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SOUTH DAKOTA

STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

** **

REPORT OF INVESTIGATIONS

No. 39

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STRATIGRAPHY AND STRUCTURE OF THE CHAMBERLAIN SECTION OF THE MISSOURI RIVER VALLEY

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By

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and

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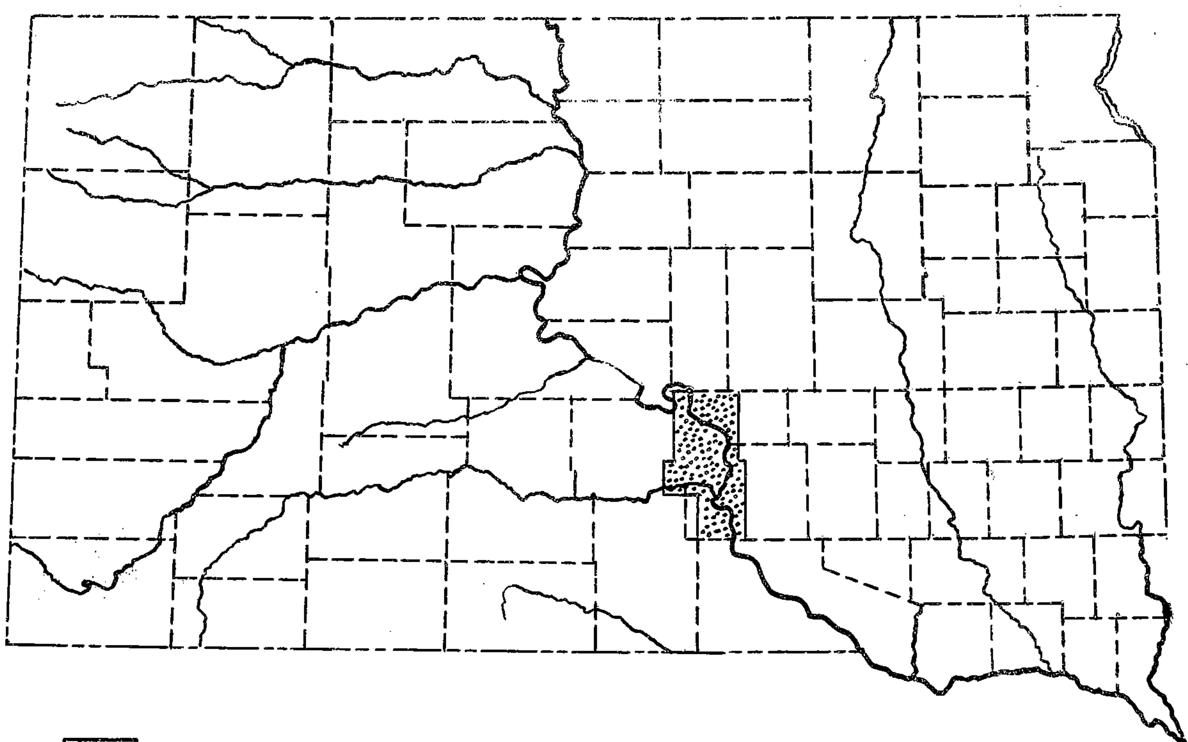

Area covered by this survey.

INTRODUCTION

The following report is concerned with the stratigraphic and structural conditions existing in the Chamberlain section of the Missouri River valley. The area lies in the three counties of Buffalo, Lyman, and Brule. (Figure 1)

It extends from the Big Bend of the Missouri in northeastern Lyman County to the Iona-Bijou Hills near the southern edge of Brule County. The survey was limited principally to the bluffs along the Missouri and to the short tributaries leading into this stream. However, due to favorable conditions, the survey was extended many miles up the White River from the point where it enters the Missouri.

This report is concerned primarily with structures and the possibility that these may have been favorable for the accumulation of oil. It is an outgrowth, however, of a survey which was undertaken in this region primarily to map and sample manganese deposits occurring in the Pierre shale. These had long attracted attention but had been considered too low-grade to be worked economically. Because of conditions which have developed in the world during the last few years--conditions which have made it necessary for this country to produce its manganese within this country--attention was again focussed on the extensive deposits of the Chamberlain area. The South Dakota State Geological Survey, in keeping with its policy of furthering the development of the state's resources, decided to conduct an appraisal of these deposits. The results of this survey are included in a separate report published by the survey.[1]

Soon after the manganese survey was undertaken, it was discovered that conditions would justify a separate report on the stratigraphy, structure, and oil possibilities of the area. This was based on a number of considerations. Preliminary investigation showed that there was a prominent anticline in the area--the type of structure that has yielded petroleum and gas elsewhere. Secondly, it was discovered that conditions were very favorable for conducting a survey. There was a key bed on which elevations could be based in determining the structure, and there was only a slight amount of slumping, a condition which makes it difficult to determine the exact structure elsewhere along the Missouri River.

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1. Gries, J. P. and Rothrock, E. P., Manganese Deposits in the Lower Missouri Valley in South Dakota, S. Dak. State Geological Survey Report of Investigations # 38, January, 1941.

Third, it was discovered that a number of artesian wells southwest of Chamberlain had and were still yielding small quantities of natural gas. Gas and oil occur under the same geologic conditions and the presence of gas in even small quantities is always of interest to those interested in prospecting for oil.

This decision was influenced, also, by the general policy of the State Geological Survey to do everything possible to encourage prospecting for oil and gas within the state--a policy that seems justified from the generally favorable geological conditions existing in the state.

Nature of the Survey

The survey was the same type as that made in the oil fields, where an indication of the structure of oil producing beds some distance beneath the surface is obtained from a determination of the structure of beds at the surface. Briefly, numerous elevations were obtained on a key bed by means of the plane-table and telescopic alidade. These were plotted on a base map and structural contours drawn. The key bed was the thin but persistent brown sandstone at the base of the Crow Creek zone of the Sully member of the Pierre shale. Elevations obtained and used on the accompanying map were sea-level elevations. All traverses were run from and checked into control points consisting of bench marks established by the Missouri River Commission, the Coast and Geodetic Survey, and the United States Geological Survey.

The survey was conducted by the same parties concerned with the manganese survey. There were three units in all, each consisting of a geologist and an engineer. Dr. E. P. Rothrock headed the survey and with Mr. D. P. Rothrock as engineer, did all of the mapping east of the Missouri River with the exception of an area in Crow Creek Valley approximately ten miles north of Chamberlain. Dr. J. P. Gries, with Mr. Harold Brookman as engineer, mapped the White River valley, a relatively small area on the west side of the Missouri near the southern edge of the area, and an area previously mentioned in Crow Creek east of the River. Dr. M. E. Wing with Mr. Ray Maloney as engineer, mapped all of the area west of the Missouri River with the exception of the White River valley and the area near the southern edge of the White River valley and the area near the southern edge of the survey already credited to the party headed by Dr. Gries.

The work was done from a central camp set up on American Island located just west of the River at Chamberlain. While the survey provided its own sleeping and eating quarters and food, the survey members were given free use of the very excellent facilities of the Chamberlain municipal tourist camp at the west end of the bridge on American Island by the Chamberlain Chamber of Commerce. This courtesy is hereby gratefully acknowledged.

The writers wish to acknowledge their indebtedness to the other members of the party for their part in the survey, and to Dr. Rothrock and his staff at Vermillion, who have given much aid to date and who will see this report to its final conclusion.

GENERALIZED COLUMNAR SECTION OF THE PIERRE FORMATION

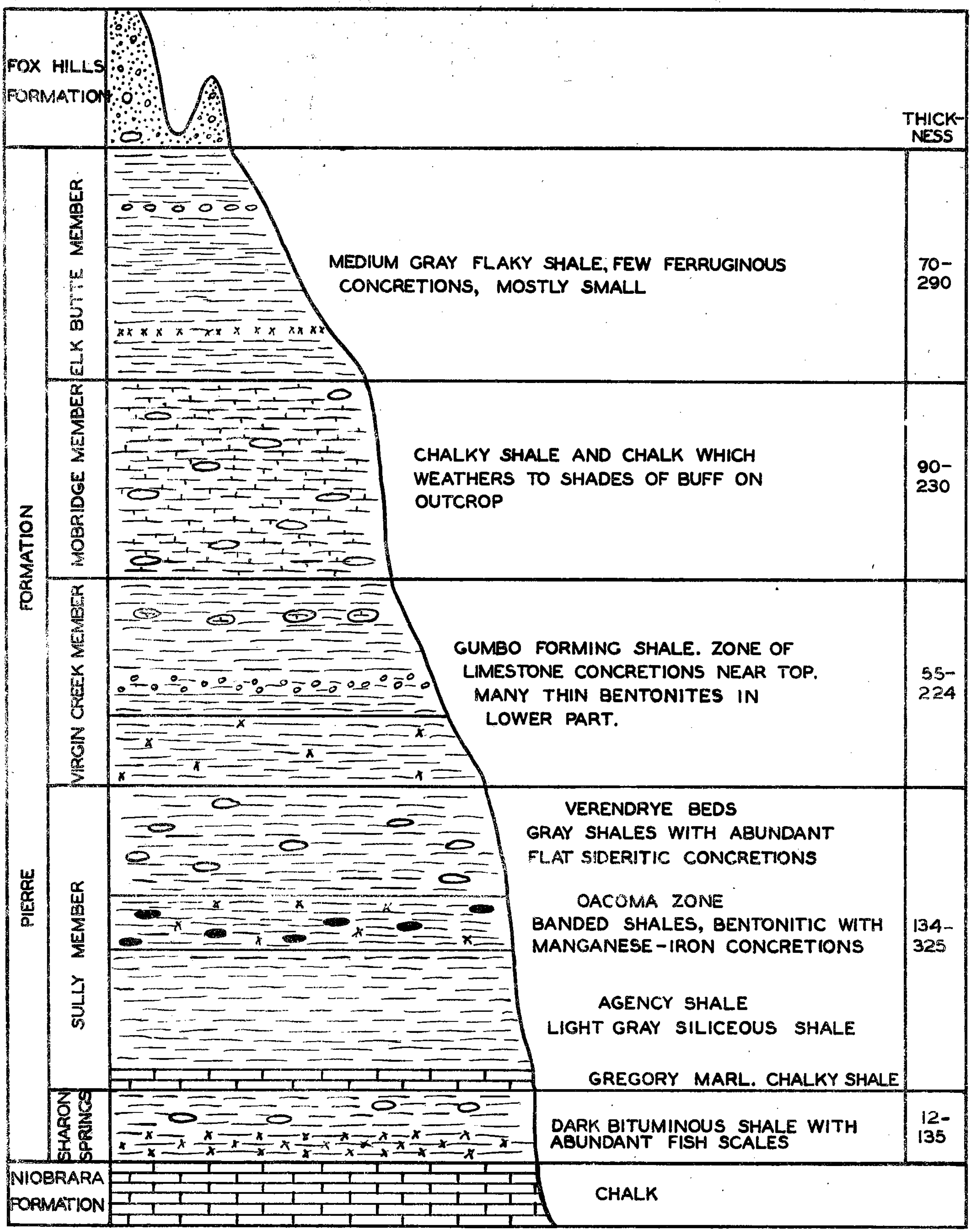

PLATE III

STRATIGRAPHY-FORMATIONS EXPOSED AT THE SURFACE

INTRODUCTION

General Description of the Area

The formations exposed along the valley of the Missouri River in the area under consideration are the Niobrara chalk and the various subdivisions of the Pierre shale. These are of Upper Cretaceous age. Some of the higher hills adjacent to the area are capped with Tertiary clays and sandstones, but these were not investigated during the course of the present study. East of the river, the bedrock is generally overlain by a mantle of clay and boulders known as glacial till, depositied by the glaciers during the Pleistocene or Ice Age. In addition, terrace gravels of late Tertiary and Quaternary age overlie the bedrock in many places, particularly west of the Missouri. The glacial till and gravels were of interest in this survey only in that they frequently obscured the bedrock, so no detailed study of them was attempted.

Detailed mapping of the area covered by this report extended from the Iona-Bijou line of hills on the south to the Great Bend of the Missouri on the north. In order that the stratigraphic study might cover as large an area as possible, however, detailed sections of the Pierre formation were measured as far south as the Rosebud bridge, Gregory County, and north to the vicinity of DeGrey, Hughes County. Similarity of the DeGrey and Ft. Pierre sections makes it possible to connect the stratigraphy of this area with that previously studied in and north of Stanley County.[1]

Previous Work

The rocks exposed along the Missouri River in South Dakota, and their fossil content, have been a matter for scientific discussion for over 100 years. A concise review of this early work has been given in a previous publication,[2] and will not be repeated here.

1. See Reports of Investigation Nos. 27, 31, and 34, South Dakota State Geological Survey.
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.

The first detailed study of the stratigraphy in this particular area was made in 1929 by D. F. Hewitt[1] of the United States Geological Survey, during the course of an investigation of the iron-manganese concretion beds in the vicinty of Chamberlain. A comprehensive study and subdivision of the Pierre formation in the Missouri Valley of South Dakota was made by Searight[2] in 1937. This classification opened the way for further detailed studies within the state. The present report summarizes the results of the fourth of a series of stratigraphic and structural surveys undertaken by the State Geological Survey since that time. Each covers the stratigraphy and economic possibilities of a limited area along the Missouri valley.

DETAILED DESCRIPTIONS

Niobrara Formation

The impure chalk which comprises the Niobrara formation is typically gray on fresh exposures. After long weathering, the formation usually presents a yellowish appearance, although some members remain gray, or become nearly white under these conditions. Numerous thin bentonite beds are characteristic of the formation, but are conspicuous only on relatively fresh outcrops.

This chalk, the lowest formation exposed within the area, occurs in bluffs along the river's edge as far north as Fort Thompson, Buffalo County, where it dips beneath the river level. Approximately 100 feet of the niobrara is exposed in the vicinity of Chamberlain, and this decreases gradually to about 20 feet at the Rosebud bridge.

Fossils are not conspicuous in the Niobrara in this area, although careful search will usually reveal masses of the typical *Ostrea congesta*. Searight[2] has correlated the exposures in this area with the Smoky Hill member of the Niobrara in Kansas.

Pierre Formation

The Pierre formation consists of a thick series

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1. D. F. Hewitt, Memo for the Press, February, 1930.
2. Moxon, A.L., Olson, O.E., Searight, W.V., Selenium in Rocks, Soils, and Plants, Technical Bull. No. 2, Agr. Exp. Sta., S. Dak. State College Agr. and Mech. Arts, May, 1939.

of gray shales, some zones of which are sufficiently calcareous to be termed marl or even chalk. These shales overlie the Niobrara with apparent conformity, and form the bedrock over most of the area under consideration. Because of the abrupt nature of the river valley, and the scarcity of vegetation on the steeper slopes, good outcrops of the various members are found throughout the Missouri valley and its major tributaries.

Searight in 1937[1] divided the Pierre shale of the upper Missouri valley of South Dakota into five members, several of which were in turn subdivided. Minor changes in nomenclature were introduced by the same writer in 1938[2] and 1939[3]. On the basis of the work outlined in this report, a further slight change is suggested resulting in an increase in the number of members from five to six. The original classification, together with all subsequent changes, is shown in Table I.

TABLE I

CLASSIFICATION AND NOMENCLATURE OF THE PIERRE FORMATION

Searight (1937)	Searight (1938)	Searight (1939)	This Report (1940)
Elk Butte	Elk Butte	Elk Butte	Elk Butte
Mobridge	Mobridge	Interior	Mobridge
Virgin Creek upper lower	Virgin Creek upper lower	Virgin Creek upper lower	Virgin Creek upper lower
Sully Verendrye Oacoma Agency	Sully Verendrye Oacoma Agency Gregory marl	Sully Verendrye Oacoma Agency Gregory	Sully Verendrye Oacoma Agency Crow Creek
Gregory upper lower	Sharon Springs	Sharon Springs upper lower	Gregory shale marl Sharon Springs

1. Searight, W.V., Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in S. Dak., op cit.
2. Moxon, A.L.; Olson, O.E.; Searight, W.V.; and Sandals, K.M., The Stratigraphic Distribution of Selenium in the Cretaceous Formation of South Dakota and the Selenuim Content of Some Associated Vegetation, Amer. Jour. Botany, Vol. 25, No. 10, pp.794-809, December, 1938.
3. Moxon, A.L.; Olson, E.O.; and Searight, W.V.; Selenium in Rocks, Soils, and Plants, op. cit.

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 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". Detailed work during the past summer 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 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 zone of Searight (1938), and the redefined Gregory member of the present report.

Subdivision: As may be noted in Table II, the shale between the Niobrara chalk and the Gregory marl is divisible in this locality 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 in these beds.

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

On steep slopes, outcrops of the fissile shale stand out in sharp, buttress-like forms, and appear nearly black from a distance. Exposures on gentle slopes appear as patches of loose, light gray shale flakes. The surface of all exposures 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 outcrop. They are usually thin, though one-foot beds are not unusual, and one measuring over two feet was observed. In a 14 foot section near the mouth of Crow Creek, Buffalo County, a total of 44 inches of bentonite was recorded. In outcrops where the basal bentonites are particularly well developed, it was noted that the associated shale was earthy in texture, quite unlike the overlying fissile beds. Details of the zone may be noted in Tables II, III, IV, V, and VIII.

Small areas of burned shale testify to the bituminous nature of this zone. Normally gray outcrops have become light pink to brick red on baking, and the individual shale fragments are quite hard and have a harsh feel. Three such patches were observed along the lower part of White River. The smallest occurs on the south side of State Highway 47, about a mile south of the White River bridge, and the largest lies on the north side of the same stream in section 32, T.104N., R. 72W.

Thickness: The fish scale is 34 feet thick at the Rosebud bridge, 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. This rather uniform thinning toward the north is believed due entirely to variation in original deposition, and not to removal after being laid down. Comparison with the Black Hills section suggests a thickening of the zone in that direction, though there is no evidence in this area to bear this out.

Paleontology: Aside from fish remains, the only fossils observed in this zone were the bones of a large reptile lying about six feet below the top of the beds, in section 11, T. 103 N., R. 72 W.

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. (For details of this zone, see particularly Table V).

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 were noted near Iona, and 14 feet near the mouth of White River. Farther north the upper contact is not conspicuous, and the zone was not measured.

Correlation: This upper shale zone does not fit the description of the Sharon Springs in the type locality. It is tentatively included with that member in this report 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 Oacoma shale was overlooked when the Rosebud bridge section was first studied.[1] Investigation this past summer shows that the chalk or marl zone conspicuous at the base of the Oacoma beds in the Chamberlain area should be correlated with this overlooked upper calcareous zone of the Gregory County area, rather than with the lower, Gregory marl.

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1. Compare Table II, this report, with Table I, page 14, Searight (1937).

Name: The name Gregory member is resurrected in this report, and used to include all beds between the base of the Gregory marl and the base of the upper calcareous 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 zones; 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: This bed has been observed by the writer only at the type locality, where it consists of about eight feet of impure, light gray chalk. Small shale pebbles and scattered sand grains are characteristic of the basal part. In the vicinity of Iona, southeastern Lyman County, the base of the Gregory shale is marked by a one to two foot layer of buff limestone overlain by a similar thickness of very calcareous shale. In the area around the mouth of White River, this horizon is characterized only by an intermittent zone of large, one to two foot, limestone concretions, and farther north even this marker is generally absent. No outcrops were studied in the 35 mile interval between Rosebud Bridge and the Bijou Hills, so it is not known whether the Gregory chalk thins into the basal limestone and concretion zone just described, or whether it becomes increasingly shaly and thickens greatly to the north. In the latter case, it may be represented in the Chamberlain area by the dominant calcareous phase of the Gregory shale. (See Table VII)

Shale Zone

Description: This shale varied 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.

These calcareous layers 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 carries 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 marl 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. Searight (1937, p. 12, and Table IV, p. 18) has noted an outcrop on Cedar Creek, west of the Great Bend, in which this latter type is particularly well developed. The details of that outcrop may be noted in Table XII.

At the type locality the basal 18 inches of the zone contains abundant fish remains, but these have not been observed within the area covered by this report.

Thickness: The thickness of the shale zone varies greatly. 27 feet were noted at the Rosebud bridge, 68 feet above the basal limestone 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 below the overlying chalk as far north as DeGrey, Hughes County.

Stratigraphic Relation: The relation of the Gregory member to the underlying beds has not yet been thoroughly investigated. At the type locality, the base of the chalk contains sand grains and small fragments of the underlying shale, but in the area under consideration no evidence of a break has been seen. Further study is needed south of this area, and especially south of the type area before the extent and importance of this suggested unconformity can be determined.

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 of the detailed section studied north of Chamberlain (Table VII) an extensive fauna was observed. In addition to the numerous Inoceramus and Baculites, many smaller types were found, most notable of which were young specimens of Pachydiscus complexus. The presence of fish remains in the basal 18 inches at the type locality has already been noted.

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 will here be 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. It forms a conspicuous part of the Pierre shale outcrop in the area under consideration.

Subdivisions: The Sully is divided into four distinct lithologic units, which are, in ascending order, the basal sand and marl, and the Oacoma, Agency, and Verendrye shale zones. Because of their importance in any detailed study of this area, a separate discussion of each is given below. Special emphasis is placed on the unique manganiferous Oacoma beds.

Crow Creek Zone

Name and Description: The basal sand and associated chalky beds of the Sully member have previously been correlated with the Gregory chalk of the Rosebud bridge section. As pointed out under the discussion of that chalk, there are actually two calcareous zones in the Gregory County section, and the Sully marl is to be correlated with the upper one, rather than with the lower or Gregory chalk. Since the name Gregory does not apply, the sand and marl at the base of the Sully member is here called the Crow Creek zone, from characteristic exposures at and south of the mouth of Crow Creek, southwestern Buffalo County. (Tables VIII, VIII-A)

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.

The cementing material is calcium carbonate. In parts of this area the cement is missing, so that the unconsolidated sand does not stand out conspicuously on the outcrop but is concealed by the overlying marl. By dissolving two random samples in dilute hydrochloric acid, it was determined that in each instance the "sandstone" consisted of sand and silt, 37%; and cementing material (CaO_3), 63%. Partial sieve analyses of the insoluble residue are as follows:

	Sample I Oacoma	Sample II De Grey
Retained on 100 mesh (.147 mm.) sieve	trace	1.7%
Passed 100, but retained on 150 mesh (.104 mm.) sieve	3.5%	7.7%
Passed 150, but retained on 200 mesh (.074 mm.) sieve	41.7	37.6
Passed 200 mesh sieve	54.7	52.9

If the dividing line between sand and silt be taken at 1/16 mm. (.0625), it is apparent that the residue consists of almost equal amounts of very fine sand and silt. Under the microscope, the sand and silt particles are shown to be sub-angular quartz grains heavily coated with iron oxide and clay. Considering the high percentage of cementing material, this bed might more properly be called a sandy or silty limestone, but because of its appearance and mode of weathering it will be referred to in this report only as a sandstone. Pebbles of the underlying shale were noted in this bed by Searight (1937, p.13), but were rarely seen during this study. 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 were recorded. Because of the persistence and uniform thickness of this bed, it makes the best key horizon in the area for structural mapping.

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. A random sample of marl from west of Oacoma (Table V) proved to be 59.0% $CaCO_3$, and 41.0% fine clay resembling bentonite.

This bed, because of its very light gray color, forms a conspicuous horizon throughout the area. 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 supporting an abundant growth of wild yucca plants. The thickness of the marl averages between six and eight feet, with a maximum of 10 and a minimum of four feet observed in the area under consideration. Less than two feet are present at Rosebud bridge, the zone is locally absent at the mouth of Medicine Creek, Lyman County, and 14 feet of marl is present southeast of DeGrey, Hughes County.

Distribution: The Crow Creek zone has been identified only in the Missouri valley and its tributaries. It is conspicuous 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.

FIGURE I

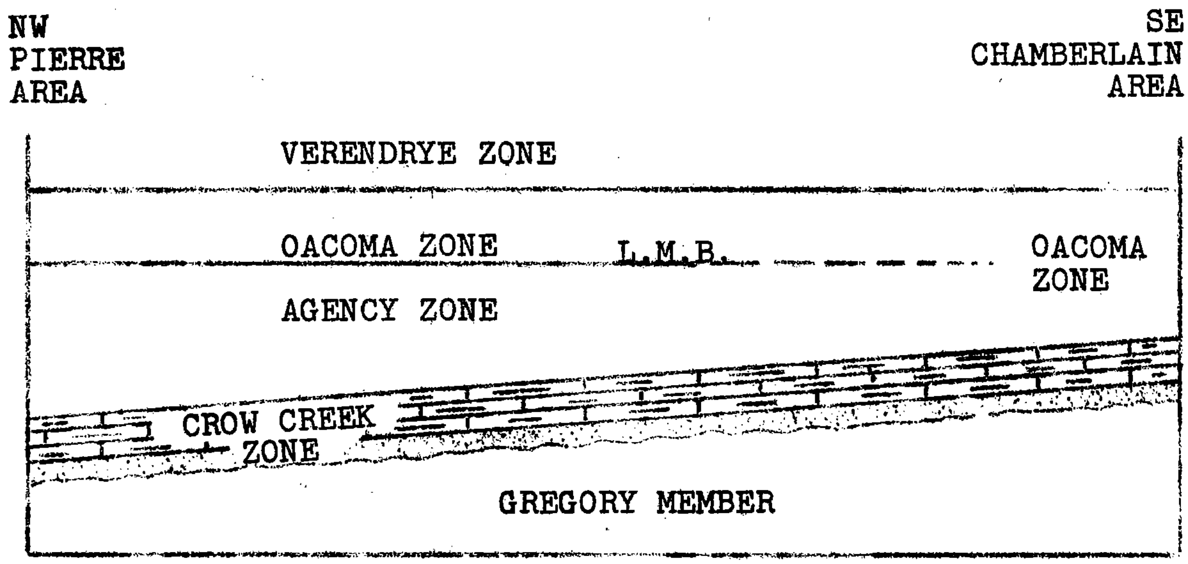


Figure 1. Ideal cross section showing the probable relation between the Oacoma zone in the Chamberlain area, and the Oacoma and Agency zones north and west of the Great Bend. The Lower Micaceous Bentonite, which has been taken as the dividing line in the Pierre area, lies essentially at the base of the concentration of concretions and bentonites. It may be traced continuously from the mouth of the Cheyenne River, south well into Lyman County, and south of there it may be only occasionally recognized.

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. At only one place, near Iona, was a variation noticeable over a short distance. There the marl varied from four to nine feet in thickness within about 100 feet. The Crow Creek was evidently laid down over a gentle ridge, for the upper contact of the zone forms a straight line. It was also noted that the sandstone was much thinner over the crest of the ridge than in the adjacent troughs.

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

Agency Zone

The Agency shale was 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. Searight subsequently traced the zone as far north as the mouth of the Moreau River, and south as far as Crow Creek, Buffalo County, where he considered it to thin out and disappear. South of Crow Creek, it was presumed that the overlying Oacoma zone lay directly upon the Crow Creek marl.

Subsequent field studies south of the type area (Gries, 1939, 1940) have shown that the Agency becomes less siliceous to the south, and resembles the Oacoma zone except for having relatively few black iron-carbonate concretions and bentonite beds. The possibility that previously unrecognized Agency beds may be present in the area under consideration will be discussed in connection with the details of the Oacoma zone.

Oacoma Zone

Name and Description: The Oacoma zone was named by Searight (1937, p. 23) for exposures along the

1. Russel, William L., The Possibilities of Oil and Gas in Western Potter County, R. I. No. 7, S. Dak. Geol. and Nat. Hist. Survey, Dec., 1930.

Missouri River, particularly those in the vicinity of Oacoma, Lyman County, just west of Chamberlain. The zone consists of gray shale, and is characterized by the presence of abundant black iron-manganese carbonate concretions and numerous thin bentonite beds.

In the Chamberlain area, this zone forms the most conspicuous part of the Pierre outcrop. The shale weathers to gumbo which is less favorable to vegetation than the adjacent beds. As the outcrops are eroded, the iron manganese concretions weather out into relief, and accumulate on the surface so that exposures appear nearly covered with the black fragments. As a result, the outcrop appears as a bare black band running parallel to the uplands. Farther north the concretions become less abundant, and the shale becomes lighter in color, so that the outcrop as a whole appears less distinctive.

Regarding the bentonites, Searight (1937, p. 24) has written:

> "The Oacoma zone consists of beds of gray shale varying from a few inches to a few feet in thickness, alternating with very thin beds of bentonite and bentonitic clay. Near Oacoma and northward to the Great Bend and southward into Charles Mix County, it may be that bentonite is more or less disseminated through the shale as well as being concentrated into thin beds of relatively pure bentonite because the outcrops in this area weather down to bentonitic gumbo. This gumbo is very sticky and plastic when wet but dries to exceptionally hard clods of very uneven and irregular shape. North of the Great Bend the Oacoma zone is composed of beds of light gray, flaky shale with thin dark clays interbedded as elsewhere. Here, however, the flaky, light gray shales are notably more resistant than the thin, bentonitic, darker beds and the zone accordingly is conspicuously banded in the outcrop. Weathering and erosion of these beds produces a stair-step effect in the outcrop, the position of the treads being determined by the position of the thin bentonitic clays and that of the lifts apparently by the distance into the outcrop to which the bentonitic clay has been weathered."

In the course of the present study it was found that the gradual change to a lighter, more flaky shale appeared to start in the vicinity of Crow Creek, rather than at the Great Bend. The bentonites are all thin, usually less than two inches, although an occasional eight or ten inch bed was measured. Because of the extreme thinness of many of these bentonites, they were frequently disseminated into the adjacent shale at the time of deposition, so that the number which now appear as distinct beds varies widely in different sections. In carefully trenched outcrops, the number counted varied between 15 and 36.

The concretions which characterize the Oacoma beds were first described in detail by D. F. Hewitt[1] as follows:

> "The manganiferous iron nodules commonly range from 2 to 3 inches in thickness and 3 to 8 inches in diameter and form persistent layers in the shale; where the quantity is low the nodules are separated, but where the quantity is high many nodules have coalesced to form continuous layers 3,4, or even 5 feet long. The color of the fresh nodules ranges from pale gray to olive-green; under the influence of weathering the carbonates change to oxides and become black. Oxidation is complete to a depth of only a foot or two, but films of oxides are found to a depth of 6 or 8 feet. Even the unweathered nodules separate readily from the shale; with exposure to air the shale dries, cracks, and falls away from the nodules. Invertebrate marine fossils are very common in the concretions, and the organic matter which these shells once contained has probably caused the development of concretions. Fragments of bones, especially vertebrae, of both terrestrial and marine vertebrate animals are common in the concretion bed.
>
> "Many geologic problems arise in the study of such concretion zones, but it will be sufficient to state here that the concretions appear to have developed in the sediments of a shallow sea shortly after burial. They are not related to processes of recent weathering that have produced the present surface but without doubt persist under the upland plains many miles east and west beyond the outcrop along the Missouri Valley."

1. D. F. Hewitt, Memo for Press, February 5, 1930.

As noted by Hewitt, many of the nodules, particularly in the upper few feet of the zone, contain abundant fossil fragments, particularly the shells of the large, clam-like Inoceramus. These shells are built up of minute prisms of calcite, arranged at right angles to the surface of the shell; the smallest fragments can be recognized by this prismatic structure.

The mineralogy of these concretions has not been thoroughly investigated. Because of the fine-grained nature of the nodules, microscopic study of the minerals is difficult. Deductions from a study of the chemical analyses indicate that the concretions consist essentially of the carbonates of iron, manganese and calcium in varying proportions.

The small, gray barite rosettes noted by Searight (1937, p. 25) were observed in an exposure along State Highway 47 north of Chamberlain, at the south end of Bad Hand Bottom, and in the vicinity of Elm Creek. Those at the northern area were one-half inch or less in diameter, but those near Elm Creek reached 5 or 6 inches in diameter. All occurred in a distinct zone.

Near the top of the Oacoma zone a one-half to two inch layer of fibrous calcite is frequently found, in which the slender calcite prisms are oriented perpendicular to the bedding plane. Similar material is abundant in the higher members of the Pierre in Haakon County, and has also been described in Elias (p. 102 and Pl. XVIII D) from the Pierre of Kansas.

Subdivision: For the purpose of the present study, the Oacoma zone has been divided into an upper and a lower division. The lower beds have relatively few concretions and few bentonites, whereas both are abundant in the upper division. The line between the two is sharp in some area, but indistinct in others.

Lower Oacoma beds: In most exposures of the Oacima zone it may be seen that the iron-manganese concretions are less abundant in the basal 10 to 20 feet. Three or four ledges may occur in this phase, or several small scattered concretions may be present, but in either case the concentration is notably less than in the overlying beds.

Further investigation reveals that the bentonites are less numerous in this phase of the zone. In the southern part of this area, a few small bentonites are usually found, but north of Crow Creek every exposure shows three prominent, four to six-inch beds with or without additional thin bentonites. In most sections these appear as an upper pair, and a single bed somewhat lower. (See Table VIII, XII, XIII) In the Lower Brule and Medicine Creek sections however, the three appear crowded together at the base of the zone.

The lower subdivision thickens rapidly north and west from this area. Thirty feet were measured on Cedar and Medicine Creeks, and approximately 50 feet was noted at DeGrey. The latter section is of particular note for the upper 12 feet of the 50-foot lower phase contains no concretions whereas the lower 38 feet persistently carries a few nodules or thin ledges.

Upper Oacoma beds: This phase includes the beds of the Oacoma zone which contain abundant iron-manganese concretions and numerous bentonites. Most of the bentonites are too thin to be followed from one exposure to the next, but in the northern part of the area, two beds could be traced with a reasonable degree of certainty. The lower of these is a one to six-inch yellow bentonite carrying abundant flakes of biotite mica. There is no question but that this is the bed upon which the structure of northeastern Stanley County was mapped. (Gries, 1940) This bed was considered to lie at the base of the Oacoma zone in that area, and was designated as the lower micaceous bentonite (LMB). In the outcrops between DeGrey and Lower Brule, this LMB consistently occurs at the base of the concentration of the iron-manganese concretions; that is, at the base of the so-called upper phase of the Oacoma zone. Although this key bed appears to lose its identity south of Lower Brule, a prominent bentonite bed usually occurs at this horizon in exposures to the south, and in isolated cases it contains mica flakes.

A second persistent zone which appears at DeGrey consists of an eight inch bentonite separated from an underlying one inch bed by two inches of shale. This appears to be the big bentonite bed (BBB) of the Stanley County report, and can be traced with reasonable certainty as far south as Oacoma.

The concretions of this upper zone occur in closely spaced layers. Individual layers may vary from nearly continuous ledges two to six inches thick, to one inch zones of scattered purplish nodules no larger than marbles. Some of these layers seem to alternate with bentonite beds. This shale, bentonite, shale, concretion, sequence is particularly clearly shown in Table VIII-A. Whether the bentonites, by their impervious nature, have restricted circulation and thus influenced the distribution of the nodules is not known.

Possible signifacance of the two phases: The details of these subdivisions of the Oacoma zone were worked out not only because of the possible use of these beds as a source of manganese, but in the hope that they might shed some light on the manner in which the siliceous Agency shale zone wedges out as it approaches this area. With the present data, two possibilities present themselves:

a. The Agency shale wedges out between the upper and lower phases of the Oacoma zone.
b. The Agency shale is represented in this area by the entire lower phase of the Oacoma zone.

The first hypothesis is suggested by the zone of light gray shale containing no concretions which lies between the LMB and the lower concretion bearing beds in the DeGrey section (Table XIII, Bed 10). This shale appears identical with the shale below the lower micaceous bed in Stanley County which is considered to be Agency, although less siliceous than in the type locality in Dewey County. The general absence of iron-manganese concretions in the Agency zone lends further support to this contention.

The second hypothesis is based on two lines of evidence. First is recognition of the fact that the complete Stanley County section of the Oacoma zone represents only the upper phase of the Oacoma of the type locality.

There is no evidence of an unconformity below the LMB, so if the shale below this horizon in and north of Stanley County is definitely the Agency, it may be assumed that the shale immediately beneath the LMB wherever found will be the equivalent of the Agency. Secondly, it is believed, though not yet proved by sufficient field work, that the pair of thick bentonites in the lower part of the Oacoma zone of this area is the same pair noted in the Agency shale in Stanley County. (Gries, 1940, p. 15) In that area, the pair consists of two 4 to 8 inch bentonites separated by from 7 to 0 feet of shale, but in this area the individual beds are from 4 to 6 inches thick, and less than one foot apart. This spreading would be expected if the Agency shale thickens as a unit from less than 20 feet in this area to well over 100 feet in northeastern Stanley County. This pair lies 8 feet below the LMB at Crow Creek and at Lower Brule, 28 feet below at Medicine Creek, and 34 feet below that horizon at DeGrey. In Stanley County the conspicuous pair was believed to lie 50 to 70 feet below the same micaceous bentonite.

It is the belief of the writer that this second hypothesis will prove correct; that is, that the lower part of the Oacoma zone in the Chamberlain area is equivalent to part or all of the Agency shale to the north. This follows Searight's concept of the Agency as a great wedge of siliceous shale, thinning to the south, but differs in adding that the scale becomes much less siliceous as it thins, and that the zone extends much farther south than previously supposed but finally loses its identity. The fact that south of Crow Creek a definite line cannot be drawn between the Agency and the Oacoma shales emphasizes the close relationship between them. This probable relationship is shown diagrammatically in Figure 1.

Distribution: The Oacoma zone has been recognized in the Missouri valley as far south as Gregory County, and has been traced north to the mouth of the Moreau River where it disappears beneath the level of the river.

Thickness: In the type locality 47 feet of shale are present between the Crow Creek marl and the top of the iron-manganese concretion zone. This same stratigraphic interval measures 23 feet at Wheeler, 32 feet just north of Bijou Hills, 42 feet on Crow Creek, 38 feet at Lower Brule, 60 feet on Medicine Creek, 63 feet on Cedar Creek, and 84 feet at DeGrey. This is a persistent increase toward the north and west.

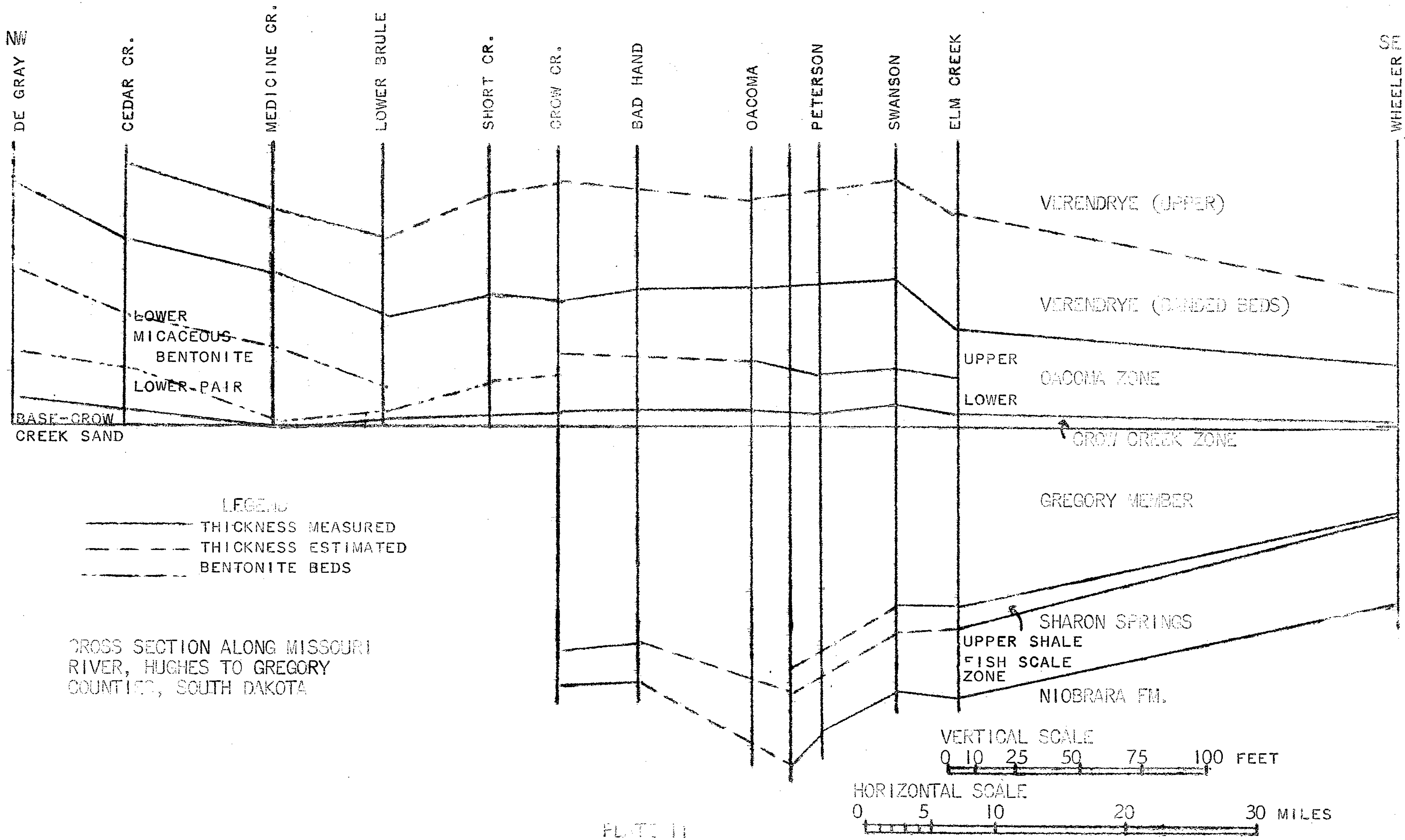

NW
DE GRAY
CEDAR CR.
MEDICINE CR.
LOWER BRULE
SHORT CR.
CROW CR.
BAD HAND
OACOMA
PETERSON
SWANSON
ELM CREEK
SE
WHEELER
VERENDRYE (UPPER)
VERENDRYE (BANDED BEDS)
LOWER MICACEOUS BENTONITE
LOWER PAIR
BASE-CROW CREEK SAND
UPPER
OACOMA ZONE
LOWER
CROW CREEK ZONE
GREGORY MEMBER
LEGEND
THICKNESS MEASURED
THICKNESS ESTIMATED
BENTONITE BEDS
SHARON SPRINGS
UPPER SHALE
FISH SCALE ZONE
NIOBRARA FM.
CROSS SECTION ALONG MISSOURI RIVER, HUGHES TO GREGORY COUNTIES, SOUTH DAKOTA
VERTICAL SCALE
0 10 25 50 75 100 FEET
HORIZONTAL SCALE
0 5 10 20 30 MILES

PLATE II

If only the upper part of the zone is considered (that above the horizon of the LMB), the thickness varies as follows: Crow Creek 20 feet; Lower Brule 29 feet; Medicine Creek 30 feet; DeGrey 34 feet; Ft. Pierre 36 feet; Cheyenne River 42 to 60 feet; and Potter and Dewey counties, 5 to 14 feet.

Stratigraphic relations: The Oacoma zone as described in the type area overlies the Crow Creek marl with conformity, though the contact is sharp. Farther north, where the lower micaceous bentonite (LMB) is considered to be the base of the zone, the contact with the underlying Agency is also one of conformity.

The upper limit of the zone is more difficult to define closely. Generally speaking, the top of the Oacoma zone may be taken as the top of the concentration of iron-manganese concretions and bentonite beds, for the overlying banded beds of the Verendrye zone contain few of either. At or near the base of the banded beds in this area there is usually found one or more thin streaks of rusty shale containing scattered white or rusty brown limestone concretions. These may be the equivalent of the rusty concretions found at the top of the Oacoma beds in the Stanley County area. The actual change from the Oacoma to the Verendrye beds is apparently one of transition, so that no hard and fast contact line can be chosen.

Verendrye 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 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. In the area under consideration, this basal 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 therein are zones of large gray to rusty limestone concretions, and occasional scattered buff lime nodules in the lowest few feet. (See Tables VI, VIII, and XII B) Above the banded beds lies typical gray gumbo-forming shale studded with large black iron-manganese concretion layers.

<u>Distribution</u>: 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.

<u>Thickness</u>: Searight gives the thickness of this zone as 88 feet at Wheeler; 130 feet at Oacoma; 170 feet on Crow Creek, Buffalo County; 170-180 feet at Ft. Pierre, 200 feet at Wendt. Subsequent measurements (Gries 1939, 1940) give 122 feet at Fort Bennett, Stanley County, and 100-110 feet in Dewey and Potter counties. The formation seems to thicken toward the west.

Measurement of the basal banded beds during this investigation show 25 feet at Rosebud Bridge; 40 feet in T. 102 N., R. 71 W., 48 feet at Oacoma; 47 feet at Crow Creek; 21 feet at Medicine Creek; and 30 feet at Cedar Creek, Lyman County.

<u>Stratigraphic relations</u>: There seems to be complete gradation between the 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 bentonites. The contact between the Verendrye and the Virgin Creek member 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.

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 member. 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. Searight has also identified the member in parts of Nebraska, North Dakota, Montana, and around the Black Hills.

In the area under consideration, the Virgin Creek occurs high on the valley sides, and forms the bedrock over much of the adjacent upland. Outcrops are not conspicuous, and the member was not particularly studied in this investigation. The character of the beds appeared to be similar to the development farther north.

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. In this area, the zone may frequently be seen in creeks and road cuts on the upland west of the river. The zone appears to thin southward from 145 feet in Dewey County to 26 feet in Charles Mix County.

The upper Virgin Creek is composed of gray shale which weathers to gumbo. It is characterized by several types of concretions. One consists of small, gray, or brown 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 containing the fossil remains of crabs. Large septarian limestone concretions are characteristic of the zone. Few thicknesses for the upper Virgin Creek are available. 100-140 feet are present at the type area, 142 feet were measured in northeastern Stanley County, and 25-30 feet have been recorded in Gregory County.

Mobridge Member

This member of the Pierre shale was named by Searight (1937, p. 44) from beds exposed in Walworth and Corson counties, near the town of Mobridge, South Dakota. 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. It is said to extend northward into North Dakota, southward into Nebraska, and westward under the Great Plains.

In this area, it occurs only on the highest parts of the upland, and appears only as a yellow, well weathered belt of calcareous shale. It was noticed by the writer around Medicine Butte in northeastern Lyman County, and around the Iona-Bijou Hills in southeastern Lyman, Brule, and Charles Mix counties. The outcrop lies close to the Missouri River south of the above hills area, and is particularly well exposed in the vicinity of Mulehead and the Rosebud Bridge.

The formation varies from about 100 feet in thickness in Gregory and Charles Mix counties, to over 200 feet in Ziebach and Haakon counties (Searight, 1937, p. 49).

Elk Butte Member

The Elk Butte member was named (Searight, 1937, p. 50) from exposures at Elk Butte, Corson County, South Dakota. It includes a thick series of dark gray shales lying between the calcareous Mobridge beds and the base of the Fox Hills sandstone. The member has not been identified farther west, and may either pinch out or grade laterally into sandstone. It lies too high stratigraphically to be found in the Chamberlain area, unless it occurs at Medicine Butte and in the Iona-Bijou Hills.

Tertiary Deposits

Tertiary sands and clays are found high on Medicine Butte and on the Iona and Bijou hills. The clays are either Oligocene or Miocene in age, and the conspicuous green quartzite which caps the Iona and Bijou hills is considered to be of Arikaree (Miocene) age.

Glacial and Terrace Deposits

During the Pleistocene epoch, the ice sheet advanced over this area from the east, burying the old topography and greatly modifying the drainage. An early ice advance apparently extended west of the present line of the Missouri, though the only evidences which remain are the isolated glacial boulders which are scattered over the area for several miles west of the river. Much later the ice advanced approximately to the present location of the river, and upon retreating, left the surface covered with its present mantle of glacial drift. This has been little modified on the uplands, but has been partially removed in the valleys of the numerous small post glacial tributaries, so that the Pierre shale is often well exposed for considerable distances back from the river.

Gravels of both late Tertiary and Quaternary age are present in the area, especially west of the Missouri, but they are not considered in the present report.

STRATIGRAPHIC SECTIONS

In the pages immediately following are presented twelve detailed sections taken at various places in the area where the formations were typically exposed. These sections were carefully measured in order to determine the exact thicknesses of the various divisions of the Pierre formation and the position of bentonites and layers of nodules and other significant features of the formation. While they may not be of interest to the layman they are inserted there for the benefit of stratigraphers and other technicians who may be interested in studying the details of this interesting formation.

TABLE II

Succession of beds, lower part of Pierre shale, exposed in river bank and road cut, south end of Rosebud Bridge, Gregory County, South Dakota

	Feet	Inches
PIERRE FORMATION		
Sully Member		
Verendrye zone		
28. shale, gray, with numerous large iron carbonate concretions; not measured		
27. shale, banded, light and dark gray, no concretions ----------------------	25	6
Oacoma zone		
26. shale, dark gray, with numerous bands of iron-manganese concretions and many bentonite beds ---------------	23	0
Crow Creek zone		
25. marl, light gray to rusty; sandy at base ------------------------------	2	0
Gregory member		
24. shale, gray to brown, with numerous flat brown concretions. Abundant fish remains in basal 18"; none above that point -----------------	26	9
23. marl, light gray, with shale pebbles and scattered sand grains at base --	7	9
Sharon Springs member		
Upper shale zone*		
22. shale, soft, bluish gray, characterized by few fine, tubelike holes; and occasional specks of red hematite; no fish remains ----------------------		3
21. bentonite ---------------------------		1
20. shale, as above ---------------------		8

* partly obscured?

	Feet	Inches
Fish Scale zone		
19. ~~concretions, small, white,~~ in persistent zone		1
18. shale, dark gray, more or less fissile, stands up in buttress-like outcrops; strewn with selenite and yellow ochrous "bloom." Fish remains abundant	6	7
17. bentonite		$1\frac{1}{2}$
16. shale, as above	13	8
15. bentonite		$1\frac{1}{2}$
14. shale, as above	1	11
13. bentonite		1
12. shale, as above	2	0
11. bentonite		1
10. shale, as above		6
9. bentonite, with two thin shale partings		11
8. shale, as above	2	5
7. bentonite		1
6. shale, as above		7
5. bentonite		1
4. shale, as above		7
3. bentonite		1
2. shale, as above	4	0
Total, Sharon Springs member	35	
NIOBRARA FORMATION		
1. chalk, gray, impure, to rivers edge, approximately	20	

TABLE III A

Detail of Niobrara-Pierre contact,
in nearby outcrop,
NW$\frac{1}{4}$, Section 9, T. 102 N., R.71 W.

	Feet	Inches
PIERRE FORMATION		
<u>Sharon Springs member</u>		
23. shale, dark gray, weathers with formation of yellow veins; fish fragments. 5 thin streaks may be bentonites; exposed	17	0
22. bentonite		$\frac{1}{2}$
21. shale, as above		3
20. bentonite		6
19. shale, as above		4
18. bentonite		10
17. shale, same, with 3$\frac{1}{4}$" bentonites	1	2
16. bentonite		5
15. shale, as above	1	7
14. bentonite	1	6
13. shale		4
12. bentonite		5
11. shale		1
10. selenite layer		$\frac{1}{2}$

	Feet	Inches
NIOBRARA FORMATION		
9. chalk	2	10
8. bentonite		½
7. chalk		6
6. bentonite		2
5. chalk	2	4
4. bentonite		1/8
3. chalk	1	1
2. bentonite		1
1. chalk, exposed	1	6

TABLE III B

Succession of beds, Pierre formation, Swanson Farm,
Brule County, South Dakota
Detailed Section, Oacoma zone
NW¼, Section 9, T. 102 N., R. 71 W.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Verendrye zone		
90. shale, gray, weathers to gumbo; numerous large black sideritic concretions; to top of exposure, not measured		
89. shale, gray to yellowish gray, banded	35	
88. shale, as above; large white concretion zone at top	4	7
Oacoma zone		
87. shale, gray, somewhat flaky	1	11
86. concretion zone, nodules flat, intermittent		1
85. shale, as above	1	1
84. concretion zone, nodules flat, intermittent		1
83. bentonite		¼
82. shale, as above	1	6½
81. bentonite		1
80. shale, as above		6
79. bentonite		1
78. shale, as above	1	0
77. concretion zone, fossiliferous, persistent		2
76. shale, as above		9
75. concretion zone, persistent		1
74. shale, as above	1	4
73. bentonite		1
72. shale, as above		4
71. concretion zone, nodules intermittent		1
70. shale, as above	1	0
69. concretion zone, nodules intermittent		1
68. shale, as above		3½
67. bentonite		½
66. shale, as above		3
65. concretion zone, fossiliferous, intermittent		3

	Feet	Inches
64. shale, as above		11
63. concretion zone, intermittent		2
62. shale as above	1	3
61. bentonite		4
60. shale, as above		8
59. concretion zone, nodular		1
58. shale, as above		3
57. bentonite		½
56. shale, as above	1	5½
55. concretion zone, fossiliferous, intermittent		1
54. shale, as above	1	11
53. concretion zone, persistent		4
52. shale, as above		9
51. concretion zone, intermittent		4
50. shale, as above		6
49. concretion zone, nodules intermittent		1
48. shale, as above		8
47. concretion zone, fossiliferous, intermittent		2½
46. shale, as above		2
45. concretion layer, persistent nodules		4
44. shale as above		6
43. bentonite		2
42. shale, as above		6
41. concretion zone		2
40. shale, as above		6
39. bentonite		2
38. shale, as above		8
37. bentonite		1
36. shale, as above		6
35. bentonite		1
34. shale, as above		7
33. concretion zone, persistent		4
32. shale, as above	2	9
31. bentonite, white		1
30. shale, as above		11
29. concretion zone, persistent		3
28. shale, as above		11
27. concretion zone, nodular		1
26. shale, as above		6
25. concretion zone, nodular		1
24. shale, as above	1	4
23. bentonite		1
22. bentonite		3
21. concretion zone		3
20. shale, as above		3
19. concretion zone, intermittent		2
18. shale, as above	1	5
17. concretion zone, intermittent		2

16. shale, as above	1	2
15. bentonite		6
14. shale, as above	3	4
13. bentonite		3
12. shale, as above		4
11. concretion zone, continuous ledge		2
10. shale, as above	2	3
9. concretion zone, nodules kidney-shaped		1
8. shale, as above	2	8
7. bentonite		¼
6. shale, as above	3	0
Total Oacoma	49	11/4
Crow Creek zone		
5. marl, light gray	7	5
4. sandstone, brown, calcareous, slabby	1	0
Gregory member		
3. shale, gray; brown to black when wet. Scattered brown concretions; no fish fragments; several calcareous zones in lower part, and 1.3 foot limestone or concretionary layer at base	69	4
Sharon Springs member		
2. shale, dark gray, numerous bentonites and fish remains	34	5
NIOBRARA FORMATION		
1. chalk, impure, several bentonites		

TABLE IV

Succession of beds, Pierre formation,
exposed along west bank of the Missouri River,
4 miles south of Oacoma, Lyman County.
Detailed section
Section 11, T. 103 N., R. 72 W.

PIERRE FORMATION		
Sully member		
Crow Creek zone		
19. marl, light gray to buff, not measured		
18. sandstone, brown, calcareous, slabby	1	0
Gregory member		
17. shale, brown to gray, abundant brown concretions and a few large white limestone concretion zones	94	10
Sharon Springs member		
Upper shale zone		
16. shale, gray, flaky, no concretions, estimated	9	0
Fish Scale zone		
15. zone of small white concretions		2
14. shale, dark gray, fissile, contains numerous fish remains; yellow "bloom" and selenite in joints and on surface	5	4

13. bentonite ------------------------		4
12. shale, as above -----------------	2	11
11. bentonite ------------------------		1
10. shale, as above -----------------	14	9
9. bentonite ------------------------		1 1/2
8. shale, as above -----------------	1	0
7. bentonite, creamy white ---------		6
6. shale, as above -----------------		2
5. bentonite ------------------------		1/2
4. shale, as above -----------------		4
3. bentonite, creamy white ---------	1	2 1/2
2. shale, earthy, selenitic at base	1	3
Total, Fish Scale zone	28	2 1/2
NIOBRARA FORMATION		
1. chalk, gray, impure; to river's edge ------------------------		

TABLE V

Succession of beds, Pierre formation, exposed in bluff along north bank of White River, 8 miles above its mouth, Lyman County, South Dakota. Detailed composite section Section 31, T. 104 N., R. 72 W.

PIERRE FORMATION		
Sully member		
Oacoma zone		
8. shale, gray, with iron-manganese concretions, to top of bluff, not measured --------------------		
Crow Creek zone		
7. marl or impure chalk, grayish white, hard ----------------------	6	3
6. sandstone, brown, calcareous, slabby -----------------------------	1	0
Gregory member		
5. shale, gray, weathers brownish, banded, contains several calcareous zones, numerous flat brown concretions, and a few zones of large, white limestone concretions; few bentonites near top--	125	4
Sharon Springs member		
4. shale, bluish to brownish gray, flaky, weathers to gentle slope; layer of large white lime concretions at top ------------------	6	5

	Feet	Inches
3. shale, bluish to brownish gray, flaky, stands in intermediate slope; bentonitic zone with small concretions at top	7	10
Fish scale zone		
2. shale, grayish brown, contains abundant fish remains; 1' bentonite 2' above base, and many thinner bentonites, zone of 1" light gray concretions at top; stands in steep outcrop which appears nearly black with distance ---	22	3
NIOBRARA FORMATION (elev. of top 1387)		
1. chalk, impure, several bentonites, to river's edge, base not exposed -------	20	10

TABLE VI

Succession of beds, Pierre formation,
exposed along state route 47 (old route U.S.highway 16),
two miles west of Oacoma, Lyman County, South Dakota.
Composite section
S.E. $\frac{1}{4}$, Section 22, T. 104 N., R. 72 W.

	Feet	Inches
PIERRE FORMATION		
<u>Sully member</u>		
Vérendrye zone		
10. shale, gray, weathers to gumbo; numerous brown to black sideritic concretions, to top of hill, not measured ----------		
9. shale, gray to yellowish-gray, banded with 6" micaceous bentonite at base and zone of white lime concretions near top ----------	18	0
8. shale, gray to yellowish-gray, banded, with local white to brown concretions near middle ----------	16	10
7. shale, rusty, calcareous, with lime concretions ----------		6
6. shale, gray to yellow-gray, banded, with many very thin bentonites --------	12	7
Oacoma zone		
5. shale, gray to yellowish-gray, non-calcareous with many bentonites and zones of iron-manganese carbonate -----	27	1
4. shale, gray, non-calcareous, few bentonites or concretion zones --------	19	9
Crow Creek zone		
3. marl, gray, soft with conchoidal fracture ----------	6	4
2. sandstone, brown, calcareous, slabby --	1	0
<u>Gregory member</u>		
1. shale, gray, with numerous bentonites and brown concretions; base not exposed	16	10

TABLE VI-A

Detailed section, Oacoma zone
SE $\frac{1}{4}$, Section 22, T. 104 N., R. 72W.

	Feet	Inches
<u>Sully member</u>		
Verendrye zone		
70. shale, rusty, calcareous, with white limestone concretions ------------		6
69. shale, gray to yellowish gray, banded	9	8
68. bentonite --------------------------		1½
67. shale, as above --------------------	2	9
Oacoma zone		
66. concretion zone, persistent --------		1
65. shale, gray ------------------------		2
64. bentonite --------------------------		¼
63. shale, as above --------------------		2
62. concretion zone --------------------		1
61. shale, as above --------------------	2	5
60. concretion zone --------------------		2
59. shale, as above --------------------		3
58. bentonite --------------------------		1
57. shale, as above --------------------		10
56. concretion zone --------------------		1
55. shale, as above --------------------		2
54. concretion zone --------------------		1
53. shale, as above --------------------		7
52. concretion zone --------------------		1
51. shale, as above --------------------		7
50. concretion zone --------------------		1
49. shale, as above --------------------		7
48. bentonite --------------------------		½
47. shale, as above --------------------		11
46. concretion zone --------------------		1
45. shale, as above --------------------		11
44. bentonite --------------------------		3/4
43. shale, as above --------------------		5
42. concretion zone --------------------		2
41. shale, as above --------------------		6
40. bentonite --------------------------		2
39. shale, as above --------------------		6
38. concretion zone --------------------		2
37. shale, as above --------------------		4
36. bentonite --------------------------		4
35. shale, as above --------------------		3
34. bentonite --------------------------		1
33. shale, as above --------------------		7
32. bentonite --------------------------		1
31. shale, as above --------------------		7
30. bentonite --------------------------		1
29. shale, as above --------------------		7

	Feet	Inches
28. concretion zone, persistent ----------		4
27. shale, as above ---------------------	3	1
26. concretion zone ---------------------		3
25. shale, as above ---------------------		1
24. concretion zone ---------------------		1
23. shale, as above --------------------	1	10
22. concretion zone ---------------------		3
21. shale, as above ---------------------		3
20. bentonite ---------------------------		1
19. shale, gray to dark gray ------------		5
18. bentonite ---------------------------		1
17. shale, as above ---------------------		5
16. bentonite ---------------------------		1
15. shale, as above ---------------------		$2\frac{1}{2}$
14. bentonite ---------------------------		1
13. shale, as above ---------------------		3
12. concretion zone, intermittent --------		1
11. shale, as above ---------------------		3
10. bentonite ---------------------------		$1\frac{1}{2}$
9. shale --------------------------------		9
8. concretion zone, intermittent --------		4
7. shale, as above ---------------------	1	2
6. bentonite ---------------------------		2
5. shale, with two zones of intermittent concretions -----------------------	2	10
4. concretion zone ---------------------		2
3. shale, as above, with few bentonites and iron-manganese concretions, not trenched ---------------------	19	9
Total Oacoma	46	$9\frac{1}{2}$
Crow Creek zone		
2. marl, light gray --------------------	6	4
1. sandstone, brown, calcareous, slabby -	1	0

TABLE VII

Succession of beds, Pierre formation,
exposed along highway 47 at south end of Bad Hand Bottom,
Buffalo County, South Dakota.
Detailed section
NW$\frac{1}{4}$, Sec. 25, T. 105 N., R. 71 N.

	Feet	Inches
PIERRE FORMATION		
<u>Sully member</u>		
Crow Creek zone		
55. chalky shale, not measured -------------		
54. sandstone, brown, calcareous, slabby ---	1	0
<u>Gregory member</u>		
53. shale, dark gray ------------------------	1	0
52. bentonite ------------------------------		$\frac{1}{2}$

	Feet	Inches
51. partly covered interval; shale exposed is dark, non-calcareous ------------	26	$9\frac{1}{2}$
50. shale, dark, non-calcareous ----------	10	8
49. shale, calcareous --------------------	2	
48. shale, slightly calcareous -----------	4	8
47. shale, calcareous; top 6" in chalky, very fossiliferous -----------------	9	1
46. shale, non-calcareous ----------------	3	0
45. calcareous layer, hard, becoming limestone in places; sticks out as prominent ledge in road cut --------	1	0
44. shale, gray, non-calcareous ----------	1	0
43. shale, calcareous --------------------	1	0
42. shale, gray, non-calcareous ----------		11
41. shale, calcareous --------------------	2	6
40. shale, non-calcareous ----------------		7
39. shale, calcareous --------------------	2	4
38. shale, black, non-calcareous ---------		1
37. shale, calcareous --------------------	1	7
36. covered interval; available exposures show shale with no fish remains. Includes upper Sharon Springs shale-	9	4
<u>Sharon Springs member</u>		
35. concretionary layer; pavement of small white nodules ----------------------		2
34. shale, with abundant fish remains ----	10	6
33. bentonite ----------------------------		5
32. shale, nearly black, with fish remains		6
31. bentonite ----------------------------		6
30. shale, same --------------------------		10
29. bentonite ----------------------------		6
28. shale, same --------------------------		4
27. bentonite ----------------------------	1	1
26. shale, same --------------------------		3
25. bentonite ----------------------------		2
24. shale, same --------------------------		2
23. bentonite ----------------------------		7
22. shale, same --------------------------		2
21. bentonite ----------------------------		1
20. shale, same --------------------------		2
19. bentonite ----------------------------		1
18. shale, same --------------------------		1
17. bentonite ----------------------------		4
16. shale, same --------------------------		11
15. bentonite ----------------------------	2	6
14. shale, black, soil-like, with fish remains ---------------------------		2
13. bentonite ----------------------------		4
12. hard layer, volcanic ash -------------		2
11. shale, black -------------------------		4
10. ash layer, hard ----------------------		$1\frac{1}{2}$

	Feet	Inches
9. shale, as above ----------------------		4
8. ash layer, hard ----------------------		2
7. shale, as above ----------------------		7
6. bentonite ----------------------------		4
5. shale, as above ----------------------		10
4. bentonite ----------------------------		½
3. shale, gray, felt-like feel, fish remains ----------------------------	1	4
2. bentonite ----------------------------		2
1. shale, brown, much yellow-colored material in cracks ------------------		7
Total Fish Scale zone -	25	6
NIOBRARA FORMATION		
Chalk, impure, to bottom of exposure -		

TABLE VIII-A
Succession of beds, Pierre formation
exposed two miles south of mouth of Crow Creek,
Buffalo County, South Dakota
Detailed section, Oacoma zone
NE¼, SW¼ Section 34, T. 106N., R. 71W.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Verendrye zone		
85. shale, gray, weathers to gumbo; not measured ----------------------------		
84. shale, light gray, banded, few scattered concretions at base, rusty white limestone concretions at top ----------------------------	9	0
Oacoma zone		
83. concretion zone, heavy 2" ledge -------		2
82. shale, light yellowish gray -----------	1	11
81. concretion zone, intermittent purple nodules ----------------------------		1
80. shale, as above ----------------------		6
79. concretion zone, persistent ledge -----		1½
78. shale, as above ----------------------		6
77. bentonite ----------------------------		1½
76. shale, as above ----------------------		4
75. bentonite ----------------------------		3
74. shale, as above ----------------------		2
73. concretion zone, intermittent ---------		1
72. shale, as above ----------------------	1	9
71. bentonite ----------------------------		½
70. shale, as above ----------------------		2
69. concretion layer ----------------------		1½
68. shale, as above ----------------------	1	5
67. concretion layer, intermittent --------		1
66. shale, as above ----------------------		3

	Feet	Inches
65. bentonite ----------------------------------		1
64. shale, as above ---------------------------		2
63. concretion layer, persistent ---------		2
62. shale, as above ---------------------------		7
61. bentonite ----------------------------------		1/4
60. shale, as above ---------------------------		1 3/4
59. concretion layer, persistent ---------		2
58. shale, as above ---------------------------		1
57. bentonite ----------------------------------		1
56. shale, as above ---------------------------		8
55. concretion layer, persistent ---------		1 1/2
54. shale, as above ---------------------------		1
53. bentonite ----------------------------------		1
52. shale, as above ---------------------------		4
51. concretion layer, intermittent --------		2
50. shale, as above ---------------------------		3
49. bentonite ----------------------------------		4
48. shale, as above ---------------------------		4
47. concretion layer (1"-4"), intermittent		4
46. shale, as above ---------------------------		2
45. bentonite ----------------------------------		2
44. shale, as above ---------------------------		3
43. concretion layer, intermittent --------		3
42. shale, as above ---------------------------		11
41. concretion layer, persistent ---------		2
40. shale, as above ---------------------------	1	0
39. bentonite ----------------------------------		1/4
38. concretion layer, persistent ---------		2
37. shale, as above ---------------------------		6
36. concretion layer, persistent ---------		2
35. bentonite ----------------------------------		3/4
34. shale, as above ---------------------------	1	0
33. bentonite ----------------------------------		3/4
32. shale, as above ---------------------------		4 1/2
31. bentonite ----------------------------------		1 1/2
30. shale, as above ---------------------------		4
29. concretion layer, persistent ---------		1 1/2
28. shale, dark gray, gummy --------------		5
27. bentonite ----------------------------------		1/2
26. shale, as above ---------------------------		4 1/2
25. bentonite ----------------------------------		1
24. shale, as above ---------------------------		8
23. bentonite ----------------------------------		4
22. shale, as above ---------------------------	2	9
21. concretion layer persistent ----------		2
20. shale, as above ---------------------------		1 1/2
19. concretion layer, persistent ---------		1 1/2
18. shale, as above ---------------------------	1	1
17. concretion layer, persistent ---------		2
16. shale, as above ---------------------------	3	0
15. bentonite ----------------------------------		6

	Feet	Inches
14. shale, as above ---------------------		6
13. bentonite ---------------------------		6
12. shale, as above ---------------------	5	6
11. bentonite ---------------------------		4
10. shale, as above ---------------------		3
9. concretion layer, intermittent ------		1
8. shale, as above ---------------------	1	0
7. concretion layer, intermittent ------		1
6. shale, as above ---------------------	6	1
Total Oacoma	42	3 3/4
Crow Creek zone		
5. marl, light gray --------------------	4	10
4. sandstone, brown, calcareous, slabby-	1	0
<u>Gregory member</u>		
3. shale, gray, gummy ------------------	13	6
2. bentonite ---------------------------		6
1. shale, as above, to bottom of gully; not measured ---------------------		

TABLE VIII

Succession of beds, Pierre formation,
exposed at and south of the mouth of Crow Creek,
Buffalo County, South Dakota
Composite section,
Secs. 23 and 34, T. 106 N., R. 71 W.

	Feet	Inches
PIERRE FORMATION		
<u>Sully member</u>		
Verendrye zone		
12. shale, gray, weathers to gumbo; contains large black sideritic concretions; not measured ----------------		
11. shale, light gray, flaky ------------	7	0
10. shale, light gray -------------------	2	0
9. shale, light gray, with rusty zone at top and 2 intermittent zones of white, rusty lime concretions in lower 15 feet ---------------------	29	4
8. shale, light gray, with zone of white, rusty lime concretions at top, and two similar, intermittent zones near base ------------------------	9	0
Oacoma zone		
upper		
7. shale, gray to yellow gray, flaky; numerous iron-manganese concretions and many bentonites ----------------	20	1

	Feet	Inches
lower (Agency?)		
6. shale, dark gray, gummy, containing 3 thick bentonites and few layers of concretions ------------	22	3
Crow Creek zone		
5. marl, light gray -------------------	5	0
4. sandstone, brown, calcareous, slabby		11
Gregory member		
3. shale, gray to brown, containing numerous flat, rusty-brown concretions. Some calcareous layers, including an intermittent 5"-6' impure marl lying 7-10 feet below the Crow Creek sand in some exposures on each side of the river in this immediate area -----------	84	00
Sharon Springs member		
Upper zone (included with Gregory shale)		
Fish scale zone		
2. shale, dark gray to black fissile, contains fish fragments and numerous bentonite beds; selenitic at base ----------------------------------	14	0
NIOBRARA FORMATION		
1. chalk, impure, weathers yellow on outcrop -------------------------------		

TABLE IX

Succession of beds, Pierre formation
exposed along the Lower Brule-Reliance road,
2 miles south of Lower Brule, Lyman County, S. Dak.
Detailed section, Oacoma zone
Section SW ¼, T. 107 N., R. 73 W.

	Feet	Inches
PIERRE FORMATION		
Sully member		
Verendrye zone		
107. Shale, gray, with numerous black concretions, to top of exposure, not measured -----------------------		
106. Shale, gray, weathers to gumbo -----	13	0
105. Shale, gray to yellowish gray ------	2	0
104. Shale, light gray, flaky, few small buff concretions, and zone of large rusty to black concretions at top ----------------------	28	0
103. Shale, light gray, flaky; rusty shale streak with black-rusty concretions at top and similar zone 1' 4" below top ------------	2	3

	Feet	Inches
Oacoma zone		
102. shale, light gray, flaky, few scattered concretions in lower 18", and zone of brown-black concretions at top ------------	3	4
101. bentonite ----------------------		1
100. shale, light gray flaky ---------		3
99. bentonite, powdery --------------		4
98. shale, as above -----------------		2
97. concretion zone, intermittent nodules ----------------------		1
96. shale, as above -----------------		10
95. concretion zone, intermittent nodules ----------------------		1
94. shale, as above -----------------		4
93. bentonite ----------------------		1
92. shale, as above ----------------		2
91. concretion zone, intermittent nodules ----------------------		1
90. shale, as above -----------------		7
89. concretion zone, intermittent nodules ----------------------		1
88. shale, as above -----------------		3
87. bentonite ----------------------		1
86. shale, as above -----------------		2
85. concretion zone, nodules fossiliferous ----------------------		½
84. shale, as above -----------------	1	0
83. bentonite ----------------------		½
82. shale, as above -----------------		3
81. concretion zone, persistent -----		3
80. shale, as above -----------------		6
79. concretion zone, intermittent ---		1
78. shale, as above -----------------		4
77. bentonite ----------------------		1
76. shale, as above -----------------		3
75. concretion zone -----------------		1
74. shale as above ------------------		8
73. bentonite, impure ---------------		2
72. shale, as above -----------------	1	0
71. bentonite ----------------------		8
70. shale, as above -----------------		1
69. bentonite ----------------------		1
68. shale, as above -----------------		4
67. bentonite ----------------------		¼
66. shale, as above -----------------		8½
65. bentonite ----------------------		1
64. shale, as above -----------------	1	1
63. concretion zone, intermittent ---		3
62. shale, as above -----------------		11
61. concretion zone, persistent -----		1½

		Feet	Inches
60.	shale, as above		2
59.	concretion zone, persistent		2
58.	shale, as above	3	0
57.	bentonite		1
56.	shale, as above		3
55.	concretion zone, persistent		2
54.	shale, as above		3
53.	bentonite		2
52.	shale, as above		2
51.	bentonite		2
50.	shale, as above		2
49.	bentonite		2
48.	concretion zone		1
47.	shale, as above	1	0
46.	concretion zone, brown, persistent		3
45.	shale, as above		7
44.	bentonite		1½
43.	shale, as above	1	0
42.	bentonite		1½
41.	shale, as above		4½
40.	bentonite		½
39.	shale, as above		3
38.	bentonite, with mica flakes		4
37.	shale, as above		6
36.	bentonite		½
35.	shale, as above		2
34.	concretion zone		2
33.	shale, as above		8
32.	bentonite, micaceous, yellow		3
31.	shale, as above		7
30.	concretion zone		2
29.	shale, as above		9
28.	concretion zone, persistent		2
27.	shale, as above		11
26.	concretion zone, persistent		2
25.	shale, as above		5
24.	bentonite, micaceous (LMB)		1
23.	shale, as above	1	1
22.	concretion zone, nodules soft, earthy		1
21.	shale, as above		11
20.	concretion zone, nodules soft, earthy		1
19.	shale, as above		9
18.	concretion zone, nodules soft, earthy		1
17.	shale, as above	1	1
16.	concretion zone, nodules soft, earthy		1
15.	shale, as above		11
14.	concretion zone, hard, persistent		1
13.	shale, as above	1	4
12.	concretion zone, nodules soft, earthy		1
11.	shale, as above		10
10.	concretion zone, nodules soft, earthy		1

		Feet	Inches
9.	shale, as above		8
8.	bentonite		2
7.	shale, as above		2
6.	bentonite, mica flakes		2
5.	shale, as above		2
4.	bentonite		2
3.	shale, as above		10
	Total, Oacoma and Agency? zones	40	3/4
Crow Creek zone			
2.	marl, light gray	3	10
1.	sandstone, brown, calcareous, slabby	1	0

Note: Basal part of section somewhat foreshortened as beds are somewhat tilted by slumping; particularly beds 1 to 6.

TABLE X

Succession of beds, Pierre formation,
near artesian well on Short Creek,
Lyman County, South Dakota.
Detailed section, Oacoma zone
Section 12, T. 106 N., R. 72 W.

		Feet	Inches
PIERRE FORMATION			
Sully member			
Verendrye zone			
141.	shale, gray to yellowish gray, not measured		
140.	shale, gray to yellowish gray, zone of large white concretions at top, few scattered black concretions in lower part	7	11
Oacoma zone			
139.	concretion zone, fossiliferous, persistent		2
138.	shale, light gray, papery		11
137.	concretion zone, blue nodules, intermittent		1
136.	shale, as above		8
135.	concretion zone, intermittent		1
134.	shale, as above		4
133.	concretion zone, brown		1½
132.	shale, as above		4
131.	bentonite		2
130.	shale, as above	1	7
129.	bentonite		½
128.	shale, as above		4
127.	concretion zone, nodular		1

		Feet	Inches
126.	shale, as above		11
125.	concretion zone, nodular		$1\frac{1}{2}$
124.	shale, as above		7
123.	bentonite		1
122.	concretion zone, fossiliferous		1
121.	shale, as above		8
120.	concretion zone		$1\frac{1}{2}$
119.	shale, as above		6
118.	concretion zone, fossiliferous		1
117.	shale, as above		2
116.	bentonite		$\frac{1}{2}$
115.	shale, as above		4
114.	concretion zone, fossiliferous		$1\frac{1}{2}$
113.	shale, as above		5
112.	bentonite		1
111.	shale, as above		6
110.	bentonite		6
109.	shale, as above		$5\frac{1}{2}$
108.	bentonite		$\frac{1}{2}$
107.	shale, as above		1
106.	concretion zone, brown		2
105.	shale, as above		7
104.	bentonite		1
103.	shale, as above		4
102.	bentonite		1
101.	shale, as above		9
100.	concretion zone, persistent		2
99.	shale, as above		6
98.	concretion zone, nodules flat, persistent		2
97.	shate, as above		8
96.	concretion zone, nodules flat, yellowish		$1\frac{1}{4}$
95.	shale, as above		3
94.	concretion zone, yellow, persistent		2
93.	shale, as above		10
92.	bentonite		$\frac{1}{2}$
91.	shale, as above		4
90.	bentonite		$\frac{1}{2}$
89.	shale, as above		8
88.	bentonite		$\frac{1}{2}$
87.	shale, as above		4
86.	bentonite		$\frac{1}{2}$
85.	shale, as above		5
84.	concretion zone, nodules flat, persistent		$1\frac{1}{4}$
83.	shale, as above		5
82.	bentonite		1
81.	shale, as above		5
80.	bentonite		1
79.	shale, as above		6
78.	bentonite		3

	Feet	Inches
77. shale, as above ------------------		5
76. bentonite ------------------------		1
75. shale, as above ------------------	2	3
74. concretion zone, nodular, persistent --------------------		$1\frac{1}{2}$
73. shale, as above ------------------		1
72. concretion zone, nodules blue, persistent --------------------		1
71. shale, as above ------------------		2
70. concretion zone, nodular, persistent ---------------------------		1
69. shale, as above ------------------		6
68. concretion zone, nodular, persistent ---------------------------		1
67. shale, as above ------------------		3
66. concretion zone, nodular, persistent ---------------------------		1
65. shale, as above ------------------		$3\frac{1}{2}$
64. bentonite ------------------------		3/4
63. shale, as above ------------------		1
62. concretion zone, nodular, fossiliferous ------------------------		2
61. shale, as above ------------------		9
60. concretion zone ------------------		3
59. shale, as above ------------------		5
58. concretion zone ------------------		2
57. shale, as above ------------------		6
56. concretion zone ------------------		2
55. shale, as above ------------------	1	1
54. bentonite ------------------------		1
53. shale, as above ------------------		2
52. bentonite ------------------------		$\frac{1}{2}$
51. shale, as above ------------------		2
50. bentonite ------------------------		1
49. shale, as above ------------------		2
48. bentonite ------------------------		2
47. shale, as above ------------------		1
46. bentonite ------------------------		2
45. shale, as above ------------------		1
44. bentonite ------------------------		2
43. shale, as above ------------------	1	4
42. bentonite ------------------------		$\frac{1}{2}$
41. shale, as above ------------------		11
40. concretion zone, brown -----------		$1\frac{1}{2}$
39. shale, as above ------------------		2
38. concretion zone, flat yellow nodules ------------------------		1
37. shale, as above ------------------		3
36. concretion zone, persistent -----		2
35. shale, as above ------------------	1	0
34. concretion zone, nodules intermittent ------------------------		$1\frac{1}{2}$
33. shale, as above ------------------	1	1

	Feet	Inches
32. bentonite ----------------------		½
31. shale, as above ----------------		3
30. bentonite ----------------------		¼
29. shale, as above ----------------		5
28. bentonite ----------------------		4
27. shale, as above ----------------		2
26. bentonite ----------------------		8½
25. shale, as above ----------------		7
24. bentonite ----------------------		½
23. shale, as above ----------------		6
22. concretion zone, nodules intermittent ----------------------		1
21. shale, as above ----------------		9
20. concretion zone, persistent ----		2
19. shale, as above ----------------	1	10
18. concretion zone, nodules rounded, persistent -------------------		2
17. shale, as above ----------------		6
16. concretion zone, nodules intermittent ----------------------		1
15. bentonite ----------------------		4
14. shale, as above ----------------		2½
13. concretion zone, nodules flat, persistent -------------------		1
12. shale, as above ----------------		7
11. concretion zone, nodules flat, persistent -------------------		1½
10. shale, as above ----------------	1	1
9. concretion zone, nodules flat, intermittent -----------------		1
8. shale, as above ----------------		6
7. bentonite ----------------------		1
6. concretion zone, intermittent --		2
5. shale, as above ----------------	1	5
4. bentonite ----------------------		1
3. shale, as above ----------------		8
Total Oacoma	46	3
Crow Creek zone		
2. marl, light gray ---------------	4	0
1. sandstone, brown, calcareous, slabby ------------------------	1	7
<u>Gregory member</u>		
shale, not measured ------------		

TABLE XI

Succession of beds, Pierre formation, exposed near mouth of Medicine Creek, Lyman County, South Dakota
Detailed section
Sec. 4, T. 107 N., R. 74 W.

	Feet	Inches
PIERRE FORMATION		
Sully Member		
Verendrye zone		
26. shale, gray, with large, black typical concretions beginning about 6' above base, not measured		
25. shale, banded gray and yellowish gray, with rusty streak about 30" above base, with few small broken buff concretions, and bones of reptile	11	3
24. concretion zone, large white to black nodules		6
23. shale, banded gray and yellowish gray	2	8
Oacoma zone		
22. bentonite		1
21. shale, gray	3	2
20. bentonite		1
19. shale, gray		2
18. bentonite		1
17. shale, gray, with numerous black iron-manganese concretions	7	2
16. bentonite		6
15. shale, as above		2
14. bentonite		1
13. shale, as above	4	10
12. bentonite		1
11. shale, as above	3	10
10. bentonite		1½
9. shale, as above	3	5
8. bentonite		2
7. shale, as above	2	7½
6. bentonite		4
5. shale, as above	7	2
4. bentonite, micaceous (the Lower Micaceous bentonite of Gries, 1940)		6
3. shale, gray, weathers to gumbo (Agency?). Contains few white and black concretions; three 2-4 inch bentonites in basal 18", two of which are micaceous	29	9
Total Oacoma and Agency (?)	64	4
Crow Creek zone		
2. sandstone, brown calcareous, slabby. The overlying marl is completely missing at this locality	1	0
Gregory member		
1. shale, gray to brown, with many brown concretions to base of exposure, not measured		

TABLE XII A

Succession of beds, Pierre formation
exposed near mouth of Cedar Creek,
Lyman County, South Dakota
Detailed section
Sec. 22, T. 108N., R. 76W.

PIERRE FORMATION	Feet	Inches
<u>Sully member</u>		
Oacoma zone		
38. shale, to top of hill; not measured		
37. bentonite		1
36. shale, gray to yellow-gray, blocky, hard, non-siliceous with 2 4" layers of brown iron-manganese concretions	2	8
35. bentonite		4
34. shale, as above	1	2
33. bentonite		4
32. shale, as above	2	6
31. bentonite		½
30. shale, as above	2	8
29. bentonite		4
28. shale, as above	6	6
27. bentonite		½
26. shale, as above	1	0
Crow Creek zone		
25. marl	8	11
24. sandstone, brown, calcareous, slabby	1	0
<u>Gregory member</u>		
Upper zone		
23. shale, gray, (with brown streaks) soft; numerous flat, rusty brown concretions	1	3
22. bentonite		½
21. shale, as above	9	1
20. bentonite		1
19. shale		3
18. bentonite		1
17. shale	1	9
16. bentonite		8
15. shale	1	4
14. shale, brownish gray, with yellow "bloom"; some beds black on edges. Small gypsum concretions one foot below color change; scattered small buff "worm-eaten" concretions and large septarian concretions with yellow calcite below this point	4	1
13. limestone concretion zone (highest)	1	0
12. shale, as above	5	3
11. bentonite, creamy white		1
10. limestone ledge	1	0
9. shale	6	3

		Feet	Inches
8.	bentonite, creamy white		3
7.	shale	3	7
6.	bentonite		½
5.	shale		5
4.	bentonite		½
3.	shale	3	9
2.	bentonite		3
1.	shale, with abundant septarian concretions, to creek bottom; base not exposed	16	6

TABLE XII B

Succession of beds, Pierre formation,
exposed near mouth of Cedar Creek,
Lyman County, South Dakota
Detailed section ¼ mile up stream from Table XIII-A
Sec. 22, T. 108N., R. 76W.

		Feet	Inches
PIERRE FORMATION			
Sully member			
Verendrye zone			
26.	shale, gray, with numerous large black concretions, to top of hill, not measured		
25.	shale, banded, gray to yellowish gray; few scattered small buff concretions in lower half	15	2
24.	shale, banded, gray to yellowish gray; almost continuous ledge of 3" black concretions at top, and "rusty" shale zone 5' below top	7	9
23.	shale, banded, gray to yellowish gray; at top and at one foot intervals below, and 3 zones of rusty shale containing scattered flat white to rusty brown limestone concretions, and a few thin black concretions	7	6
Oacoma zone			
22.	bentonite, hard		1
21.	shale, gray, with black iron-manganese concretions	1	8
20.	bentonite		4
19.	shale, as above	1	9
18.	bentonite		6
17.	shale, same		2
16.	bentonite		1
15.	shale, as above	8	0
14.	bentonite		1
13.	shale, as above		11
12.	bentonite		1½
11.	shale, as above		10½

	Feet	Inches
10. bentonite		1½
9. shale, as above	4	4
8. bentonite		1½
7. shale, as above		8
6. bentonite		1
5. shale, as above	4	2
4. bentonite		2
3. covered interval, consists of gray shale with numerous bentonites and black iron-manganese concretions	40	
Total Oacoma	64	3
Crow Creek zone		
2. marl	9	0
1. sandstone, brown, slabby	1	0

Note: Tables XII-A and XII-B may be tied together on the Crow Creek sand, giving a section complete except for a short interval in the lower part of the Oacoma zone. As noted previously, the lower Oacoma may represent the Agency shale farther north.

TABLE XIII

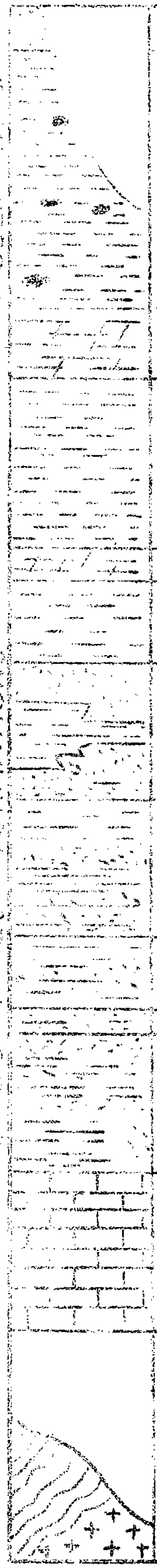
Succession of beds, Pierre formation, exposed along De Grey-Joe Creek road, one and one-half miles southeast of De Grey, Hughes County, South Dakota

	Feet	Inches
PIERRE FORMATION		
<u>Sully member</u>		
Verendrye zone		
14. shale, gray, weathers to gumbo; numerous black sideritic concretions; not measured		
13. shale, yellowish-gray, flaky, with large black concretion zone at top	7	10
Oacoma zone		
Upper		
12. shale, gray, hard, platy, with blue stained joints; many bentonites and iron-manganese concretions	33	7
11. bentonite, yellow, with biotite flakes (LMB)		6
Lower (Agency?)		
10. shale, light gray, somewhat papery, no visible bentonites or concretions; stands in steep outcrop	12	4
9. shale, gray, weathers to gumbo; contains few bentonites and scattered iron-manganese concretions	21	0

	Feet	Inches
8. bentonite ----------------------------------		6
7. shale, as above --------------------------	1	0
6. bentonite ----------------------------------		6
5. shale, as above --------------------------	8	8
4. bentonite, slightly micaceous -----------		6
3. shale, as above --------------------------	6	2
Oacoma-Agency, Total	84	9
Crow Creek zone		
2. marl, light gray, with brown slabby sandstone at base --------------------------	14	1
<u>Gregory member</u>		
1. shale, brown to gray, many rusty-brown concretions; layer of one-foot gray septarian concretions about 37 feet below top; to level of road (hand leveled) ------------------------------	42	0

PLATE III

Generalized Columnar Section



0 - 100	Surficial materials.	Soil, till, gravel, silt, loess, etc.
300 - 750	Pierre formation.	Gray to brown shale, with concretions and bentonite beds.
200	Niobrara formation.	Chalk and calcareous grey shale.
500	Carlile shale.	Dark gray to black shale.
60	Greenhorn formation.	Limestone and shale.
275	Graneros shale.	Dark gray shale.
250 - 500	Dakota formation. Fuson shale. Lakota formation.	Sand, some shale. Varicolored shale. Sandstone, some shale
450	Morrison formation. Unkpapa sandstone. Sundance formation.	Sand, clay, and shale.
150	Spearfish formation.	Redbeds.
50	Minnekahta &Opeche	Sandstone & redbeds.
400	Minnelusa formation.	Sandstone, shale, limestone, gypsum and redbeds.
500	Pahasapa limestone.	
	Probable Cambrian, and possible Ordovician, Silurian, and Devonian formations.	
	Pre-Cambrian metamorphic and igneous rocks	

STRATIGRAPHY - THE SUBSURFACE FORMATIONS

Introduction

The area covered by this survey lies between two large and fairly well outlined structural features of the state; the buried quartzite ridge on the east and the Lemmon syncline on the west. It is consequently a region where subsurface changes of considerable importance may be expected within short distances. Although many artesian wells have been drilled in the area, they afford little subsurface data for two reasons. First, all of them are water wells and none have gone deeper than the so-called Dakota and Lakota sandstones; and second, the records are driller's logs, only a few of which are of sufficient detail to be of use in stratigraphic work. No sample cuttings are available for study.

Wells a short distance to the east of Chamberlain have encountered Sioux quartzite immediately below the artesian sandstones. Wells a considerable distance to the west and northwest of the area, within the Lemmon syncline, indicate that the succession of beds lying below the artesian sands is in most respects very much like the section exposed around the Black Hills. Somewhere in the interval between these areas, the pre-Cretaceous rocks must thin and wedge out against the quartzite ridge. The nature and position of this overlap, and the changing lithology of the beds involved, is of utmost importance in the study of the oil and gas possibilities of the area.

Because only the Cretaceous formations are known from records in this immediate area, the following descriptions of the subsurface stratigraphy will be divided into (a) a general discussion of the pre-Cretaceous rocks as they are known in the Lemmon syncline and around the Black Hills, and (b) a discussion of the Cretaceous rocks as they are known both in the west river area and in wells in this region.

Pre-Cretaceous Formations

There are only two deep wells between Chamberlain and the Black Hills whose records are sufficiently detailed to be of use in tracing the Paleozoic and early Mesozoic formations eastward from the Hills toward this area. One is the Hunter No. 1 (Gypsy)[1] in eastern Pennington County, the other the Standing Butte test[2] in northeastern Stanley County.

1. See appendix, p. v.
2. See appendix, p. iii.

The former is 150 miles west of Chamberlain, the latter 95 miles northwest. Obviously, these are too far away to serve as a guide to the formations which may be present in the Chamberlain area, but they do serve to show the manner in which these beds tend to change character as they are followed eastward. In the following paragraphs each of the formations known in western South Dakota will be briefly described, and where possible, known changes in thickness and lithology will be noted. The oldest and lowest beds will be discussed first, then the progressively younger and higher formations will be taken up in order of deposition.

The oldest exposed rocks in the Black Hills area are a series of dark colored schists, slates, and quartzites of Algonkian age, cut by the Harney Peak granite. In the eastern part of the state, pre-Cambrian time is represented primarily by the thick, pink, Sioux quartzite which is also occasionally intruded by granite. The old pre-Cambrian land surface in the southeastern part of the state is very irregular, and its configurations are only imperfectly known from well records and magnetometer surveys.[1] The most conspicuous feature appears to be a broad irregular ridge which extends from the vicinity of Sioux Falls, westward toward Chamberlain. This quartzite surface dips gently to the west, and undoubtedly underlies the Chamberlain area at an undetermined depth. The quartzite was reported in the White Lake city well at a depth of 850 feet, or 794 feet above sea level. None has been encountered at Chamberlain, where the deepest well reached an elevation of 564 feet, nor in any wells west of that town.

The oldest Paleozoic sediments in the Black Hills consist of a series of alternating sandstones and shales (Deadwood formation) deposited by the late Cambrian sea. Overlying these in the northern Hills, but missing to the south, are a shale and thick limestone (Whitewood formation) of Ordovician age. No Silurian or Devonian rocks are found in the Black Hills section, but they are known to be present in eastern Montana, and have been tentatively identified in North Dakota. No early Paleozoic rocks have been encountered in eastern South Dakota, and it is very doubtful if any are present in this area.

The Mississippian limestones (Englewood and Pahasapa) reach a maximum thickness of 700 feet in the Hills, and are known to be widespread in and east of the Rocky Mountains. The Hunter No 1 reached this horizon, and the Standing Butte

1. See W. H. Jordan and E. P. Rothrock, A Magnetic Survey of South Dakota, Report of Investigations No. 37, S. D. Geol. Survey, November, 1940.

test was finished in the Pahasapa after penetrating it for nearly 500 feet. In the Black Hills, a thick Pennsylvanian sandstone with interbedded shales and limestones (Minnelusa formation) overlies the Mississippian limestone. Eastward the formation becomes much more shaly, and the amount of sand decreases, as shown in the logs of the Hunter and Standing Butte wells. The Permian period is represented in the Hills, and as far east as the Hunter well by a purplish-red shale (Opeche) and a thin red and white limestone (Minnekahta), with a combined thickness of up to 160 feet. Eastward these become much more shaly and sandy, and thin considerably.

The lowest Mesozoic rocks are the redbeds and gypsum, (Spearfish formation) of Triassic, or Permo-Triassic, age. These reach a thickness of nearly 700 feet in their outcrop around the Hills, 283 feet in the Hunter well, and thin to about 150 feet in Stanley County. A series of varicolored clays and sands of Jurassic age (Sundance, Unkpapa, and Morrison formations have a total thickness of 600 feet in the Hills area, 347 feet in the Hunter well, and well over 400 feet at Standing Butte.

Cretaceous Rocks

The oldest Cretaceous rocks in South Dakota belong to the Lakota-Fuson-Dakota group. At their outcrop around the Black Hills, this group consists of two distinct sandstones separated by a thin shale member.[1] In good well records west of the Missouri River, these three formations can usually be distinguished, though their individual thicknesses often vary considerably. A study of many artesian wells over the entire state indicates that to the east this series becomes more a group of lenticular sandstones interbedded with shale and sandy shale.[2] It is the practice among drillers, particularly west of the River, to call the first sandstone sufficiently clean to yield an artesian flow the Dakota sandstone, and a second sand, if one is penetrated, the Lakota. It is obvious that the first water sand does

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1. The thin Minnewasta limestone is found between the Fuson and Dakota in the southeastern Black Hills, but has only been tentatively identified in one deep well (Hunter) to the east of the area.
2. For discussion and bibliography of papers relative to the nature of the Dakota sandstone, see E. P. Rothrock, Artesian Conditions in West Central South Dakota, S. D. Geol. Survey, R.I. # 26, 1926, p. 27.

not always occur at the same horizon under these conditions. Presence of stray sands in the overlying shales, particularly east of the Missouri, further complicates the picture. These facts account, at least in part, for the variation in the elevation of the first sandstone reported in wells in any given area.

In the Chamberlain area, most records of the artesian sands indicate an upper zone of thin sands and shale, underlain by a zone of relatively clean sandstone. In the Chamberlain City well[1], this sequence is in turn underlain by about 80 feet of "white shale" and another sandstone of undetermined thickness. This strongly suggests that the full Lakota-Fuson-Dakota series extends this far east. There are probably several thin sandstones in the base of the overlying Graneros shale, and on the basis of drillers' logs alone it is not possible to determine the contact between the Dakota and Graneros. Since many farm wells have not penetrated below the highest of these sands, it is convenient in this discussion to include them all in the Dakota. On this basis the Dakota sandstone is 189 feet thick at Chamberlain.

The Benton shales which overlie the Dakota include the Graneros, Greenhorn, and Carlile formations. In outcrops the three can be readily distinguished, for the Greenhorn consists of a series of thin limestones and calcareous shales which form a low, yellowish ridge. In wells, however, the Greenhorn lime layers are frequently not noticed, and the Benton group may be logged as a series of black, gray, or brown shales. In the central part of the state, a thin 15 to 30 foot sandstone frequently occurs just above the middle of the shales, and has usually been considered to mark the horizon of the Greenhorn. Examination of a good set of well cuttings from the area should determine the validity of this correlation.

If the basal sands are included in the Dakota, the Benton shales are slightly over 300 feet thick in this area. This compares with a maximum of 672 feet at Standing Butte, 854 feet in the Hunter No. 1, and 1500 to 2000 feet on the east side of the Black Hills. In the Chamberlain City Well, this is divided into Graneros shale, 175; Greenhorn (?) sandstone, 17; and Carlile shale, 121 feet.

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1. See appendix, p. i.

The upper part of the Niobrara chalk is exposed along the Missouri and its tributaries throughout the area, but the base is not exposed. It is difficult for drillers to distinguish the soft chalk from the underlying shale in many places, so that their records of the thickness of the formation vary widely. The more reliable records indicate that 240-250 feet may be the true thickness throughout the area.

Conclusion

It is probable that many of the pre-Cretaceous formations described above are missing in this area. Any which may persist this far east are undoubtedly greatly thinned, and their lithologic character much changed. There is no known way, short of drilling, to determine the place at which the various formations wedge out against the quartzite. Certainly the shore line between the pre-Cretaceous seas and the quartzite land mass must have shifted constantly.

There appears to be little lateral change in the Cretaceous sediments in this immediate area. The sequence at Pukwana[1] is almost identical with that at Chamberlain. From the Missouri on west, the only change appears to be a gradual thickening of the Benton shales, the disappearance of the middle (Greenhorn?) sandstone, and the appearance of the typical calcareous Greenhorn lime and shale sequence.

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1. See appendix, p. ii.

STRUCTURE

Regional

Chamberlain lies in an area in which the deeper formations dip gently to the northwest into the Lemmon syncline. As may be seen from Plate IV, however, Chamberlain lies at least 100 miles east of the axis of the syncline and slightly east of the broad, flat, structural terrace on which Pierre stands.

More important is the fact that Chamberlain lies slightly north of west of the Sioux Quartzite outcrop area and that this ridge of very resistant Pre-Cambrian rock probably extends beneath the surface into the Chamberlain area. A magnetometer survey of the ridge conducted in 1940[1] indicates that one ridge extends west and south of Mitchell to the Missouri River, where it either turns abruptly northwest or is joined by a ridge trending in that direction. This latter part of the ridge passes through the center of the region covered by this report. Structures in this area, therefore, probably lie over old buried ridges or peaks in the quartzite. Such structures are caused by differential settling of sediments deposited over the peaks, and are favorable for the accumulation of oil.

The general picture of the regional structure, therefore, presents a broad, flat terrace some 60 miles wide sloping westward toward the geosyncline, which dominates the structure of western South Dakota, at a rate of 1 or 2 feet per mile. Beneath the back or eastern side of this ridge younger sediments have draped themselves, forming the local structures to be described.

Local

The principal structure of the surface formations, as determined in the present survey, is a prominent "high" lying west of Chamberlain and trending northwest to a point

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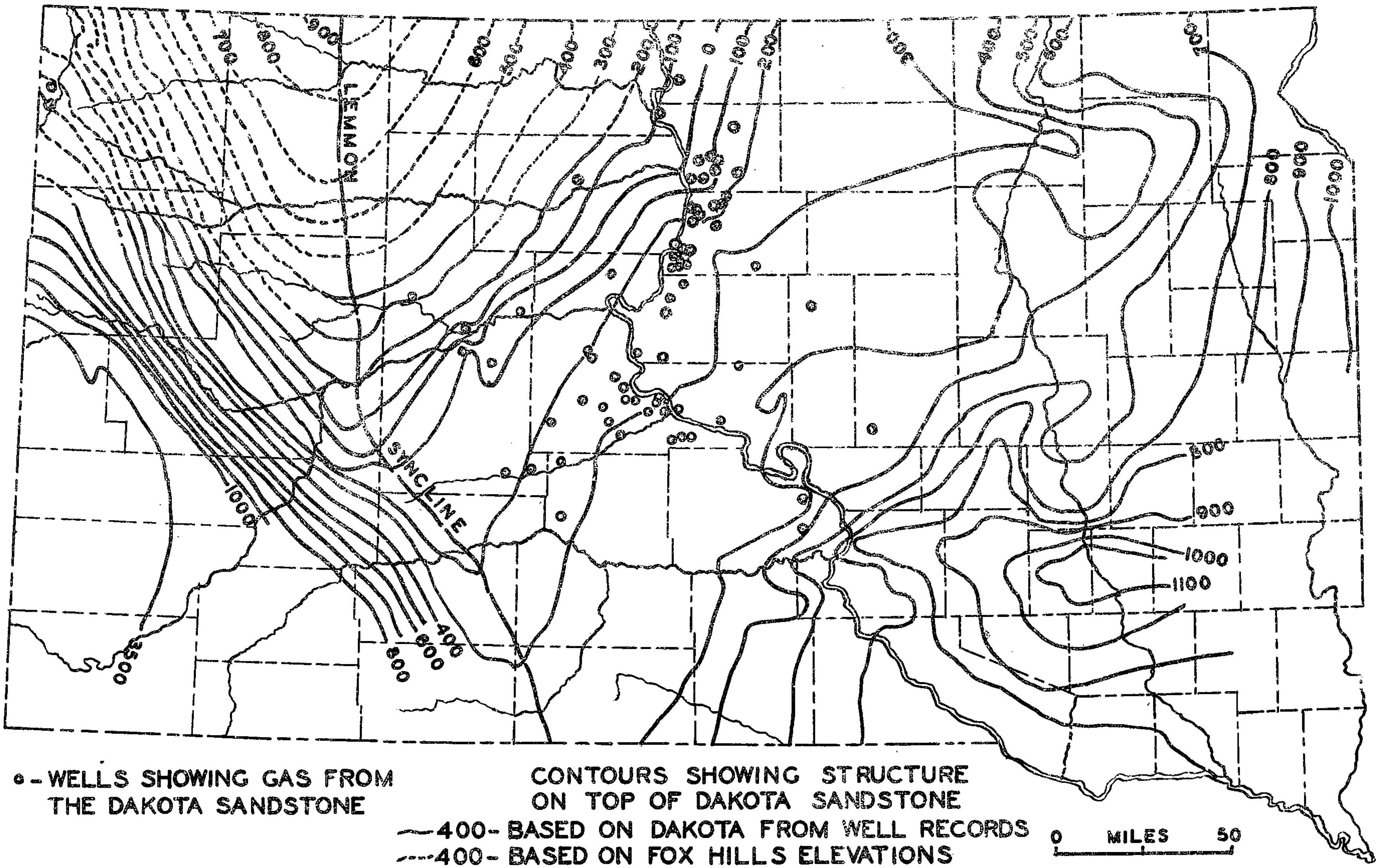
1. W. H. Jordan and E. P. Rothrock, A Magnetic Survey of Southeastern South Dakota, S. D. State Geol. Survey R. I. # 33, February, 1940.

PLATE IV

GAS AND STRUCTURE MAP
OF SOUTH DAKOTA



o - WELLS SHOWING GAS FROM THE DAKOTA SANDSTONE

CONTOURS SHOWING STRUCTURE ON TOP OF DAKOTA SANDSTONE
—400- BASED ON DAKOTA FROM WELL RECORDS
----400- BASED ON FOX HILLS ELEVATIONS
DATUM SEA LEVEL

0 MILES 50

slightly west of the Big Bend of the Missouri River. Either this consists of a simple anticline splitting near its southern extension so that one axis lies west of Oacoma and the other through Chamberlain, or there may be two separate anticlines.

This uncertainty regarding the exact nature of the structure is due to the fact that the survey was limited by exposures of the key bed to the bluffs of the Missouri River and its tributaries. Thus, the eastern side of the structure and both the northern and southern ends which lie in the Missouri River valley were fairly well defined. The top of the structure and its western limb, however, could not be determined because these occur under the uplands northwest of Chamberlain where key beds are not exposed.

Reference to the accompanying map will show the size and shape of this structure. There are a number of points in the vicinity of Chamberlain where the key bed has an elevation of 1540 feet. Five miles northwest of Oacoma there is an area where the key bed has an elevation better than 1560 feet. From this high point there is a pronounced dip toward the southwest, the key bed dropping to an elevation of 1450 feet several miles up White River. Toward the southeast there is a similar dip down the Missouri. Toward the northeast there is a well established dip across the Missouri River and into Buffalo County. Toward the northwest the evidence seems to be that there is a continuation of this structure into the region just west of the Big Bend of the Missouri River. Only in the one direction, toward the west, was it impossible to determine dip of the beds. If the survey could have been extended in this direction, a completely enclosed structure of considerable magnitude might have been outlined.

While it is probable that possible oil bearing sands will have the same general structure as that of the surface beds this concordance does not necessarily exist. It may be that thickening and thinning of intervening beds may cause the structure to change with depth.

There are insufficient data concerned with variations in thickness of the Pierre and other Cretaceous formations to determine the effect of these on the structure of beds below the key bed. It seems generally established, however, that there is a progressive thickening of these beds toward the northwest. The general effect of this would be to increase the dip of beds below the key bed in that direction and to increase the dip in the opposite direction or toward the southeast. This would make more certain the existence of a west limb to the structure described above and yet would not completely eliminate the east dips recorded in the present surveys, unless the thickening toward the west were at an excessive rate.

Reported local variations in thickness might be due to lack of knowledge of the stratigraphy of the Pierre. Such variations, if they occur, would clearly cause the structure of beds below the key horizon to be different than that of the key bed. Thus, the thickening of the Gregory up the White River would cause the dip of all beds below the Gregory to be greater in that direction. This would increase the importance of the structure west of Chamberlain. It is believed, however, that local variations in thickness of a bed are largely compensated by the opposite variation in the thickness of other beds in the same locality.

Since structure is the most important consideration in prospecting for oil and gas, it is strongly recommended that the present type of survey be extended westward from the Big Bend, and thus determine, if possible, whether the structure described above extends toward the northwest into the Big Bend country.

Additional information regarding the structure might be obtained, also, by drilling a series of shallow wells on the uplands northwest of Oacoma. It is possible that a key horizon, such as the Crow Creek sand and marl, might be identified in these wells and thus additional elevations be obtained that would clearly locate the high point of the structure, and show the nature of its extension toward the northwest.

A geophysical survey might also be advisable before deep drilling is undertaken.

OIL AND GAS POSSIBILITIES IN THE AREA

Too little is known concerning the deeper formations to justify a conclusive statement regarding possibilities of finding oil or gas in paying quantities in the Chamberlain area. However, certain conditions existing in the area are considered favorable.

In the first place the structure as outlined above seems favorable. The structure was determined by means of a plane table survey under the most favorable conditions, with a key horizon that could be easily identified over a wide area and in a region where there had been little slumping. The structure may be of the same type as some of those in eastern Kansas which have formed over buried hills or ridges.

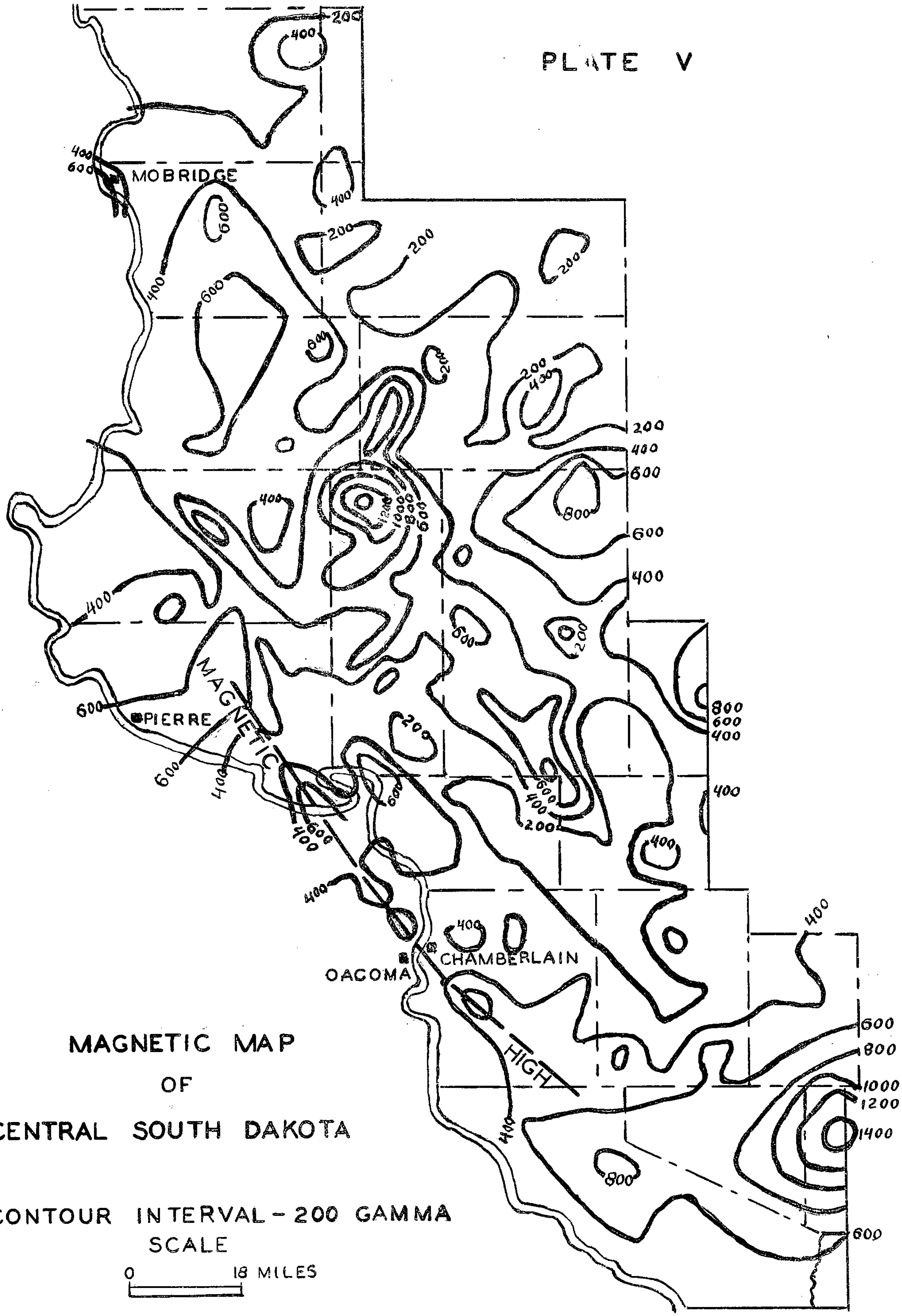
Secondly, with many of the formations east of the Lemmon trough thinning toward the east or pinching out, it is probable that stratigraphic traps have been developed which would be important in the accumulation of oil and gas.

Third, while the Dakota sandstone may have been tested by artesian wells, there is a thick series of Paleozoic formations not far below the Dakota which have not been tested. These contain good source beds and porous beds which might serve as reservoir formations in which oil and gas might accumulate. A test well, therefore, should extend at least to a depth of 1500 feet if drilled in the river bottom near Chamberlain, or 2000-2500 feet if drilled on high land in the northwestern part of the area mapped, so as to test at least these upper Paleozoic beds. Should pre-Cambrian quartzite or granite be encountered a complete test should be drilled until the quartzite or granite of the pre-Cambrian is encountered. No oil will be found in pre-Cambrian rocks.

Fourth, a number of artesian wells in Bull Creek valley yield natural gas in a manner similar to that of wells in the Pierre gas field. The full significance of this occurrence is not understood. It is known, however, that oil and gas commonly occur together and that seeps of these products have lead to the discovery of many important oil fields during the past.

It was reported by ranchers in Bull Creek valley that both 400 foot wells and Dakota sandstone wells approximately 900 feet deep yield gas. This might indicate that the gas is migrating upward through the shale and that its source lies below the Dakota formation.

PLATE V



MAGNETIC MAP

OF

CENTRAL SOUTH DAKOTA

CONTOUR INTERVAL - 200 GAMMA

SCALE

0 18 MILES

Fifth, the Chamberlain area lies on the edge of a larger area covered by a magnetometer survey during 1939 and 1940 by Dr. W. H. Jordan.[1] Reference to Dr. Jordan's map which is reproduced herein (Plate V) will show that the prominent structure as defined in the present survey corresponds in its location to a magnetic high trending from the northwestern corner of Lyman County toward the southeast through Chamberlain.

This is the first time that a magnetometer and a plane table survey have been conducted by the State in the same area in South Dakota. Consequently the agreement as to results is very interesting. The full significance of a magnetometer survey is not clearly understood. It must be noted, however, that magnetic and structural surveys do not directly indicate the presence of oil. Both point to conditions that may be favorable to oil accumulation. Certainly the agreement as to results makes the area doubly important in the search for oil and gas. If a test well were drilled in the axis of this anticline and the well were successful it would greatly enhance the possibilities of other areas of high magnetic intensity which may be located by the magnetometer.

There are a number of other conditions in the Chamberlain area which might interest the prospective driller. Both Chamberlain and Oacoma are served by the Chicago, Milwaukee, St. Paul and Pacific Railroad. This road traverses the uplands northwest of Oacoma where the most favorable drilling sites appear to lie. It might be possible to establish temporary loading and unloading facilities near the site of the well and thus avoid hauling heavy equipment over mediocre country roads.

Chamberlain and Oacoma both are situated on U. S. Highway 16, an all-paved road over which most of the traffic to and from the Badlands and Black Hills passes. The side roads are strictly dry weather roads and are adequate for light traffic.

Water for drilling might be trapped behind temporary dams or might be obtained from an artesian well, a number of which exist in the area.

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1. W. H. Jordan and E. P. Rothrock, A Magnetic Survey of Central South Dakota, S. Dak. Geol. Survey R. I. No. 37, November, 1940.

APPENDIX

Well Records

City of Chamberlain Well

Location: City of Chamberlain; T. 104 N., R. 71 W., Sec. 15
Drilled: Page Guthrie (1890); Mahanna & Johnson (1900).
Completed: To 795 ft. in 1890; to 1983 ft. in 1900.
Source: Brule County Auditor in 1938.
Elevation: 1547 feet.

0 - 3	Soil
3 - 20	Clay
20 - 30	Marl
30 - 110	Clay
110 - 125	Blue Clay
125 - 155	Oil rock
155 - 200	Chalk rock
200 - 250	Chalk rock, dark
250 - 300	Chalk rock
300 - 400	Chalk rock
400 - 415	Shale
415 - 521	Slaterock
521 - 525	Sand rock
525 - 538	Sand rock
538 - 550	Shale
550 - 600	Shale with thin layers of clay
600 - 713	Shale
713 - 716	Shell and hard rock contains iron.
716 - 720	Sand rock. <u>First flow</u>.
720 - 750	Shale
750 - 758	Chalk
758 - 760	Sand rock - <u>Water</u>
760 - 775	Sand rock
775 - 780	Shale
780 - 795	Mixture of shale, sand, and pyrites. Drilling below this point so mixed the formation and <u>flowing water</u> could not tell what it was.
800 - 806	Sand rock
806 - 812	Soft shale
812 - 850	Hard sand rock
850 - 892	Soft sand rock
892 - 902	Quick sand
902 - 960	White shale
960 - 980	White shale; <u>water</u> flowed 2" over 6" pipe
980 - 983	Sand: In this vein the flow increased to 44" above the top of a 4" pipe which was put through.

Chamberlain City Well

Correlation

0 - 110	Recent
110 - 155	Pierre formation
155 - 400	Niobrara
400 - 713	Carlile, Greenhorn, Graneros formations. Sand at 520 - 540 may be Greenhorn.
713 - 900	Dakota formation.
980 - 983	Possible Lakota formation.

Log of McClure Well

Location: Sec. 31, T.108 N., R. 78 W., Lyman County, S. Dak.
Completed: Before 1909
Source: U.S.G.S. Water Supply Paper 227, p. 120
Elevation: 1917 ft.

0 - 20	Yellow shale
20 - 820	Blue shale
820 - 1090	Black shale
1090 - 1094	Hard shale
1094 - 1294	Black slate with layers of hard limestone
1294 - 1320	Sandy shale
1320 - 1470	Black shale with sandy streaks
1470 - 1510	Muddy sandstone, black shale, and shelly limestone.
1510 - 1550	Gray shale and fine sandstone, mixed.
1550 - 1552	Very hard rock
1552 - 1555	Shale
1555 - 1585	Sandstone
1585 - 1623	Sandy shale

Log of Well on Carpenter Farm, near Pukwana

Location: Sec. 35, T.104 N., R. 70 W., Brule County, S. Dak.
Completed: 1896
Source: J.S. Sanborn (U.S.G.S. Water Supply Paper 227, p.75, and U.S.G.S. 18th Annual Report, Part IV, p. 568.)
Elevation: 1583

0 - 60	Black loam
60 - 72	Yellow sand
72 - 196	Blue clay
196 - 435	Chalk rock
435 - 536	Black clay
536 - 559	First sand
559 - 749	Blue-black clay
749 - 771	Second sand
771 - 845	Light chalky clay
845 - 907	Third sand ("Dakota" sandstone)

STANDING BUTTE WELL

Location: NW¼, Sec. 9, T. 7N., R. 27E., Stanley County
Drilled: South Dakota Development and Refining Co.,
Completed: 1926
Source: Information furnished by the company
Elevation: 1958.1 feet (by S. D. Geol. Survey)

	Thickness	Depth
Pierre Shale		
"Pierre" shale	927	927
Niobrara (?) Formation		
Shale rock, gray	6	933
Shale, gray, sandy, carrying dry gas .	30	963
Carlile Shale		
Shale	437	1400
Greenhorn Formation		
Sand and Water	50	1450
Graneros shale		
Shale	285	1735
Dakota formation		
"Dakota" sandstone carrying water with gas and oil showing	170	1905
Fuson formation		
"Fuson" shale	35	1940
Lakota formation		
"Lakota stone	36	1976
Morrison formation		
"Morrison" shale	214	2190
Morrison or Sundance		
"Base of the Morrison or upper Sundance"	80	2270
Sundance formation		
Limerock, penetrating lower sandstone.	9	2279
Water sand	11	2290
Lime rock	2	2292
Pyrites, iron, shell	2	2294
Sand, loose white	13	2307
Shale, gray	18	2325
Water sand, with great water flow	25	2350
Coal	6	2356
Sandstone	26	2382
White sand	3	2385
Sandstone	7	2392
Fullers earth	10	2402
Sandstone	3	2405
Clay	7	2412

	Thickness	Depth
Spearfish formation		
Redbeds carrying streaks of gypsum and sand	147	2559
Minnekahta		
Oil sand	1	2560
Red bed	4	2564
Tar sands carrying oil	6	2570
Opeche		
Red beds	45	2615
Minnelusa		
Sand, showing tar	5	2620
Sand, black	5	2625
Sandrock, hard, showing gas and tar	32	2657
Shale, black, flaky	2	2659
Gypsum	1	2660
Broken fragments of sand and shale,more gas	5	2665
Broken formation, some gypsum	5	2670
Sandrock	10	2680
Broken formation	5	2685
Shale, tough, gray	42	2727
Pink formation, showing lime	3	2730
Pink rock	25	2755
Limestone shells, conglomerate between	9	2764
Pink sticky formation	7	2771
Conglomerate	10	2781
Shale, gray	6	2787
Conglomerate	11	2798
Conglomerate, gas showing	32	2830
Broken formation, gypsum and lime	10	2840
Lime and gypsum	8	2848
Shale, red	25	2873
Shale, black	4	2877
Shale, red	3	2880
Lime, gypsum, black shale	30	2910
Clay, yellow, tough	10	2920
Shale, red	10	2930
Sandstone, hard, shell	5	2935
Sand, small flow of water	5	2940
Sand, very sharp	27	2967
Shale, light, sandy	23	2990
Shale, gray, sandy	20	3010
Sandy, heavy water flow	17	3027
Pahasapa		
Lime, white, medium hard	63	3090
Lime, very hard	70	3160
Lime, medium hard	10	3180
Lime, with hard, medium and soft layers	338	3508

HUNTER #1 (GYPSY) WELL

Location: NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 28, T. 3N., R. 16E., Pennington County.
Drilled: Gypsy Oil Company, 1931.
Source: Bull. Amer. Assoc. Petrol. Geol., Vol. 23, No. 8, 1939.
Elevation: 2956.9 (by S. D. Geol. Survey)
Remarks: This log is the result of a restudy of the cuttings of the well by Max Littlefield, Geologist, Gulf Oil Corporation. Both the lithologic descriptions and correlation differ somewhat from the log as originally published in S. D. Geological Survey Report of Investigations 4, pp. 28-30. The following correlations appear to be quite logical, although the present writer seriously doubts the correlation of the "Pre-Mississippian (?) Dolomite."

	Thickness	Depth
Fox Hills Sandstone		
Surface to an undetermined depth. No samples were taken before setting surface pipe at depth of 238 feet	238	238
Pierre Shale		
Gray to gray-green shales with zones of siderite concretions, chalky shales and thin interbedded bentonites	1662	1900
Niobrara Chalk		
Gray to gray-green shales, some zones of which are highly chalky	220	2120
Chalk, shaly, gray to white	50	2170
Carlile Shale		
Shale, greenish gray; with small amounts of included silt and fine sand	80	2250
Shale, greenish gray; with interbedded layers of shaly siltstone and fine sand, as shown in cores taken from 2266 to 2276 and 2347 to 2358 feet. The latter core showed traces of gas	140	2390
Shale, dark gray. Zones of siderite concretions, included fine sand and thin bentonites	80	2470
Shale, dark gray to black; with chalky spots. Zones of sideritic limestone concretions ..	93	2563
Greenhorn Limestone		
Limestone, brown to gray, crystalline	12	2575
Graneros Shale		
Shale, dark gray to black, calcareous, with chalky zones	35	2610
Shale, greenish gray; with glauconitic silt .	80	2690

	Thickness	Depth
Shale, dark gray to black, chalky spots ...	120	2810
Shale, dark gray to black; with many calcium carbonate concretions or thin beds of limestone	65	2875
Shale, greenish gray to black; in part silty and sandy, with zones containing thin interbedded fine sands	149	3024
Dakota Sandstone		
Sand, interbedded layers of fine, medium, and coarse. Partings of carbonaceous shale. Interbedded shale layers from 3047 to 3082 feet. Fresh water rose 1400 feet in drill-stem tester in one hour from 3026 to 3041 feet	58	3082
Fuson Shale		
Shales, gray, drab, and maroon, in part sandy	72	3154
Minnewasta Limestone		
Interbedded shales and limestone. Limestones range from brown and sideritic to gray and crystalline	24	3178
Lakota Sandstone		
Shales, gray, with both included and interbedded silt and sand. Thirteen-inch casing cemented at 3209 feet	135	3313
Shale, dark gray; with interbedded gray to brown limestone	10	3423
Sand, medium, well sorted to 3376 feet; contains interbedded shale layers below that point. Fresh water rose 2300 feet in drill-stem tester in one hour from 3325 to 3339 feet	84	3507
Conglomeratic sand, poorly sorted	13	3520
Morrison Shale		
Clay shales, red, brown, yellow, green, gray and black	40	3560
Unkpapa Sand		
Sand, fine to coarse; with pebbles as large as 4 mm. in diameter. Clean and shale free. Fresh water rose 3000 feet in drill-stem tester in 15 minutes from 3461 to 3475 feet	28	3588
Shales, gray to green, sandy; grading down into fine sand with green, pink, white, and brown clay	42	3630
Sundance Series		
Clay and shale, green, glauconitic, sandy .	32	3662
Limestone, gray-brown, dense	3	3665
Interbedded green shales, shaly glauconitic siltstones and sand with interstitial green clay	202	3867

	Thickness	Depth
<u>Spearfish Shale</u>		
Sand and siltstone, white to pink, with interbedded red clay and shale	169	4036
Shale, red, gypsiferous	114	4950
<u>Minnekahta Limestone</u>		
Limestone, light brown, cream-colored, and pink; somewhat porous	30	4180
<u>Opeche Shale</u>		
Shale, red, in part silty; with a few thin beds of anhydrite	102	4282
<u>Pennsylvanian Series</u>		
Limestone, dense, white to pink	39	4321
Shale, pink, calcareous	15	4336
Interbedded pink limestones, anhydrites; sands; and red and green shales	78	4414
Anhydrite; with interbedded dense brown limestone	16	4430
Shale, red and green	7	4437
Anhydrite, white	13	4450
Sands and shales, red and green, anhydritic ..	11	4461
Anhydrite, white	25	4486
Interbedded pink and brown limestones; red sand; and red and green shales	39	4525
Limestone, dense, pink, anhydritic	22	4547
Interbedded red and green shales, clayey sands, and anhydrite	53	4600
Interbedded pink limestone and anhydrite	15	4615
Shale, red and green, silty	10	4625
Limestone, red, and limy fine sand	9	4634
Interbedded limestones, brown to pink, anhydrite	26	4660
Sand, poorly sorted, calcareous	5	4665
Interbedded brown limestone, white anhydrite and thin layers of sandy green shale	23	4688
Interbedded green shale, gray sand, and thin brown limestones	39	4727
Limestone, brown, dense; with chalcedony	15	4742
Interbedded brown limestone, sand, dark shales, and anhydrite. Some fragments of sand and limestone showed oil stain	20	4762
Limestone, brown; with interbedded dark shales. Some limestone fragments showed oil stain ..	8	4770
Anhydrite; with interbedded limestone. Changed to cable tools. Cemented 9-inch casing at 4513 feet. No showing of oil or gas when plug was drilled. One-half bailer of dilute water per hour from 4513 to 4573 feet	13	4783
Limestone, brown to gray, silty, sandy; with interbedded thin dark shales and rare spots of anhydrite	55	4838
Interbedded clayey sand and siltstone and varigated shales	65	4903

	Thickness	Depth
Limestones, dense, white to pink	32	4935
Shales, variegated	9	4944
Shales, dark gray; with thin brown crystalline limestones	18	4962
Limestone, dense, white, brown, and pink; with partings of variegated shale	60	5022
Interbedded sands and shales. Sands poorly sorted, fine to coarse, hematitic. Shales variegated	18	5040
<u>Mississippian</u> <u>Series</u>		
Limestone, light brown, dense, cherty ...	20	5060
Limestone, dense, light brown; with chert, chalcedony, and secondary quartz. Cavernous porosity. Fresh water rose 3850 feet in hole from interval 4855 to 4872 feet	9	5069
Limestone, dense, white to light gray, cherty	65	5134
<u>Pre-Mississippian</u> (?) <u>Dolomite</u>		
Dolomite, brown to pinkish, finely crystalline; with porosity between crystals and in small vugs. Seven inch casing was set at 4930 feet and fresh water rose 4000 feet in the hole from 4934 feet	77	5211
<u>Total</u> <u>depth</u>. Dry and abandoned at		5211