cone-in-cone	1
6	Shale, with dark conc. and baculites	100
5	Groat sandstone, thins to east	0 - 30
4	Shale, light gray, silty to sandy concretions	25
3	Shale, light gray, silty, with rusty concretions and cone-in-cone	100
2	Shale, light gray, with small rusty concretions below, larger above. Numerous baculite fragments	200
1	Niobrara calcareous shale	

Section XIII

Succession of beds, Pierre Formation, Mud Butte, Section 36, T. 11 N., R. 2 E., Butte County, South Dakota.

		Feet	Inches
5	Shale, gray, sandy, grading upward to shaly sandstone. Contains layers and concretions of cemented sandstone--to top of butte......	26	4
4	Shale, gray, silty, with numerous gray silty concretions up to 1 foot across............	14	5
3	Shale, bluish-gray, non-calcareous, with small rusty concretions; some gray rusty concretions in upper 10 feet.................	45	8
2	Shale, gray, with large concretions sometimes coated with heavy buff cone-in-cone; partly grassed over...........................	65	
1	Same grassed over, to base of butte, not measured..................................		
	Total section measured	151	5

Section XIV

Succession of beds northwest of Mud Butte, probably in Section 26, T. 11 N., R. 2 E. This section apparently lies immediately above the preceding one.

2	Sand, argillaceous, mostly loose, but with 5 inch to 5 foot spherical sandstone concretions. 2 foot calcareous layer at top	30	7
1	Shale, sandy; zone of sandy limestone concretions at top; not measured..........		

Section XIVa

A section extending from the top of this sandstone zone to above the conspicuous one foot white shale, was measured in sections 2 and 11, T. 11 N., R. 2 E. Because the traverse extended down dip for over half a mile, the section was considerably foreshortened, and the intervals are not recorded here.

Section XV

Succession of beds, Antelope Butte, Section 20, T. 12 N., R. 3 E., Butte County, South Dakota.

7 Shale, medium to dark gray, weathers to gumbo crust but is powdery beneath. Contains large rusty septarian concretions with yellow calcite; some coated with heavy

Section XV, cont'd.

		Feet	Inches
	buff cone-in-cone. On top of butte are large blocks of residual quartzite, let down from the "Fox Hills". To top of Butte....................................	26	0
6	Shale, grassed interval; rusty concretions numerous, including one at base with cone-in-cone............................	31	0
5	Shale, weathers to bare gumbo, contains one or more bentonite streaks.................	10	0
4	Shale, as above, with Serpula, small "worm eaten" concretions, and several bentonites, one of which is apparently at least 1 foot thick; large cone-in-cone concretion at base..........................	46	5
3	Shale, similar but no Serpula or "worm-eaten" concretions........................	32	4
2	Shale, gray with gray limestone concretions containing yellow and dark brown calcite; some very fossiliferous. Appear to represent the main tepee butte horizon	30	0
1	Shale slope, grassed over, to base of butte not measured............................		
	Total section measured..	175	9

Section XVa

A section extending from the main tepee butte zone up through the Serpula and "Wormeaten" concretion zone was measured in Sections 20, 29 and 30, T. 10 N., R. 6 E. Because this traverse extended down dip, the intervals were foreshortened, and are not given here.

This traverse started from the top of the Two Top oil test. The writer has examined cuttings from this test to a depth of 1180 feet, at which depth the hole was still in the Pierre shale. This means that the main tepee butte zone is at least 1200 feet above the base of the Pierre, rather than 1000 feet as estimated by Darton (Newell Folio, No. 209, page 3).

Section XVI

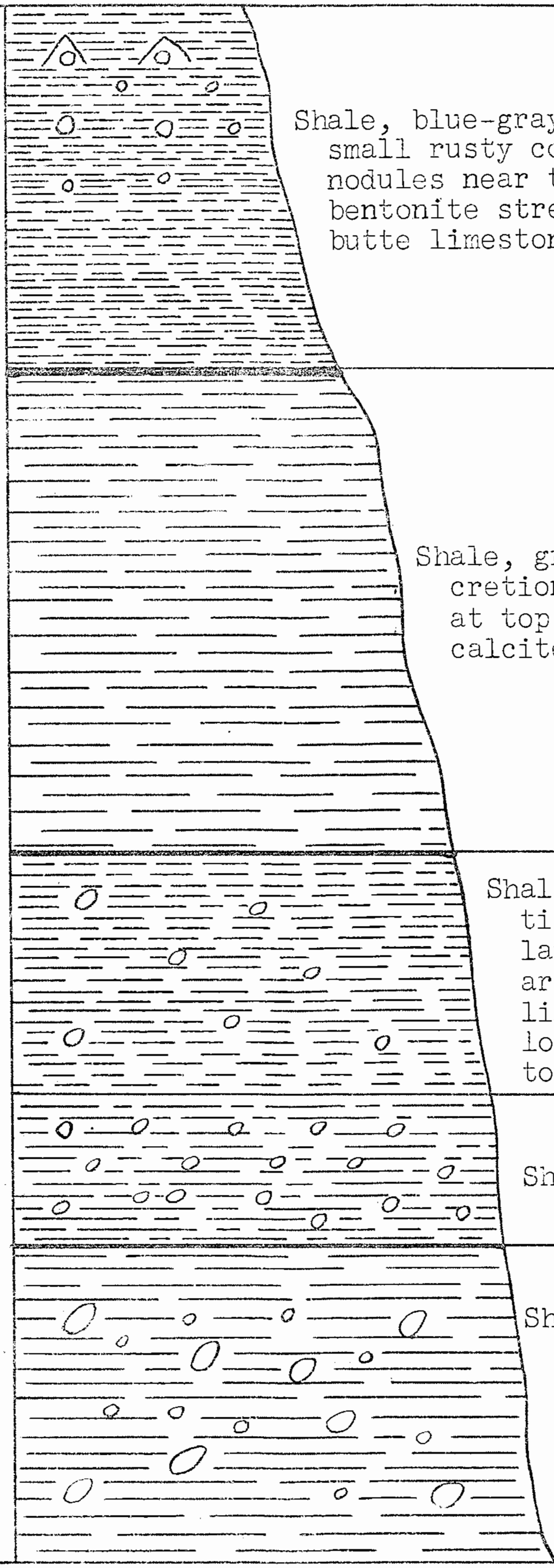
Succession of beds, Pierre Formation, exposed in bare hills south of Belle Fourche River, Section 6, T. 4 N., R. 11 E., Meade County. This Section is considerably east of the area included by the other sections, but affords the best tie between the Serpula zone and the base of the upper tepee butte zone. The intervals appear to be about the same in the area under consideration.

Section XVI

Belle Fourche River

PIERRE FORMATION

SOUTH OF BELLE FOURCHE RIVER, SECTION 6, T.4 N., R.11E., MEADE COUNTY



	Thickness
Shale, blue-gray, weathers to gumbo. Some small rusty concretions and small white nodules near top, as well as some thin bentonite streaks; lowest upper tepee butte limestones lie at top.	40'0"
Shale, gray, flaky, with rusty concretions. One two foot bentonite at top contains layers of fibrous calcite and some barite.	53'8"
Shale, gray with rusty concretions; larger ones may have layer of buff cone-in-cone around them; some serpula-like tubes up to 6 inches long. Probably a heavy bentonite at top.	25'6"
Shale, gray with numerous purplish-black concretions.	16'0"
Shale, gray, weathers to gumbo. Many large rusty or purplish-black concretions; small "wormeaten" concretions and serpula. Probably a heavy bentonite near top.	36'5"

Section XVI, cont'd.

		Feet	Inches
5	Shale, blue gray, weathers to gumbo. Some small rusty concretions and small white nodules near top, as well as some thin bentonite streaks; lowest upper tepee butte limestones lie at top..............	40	0
4	Shale, gray, flaky, with rusty concretions. 1-2 foot bentonite at top contains layers of fibrous calcite and some barite........	53	8
3	Shale, gray with rusty concretions; larger ones may have layer of buff cone-in-cone around them; some Serpula-like tubes up to 6 inches long. Probably a heavy bentonite at top............................	25	6
2	Shale, gray, with numerous purplish-black concretions..............................	16	0
1	Shale, gray, weathers to gumbo. Many large rusty or purplish-black concretions; small "wormeaten" concretions and Serpula. Probably a heavy bentonite near top..................................	36	5
	Total section measured...	171	7

Section XVIa

A section extending from the bentonite with fibrous calcite and barite, up into the upper tepee butte zone was measured northwest of Rothford, in Sec. 18, T. 11 N., R. 6 E., Butte County. The traverse extended for a considerable distance down dip, so that the section is foreshortened. For that reason the measured intervals are not recorded here.

Section XVII

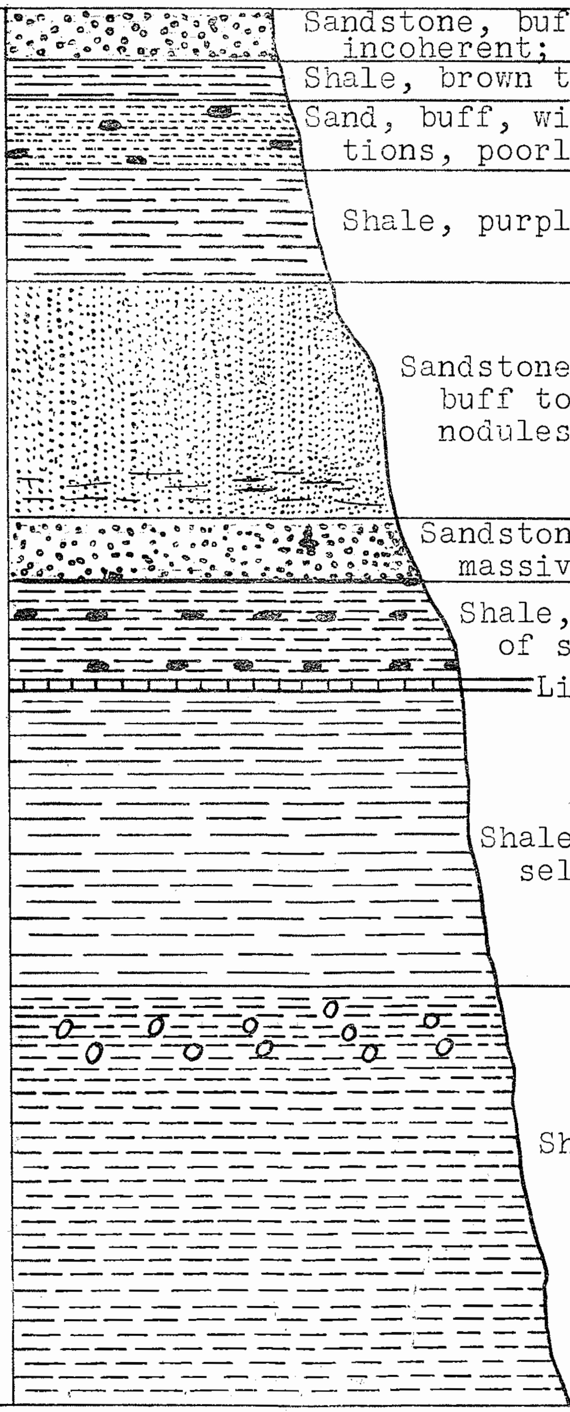
Partial succession of beds exposed on southeast side of Castle Rock, probably in Section 24, T. 12 N., R. 5 E., Butte County. The lower beds were too grassed over; the upper beds obviously Tertiary.

		Feet	Inches
6	Lignite and lignitic clay....................	10	0
5	Sand and sandy shale, not well exposed.........	74	0
4	Sandstone, brown, slabby.....................	1	0
3	Shale, bluish gray, with much yellow "bloom"................................	8	7
2	Shale, gray with some bloom. Zone of white slabby sandy limestone at top; zone of large gray fossiliferous concretions at base; zone of 1 foot white micaceous nodules 2 feet above base..................	53	0
1	Shale, gray, not measured..................		
	Total section measured..........	146	7

Section XVIII

Figure 8

PIERRE AND FOX HILLS SECTION
EXPOSED ON SOUTH SIDE OF TWO TOP PEAK SECT.35 T.12N. R.4E. BUTTE CO.



	Thickness
Sandstone, buff, some compact, some incoherent; forms top of butte.	14'0"
Shale, brown to gray, carbanaceous.	12'6"
Sand, buff, with some rusty concretions, poorly exposed.	22'6"
Shale, purplish-brown, carbonaceous.	33'0"
Sandstone, massive, fine; weathers buff to pink; contains cemented nodules; some shale in lower part.	73'0"
Sandstone, buff to brown or gray, massive to slabby.	20'6"
Shale, gray, sandy, with layers of sandy calcareous concretions	29'6"
Limestone rusty outside, gray inside; no fossils or calcite veins.	6"
Shale, gray, some bentonite and selenite.	91'8"
Shale, gray, with zone of large gray fossiliferous concretions near top; to base of slope.	129'0"

Section XVIII

Succession of beds, Pierre and "Fox Hills", exposed on south side of Two Top Peak, Section 35, T. 12 N., R. 4 E. Butte County, South Dakota.

		Feet	Inches
10	Sandstone, buff, some compact, some incoherent; forms top of butte............	14	0
9	Shale, brown to gray, carbonaceous........	12	6
8	Sand, buff, with some rusty concretions, poorly exposed..........................	22	6
7	Shale, purplish-brown, carbonaceous.......	33	0
6	Sandstone, massive, fine; weathers buff to pink; contains cemented nodules; some shale in lower part.....................	73	0
5	Sandstone, buff to brown or gray, massive to slabby............................	20	6
4	Shale, gray, sandy, with layers of sandy calcareous concretions..................	29	6
3	Limestone, rusty outside, gray inside; no fossils or calcite veins.............		6
2	Shale, gray, some bentonite and selenite..	91	8
1	Shale, gray, with zone of large gray fossiliferous concretions near top; to base of slope..........................	129	0
	Total measured section	426	2

Section XVIIIa

The nature of the beds lying between the upper tepee buttes in Sections 5 and 6, T. 11 N., R. 4 E., and the base of the above section may be seen along the track and in the gullies in the intervening area, but the interval represented can only be estimated.

IV. STRATIGRAPHY

THE PIERRE FORMATION SOUTH OF THE BLACK HILLS

During the present survey, about 10 days were spent south of the Black Hills, primarily in Fall River and Custer counties. Samples were collected at intervals from the vicinity of Ardmore to as far north and east as the Pierre outcrops near Rapid City. Several sections were measured.

Darton[1] has described the Pierre of this area as consisting of about 1200 to 1300 feet of shale; the lowest 150 feet of which is black and fissile, the rest dark bluish-gray. A zone of limestone masses which weather out into tepee buttes is noted about 1000 feet above the base.

In the present investigation, it was found that nearly all the good outcrops for detailed study lie along the Cheyenne River, and these appear to be limited to the lower and middle part of the Pierre formation. The attention of the present workers was therefore confined to this lower part, and no effort was made to measure intervals in the higher members.

Except for the black fissile beds of the Sharon Springs member, there appear to be few key horizons which can be traced from one outcrop to another. Exposures are generally smaller than those north of the Hills, and much less continuous than those along the Missouri, so the scarcity of traceable beds is a serious handicap to building up a composite section of the Pierre formation.

Five detailed sections are included here to show the nature of the formation, even though they do not form one continuous sequence.

The basal beds of the Pierre in this area are correlated with the Sharon Springs member of the Missouri Valley and the type locality in Kansas. This member consists of dark gray

---

1. Darton, N.H., Oelrichs Folio, No. 85, U. S. Geol. Survey, 1902. See also subsequent folios as follows: Newcastle (107), Edgemont (108), and Central Black Hills (219).

to black fissile shale containing abundant fish remains. It weathers to steep buttresses along drainage lines, and to a low, bare ridge where the relief is less. The beds are characterized by many bentonites, ranging in thickness from a fraction of an inch to over three and one-half feet. As many as 35 beds, most of them less than two inches thick, have been counted in a single exposure. Several zones of large biscuit shaped concretions averaging perhaps 1 x 3 feet characterize the upper part of the member. The details of the zone in this area have been worked out by Spivey[1], so only one detailed section is included here.

The Sharon Springs lies conformably upon the Niobrara, and in many places the exact contact can be located only by use of acid. The upper limit of the zone is sharp, but appears to be gradational.

The thickness in Fall River County is approximately 150 feet. In Section XIX, an easily accessible outcrop of this member is described in detail. There is some doubt as to the Niobrara-Pierre contact because of a covered interval, but from nearby outcrops it is evident that at least 175 feet, and perhaps over 200 feet may be assigned to the Sharon Springs in this exposure.

This outcrop of fissile shale with contrasting beds of bentonite is a conspicuous feature around the southern edge of the Black Hills. As previously pointed out, this member appears to be lacking north of the Hills. Spivey followed the zone northeastward as far as the vicinity of Rapid City (Sec. 34, T. 2 N., R. 8 E.), and it has not been noted north of that point. The beds are apparently greatly reduced in thickness, but whether this is due to thinning of the entire zone, or to erosion of the upper beds is not clear. The writer does not know how far north these beds may be traced on the west side of the Hills, but they are probably represented in northeastern Wyoming by the Pedro bentonitic zone at the base of the Gammon Ferry member of Rubey.[2]

The beds immediately overlying the Sharon Springs consist of flaky, brownish-gray shale, which contains many small con-

---

1. Spivey, R. C., <u>Bentonite in Southwestern South Dakota</u>, Report of Investigations No. 36, S. Dak. Geol. Survey, April, 1940.
2. Rubey, W. W., op. cit., p. 165.

cretions and baculites. This closely resembles the basal Pierre beds north of the Hills, and probably is to be correlated with the Gregory member of the Missouri River section. These in turn grade upward to grayer, bentonitic shales with abundant concretions of several types. No detailed section of the beds immediately overlying the Sharon Springs was measured.

Sections XX and XXI show the details of a 200 foot sequence which lies perhaps two or three hundred feet above the fissile shale member. Bentonites seem to offer the only good key horizons in the area. Thick bentonites, especially if associated with considerable light colored fibrous calcite, stand out sharply on gumbo slopes and may be traced for considerable distances where the beds do not dip too steeply. It seems likely that one of these bentonites is the one noted in several sections north of the Black Hills.

Sections XXII and XXIII show the nature of the beds in the middle part of the Pierre, probably not so far above the previous two sections. Both outcrops are fossiliferous, and offer opportunity for later paleontological study.

The tepee buttes which are so numerous on the upland around Oelrichs and Smithwick were examined, but no attempt was made to determine the interval between them and the lower beds.

Limited time prevented an effort to trace the outcrops down the Cheyenne River to tie up with the Sage Creek area, or the exposures of Interior beds in the Badlands area.

Section XIX

Succession of beds exposed in cut bank on north side of the Cheyenne River, in Section 2, T. 8 S., R. 6 E., Fall River County, South Dakota.

		Feet	Inches
Pierre Formation			
57	Shale, brownish gray, with many small rusty concretions and baculite casts. Usually supports vegetation..........		
Sharon Springs Member			
56	Shale, breaks down to blue-gray flakes, but stands up in steep faces which appear nearly black from a distance. Fish scales abundant in some beds. No vegetation cover below here........	3	0
55	Shale, as above, with zone of cone-in-cone concretions up to 1 x 2 feet at top................................	12	5
54	Shale, as above, grading laterally into intermittent lenses of limestone up to 3 x 30 feet.....................	3	1
53	Shale, as above, with zone of limestone concretions from 6' to 1 x 5 feet; 2" rusty streak at top.........	2	0
52	Bentonite...............................		$1\frac{1}{2}$
51	Shale, as above........................	1	2
50	Bentonite...............................		1
49	Shale, as above........................	4	6
48	Bentonite; in and above is a zone of cone-in-cone from 1 to 18" thick......		1
47	Shale, as above........................		4
46	Limestone, weathers rusty-purple.......		1
45	Shale, with one thin bentonite. One foot above base is an occasional 6-8" x 18" limestone, sometimes with dark coating.........................	4	5
44	Bentonite...............................		1
43	Shale, with zone of small purple-brown concretions one foot below top........	11	5
42	Bentonite, with occasional 18" x 5-6' cone-in-cone concretions..............		6
41	Shale, as above........................	3	6
40	Bentonite...............................		1
39	Shale, fish bones noted 4' below top...		10
38	Shale, with persistent zone of 10 x 18" gray to buff limestone concretions at top and smaller ones below...........	27	6

Section XIX, cont'd.

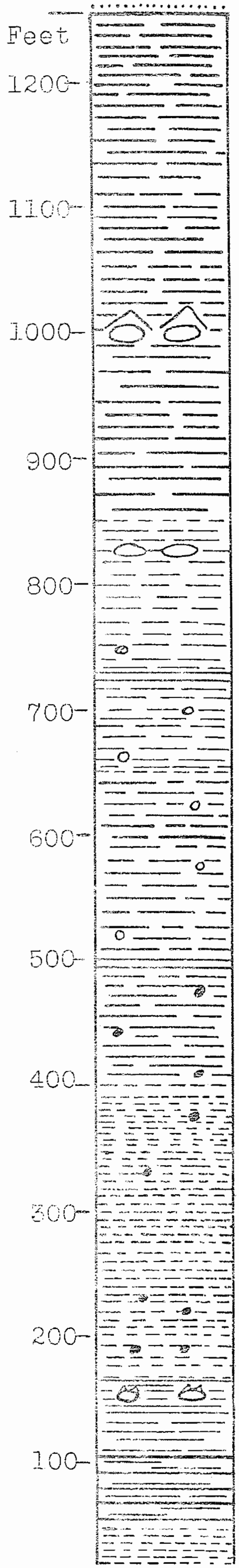
		Feet	Inches
37	Bentonite		6
36	Shale, as above	2	2
35	Bentonite, with gypsum, and red stain in joints		10
34	Shale, gray, flaky, weathers to steeper slope below here	4	5
33	Shale, as above, with zone of 1 x 2' bluish buff limestone concretions at top	3	0
32	Bentonite with few 8" concretions of radial gypsum		8
31	Shale, as above	1	1
30	Bentonite, with 1½" flat limestone at base	1	4
29	Shale, as above		3
28	Bentonite		5
27	Shale, as above		6
26	Bentonite		5
25	Shale, with pair of ¼" bentonites, and zone of 6" limestone concretions near top	2	8
24	Bentonite, with radiating gypsum concretions up to 6 x 10"		6
23	Shale, as above		3
22	Bentonite		6
21	Shale, as above		2
20	Bentonite (ARDMORE)	3	6
19	Shale, as above	1	0
18	Bentonite		6
17	Shale, gray, with gypsum, bloom, few very thin bentonites	27	4
16	Bentonite		½
15	Shale, as above		8
14	Bentonite		8
13	Shale, as above		1
12	Bentonite		½
11	Shale, more fish remains	2	0
10	Bentonite		½
9	Shale, as above	2	6
8	Bentonite		2
7	Shale, more papery	10	8
6	Bentonite, calcareous	1	0
5	Shale, as above	2	7
4	Bentonite		1½
3	Shale, as above	4	6
2	Bentonite, bluish		1½
1	Covered interval, shale believed to be largely Pierre	58	6
	Total Section measured	220'	11"

Niobrara Formation

Shale, bluish-gray, calcareous, with 6" bentonite one foot below top, at river's edge

GENERALIZED SECTION OF PIERRE FORMATION
SOUTH OF THE BLACK HILLS

Figure 9



Zone of large limestone masses which give rise to conspicuous zone of tepee buttes.

Shale, gray, weathers buff.

Shale, gray to bluish-gray, with several conspicuous bentonites carrying much fibrous calcite. Contains rusty concretions of all sizes, plus large gray fossiliferous concretions in upper part. Large Inoceramus in lower part.

Shale, medium gray, non-calcareous, with large rusty concretions and occasional bentonite up to 8" in thickness.

Shale, brownish-gray, with small to medium sized rusty concretions, and numerous baculites and Inoceramus.

Shale, dark gray, fissile, with fish remains. Numerous bentonites. 3 or more zones of large, non-fossiliferous concretions at top sometimes weathers out to tepee buttes.

Niobrara, blue-gray, chalky shale, weathers buff.

Section XX

Succession of beds, Pierre formation, exposed in cut bank along the south side of the Cheyenne River, in Section 9, T. 7 S., R. 8 E., Fall River County.

		Feet	Inches
	Gravel, not measured		
Pierre Formation			
12	Shale, medium gray, non calcareous, with rusty concretions up to 10" x 2'......	12	0
11	Bentonite, pure..........................		3
10	Shale, same..............................	1	8
9	Bentonite, pure..........................		8
8	Shale, as above..........................	21	0
7	Bentonite, very calcareous, some fibrous calcite; biotite flakes near top........		8
6	Shale, with abundant rusty concretions...	30	0
5	Bentonite................................		1½
4	Shale, as above..........................	4	1
3	Shale, with zone of light gray fossiliferous limestone concretions 4 feet above base.....................................	12	10
2	Bentonite................................		1½
1	Shale, gray, more or less calcareous, with several thin bentonites, and zone of light gray limestone concretions 4½ feet above base (base at river's edge)	40	1
	Total section measured	123	6

Section XXI

Succession of beds, Pierre formation exposed in cut bank along north side of Cheyenne River, in Section 2?, T. 7 S., R. 8 E., Fall River County.

		Feet	Inches
	Gravel, terrace, not measured		
Pierre Formation			
9	Shale, blue-gray, crumbly to flaky, weathers to gumbo; with rusty concretions. Upper 10 feet weathered to brownish gray.......	32	0
8	Shale, more abundant concretions, including zone with cone-in-cone at top............	9	0
7	Shale, with persistent zone of rusty concretions with Inoceramus...................	19	6
6	Shale, with intermittent zone of 1 x 6 foot cone-in-cone concretions at top, and others without cone-in-cone throughout...	1	6
5	Shale, with intermittent zone of large rusty limestone concretions with cone-in-cone up to 1 x 6 feet.............................	12	9

Section XXI, cont'd.

		Feet	Inches
4	Bentonite..................................		4
3	Shale, as above............................	1	4
2	Bentonite, with some prismatic calcite, somewhat micaceous.........................		8
1	Shale, gray, to river's edge, not measured		
	Total Section Measured	93	1

Note: Beds 2, 3 and 4, Section XXI are believed to correspond to beds 9, 10 and 11, Section XX. This gives a continuous measured section totaling 202 feet 3 inches.

Section XXII.

Succession of beds, Pierre formation along French Creek just above its mouth; just north of Bower, T. 5 S., R. 10 E., Custer County, S. Dak.

		Feet	Inches
	Gravel, not measured		
	Pierre Formation		
12	Shale, gray, non-calcareous....................	5	3
11	Bentonite, calcareous..........................		3
10	Shale, non-calcareous..........................	5	0
9	Bentonite......................................		1½
8	Shale, as above................................	2	6
7	Bentonite, overlain by up to 8" of massive and fibrous calcite..........................		2
6	Shale, brownish gray, slightly calcareous....	7	7
5	Shale, bluish-gray, some zones calcareous, few or no concretions.......................	13	4
4	Shale, gray; with rusty concretions up to 1 x 3', fossiliferous, some with cone-in-cone..	12	8
3	Bentonite, micaceous, overlain by up to 1' of fibrous calcite........................		1
2	Shale, gray, few rusty concretions...........	10	7
1	Shale, bluish-gray to gray, non-calcareous, with large fossiliferous rusty concretions having small gray nodules on the surface; to creek..	43	4
	Total Section Measured..	100	10½

Note: Bed 7, Section XXII, is believed to correspond to bed 2, Section XXIII. This gives a continuous measured section of 214 feet, 4 inches.

Section XXIII

Succession of beds, Pierre formation, in bluffs a short distance back from the Cheyenne River, opposite the previous section; in Washington County. Composite of two nearby sections.

		Feet	Inches
Pierre Formation			
12	Shale, gray, to top of bluff, not measured, approximately....................	6	
11	Shale, maroon, with brick red, and white nodules. (Interior beds?)...........	5	9
10	Shale, gray, with limestone concretions..................................	21	0
9	Bentonite....................................	1	
8	Shale, gray, scattered limestone concretions..................................	4	7
7	Shale, zone of very fossiliferous gray limestone concretions at top...............	14	0
6	Shale, zone of very fossiliferous gray limestone concretions at top...............	38	9
5	Shale, with intermittent zone of light colored limestone concretions with some cone-in-cone at top..................	15	6
4	Bentonite....................................		2
3	Shale, gray....................................	19	0
2	Bentonite with fibrous calcite..............	1	0
1	Shale, with large irregular rusty limestone concretions in lower part, zone of fibrous calcite near middle; to base of slope............................	86	0
	Total Pierre Measured.........	212	9

V. ECONOMIC POSSIBILITIES

Aluminum

Aluminum is one of the most abundant metals. The average aluminum content of the igneous rocks in the earth's crust has been estimated at 8.08%.[1] In the sedimentary rocks, it ranges from a small fraction of one per cent, as in pure sandstones or limestones, to as much as 45% in some clays.

Aluminum content of a rock or mineral, as reported in a chemical analysis, may be given in terms of per cent of metallic aluminum (Al), or in per cent of Alumina (Al_2O_3). The latter is customary. Alumina contains 52.9% aluminum, and 47.1% oxygen. Thus an aluminum ore reported as containing 50% alumina actually contains only 26.4% (.50 x 52.9) aluminum. Both terms will be used in this discussion.

The following list indicates the aluminum content of the most abundant aluminum bearing minerals:

		Per Cent Al
Diaspore	$Al_2O_3 \cdot H_2O$	45.0
Gibbsite	$Al_2O_3 \cdot 3H_2O$	34.6
Boehmite	$Al_2O_3 \cdot H_2O$	45.0
Alunite	$K_2Al_6(OH)_{12}(SO_4)_4$	19.6
Kaolin	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	20.9
Sericite	$K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$	20.4
Nepheline	$NaAlSiO_4$	17.6
Feldspars	Al silicates of K,Ca,Na	variable
Cryolite	Na_3AlF_6	12.8

As arranged above, these minerals fall into several chemical groups. The first three contain aluminum as an oxide, the fourth as a basic sulphate, the next four as aluminum silicates and the last one as a fluoride.

Bauxite is the principal ore of aluminum. It is not a true mineral, but consists of a mixture of two or more hydrous aluminum oxides in varying proportions. These include gibb-

---

1. Clarke, F. W., The Data of Geochemistry, 5th Ed., U. S. Geol. Survey Bull. 770, p. 29, 1916.

site, boehmite, and diaspore. Bauxite is formed by extreme weathering of aluminum rich rocks.

Cheap production of aluminum has always been a metallurgical problem because of the difficulty of recovering the metallic aluminum from the various compounds in which it occurs in the ores.

Cryolite was the first mineral from which it was produced, but deposits were small and the aluminum content low, so that the practice ceased when metallurgical advances made other ores available.

The Hall-Héroult method for recovering aluminum from bauxite by an electrolytic process, using cryolite as a flux, was established on a commercial basis in 1888. Since that time, the world's supply of the metal has been recovered from bauxite deposits in many countries, the most important of which are France, United States, Russia, Dutch Guiana, British Guiana, Hungary, Italy and Yugoslavia.

Two very recent developments are the recovery of aluminum as a byproduct during the production of potash from alunite, and the announcement by engineers of the Tennessee Valley Authority of a commercial method of recovering aluminum from clays.[1] The actual process has not been made public, and it is doubtful if the cost is low enough to compete with bauxite production under normal conditions.

The question is often raised as to why aluminum cannot be made from aluminum bearing shales such as those of the Pierre formation. The answer lies first in the fact that this aluminum occurs in the form of silicates, the hardest group from which to recover the metal, and secondly in the fact that these shales have a much lower aluminum content than other deposits not yet developed.

The first objection can apparently soon be overcome by adoption of the T.V.A. or some similar process for recovery of aluminum from clays, still assuming cost to be no consideration.

---

1. Minerals Yearbook, Review of 1940, U. S. Bureau of Mines, p. 1235.

The second point may be answered by comparing the aluminum content of the Pierre with the known reserves of higher grade ores whose metallurgy is no more difficult or expensive. Table II shows analyses of samples of Pierre shale collected along the Missouri River during the present survey. The highest alumina content observed is 22.3% (12.67% aluminum). The average of 6 other miscellaneous samples of Pierre whose horizon is not known, but collected around the Black Hills, is 18.8 per cent alumina.

Among higher grade ores which are known in this country, the bauxite reserves come first. Deposits occur in Arkansas, Georgia, Alabama, Tennessee, and Mississippi, with about 90% of the output coming from the first named. United States bauxite deposits have not been considered previously unless they contained an alumina content of over 50%, and those mined have usually run about 56-59%. Extensive testing of deeply buried and low grade deposits, which could easily be developed where cost is not the dominant factor, has boosted estimates of the U. S. bauxite reserve to around 40,000,000 tons.

Current consumption of bauxite in the United States is estimated at about one and one half million tons a year. This has included a high percentage of imported ore, but even if it becomes necessary to rely entirely upon our own reserves during the current war, it is obvious that our reserves will last for many years.

Limited deposits of alunite in several western states could be developed for aluminum recovery under a war-time economy. The total reserve is probably small, but because of ease of treatment with the additional recovery of potash, these will probably be worked before even the richest clays. The small start along this line at Marysville, Utah, has already been mentioned.

Finally, there are extensive deposits of clay containing much higher alumina than the Pierre shale. Many kaolin-rich residual deposits are known in the southeastern states. Pure kaolin contains 39.8% alumina, and much material is known which will run above 36%. Deposits of diaspore clay in Missouri are reported to run as high as 70% alumina.

TABLE II

WHEELER BRIDGE SECTION

Section 3, T. 96 N., R. 68 W., Gregory Co.

Sample No.	Member of Pierre Formation	Per Cent Aluminum
1.	Elk Butte	12.67
2.	Mobridge	8.21
3.	Upper Virgin Creek	11.52
4.	Lower Virgin Creek	10.96
5.	Verendrye	8.64
6.	Oacoma	10.97
7.	Gregory chalk	4.52

ALUMINUM CONTENT OF THE PIERRE SHALES

Sample No.	Member of Pierre Formation	Location	Per Cent Aluminum
8.	Verendrye	Stanley County	9.74
9.	Oacoma	Stanley County	7.15
10.	Virgin Creek	2 miles east of Teton, Stanley Co.	10.84
11.	Gregory Shale	Sec. 32 T. 9 S., R. 5 E., Fall River Co.	12.27
12.	Sharon Springs	Sec. 32, T. 9 S. R. 5 E., Fall River Co.	8.04

Barite

Barite (Barium sulphate, $BaSO_4$) may be white, or various shades of gray, blue or brown in color, and has an unusually high specific gravity (4.3 - 4.6) for a mineral with a non-metallic luster. It may appear in crystalized form either as individual crystals or as cleavable masses. When it occurs in very finely crystalline form it is described as massive. Another occurrence is in irregular nodules having a fibrous, radiating structure, and is known as barite "roses" or "rosettes".

Gray barite rosettes are frequently found in the Pierre, and range in size from less than one-fourth inch in diameter to nearly continuous ledges from two to four inches thick. These are usually associated with bentonite. In a few localities in Butte County, it would be possible to pick up several hundred pounds of weathered rosettes by following a bentonite outcrop less than half a mile.

A second occurrence of barite in the Pierre is in the large septarian limestone concretions, the cracks of which are occasionally filled with light to medium brown barite, associated with golden calcite. Although resembling amber in its beauty, this so-called "golden barite" is too soft and too brittle to be used as an ornamental stone in jewelry.[1] Perfect crystals have some small value as display pieces in mineral collections.

Because of the abundance of large deposits of barite in several of the southeastern states, scattered deposits of the Pierre type would have no value, even if close to markets. Barium compounds are used primarily as a filler in such products as rubber, paper, and plastics. It serves as a pigment and extender in paint. A recent use is to increase the weight of drilling muds used by the oil industry.

---

1. Connolly, J. P., and O'Harra, C. C., The Mineral Wealth of the Black Hills, S. Dak. School of Mines, Bull. 16, p. 344, 1929.

Bentonite

Bentonite is the name given to the fine-grained, soapy feeling, yellow clay sometimes found interbedded with shales or other marine sediments. It has been formed by the alteration of beds of volcanic ash which fell into the sea when the enclosing deposits were being laid down. Thickness of the beds at any place is a measure of the magnitude of the volcanic eruption, the distance from the source, and the strength and direction of the winds prevailing at the time.

The various grades of bentonite are in demand for many different uses, particularly as a bonding agent in molding sand, as a thickener in drilling mud, and, in the case of the Ardmore bentonite of South Dakota, as a water softener.

Bentonite is common throughout the Pierre formation wherever it crops out, but only locally are the beds thick enough to justify commercial development. Apparently the source of this ash was to the west of this region, for in general the bentonite beds are thicker around the Black Hills than they are along the Missouri River valley.

In the central part of the state, the Pierre bentonites seldom reach a thickness of more than one foot. The greatest concentration of beds is in the Sharon Spring member, a few feet above the contact with the Niobrara chalk. In one outcrop near Chamberlain a total of 44 inches of bentonite was noted in an interval of 14 feet. (Gries and Rothrock, 1941, p. 10).

Bentonites of the Sharon Springs member reach individual thicknesses of over three feet south of the Black Hills. These were first developed near Buffalo Gap, but since 1917 the only mining operations have been near Ardmore. The nature and distribution of the bentonite in this area has been fully covered in a recent report of this survey.[1]

---

1. Spivey, R. C., Bentonite in Southwestern South Dakota, S. Dak. State Geol. Survey, R.I. No. 36, 1940.

North of the Black Hills this lower zone is apparently missing. A bentonite which frequently reaches a thickness of over a foot occurs high in the formation (See Sections XVI and XVIa), but it contains so much fibrous calcite that its development has not been successful.

The extensive bentonite beds exploited in the Belle Fourche-Wyoming area are found in the somewhat older Graneros formation.[1]

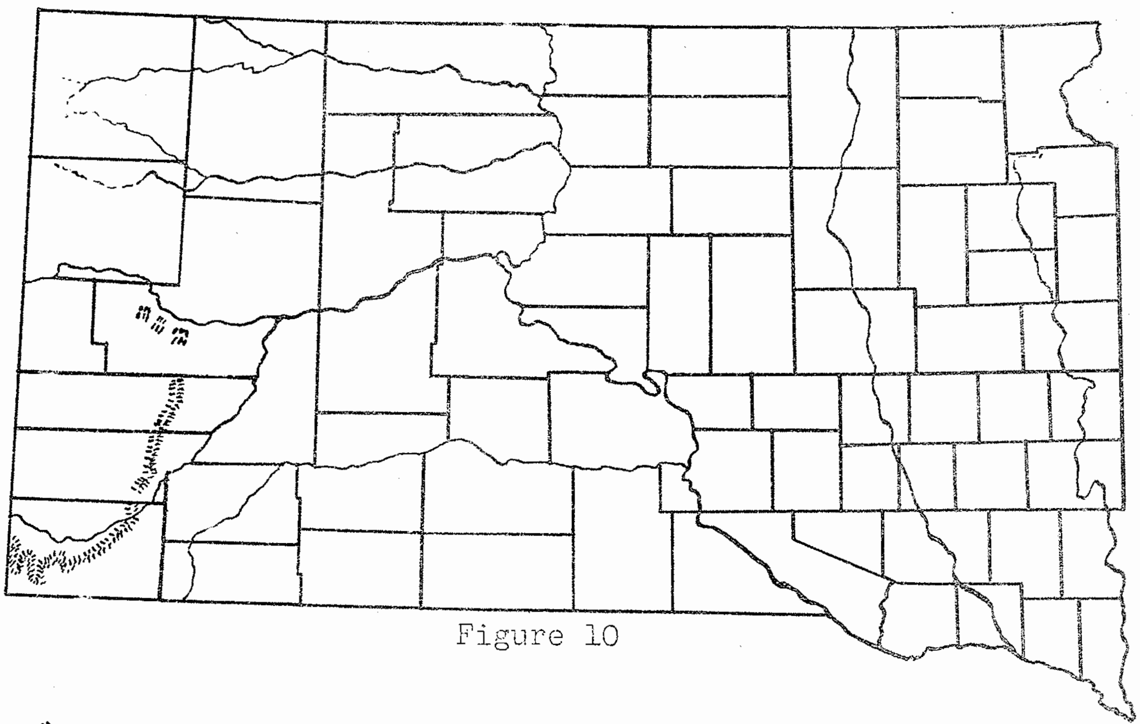


Figure 10

Outcrop of Pierre bentonite, showing distribution of beds of commercial thickness. Outcrop around southern hills is in the Sharon Springs member. Dotted outcrop in Meade County indicates area where some development work has been done on a thick bentonite probably in the Virgin Creek Member.

---

1. Wing, M. E., Bentonite of the Belle Fourche District, South Dakota, S. Dak. Geol. Survey, R. I. 35, 1934.

Cement

The Pierre shale has been used as an ingredient of the Portland Cement manufactured at the State Cement Plant at Rapid City since December, 1924. Investigations made before the erection of the plant showed that either the Graneros or Pierre shale would be satisfactory when mixed in proper proportions with the Minnekahta limestone, but that the "Pierre shale mixture requires less coal in burning than does the Graneros shale, and that it makes a little better grade of cement."[1] The shale, which is used in the approximate ratio of one part shale to four parts limestone, is obtained from a quarry located along the Northwestern Railroad and U. S. Highway 14-16, about 5 miles east of Rapid City. The exact horizon of the Pierre from which the shale is taken has not been determined, but it is believed to lie near the middle of the formation.

The following is a typical analysis of the material quarried:[2]

SiO_2	56.22
Al_2O_3	19.63
Fe_2O_3	6.84
CaO	2.57
MgO	1.90
SO_3	1.78
Ign. loss	9.60
N D	1.46
Total	100.00

Equally satisfactory material could be obtained from the Pierre shale throughout its area of outcrop. Particularly favorable areas for cement manufacture would be around the Black Hills, or in the lower Missouri Valley; that is, adjacent to a source of limestone or chalk.

---

1. J. P. Connolly and C. C. O'Harra, The Mineral Wealth of the Black Hills, S.Dak. School of Mines Bull. 16, 1929, p.273.
2. Ibid., p. 275.

Chalk

Chalk, or chalk rock, is a soft porous form of limestone. Pure chalk may be used in the manufacture of whiting; the impure varieties are extensively used in the manufacture of portland cement. Locally, where other building stone is not available, chalk has been used with varying success.

Chalky beds occur in the Pierre in the basal Gregory and Sully members, and locally in the Mobridge member. These range from nearly pure chalk, to marl and calcareous shale. In general they are too impure, and in most cases, too thin, to have any economic value. The best of the Pierre chalk beds lie along the lower Missouri River valley, in the same area where the Niobrara chalk crops out. As a result, when chalk has been needed for local use, the thicker, purer, and more accessible Niobrara has consistently been chosen.

Clay

Clay may be defined as any earthy material which is sufficiently plastic when wet to be molded, and which will harden under fire. Pure clay is made up of a group of closely related minerals, the so-called clay minerals, which are hydrous silicates of aluminum. Impure clays and shales include in addition many other minerals, including quartz, calcite, limonite, pyrite, gypsum, mica, and organic matter.

These various impurities may change the plasticity, fusion point, color after firing, shrinkage, strength and other physical properties, and hence limit the uses to which any given deposit may be put. Reference to the analysis given under the discussion of cement shows the Pierre shale to be high in silica, iron, calcium and magnesium, and low in alumina. Many zones are also high in organic matter. This material would, nevertheless, be satisfactory for the manufacture of common red brick and tile, and has probably been used locally for that purpose in several places within the state.

Gas

Natural gas has been encountered in the Pierre shale when drilling for artesian water in lower formations. When gas is thus encountered, it is usually also found in the succeeding formations, particularly the Greenhorn limestone and Dakota sandstone. Because it is necessary to case off the shales to prevent collapse of the hole, only the gas from the Dakota is available from the completed well. The writer knows of no case where gas from the Pierre shale has been utilized.

Gypsum

Shining gypsum crystals are often a conspicuous feature of the Pierre outcrops, and frequent requests are received as to their identity and possible value.

The gypsum in the Pierre shale is of the transparent variety known as selenite. Chemically it is a hydrous calcium sulphate, $CaSO_4 \cdot 2H_2O$. It occurs in flat, diamond shaped crystals or as irregular fragments which are imperfect or partially dissolved crystals. The mineral tends to split into thin plates which resemble mica, but selenite is much softer (can be easily scratched with the fingernail) and is less flexible than mica.

Except for an occasional thin bed of impure gypsum at the contact between the Pierre and the Niobrara, the gypsum is present only in scattered crystals ranging from microscopic size to over one foot in length. They have no commercial value.

Gypsum is used in the manufacture of plaster of paris, but the supply comes from bedded deposits which may be several tens of feet thick and many acres in extent. Gypsum used in South Dakota comes from the Triassic Spearfish formation around the Black Hills.

Manganese

Manganese is essential for the manufacture of steel. About 14 pounds is required for the production of one ton of ordinary steel, and more for the special manganese-alloy steels which are known for their toughness. This manganese is added in the form of ferro-manganese, a mixture containing about 80% manganese, 12% iron, and the remainder mostly carbon. The purpose of the ferro-manganese is to remove harmful impurities, and hence to produce a pure steel.

Ferro-manganese is produced only from high grade ores, that is, those carrying over 48% manganese. Only very small deposits of ferro-grade ore are known in this country. In the past the United States has imported about 90% of its high grade ore, most of it coming from Russia, Gold Coast, India, Brazil, and Cuba. In 1942, with the steel industry working at capacity, it is estimated that approximately 1,250,000 long tons of high grade ore will be required for the manufacture of ferro-manganese.[1]

In the present emergency it is necessary to develop a method of concentrating some of our abundant low grade ores into a high grade product from which ferro-manganese can be made. It is in this connection that the manganese-iron-carbonate concretions of the Pierre shale have received attention.

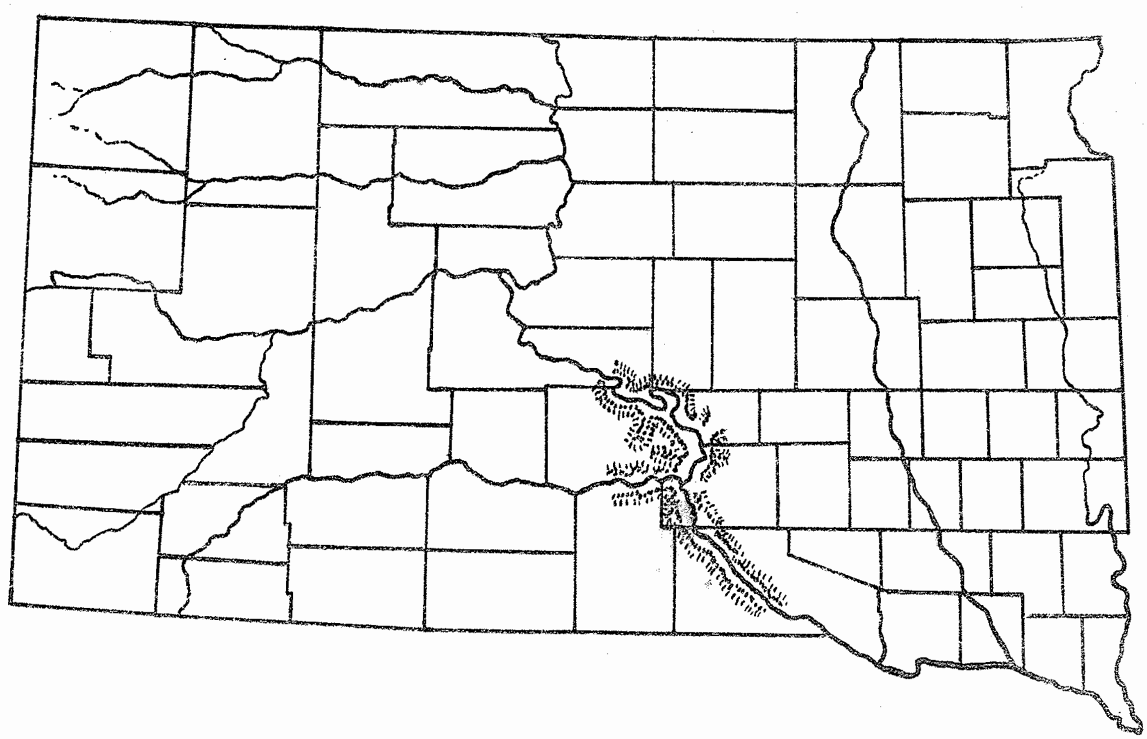
These concretions, or nodules, may be seen covering many of the slopes and knolls along the river breaks in the vicinity of Chamberlain and Oacoma. They are typically about the size and shape of a potato, but many are up to six inches in thickness and a foot or more in diameter. Close examination will also reveal smaller nodules down to almost microscopic size, but only those larger than marbles are normally noticed.

The concretions are bluish gray to olive green on fresh surfaces, but they darken rapidly upon weathering, so that the outside, of those on outcrops, is invariably purplish black. The depth of color change is apparently a function of length of time of weathering for those which have weathered for a long time are frequently black clear through.

---

1. DeVaney, F. C., Concentration of Chamberlain, South Dakota Manganese Ore, Black Hills Engineer, p. 201, February, 1942.

Figure 11



Area of heavy concentration of manganese-iron concretions in the Agency-Oacoma zone.

Superficially a fresh concretion appears to be of homogeneous light gray material, often spotted with fragments of fossil shells. However, chemical and mineralogical studies indicate that the composition is very complex.

The relatively high manganese content of the concretions in the Agency-Oacoma zone was first noticed by individuals interested in hydro-electric development in the vicinity of Chamberlain. Subsequently the General Manganese Corporation became interested, and retained the John Savage Company of Duluth, Minnesota, to conduct an investigation of the area in which these nodules were abundant. A report was made to the company in January 1929.[1] In the summer of 1929, further investigation was made by D. F. Hewett, of the U. S. Geological Survey, and the conclusions released to the public in February 1930.[2] The next detailed study of the area was made by the State Geological Survey in July and August, 1940.[3]

The results of these investigations have been summarized in the above mentioned report, and only the conclusions are tabulated here:

1. The nodules occur in a zone averaging between 45 and 50 feet in thickness.
2. The outcrops of this zone parallel the Missouri and its tributaries in a narrow band extending from the southern edge of the state up to the mouth of the Moreau River, but the nodules are abundant only in the area between the Bijou Hills and the Great Bend.
3. The nodules make up from 6 to 10 per cent of the shale.

---

1. See Scholl, L. K., _A Reconnaissance of Manganese Occurrence in the Chamberlain District, South Dakota_, unpublished report, June 10, 1940. On file in library of S. D. School of Mines, Rapid City, S. D.
2. Hewett, D. F., _Manganese-Iron Carbonate Near Chamberlain, S. D._, Memorandum for the Press, U. S. Geol. Survey, February 5, 1930.
3. Gries, J. P. and Rothrock, E. P., _Manganese Deposits of the Lower Missouri Valley in South Dakota_, S. D. Geol. Survey, Report of Investigations No. 38, January 1941.

4. The nodules average about 17% manganese; the shale and nodules together thus averaging about 1.8% manganese.

5. By utilizing only the shale exposed in outcrops, it has been estimated that between 124 and 300 million short tons of manganese are available between Bijou Hills and the Great Bend.

Utilization of such a low grade deposit brings up two groups of problems: those connected with mining and concentration of the ore, and those metallurgical problems concerned with recovering the manganese from the nodules.

Beginning in the fall of 1940, the U. S. Bureau of Mines began an investigation of the mining and separation methods, and at the present time has a 750 ton pilot mill in operation $4\frac{1}{2}$ miles west of Oacoma. For description and results of this experimentation, the reader is referred to the paper by DeVaney, previously mentioned.

Research on the metallurgy of these ores has been conducted by several agencies. The outlines of this work have been summarized elsewhere,[1] and need not be repeated here.

Reports of a new smelting process, and of one or more large concentrating plants in the Chamberlain area, are currently being carried in the press, but cannot be verified as this goes to press.

It must again be borne in mind that operations in such low grade deposits are feasible only under a war economy, and appear likely to be restricted or terminated when international trade relations are restored.

---

1. For metallurgical data, see:
South Dakota Manganese Ores, Tennessee Valley Authority, Department of Chemical Engineering, Chemical Research Division, April 26, 1940.
Scholl, L. K., A Reconnaissance of Manganese Occurrence in the Chamberlain District, South Dakota, unpublished report, June 10, 1940.
Gries, J. P. and Rothrock, E. P., Manganese Deposits of the Lower Missouri Valley in South Dakota, S. D. Geol. Survey Report of Investigations No. 38, January, 1941.

Oil Shale

An oil shale may be defined as a shaly or sandy material from which petroleum may be obtained by distillation but not by treatment with solvents. Using this definition, the Sharon Springs Member of the Pierre may be described as a very low grade oil shale.

A sample of "oil shale" presumably from the Sharon Springs, collected southeast of Hot Springs, Fall River County is reported to have yielded $2\frac{1}{2}$ gallons of crude oil per ton.[1] A sample of Sharon Springs, collected along the Missouri River during the present survey showed the following results as reported by the State Chemical Laboratory:

Oil	present
Moisture	2.92%
Loss on ignition	21.96
Organic matter	19.04

Although very little oil has yet been produced from shale in this country, great reserves exist, and will undoubtedly be of great importance in the future. At the present time, only shales containing over 30 gallons to the ton are considered in estimating reserves, although the government, in leasing oil shale lands, has indicated that it may consider 15 gallon-to-the-ton shale as commercial grade.

Using the 30 gallon limit, it has been estimated that oil shales in the United States are capable of producing a total of 160 billion barrels of oil, 120 billion of which may come from the Green River beds of Colorado and Utah.[2]

---

1. Connolly, J. P., and O'Harra, C. C., The Mineral Wealth of the Black Hills, S. D. School of Mines, Bull. 16, 1929, p. 378.
2. McKee, R. H., Oil Shale, p. 14, Chemical Catalogue Company, New York, 1925.

Soils

Soil derived from the Pierre shale covers an estimated 12,000,000 acres in South Dakota, nearly all of it west of the Missouri. The economic effect of the formation on agriculture and grazing is consequently great.

Soil surveys, some in detail, some of a reconnaissance nature, have been made by the U. S. Department of Agriculture. These describe the various soils, show their distribution, and offer suggestions as to their adaptability to the raising of various crops.[1]

Of concern to those living in Pierre shale areas is the fact that some members of the Pierre are high in selenium, whose compounds give rise to "alkali disease" in cattle and selenium poisoning in humans. A recent report has described the varying selenium content of the different members and zones of the Pierre, and has discussed the ability of different plants to absorb selenium from the soil and thus put it in form available to humans and animals.[2] The need for further detailed work in highly toxic areas is stressed.

---

1. See Soil Survey of Belle Fourche Area, South Dakota, 1908 and Reconnaissance Soil Survey of Western South Dakota, 1911, both published by the United States Department of Agriculture.
2. For a comprehensive study of this problem, see: Moxon, A. L., Olson, O. E., and Searight, W. V., Selenium in Rocks, Soils and Plants, Tech. Bull. No. 2, Dept. of Exp. Chem., Agri. Exp. Sta., S. D. State Coll. Agri. and Mech. Arts, May, 1939.

Water

The Pierre shale is too impervious to yield water, so wells drilled into the formation are almost always dry. Occasionally a small amount of water may be carried in joints and bedding planes near the surface, but this water is usually highly mineralized.

In areas where the Pierre is overlain by a thin mantle of clay, sand, or gravel, water is frequently encountered at the contact of the two formations. In the case of large diameter dug wells, it is common practice to dig a few feet into the shale to form a reservoir in which the water may accumulate.

Stock dams are frequently built on the Pierre. It was originally common practice to scoop the weathered surface material from the reservoir and use it to make the dam, thus deepening the finished pond and making the dam in one operation. However, it was found that in many cases the unweathered shale thus exposed in the bottom was so jointed that the water seeped down through the shale and escaped, even though the dam itself was tight. It is now customary to build the dam out of weathered material brought down from the hillsides opposite the dam, and to leave the weathered material in the basin undisturbed. In this way both the basin and the dam are formed of clayey, impervious material, and the results have been much more satisfactory.