State of South Dakota
George T. Mickelson, Governor
STATE GEOLOGICAL SURVEY
E.P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS
No. 34

A STRUCTURAL SURVEY OF NORTHEASTERN STANLEY COUNTY SOUTH DAKOTA

by
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A STRUCTURAL SURVEY OF NORTHEASTERN STANLEY COUNTY, SOUTH DAKOTA

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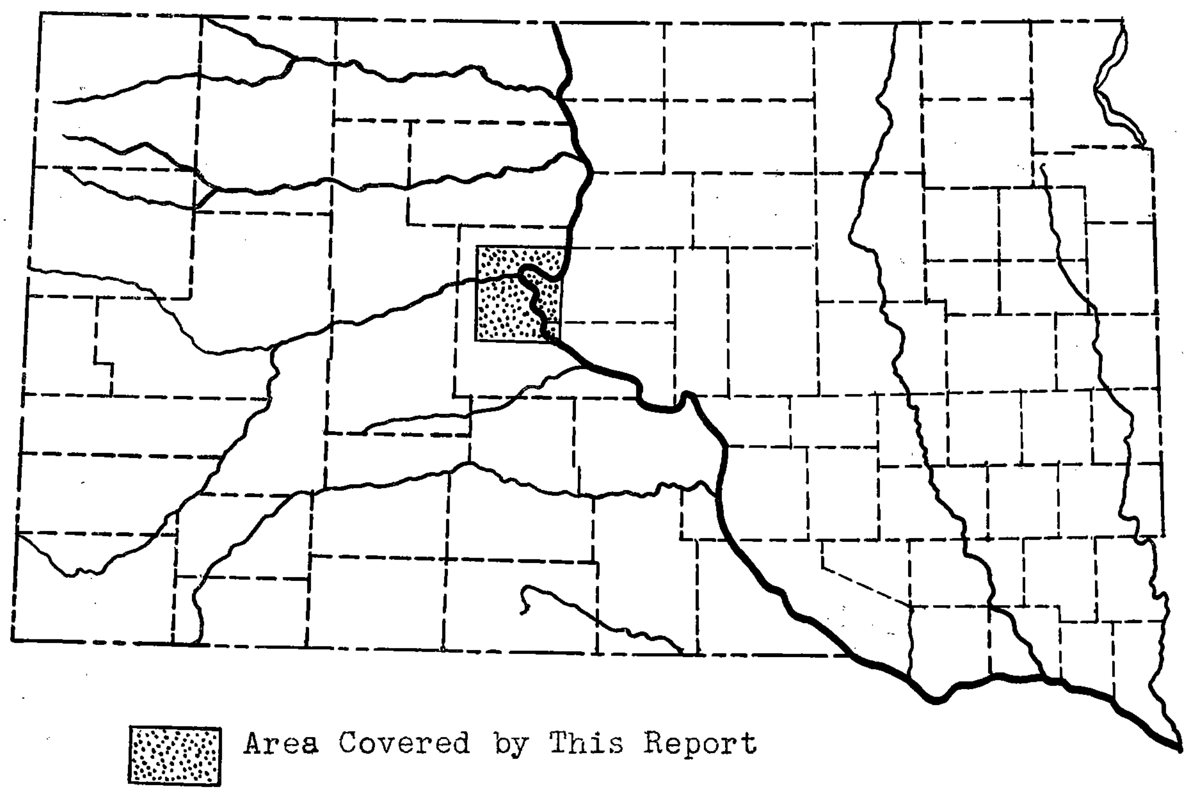

Area Covered by This Report

I. INTRODUCTION

LOCATION

The area covered by this report is located in the central part of South Dakota, and includes the northeastern part of Stanley County, together with adjacent parts of Armstrong, Sully, and Hughes counties. (Figure 1) The report includes a detailed structural study of the Missouri and Cheyenne River valleys, extending roughly from the Oahe Mission on the south, up the Missouri to the mouth of the Cheyenne, and thence up the Cheyenne for a distance of approximately ten miles. It thus includes the dissected portion of an area measuring about 25 miles north and south and 1[illegible] miles east and west. As the study is based on formations which are exposed only in the lower part of the breaks, the width of the strip actually mapped is variable, and ranges in width from one to five miles on either side of the two rivers and their tributaries. (See accompanying outcrop and structure map.)

PURPOSE OF THIS REPORT

This investigation is the third of a series of studies undertaken by the South Dakota Geological Survey to determine the detailed structure of the surface rocks of the upper Missouri River Valley with special reference to oil and gas accumulation. Lack of geological information concerning the region has greatly retarded the proper prospecting of its gas and oil possibilities. The results of these studies are published as Reports of Investigations of the State Geological Survey. The individual report of each specific area is primarily intended to serve as a guide for anyone desiring to test the particular area in the most efficient manner. The most suitable structures for gas and oil accumulation are indicated, and some of the problems connected with test drilling are outlined.

Special interest in the gas possibilities of the upper Missouri River Valley has been brought about by the presence of small quantities of gas encountered in many of the artesian wells drilled in the area within the last forty-six years. In many cases the flow of gas has been sufficient to supply the well owner with lighting, heating and cooking gas over a period of many years. Several such wells drilled in Pierre have supplied that town with natural gas since 1894.[1] The fact that the gas producing wells are more or less closely grouped has led to the suggestion that the accumulation of gas may be due at least in part to the structure of the underlying rocks. In this series of studies, special effort has been made to correlate the gas producing wells with the structure of the surface rocks.

In the area covered by this report, only three of the artesian wells are known to produce gas, and two of these are located just beyond the area mapped, so that their exact position relative to the structure is uncertain. (See accompanying map.) The first of these was drilled at old Lacy in 1918. It supplied gas for heating and lighting of a dwelling for several years, and even though it is now running wild, it is still yielding a considerable amount of gas.

Further interest in the oil and gas possibilities of northeastern Stanley County have resulted from the discovery of gas, together with a reported show of oil, in the Standing Butte test well, drilled by a local company in the north-central part of the County. This well was completed in 1925.

Discovery and development of even small quantities of gas would be of considerable benefit to ranchers, farmers, and nearby towns, whereas the development of larger resources, either of oil or gas, would be of immeasurable benefit to the entire State.

PREVIOUS WORK

The first geological report on the oil and gas possibilities of the upper Missouri Valley within South Dakota was published by the State Geological Survey in

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1. For history of development of gas resources at Pierre, see appendix, ix.

1930.[1] Although different lithologic phases of the Pierre shale in this region had long been noted, it was not until this first detailed survey was completed that certain of these features was recognized to be sufficiently constant over wide areas to serve as key horizons upon which structural mapping might be done. The presence of numerous small structures in the Pierre shale was established at that time, and the foundation laid for more extensive and more detailed surveys in this region.

Subsequent field and laboratory work by Dr. W. V. Searight of the University of South Dakota has resulted in the division of the Pierre formation within this state into five principal subdivisions, some of which are themselves divisible into definite zones.[2]

The first practical test of this subdivision was undertaken by this survey during the summer of 1937, at which time the structure of the surface rocks of the Pierre gas field was determined by mapping on a key horizon within one of these zones.[3] The validity of the

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1. Russell, 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.
2. Searight, W. V., Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in South Dakota, R.I. No. 27, S. Dak. State Geological Survey, January 1937.
   A. L. Moxon, O. E. Olson, W. V. Searight and K. M. Sandals, The Stratigraphic Distribution of Selenium in the Cretaceous Formations of South Dakota and the Selenium Content of Some Associated Vegetation, Amer. Jour. Botany, vol. 25, no.10, pp. 794-809, December 1938.
   A. L. Moxon, O. E. Olson, and W. V. Searight, Selenium in Rocks, Soils, and Plants, Technical Bull. No. 2, Agri. Exp. Sta., S. Dak. State Coll. Agri. and Mech. Arts, May 1939.
3. Wing, Monta E., A Structural Survey of the Pierre Gas Field, South Dakota, R.I. No. 29, S. Dak. State Geological Survey, March 1938.

Note: Subsequent reference to these papers will be made by author's name and page number in the text.

subdivisions of the Pierre formation was shown so clearly in that study that an area in Potter and Dewey counties was surveyed in the 1938 field season[4], and the structure of the area included in this report was determined in the summer of 1939.

NATURE AND SCOPE OF THE WORK

Field work in connection with the present report was carried on during the months of July and August, 1939. As most of the area covered lies on the west side of the Missouri River, a permanent camp was established at a central location near the river in Stanley County. Mapping of outcrops east of the Missouri was done from a temporary camp established near Pierre.

The field work consisted primarily of a plane table survey; a method frequently used in determining geological structures in areas where outcrops are numerous. In this type of work, the elevation of the outcrop of some readily recognized key bed is determined at frequent intervals by means of a plane table and telescopic alidade, and the structure of the surface rocks determined by contouring points of equal elevation on the resultant map. In areas whose general structure and geologic history are known, the structure of deeper rocks may be predicted with considerable accuracy from such a surface study.

Two planetable parties were used, each consisting of an instrument man, rodman, and geologist who served as a second rod man. Instrument men were Mr. H. E. Brookman and Mr. R. P. Maloney; geologists were Mr. Frank Byers and the writer. Assistants for the season were Mr. Richard Aroner and Mr. Rodney Madson. Elevations were determined by plane table surveys, controlled at frequent intervals either by Missouri River Commission or U. S. Geological Survey bench-marks in the area. In a few instances, other points whose elevation had previously been established by other surveys such as the Standing Butte well and irrigation survey stakes, were used to save the time required to carry precise level lines into the northern edge of the area.

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4. Gries, John Paul, A Structural Survey of Part of the Upper Missouri Valley in South Dakota, R.I. No.31, S. Dak. State Geological Survey, January, 1939.

The key horizon upon which mapping has been done is the contact of the Agency shale and the overlying Oacoma.[1] The "stepped" outcrops of the Oacoma are by far the most outstanding lithologic features in the area, but as the formation crops out in the lower part of the local geological section, exposures are found close to the Missouri and Cheyenne rivers in most places, and even in the deeper tributaries the formation passes below the bed of the stream within four or five miles of its mouth. As will be pointed out in a later detailed description of the Oacoma zone, there are several distinct bentonite beds which can easily be distinguished. By frequently measuring detailed sections of the zone, it has been possible to determine elevations on upper beds when the lower contact of the zone was not exposed, and to correct those elevations to the elevation of the base of the formation with considerable accuracy. This has made it possible to carry the survey much farther up the Cheyenne and the larger tributary creeks than would otherwise be possible.

In parts of the area east of the Missouri River, mapping was complicated by the presence of glacial drift which largely obscured outcrops of the underlying bedrock. Gravel terraces on both sides of the river also covered small areas, but to a lesser extent than the drift.

In addition to the outcrop study, all available information concerning the few artesian wells in the area was obtained. Their location and elevation are given in the report, together with available logs and water and gas analyses. Where possible, the particular zone in which the well was started was determined in order that the elevation of the base of the Oacoma at that point might be estimated.

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1. This same horizon was used in the report on Potter and Dewey counties (R.I. #31). In the report on the Pierre Gas Field (R.I. #29) mapping was done on a concretion zone which lies about 20 feet above the base of the Oacoma. This correction should be borne in mind when comparing the elevations of the structures in these adjacent areas.

The present work has purposely been limited to the river breaks, where almost continuous, easily recognized outcrops are available. The possibilities of extending the survey west of the Missouri breaks by mapping on a higher zone will be discussed in more detail under the description of the upper members of the Pierre formation. An effort has been made during the course of this survey to determine the constancy of some of these upper key horizons, with a view toward their possible use in later and more extensive work. Some of these beds which may prove useful farther west, however, are not present close to the river, and hence have not been included.

OACOMA ZONE OF PIERRE FORMATION

Two Miles South of Ft. Bennett
Stanley County

Step and weathering characteristics as developed in the type area. Bentonitic beds make the treads and non-bentonitic shales the riser.

Gumbo from Verendrie beds washing over Oacoma beds at the top of the outcrop.

II. STRATIGRAPHY--SUBSURFACE FORMATIONS

Except for a few small areas, the thick Pierre shale forms the bedrock over all of central South Dakota. Consequently, for a description of the formations lying below the Pierre in this area, we must rely upon deep well records. Our knowledge of the Cretaceous rocks down to and including the Dakota sandstone is furnished by many artesian well records, but below that horizon the data is meager. We must turn to the Black Hills, where these older rocks crop out, and to the few exceptionally deep wells lying between the Missouri Valley and the Hills. By a comparison of the records of these wells and the Black Hills outcrops, it is possible to trace the formations eastward under the plains. (See Plate II) Thus the gradual changes in thickness and lithologic character of the various formations can be observed and a close estimate made of conditions existing beneath any particular area. Because of the record of the deep Standing Butte test well on the west side of the area covered by this report, the character of many of the deeply buried formations is fairly well known. Plate I shows the probable character and thickness of the formations to be encountered in deep drilling in this region.

A brief description of the characteristics of each of these formations follows, beginning with the lowest and oldest, and progressing toward the surface. Detailed logs of several significant wells are included in the appendix. More complete descriptions of these formations at their outcrop may be found in the Black Hills Folio[1], and detailed studies of sample cuttings from the Hunter[2], Zeal[3], and Ole Tanberg[3] wells are available.

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1. Darton, N.H. and Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Central Black Hills Folio, No. 219.
2. Littlefield, Max, Log of the Wildcat Well in Pennington County, South Dakota, Bull. Amer. Assoc. Geol., Vol. 23, No. 8, p. 1234, August, 1939.
3. Aplin, E.R., A Micro-Fossiliferous Upper Cretaceous Section from South Dakota, Journal of Paleontology, Vol. 7, No. 2, pp. 215-220, June, 1933.

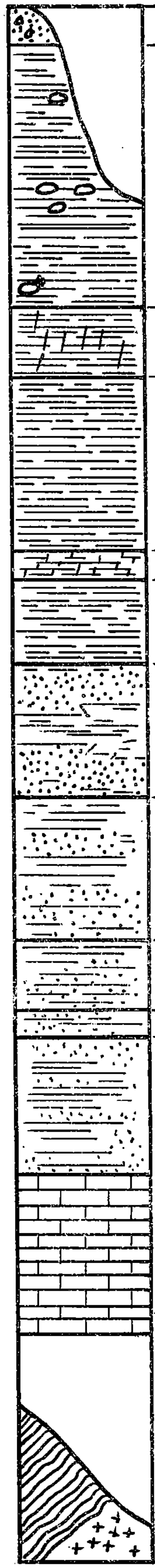
Beneath the Paleozoic sedimentary rocks lies an unknown thickness of igneous and metamorphic rocks of pre-Cambrian age. In the Black Hills they consist primarily of schist, quartzite, and granite, but in the eastern part of the state, the thick Sioux quartzite is the most conspicuous member. As oil and gas do not occur in pre-Cambrian rocks, prospecting should not be extended into these formations.

PALEOZOIC ROCKS

The first Paleozoic formation in the Black Hills consists of a series of alternating sandstones and shales (Deadwood formation) deposited by the upper Cambrian sea. Overlying these in the northern Hills, but missing to the south, are a shale and thick limestone (Whitewood) 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, so there is a slight possibility that they 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 Standing Butte well was finished in the Pahasapa limestone after penetrating nearly 500 feet of the formation (see appendix i). The Hunter well in eastern Pennington County also reached this horizon. In the Black Hills, a thick Pennsylvanian sandstone with interbedded shales and limestones (Minnelusa formation) overlies the "big lime". 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 Black 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. In this area there seems to be a more complete transition from Permian into Triassic beds than is indicated by the Black Hills section.

MESOZOIC ROCKS

Triassic redbeds and gypsum (Spearfish formation), which reach a thickness of nearly 700 feet in their outcrop around the Black Hills, thin to about 150 feet in



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 GRAY SHALE
500	CARLILE 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	

PLATE 1 GENERALIZED COLUMNAR SECTION

Stanley County. A series of varicolored clays and sands of Jurassic age (Sundance, Unkpapa and Morrison formation) lying above the Spearfish formation have a total thickness of 600 feet in the Hills area, and well over 400 feet in the Standing Butte well.

The oldest Cretaceous rocks in the region 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, these members can be distinguished, though the thickness of the individual members is extremely variable. A study of many artesian well records 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 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 not always occur at the same horizon under these conditions. Presence of stray, dry sands in the base of the overlying Graneros formation 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.

Between the Dakota sandstone and the base of the Pierre formation is a thick series of gray shales and chalk. The members of this series are, in ascending order, the Graneros shale, the Greenhorn limestone and calcareous shale, the Carlile shale, and the Niobrara calcareous shale or chalk. These formations are difficult to separate in well cuttings except by microscopic study of sample drill cuttings saved at regular intervals. Minor changes in lithology and fossil content can be observed in this way which

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1. The thin Minnewasta limestone is found between the Fuson and Dakota formations in the southeastern Black Hills. It has been recognized in only one deep well (Hunter) to the east of the Hills.
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. Dak. Geol. Survey R.I. # 26, 1936, p. 27.

cannot be determined by the driller. For this reason the thickness of any particular formation as determined by the driller may vary considerably from that determined after careful sample study.

The thickness of the Graneros shale as shown by drillers' logs in this general region is uniformly close to 275 feet, but the thickness increases rapidly toward the Black Hills. (Plate II) The formation is usually recorded in drillers' logs as a blue or black shale. Under the microscope, the shale appears dark gray, becoming brown or nearly black near the top.

The Greenhorn and Carlile formations cannot be accurately separated except from sample studies. The difficulty lies in the fact that the Greenhorn contains only scattered lenses of limestone which can be recognized by the driller. The upper part which is dominantly calcareous shale is grouped with the overlying Carlile shale. The latter is consistently logged as black shale. In drillers' logs of wells in this area the combined thickness of these two formations varies from 475 to 560 feet; the latter figure is comparable with those obtained at the outcrops east of the Black Hills. Variations seem more likely due to difficulty in picking the exact upper contact than in actual differences in thickness of the formation.

Between the Carlile and the Pierre shales lies the very calcareous Niobrara formation. Although it appears as a cahlk in outcrops, it shows only as a gray to black calcareous shale in wells. Searight (page 4) considers the relation between the Pierre and the Niobrara to be one of conformity. The similarity of the Niobrara to the lowest beds of the Pierre makes it practically impossible for the driller to locate the division point. Under the microscope the contact is easily located because of the characteristic "speckled" appearance of the Niobrara. However, there are not enough sample studies available to show the variations in thickness of the formation in the central part of the state. About 200 feet are usually exposed in outcrops. In drilling 50 feet or so of "gray, sandy shale" are usually reported; the upper, softer part of the formation being recorded as "Pierre shale."

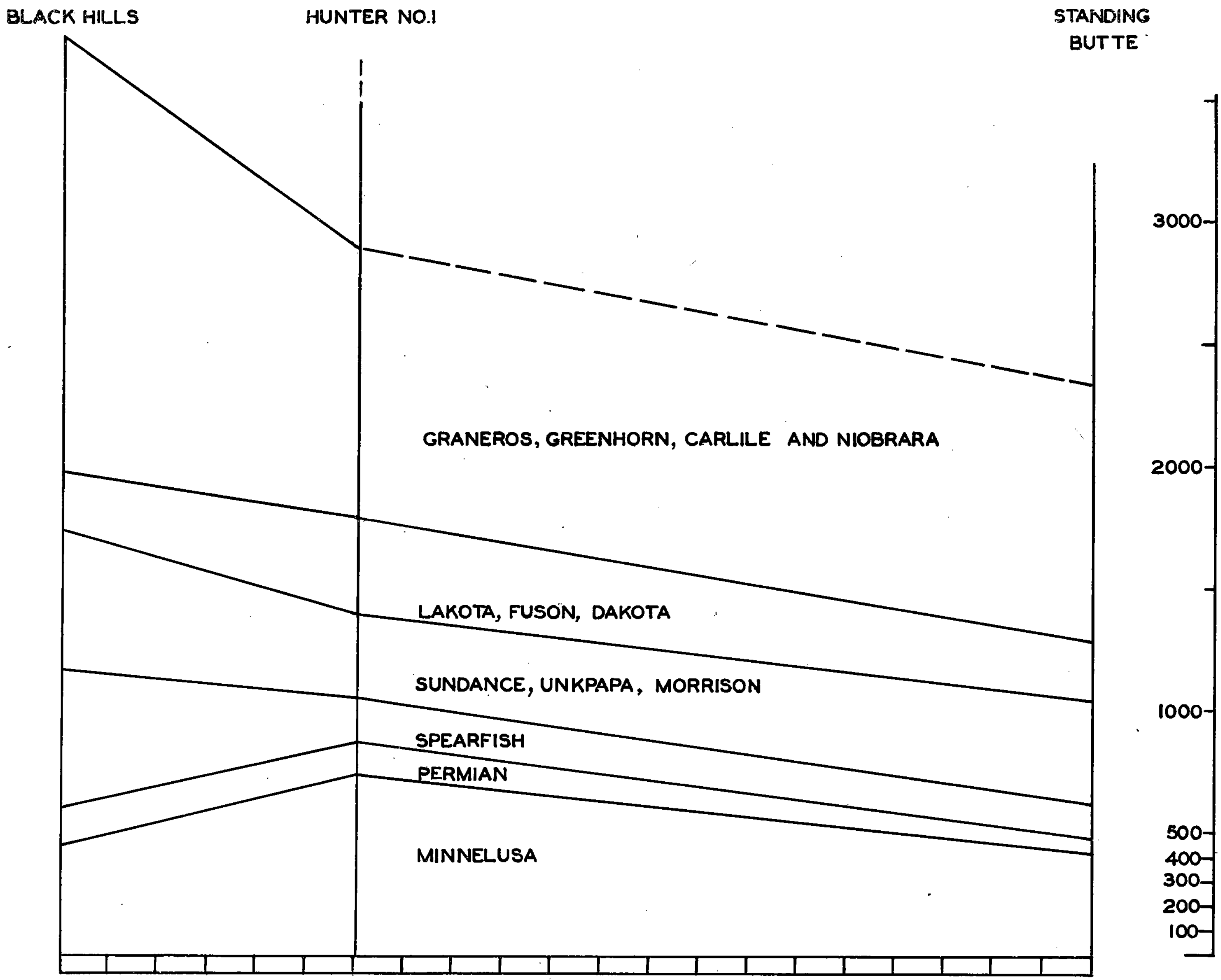

PLATE II. WEST-EAST SECTION SHOWING THICKENING OF BEDS IN SYNCLINE, AND TOWARD THE BLACK HILLS. BASE OF SECTION IS TOP OF THE PAHASAPA LIMESTONE

III. STRATIGRAPHY--THE EXPOSED FORMATIONS

Two distinct types of formations appear at the surface in this area. One includes the different members of the Pierre shale which form the bedrock, the other comprises the surficial mantle of glacial till, silt, loess, and terrace gravel which overlies the shale in much of this region.

PIERRE FORMATION

The Pierre formation may be described as a thick series of gray shales lying with apparent conformity upon the Niobrara chalk and beneath the Fox Hills sandstone. It underlies a large portion of the state. West of the Missouri River it is present at or below the surface everywhere except over and around the Black Hills and a few small areas in the lower Missouri Valley. East of the river the distribution is not so well known due to the mantle of glacial drift which overlies it. Well records and outcrops in which it has been identified indicate that it is also present under most of that part of the state.[1]

The Pierre shale forms the bedrock throughout the area under consideration. The total known thickness of the uneroded Pierre in South Dakota has been shown by Searight (page 56) to vary between 400 and 1100 feet. However, in this area the present topography has been carved in the Pierre shale, so that locally much of the formation has been removed by erosion. Consequently, the remaining thickness at any point depends not only upon the structure of the bedrock, but upon the surface elevation. The thickness of the formation, therefore, ranges from probably less than 300 feet in the Missouri Valley on one of the structural highs to as much as 800 feet on the upland in the northwestern corner of the area mapped.

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1. For details of the distribution of the Pierre formation see Geologic Map, State of South Dakota, compiled by M. E. Kirby, State Geological Survey, Vermillion, South Dakota, 1932.

The first attempt to subdivide the Pierre formation on the basis of lithology was made by W. L. Russell in 1930. That portion of the Pierre exposed in Potter County was separated into eight lithologic zones, but only one of these, the Agency, was named and no detailed sections were given. Searight subsequently studied the entire Pierre shale section in the Missouri Valley of South Dakota, and extended his observations to other parts of the state and to outcrops in adjacent areas. As a result of this work, he has subdivided the Pierre formation into five distinct members, several of which may in turn be further subdivided into zones. Plate III shows the generalized columnar section of the Pierre as worked out by Searight. Although all of the members are not exposed in this immediate area, each will be discussed here in some detail. Detailed sections of several subdivisions of the Sully and Virgin Creek members are included to show their local development.

Sharon Springs Member

This member has been named by Elias[1] for exposures in west central Kansas. Corresponding beds in South Dakota were included by Searight (page 10) with the Gregory member, until their correlation with the Kansas beds was recognized (Moxon, Olson, Searight, Sandals, page 796)and Moxon, Olson, Searight, page 20.) It is now defined as including all beds lying above the Niobrara formation and below the Gregory marl.

The formation crops out along the Missouri River and its tributaries from Yankton north to the vicinity of the Big Bend. It has also been identified by Searight in Shannon County and around the Black Hills.

As recognized in South Dakota, the member is divisable into two zones. The lower one consists of dark, nearly black beds of bituminous, fissile shale, interbedded with bentonites which thicken toward the Black Hills. The upper member is somewhat less fissile, and contains only a few bentonites, but is characterized by an abundance of small and large ironstone concretions.

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1. Elias, Maxim K., Geology of Wallace County, Kansas, Bulletin 18, State Geological Survey, Kansas, 1931, page 56.

GENERALIZED COLUMNAR SECTION OF THE PIERRE FORMATION

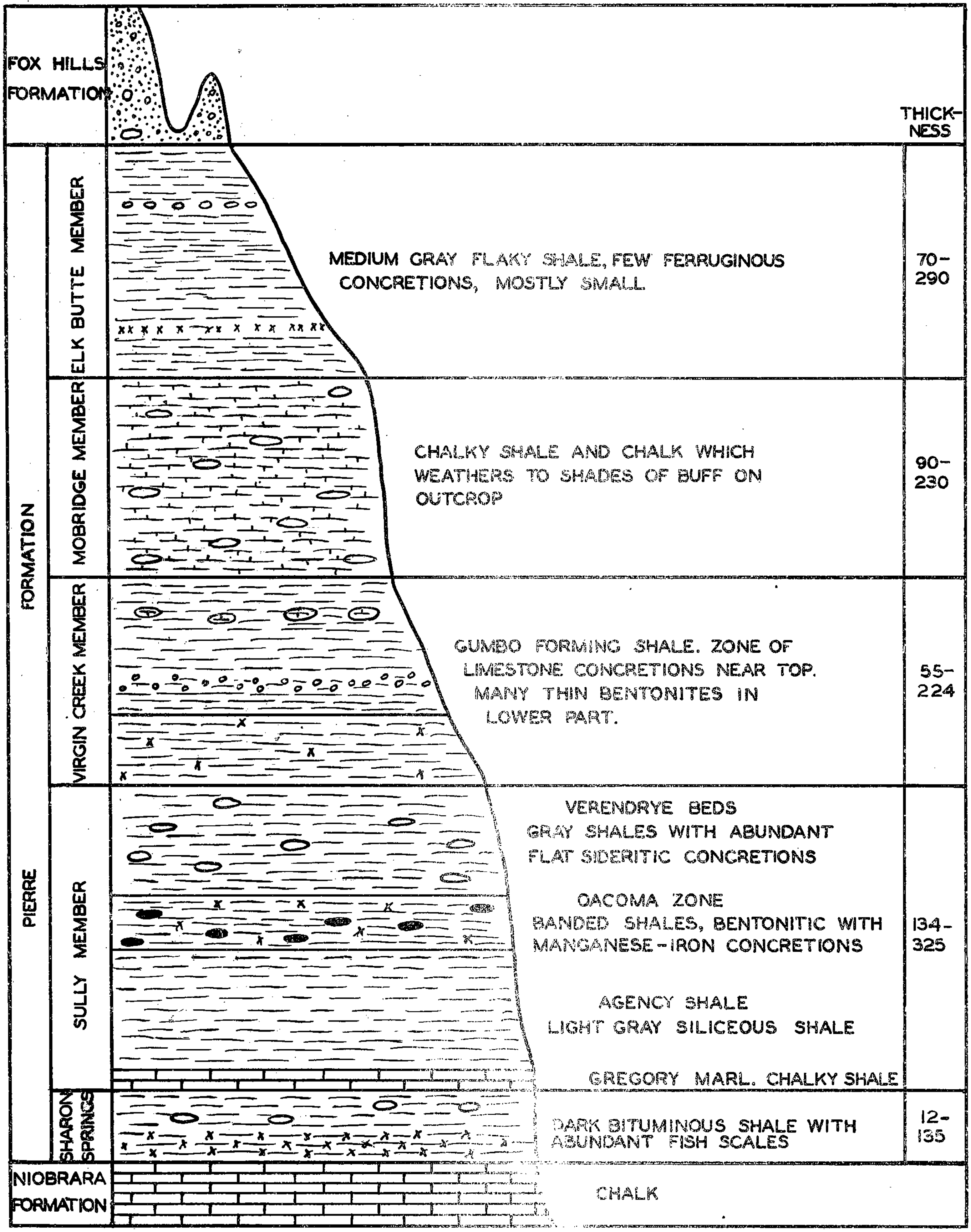


PLATE III

According to Searight, the Sharon Springs is separated from the overlying Gregory zone by an unconformity. Consequently the thickness observed for the member is due in part to original deposition, and in part to erosion immediately after deposition. Thicknesses of 7 feet at Yankton, 155 feet at the mouth of White River, and 200-250 in Butte County are suggestive. Because of the possible erosional nature of its upper surface, and the fact that the member cannot be identified in drillers' logs, there is little evidence as to its thickness in Stanley County. It is doubtful if more than 150 feet is present, and possibly much less than that.

Sully Member

The Sully member was named by Searight (page 21) for characteristic exposures along the Missouri in the area under consideration, although the type localities for the different subdivisions of the member range from Gregory County on the south to Dewey County on the north. The thickness of the member (excluding the thin Gregory zone) varies between 134 and 315 feet according to Searight (page 34), but there is evidence in this area that a maximum figure of 380 feet would not be excessive.

The Sully has been defined as including the group of shales lying between the dark, concretion-bearing shales of the Sharon Springs member, and the base of the highly bentonitic beds which form the lower Virgin Creek member. Beds belonging to this member are exposed along the Missouri River in South Dakota from the Nebraska state line northward to Mobridge, Walworth County, and have been observed as far east as Yankton and as far west as Meade counties.

The Sully member has been divided into four zones (Moxon, Olson, Searight and Sandals, page 596) which are valid wherever the beds are found in South Dakota, and further work may extend their use into adjacent states. These are, in ascending order, the Gregory, Agency, Oacoma, and Verendrye shale zones. As the upper three of these are characteristically exposed along the Cheyenne and Missouri rivers in northeastern Stanley County, and the structure of the surface rocks has been mapped on the contact between the Agency and Oacoma zones, these divisions of the Sully member are here discussed in considerable detail.

Gregory marl zone: This member was named by Searight (page 10) from exposures along the Missouri River in Gregory County, South Dakota. It crops out along the river breaks as far north as a point about 12 miles east of Pierre, Hughes County, where it disappears below the level of the Missouri River. It is consequently not exposed in the area under consideration, but undoubtedly underlies the region at no great depth.

In exposures the Gregory consists of a characteristic series of thin beds of light colored chalky shale or marl, underlain by up to two feet of fine-grained, slabby brown sandstone. Small shale pebbles are said by Searight to be present in the basal beds. It is doubtful if the chalk would be noticed in drilling through the formation, but the sandstone might easily be detected in drill cuttings. The zone is reported by Searight as 21 feet thick in Charles Mix County, and about 10 feet at its northernmost exposure east of Pierre. It is likely less than 10 feet thick in northeastern Stanley County.

The microfauna of the Gregory grades upward into the Agency shale, and it is quite possible that the Gregory grades laterally into the Agency to the west (Moxon, Olson, Searight, page 22).

Agency shale zone: This zone was named by Russell (page 5) from typical exposures along the Missouri River at the Cheyenne River Indian Agency in Dewey County. The Agency zone first appears near Crow Creek, Buffalo County, as a light gray shale lying between the Gregory member and the overlying bentonitic Oacoma zone of the Sully member. The outcrop is continuous in the Missouri River Valley and for short distances up the principal tributaries, as far as the mouth of the Moreau River, where it disappears beneath the floor of the valley.

At the type locality, the Agency zone is composed of light gray, siliceous shale, which weathers to brittle plates or chips, rather than to gumbo. In fresh exposures the shale breaks out into rectangular blocks several inches to a foot or more square and several inches thick. The joints are frequently stained dark brown or purple. The shale becomes much less siliceous to the south, and is only slightly siliceous in the area under consideration. In general, the outcrops weather to a silvery gray, though locally they may take on a dark brown color. This is a surface stain, and is conspicuous only when the outcrops are thoroughly dried by the sun. The discoloration may stop at the top of the zone, or may extend a few feet into the overlying Oacoma beds.

Large rust-colored calcareous concretions are present in the formation in this area, but are rather irregular in their distribution and are consequently not characteristic. Locally, smaller and black iron-manganese carbonate concretions may be present.

Two distinct groups of bentonites have been observed in the Agency in this area, both well down in the zone. One consists of a pair of four to eight inch bentonites lying from seven to nine feet apart. These are conspicuous just above the bridge across the mouth of Chantier Creek, at the mouth of Brush Creek, and in some of the cut banks along the lower Cheyenne River. Because of poor exposures and considerable slumping where they were exposed, the exact interval from this pair to the top of the Agency zone is not known. Although they appear at the mouth of Chantier Creek to lie not over 25 feet below the base of the Oacoma, other measured intervals suggest that 50 to 70 feet is a more nearly correct figure.

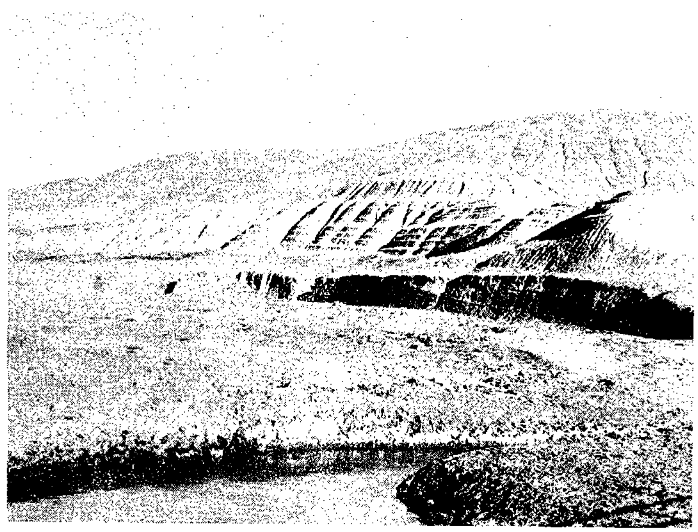
Where well exposed, the other bentonitic phase consists of four very thin bentonites in an interval of about six feet. Although they were not found in any outcrop in which the other bentonites were exposed, they are thought to lie a few feet above the big pair. Further field work may show the relationship between the bentonites found in this area, and those observed about 70 feet below the top of the Agency zone at the type locality.

The base of the zone is below the surface of the river except for a short distance near the south end of the area of outcrop. Consequently, little is known as to the total thickness of the Agency in this area. Measurements a few miles north of the type area show over 150 feet exposed above the river's edge. 115 feet are measured at Cheyenne Agency, and similar thicknesses are observed at structurally high points down as far as the Pierre gas field. South of that area the zone thins rapidly. Outcrops of the Agency thus appear to be the southern edge of a great wedge of siliceous shale, gradually thickening to the north, whose east and west limits are not yet known. Inasmuch as the base is exposed over only a small area, its stratigraphic relation to the Gregory is not known. The contact with the Oacoma appears to be one of gradation, with no visible evidence of a break in sedimentation.

<u>Oacoma</u> <u>shale</u> <u>zone</u>: The Oacoma zone was named by Searight (page 23) from characteristic exposures at Oacoma, Lyman County, and northward along the Missouri River to the Great Bend. Part of his description is given below to show the variation in the zone over a wide area in the Missouri Valley.

> "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

Hunting Bentonite Key Bed Beneath
Weathered Surface of Oacoma Zone.



Outcrop at Mouth of Chantier Creek

Light Oacoma Beds Showing Characteristic "Step"
Weathering Overlain by darker Verendrye Beds

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....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 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."

This zone of alternating light and dark shale overlying the siliceous Agency zone had previously been observed in Potter County by Russell (page 4) who gave it the designation "bed LD" (light-dark).

The Oacoma crops out along the Missouri and its tributaries from Charles Mix County, north to the mouth of the Moreau River. On the basis of microfossils, Searight has also identified it as far east as Yankton County, and from well cuttings in Todd and Pennington counties in the western part of the state.

The thickness of the Oacoma bentonitic zone ranges from about five feet in Potter County (Gries, page 15) to over 60 feet in the northwest corner of the area under consideration. From Ft. Pierre north to old Fort Bennett, the thickness varies only between 32 and 36 feet. One mile above the mouth of the Cheyenne it has a thickness of nearly 47 feet, and at the point where the base disappears below the valley floor a few miles up the Cheyenne, the zone has thickened to over 60 feet. In that part of the outcrop area lying north of Pierre, the formation thus has a tendency to thin to the northeast and thicken toward the west.

Continuing the work started in Potter and Dewey counties in 1938, considerable study has been devoted to the details of the bentonite beds which characterize the Oacoma zone. Inasmuch as most of the bentonites in this area are thin, individual beds are frequently disseminated in the shale and consequently appear to be discontinuous. The number observed in detailed sections varies between 17 and 28. As many as 13 were counted in Potter County sections. Most of the beds are less than one inch in thickness, but thicknesses of up to 10 inches are found.

The thicker, more persistent bentonites were often found to have characteristics which made it possible to trace them throughout the area. They have consequently been used as key horizons wherever the base of the zone was not exposed. Frequent measurement of the interval between these bentonites and the base have made it possible to correct all elevations to that horizon.

The lowest persistent bentonite has been taken as the base of the Oacoma zone. Not more than one discontinuous quarter inch bentonite has been observed in the several underlying feet of shale. This basal bentonite can easily be identified by its uniform thickness of four to six inches by the fact that the rusty stain characteristic of the Agency often stops sharply at that point, and by the presence in the bentonite of abundant flakes of biotite mica ranging up to one millimeter in diameter. In this study it has been referred to as the lower micaceous bentonite (LMB). The zone has been seen by the author as far south as Lower Brule, Lyman County. A characteristic section is as follows:

	Shale, light gray, slightly siliceous	
1.	Shale, bentonitic, grading down into impure bentonite....................	$4\frac{1}{2}$"
2.	Bentonite, olive green to yellow, with biotite flakes grading from large at base to small at top...............	$1\frac{1}{4}$
3.	Bentonite, pure, grading from dark gray at base to yellow at tip. No mica................................	$\frac{1}{4}$
	Shale, typical Agency, but joints stained brilliant blue or purple....	1

A thick bed of pure or slightly micaceous bentonite occurs regularly at a distance varying from 17 to 27 feet above the base. One or two thin bentonites occur typically within a foot below the big bed. The latter has been designated the big bentonite bed (BBB). This series is well developed in the type locality near Oacoma. A characteristic sequence is as follows:

Bentonite	6-10"
Shale	2
Bentonite	½- 1
Shale	5
Bentonite	½- 1

TABLE I

<u>Succession of beds, Oacoma zone, along Bad River, just west of Ft. Pierre, Stanley County, South Dakota.</u>

Detailed section, north bank, Sec. 33, T. 5 N., R. 31 E.

	Feet	Inches
<u>Verendrye zone</u>		
Shale, dark gray when wet, light yellowish gray when dry; weathers to gumbo		
<u>Oacoma zone</u>		
49. Bentonite..........................		¾
48. Shale, light gray, slightly siliceous		3
47. Bentonite..........................		1¼
46. Shale, as above....................		3
45. Bentonite..........................		1½
44. Shale, as above....................	1	½
43. Bentonite..........................		¼
42. Shale, as above....................	1	9
41. Bentonite..........................		¼
40. Shale, as above....................		6
39. Bentonite..........................		½
38. Shale, as above....................	4	5
37. Bentonite..........................		½
36. Shale, as above....................	4	10
35. Bentonite..........................		¼
34. Shale, as above, with layer of rusty concretions..........................		6

	Feet	Inches
33. Bentonite, micaceous (UMB)..........		2
32. Shale, as above....................	1	6
31. Bentonite..........................		¼
30. Shale, as above....................		1½
29. Bentonite..........................		¾
28. Shale, as above....................		10
27. Bentonite..........................		1
26. Shale, as above....................	2	5½
25. Bentonite (BBB)....................		10
24. Shale, as above....................		2
23. Bentonite..........................		¾
22. Shale, as above....................		5
21. Bentonite..........................		½
20. Shale, as above....................	2	2
19. Bentonite..........................		¼
18. Shale, as above....................		4
17. Bentonite..........................		¾
16. Shale, as above....................		4
15. Bentonite..........................		¾
14. Shale, as above....................		4
13. Bentonite..........................		¾
12. Shale, as above....................		4
11. Bentonite..........................		¾
10. Shale, as above....................		5
9. Bentonite		¾
8. Shale, light gray, slightly siliceous..........................	1	9
7. Bentonite...........................		1½
6. Shale, as above.....................	3	10½
5. Bentonite...........................		¼
4. Shale, as above.....................	3	6
3. Bentonite...........................		¼
2. Shale, as above.....................	1	8
1. Bentonite, micaceous (LMB)..........		4
Total Oacoma	36	4

<u>Agency zone</u>

	Feet	Inches
Shale, light gray, slightly siliceous..........................	2	6
Bentonite..........................		¼
Shale, as above, to water level.....		

TABLE II

Succession of beds, Oacoma zone, exposed near mouth of Chantier Creek, Stanley County, South Dakota.

Detailed section, north valley wall, SW ¼, Sec. 10, T. 6 N., R. 29 E.

Verendrye zone	Feet	Inches
11. Shale, dark yellowish gray, bentonitic, with many iron-manganese concretions; Weathers to gumbo. To top of hill.......	45	2
10. Bentonite......................		1
9. Shale, as above, with iron-manganese concretion layer at base....	2	4
8. Bentonite......................		1½
7. Shale, as above, no concretions.	5	2
6. Shale, as above, iron-manganese concretions throughout..........	4	
5. Shale, as above, no concretions.	2	
4. Break in slope, bentonite (?)		
3. Shale, as above, no concretions.	13	7½
2. Concretion layer		1
1. Shale, as above................	1	5
Total Verendrye Exposed	74	0

Oacoma zone	Feet	Inches
34. Bentonite......................		½
33. Shale, light gray, non-siliceous, bentonitic......................	1	1
32. Shale, as above, zone of 1 foot rusty limestone concretions at top	1	2½
31. Bentonite, micaceous (UMB)......		½
30. Shale, slightly gritty..........	1	6
29. Bentonite, pure, hard...........		1
28. Shale, as above, bed of _Inoceramus_ shells at base.......	2	
27. Bentonite, hard, gritty (BBB)...		7
26. Shale, as above................		2
25. Bentonite......................		½
24. Shale, as above................		4
23. Bentonite......................		½
22. Shale, as above................	5	6½
21. Shale, bentonitic..............		½
20. Shale, light gray, slightly siliceous......................	4	7

		Feet	Inches
19.	Bentonite...........................		½
18.	Shale, as above....................	1	
17.	Bentonite,soft......................		1
16.	Shale, as above, approximate level of iron-manganese concretion zone..		6
15.	Bentonite...........................		1
14.	Shale, as above.....................		3
13.	Bentonite, soft.....................		3
12.	Shale, as above.....................	4	7
11.	Bentonite...........................		1
10.	Shale, as above.....................		6
9.	Bentonite...........................		1
8.	Shale...............................	1	
7.	Bentonite...........................		¼
6.	Shale, gray, non-gritty, iron-stained joints below this level.........	1	6
5.	Bentonite...........................		2
4.	Shale, as above.....................	1	3
3.	Bentonite...........................		¼
2.	Shale, as above.....................	3	5½
1.	Bentonite, micaceous (LMB)...........		6
	Total Oacoma	33	1

<u>Agency shale zone</u>

		Feet	Inches
5.	Shale, gray, slightly siliceous, non-calcareous.........................		4
4.	Bentonite...........................		¼
3.	Shale, as above.....................	9	7
2.	Bentonite...........................		¾
1.	Shale, as above, to creek bottom....		

TABLE III

Succession of beds, Oacoma zone, exposed just south of Old Fort Bennett, Stanley County, South Dakota.

Detailed section, SW $\frac{1}{4}$, Sec. 8, T. 8 N., R. 29 E.

		Feet	Inches
	Verendrye zone		
	Shale, soft, dries yellowish gray, weathers to gumbo.......		
	Oacoma zone		
37.	Bentonite.....................		$\frac{1}{2}$
36.	Shale, light gray, slightly siliceous..................		6
35.	Bentonite.....................		$\frac{1}{2}$
34.	Shale, as above...............		8
33.	Bentonite.....................		2
32.	Shale, as above...............	1	$\frac{1}{2}$
31.	Bentonite.....................		$1\frac{1}{4}$
30.	Shale, as above...............		11
29.	Bentonite.....................		$\frac{1}{4}$
28.	Shale, as above...............	1	7
27.	Bentonite.....................		$\frac{3}{4}$
26.	Shale, as above...............		10
25	Bentonite.....................		$\frac{3}{4}$
24.	Shale, as above, iron-manganese concretions at top..........		10
23.	Bentonite.....................		$\frac{1}{4}$
22.	Shale, as above...............		11
21.	Bentonite.....................		$\frac{3}{4}$
20.	Shale, as above...............	1	$3\frac{1}{2}$
19.	Bentonite.....................		$\frac{1}{2}$
18	Shale, as above...............		10
17.	Bentonite, impure.............		$\frac{1}{2}$
16	Shale, as above, zone of large rusty concretions at top......	1	5
15	Bentonite, micaceous (UMB)....		6
14.	Shale, as above, no concretions		7
13.	Bentonite		$1\frac{1}{2}$
12.	Shale, as above...............	1	10
11.	Bentonite		3
10.	Shale, as above...............	2	7
9.	Bentonite.....................		4
8.	Shale, as above	5	$\frac{1}{2}$
7.	Bentonite (?) forming shelf		
6.	Shale, as above, small iron-manganese concretions below	6	[illegible]
5.	Bentonite.....................		

	Feet	Inches
4. Shale, as above......................	2	
3. Bentonite............................		1½
2. Shale, as above......................	3	7
1. Bentonite, micaceous (LMB)...........		6
Total Oacoma	36	0

Agency zone

Shale, light gray, somewhat siliceous

TABLE IV

Succession of beds, Oacoma zone, exposed along Cheyenne River, just west of mouth of Brush Creek, Stanley County, South Dakota.

Detailed section, SE¼, Sec. 5, T. 9 N., R. 28 E.

	Feet	Inches
Verendrye zone		
Shale, dark gray when wet, light yellowish gray when dry; weathers to gumbo		
Oacoma zone		
56. Shale, light gray, platy, slightly siliceous	2	6
55. Bentonite		1
54. Shale, as above	2	1
53. Bentonite		½
52. Shale, as above	1	4
51. Bentonite		3
50. Shale, as above	1	5
49. Bentonite		2
48. Shale, as above, with Fe-Mn concretions	2	8
47. Bentonite		¾
46. Shale, as above, no concretions		6
45. Bentonite		½
44. Shale, as above, with layer of large rusty concretions	1	
43. Bentonite		½
42. Shale, as above, no concretions	1	3
41. Bentonite		½
40. Shale, as above		3
39. Bentonite		¼
38. Shale, as above		2½
37. Bentonite		¼
36. Shale, as above	1	4
35. Bentonite		½
34. Shale, as above	2	8
33. Bentonite, micaceous at base (UMB)		1½
32. Shale, as above		4
31. Bentonite		½
30. Shale, as above	2	8
29. Bentonite		½
28. Shale, as above	1	6

		Feet	Inches
27.	Bentonite..........................		3
26.	Shale, as above....................		8
25.	Bentonite..........................		¼
24.	Shale, as above....................	1	10
23.	Bentonite, slightly micaceous (BBB)..		10
22.	Shale, as above....................		1
21.	Bentonite..........................		¾
20.	Shale, as above....................		5
19.	Bentonite..........................		¾
18.	Shale, as above, Inoceramus zone at base	2	5
17.	Bentonite..........................		½
16.	Shale, light gray, slightly siliceous	4	6
15.	Bentonite..........................		¼
14.	Shale, as above....................	1	
13.	Bentonite..........................		½
12.	Shale, as above, platy.............	1	9
11.	Bentonite..........................		½
10.	Shale, as above....................	4	2
9.	Bentonite..........................		1½
8.	Shale, light gray, slightly siliceous, with some small manganese concretions		8
7.	Bentonite..........................		3
6.	Shale, as above....................	3	4
5.	Bentonite..........................		¾
4.	Shale, as above....................		4
3.	Bentonite..........................		1
2.	Shale, as above....................		8
1.	Bentonite, micaceous (LMB).........		3
	Total Oacoma	46	8½

Agency zone

Shale, light gray, slightly siliceous; outcrop stained brown. Few scattered bentonites in lower part of section.

A thin, one-half to two inch bentonite carrying biotite flakes is frequently observed immediately beneath the zone of rusty concretions, and has been called the upper micaceous bentonite (UMB).

Along the Cheyenne River, especially where the lower part of the Oacoma zone is not well exposed, a pair of two to four inch bentonite beds, lying a short distance above the rusty concretions, was found to be persistent, and has been named the upper bentonite pair (UBP). Close-lying pairs or triplets of bentonites in other parts of the section were useful over short distances, but could not be followed throughout the area.

In three places, individual bentonite beds were observed to attain a thickness of several feet over an area several yards in diameter. In these lenses the material is not altered to bentonite but is harsh, consolidated, nearly white volcanic ash. Two such occurrences were noted on Mission Creek, and one in Section 17 (?), T. 8 N., R. 29 E. A similar lense has been observed in Potter County. (Gries, page 12)

Black iron-manganese carbonate concretions are characteristic of the entire zone south of Great Bend, but are much less abundant north of that place. In this area, they are occasionally very abundant in the lower 12-15 feet of the zone, but they are by no means typical of it.

A zone of large, white, calcareous concretions is conspicuous in the upper part of the zone throughout much of this region.[1] They are typically less than one foot thick, but may range from a few inches to several feet in diameter. Upon weathering, they break along many parallel vertical cracks, the fresh surfaces of which soon turn rusty colored.

A band of large concretions is occasionally found at a horizon about 5 to 7 feet above the rusty concretion zone. They are characteristically white in the center, but coated with a heavy layer of iron-

1. The structure of the Pierre Gas Field (R.I. 29) was mapped upon this zone of concretions.

manganese carbonate. When unweathered, they resemble the black concretions in the overlying Verendrye beds. These upper concretions are occasionally nearly white, and may be mistaken for the lower, "rusty", concretions when the latter are not developed.

The Oacoma beds stand out prominently wherever they are exposed, because of their light color and the stepped nature of their outcrops. The upper few feet are frequently covered by gumbo from the overlying Verendrye zone. Bones of marine reptiles and fragments of invertebrate fossils are occasionally found on the surface.

In this area, the contact between the Oacoma and the underlying Agency shale is believed to be one of conformity. Despite the variations in the thickness of the zone, the contact with the Verendrye is also thought to be conformable. Variations in thickness are due to differences in rate of deposition, as shown by the fact that the intervals between recognizable bentonites is greater in the thicker sections. The Oacoma is consequently regarded as a transition zone between the more or less siliceous Agency and the non-siliceous Verendrye zones.

<u>Verendrye zone</u>: The uppermost subdivision of the Sully member has been called the Verendrye zone by Searight (page 25) from exposures near the Verendrye monument at Ft. Pierre, immediately south of the area covered by this report. It includes the beds between the top of the Oacoma zone, and the base of the bentonitic lower Virgin Creek member.

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

The Verendrye beds consist of light to medium dark gray shale which contains large, flat, iron-manganese carbonate concretions in more or less well defined layers or zones. The concretions may reach a diameter of several feet, but are usually six inches or less in thickness. They are typically gray or

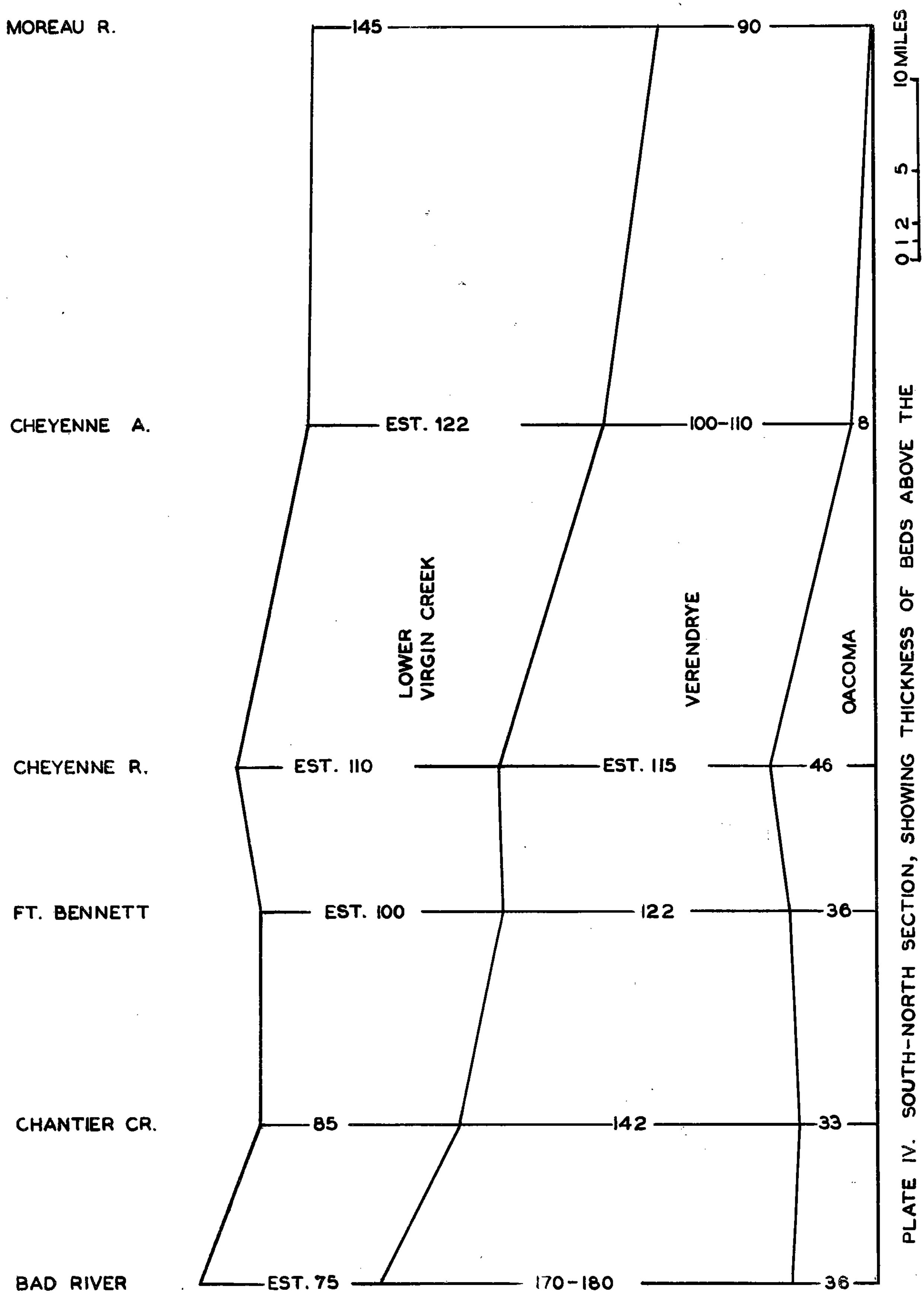


PLATE IV. SOUTH-NORTH SECTION, SHOWING THICKNESS OF BEDS ABOVE THE TOP OF THE AGENCY SHALE.

greenish gray on the interior, but weather to a purplish black on the surface.

The shale weathers first to chips of yellowish gray color, and then to brownish gray gumbo. A weathered slope, therefore, seldom shows shale flakes, but rather, a checked, gumbo surface distinct from the flaky exposures of the Agency and Oacoma beds. Outcrops may show some stepping, though less pronounced and on larger scale than that in the Oacoma. Distinct bentonite beds are rarely noticed in the Verendrye zone, although many may be found by digging. Judging from the tendency to weather to gumbo, it is likely that the formation also contains much disseminated bentonite.

The beds in this zone have a pronounced tendency to slump, so that the overlying Virgin Creek beds are commonly let down, making it difficult to determine the true thickness of the Verendrye. The contact between this zone and the Virgin Creek is not typically well exposed. It lies somewhere in the few feet between the highest iron stone 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 between the grayish brown bentonitic shale of the lower zone and the blue-gray flaky shale of the upper. For field purposes, the contact is placed at the base of the lowest visible bentonite in the lower Virgin Creek.

Careful measurements on the least slumped outcrops indicate that the zone thickens gradually to the south and perhaps to the west. In Dewey County a maximum of between 100 and 110 feet was recorded. Searight gives 110 feet for Sully County opposite old Ft. Bennett, but a section in Stanley County 2 miles south of Ft. Bennett shows 122 feet. Near the southern edge of the area mapped, 142 feet was measured. (See page 25) Searight reports 170-180 feet at the type locality in Ft. Pierre, and over 200 feet at Wendt, on Bad River, about twenty miles southwest of Ft. Pierre. Less reliable measurements in tributaries west of the Missouri in this area also suggest thickening toward the west.

Virgin Creek Member

The Virgin Creek member was named by Searight (page 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, it forms the upper parts of the breaks and the uplands adjacent to them. It is consequently the bedrock formation over much of Stanley County. Because the member lies so high in the breaks, good unslumped outcrops are rare near the river where the present survey was conducted. Details of the local development of the Virgin Creek are based on exposures in and near Chantier Creek, near the southwestern edge of the area mapped.

Lithologically, the member is divided into an upper and a lower division. Because these are readily recognized lithologic units, and because further mapping in the area will require the use of these subdivisions, they are here discussed separately.

Lower Virgin Creek: This zone consists of medium hard, gray shale which weathers to small silvery flakes, and is also characterized by the presence of a large number of thin bentonite beds. In the type area the Lower Virgin Creek is divided into two distinct units, the lower of which contains the abundant bentonites. Between these and the base of the "wormeaten" zone which marks the upper Virgin Creek, is a zone of gray shale containing but a few thin bentonites. This division does not appear to be a natural one, and the two zones have not been distinguished in this area.

Although a wide assortment of concretions are characteristic of the lower Virgin Creek in Dewey County, few concretions of any sort are present in this area. Iron-manganese carbonate concretions similar to those in the Verendrye are distributed sparingly. Very few of the small, white, "oolitic" concretions typical of the lower zone farther north have been noted locally.

A light colored siliceous phase of the lower Virgin Creek, present in northern Dewey County (Gries, page 26) has not been observed in Stanley County.

The lower Virgin Creek beds apparently thin to the southward in the Missouri Valley. In northeastern Dewey County, a total thickness of 145 feet was observed. About 25 miles southeast, in Potter County, 133 feet was measured. In this area $85\frac{1}{2}$ feet are present, and Searight reports 74 feet at Wendt, in the southern part of Stanley County. The same beds appear to be about 26 feet thick in Charles Mix County.

TABLE V

Succession of beds, Pierre shale, exposed in Missouri River breaks, a short distance south of the mouth of Chantier Creek, Stanley County, South Dakota.
Detailed section
NE$\frac{1}{4}$, Sec. 27, T. 6 N., R 29 E.

Upper Virgin Creek	Feet
9. Shale, gray, chalky, weathers yellow (Mobridge?). Contains Belemnitella. Base marked by a layer of small, ironstained concretions and baculites. To top of hill..........	71
8. Shale, gray, calcareous; contains "crab" zone and some white limestone concretions....................	38
7. Shale, gray, non-calcareous, contains several bentonites............	13
6. Shale, gray, non-calcareous; zone of large white concretions at base, one at top and one between; some bentonite......................	23

	Feet
5. Shale, gray, non-calcareous, weathers to gumbo; contains worm-eaten concretions and serpula. Some bentonites in upper part....................	68
	213
Lower Virgin Creek	
4. Shale, gray, flaky, weathers to silvery sheen. Many bentonites, especially at base....................	85½
Verendrye zone	
3. Shale, gray, non-siliceous, bentonitic. Weathers to yellow-gray flakes, then to gumbo. Iron-manganese concretions abundant............................	142
Oacoma zone	
2. Shale, banded, with many bentonites....	32
Agency zone	
1. Shale, slightly siliceous, light gray; to river level........................	

Upper Virgin Creek: Only the lower beds of this member are consistently present close to the breaks, and they are usually weathered down to gentle or grassed-over slopes. In the higher parts of the area the entire thickness of the member is apparently represented, although as pointed out below, the upper limits of the zone are somewhat difficult to determine.

The upper Virgin Creek member is composed of gray shale which weathers to gumbo. Thin bentonite beds are abundant. The lowest beds are characterized by two types of small, diagnostic concretions. One consists of small, gray or brown concretions which weather nearly white on the surface, and are perforated with many small holes. Russell (pages 3 and 4) noticed the "wormeaten" appearance of these concretions in Potter County, and designated the zone as "bed WE". A second type includes small cylindrical concretions, grayish or buff in color, with a soft core which wears out, leaving hollow cylinders often termed "Indian Beads". These have doubtfully been identified as worm tubes (Serpula(?) walacensas Elias) but their relation to some type of plant seems more likely. At a somewhat higher horizon, small, bluish-gray limestone concretions containing the fossil remains of crabs are occasionally found. Of the three types, the latter are the most spotty in their distribution, due, no doubt, to the gregareous nature of the crabs.

Zones of large, white or buff limestone concretions also characterize the upper Virgin Creek member. About 70 feet above the base in this area, is a zone averaging 23 feet thick, which contains three distinct bands of these concretions. These are frequently septarian, their cracks filled with yellow calcite. Scattered limestone concretions may occur also above this persistent zone. Very highly fossiliferous concretions of this type, containing the Sage Creek fauna, are found around the Black Hills and in parts of North Dakota and Montana, and as far east as Midland, South Dakota.

Buff shale beds, separated from the underlying gray shale by a sharp line of demarcation, are conspicuous on some of the bare knolls close to the breaks. Because of their resemblance to the Mobridge beds described by Searight, they were carefully examined. At the base is a persistent bed of small (1"-3") rusty looking concretions which are, in nearly all cases, casts of segments of baculites. Tests with acid reveal that not only were the buff beds calcareous, but that up to forty feet of the underlying gray shale was more or less calcareous, also.[1] (See horizon 8, Table V, page 31) Because the buff beds contained such fossils as Belemnitella, and were evident only on isolated and well weathered points, it was concluded that they may be only a weathering phase of the Upper Virgin Creek.

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1. A calcareous zone previously observed in the upper Virgin Creek in part of Stanley County (Moxon, Olson, Searight, pages 27, 47) is said to be 10 feet thick, and to lie about 30 feet above the base of the zone. The base of the calcareous zone under consideration lies roughly 100 feet above the top of the lower Virgin Creek, and extends upward continuously for over 100 feet.

It is quite possible, however, that these upper beds belong to the overlying Mobridge member. If the Mobridge must be distinguished from the upper Virgin Creek primarily by its calcareous nature, the contact in this case can be determined only by acid tests, for the shale above and below the dividing line appears identical as to lithology, color and weathering. If the zone of small concretions be taken as the contact, the calcareous or non-calcareous criterion must be abandoned, as must the change from gray to yellow weathering beds, for the beds above the zone weather yellow only upon extended weathering. A possible criterion, judging from limited observations, is that the beds below the zone of rusty concretions weather to gumbo, those above may not. Pending further study, this entire section is classified as upper Virgin Creek.

No figures for the complete thickness of the upper Virgin Creek are available. Searight (page 43) estimates it at the type locality to be between 100 and 140 feet. In this area, 213 feet have been measured in one exposure where the top is missing by erosion. Should the upper 71 feet of buff beds be assigned to the Mobridge member, 142 feet would still remain as undoubted upper Virgin Creek.

Mobridge Member

This member of the Pierre shale was named by Searight (page 44) from beds exposed in Walworth and Corson counties, near the town of Mobridge. As originally defined, the member includes beds of chalk, chalky shale, sandy shale, and perhaps some sandstone beds lying between the Virgin Creek and the Elk Butte members. It is said to extend northward into North Dakota, southward into Nebraska, and westward under the Great Plains.

Recently, Searight has suggested that his Mobridge may be correlated with the Interior beds described by Ward[1] from near Interior, Jackson County,

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1. Ward, Freeman, The Geology of a Portion of the Badlands, S. D. Geol. and Nat. Hist. Survey, Bulletin 11, pp. 17-18, 1922.

and that the name Interior should take precedence over the term Mobridge (Moxon, Olson, Searight, page 23). Because of the possibility that the Interior beds are the result of weathering of an old surface of Pierre shale before the deposition of the "Badlands" beds, rather than a primary sedimentary phase of the Pierre[2], the complete equivalence of all the Interior beds to the Mobridge member appears to the writer to be in doubt. The term Mobridge is therefore retained in this paper, and used as originally defined.

Searight (following page 43) shows the Mobridge member as the bedrock over a large area in north central Stanley County. As these beds lie at a considerable distance above the main drainage, they were not studied during this survey except as noted in the discussion of the upper Virgin Creek member. West of the Missouri, the Mobridge beds are said to become more sandy, and to weather to a characteristic buff color. Because it reaches thicknesses locally of 200 to 300 feet, considerable detailed study of the member will be necessary before concretionary or sandy zones within it can be used for structural mapping purposes.

Elk Butte Member

The Elk Butte member was named by Searight (page 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 to the west, and may either pinch out or grade laterally into sandstone. It lies too high stratigraphically to be found in northeastern Stanley County.

GLACIAL AND POST-GLACIAL DEPOSITS

These unconsolidated surficial deposits, lying primarily on the east side of the Missouri River, are the result of deposition during the Pleistocene

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1. Wanless, Harold R., Lithology of the White River Sediments, Proc. Amer. Philos. Soc., Vol. lxi, no. 3, 1922, pp. 184-269; especially pp. 194-202.

or ice age, and the Recent, or post-glacial periods. Although an early advance of the great continental ice sheet is believed to have covered part, if not all of the area under consideration, deposits made by it have been largely removed by subsequent erosion. A later advance of the ice covered the region east of the present Missouri River with a heavy mantle of glacial till which has been little eroded except close to the river and along the major tributaries.

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

IV. STRUCTURE

GENERAL STRUCTURE

The dominant structural feature of west central South Dakota, as determined on the top of the Dakota sandstone, is the broad, northwest plunging Lemmon syncline. (See Plate V) The axis of this broad trough, which lies between the Black Hills uplift and the crystalline area in the eastern part of the state, runs nearly north-northwest through Kadoka, Philip and Lemmon. The area covered by this report lies well up on the east flank of the syncline, at the edge of a broad structural terrace. The regional dip of the Dakota sandstone under northeastern Stanley County is northwest, about two feet to the mile, but this increases to about 10-12 feet per mile a short distance west of this area.

The top of the Agency shale, the lowest horizon which can be determined from outcrops, appears to lie at about the same elevation throughout the area, if local structures are not considered, but it shows a definite northwest dip in the northwestern corner of the area. The point at which the dip increases corresponds with the apparent edge of the terrace in the Dakota sandstone. The fact that the Agency dips less than the Dakota is explained by a known thickening toward the Black Hills of the intervening Graneros, Greenhorn, Carlile, and Niobrara formations. (See Plate II)

A few measurements on a persistent concretion zone in the upper Virgin Creek member suggests that in the eastern edge of the area, at least, there is a slight eastern dip at these upper beds. This would indicate a slight westward thickening of the combined Oacoma, Verendrye, and lower Virgin Creek beds. Further intervals and elevations should be measured in the western part of the county to check this point.

There is also evidence that the formations between the Dakota and the top of the Agency zone thicken to the north. The Dakota sandstone lies about 160 feet lower at Cheyenne Agency than it does at Pierre, but the top of the Agency zone lies 90 to 100 feet higher at the Agency than at Pierre. This difference of about 250 feet is the equivalent of an increase in interval of about 6 feet per mile to the north. Whether this increase is in the beds between the Dakota and the Pierre shale, or in the lower members of the Pierre is not known. The former condition appears more likely.

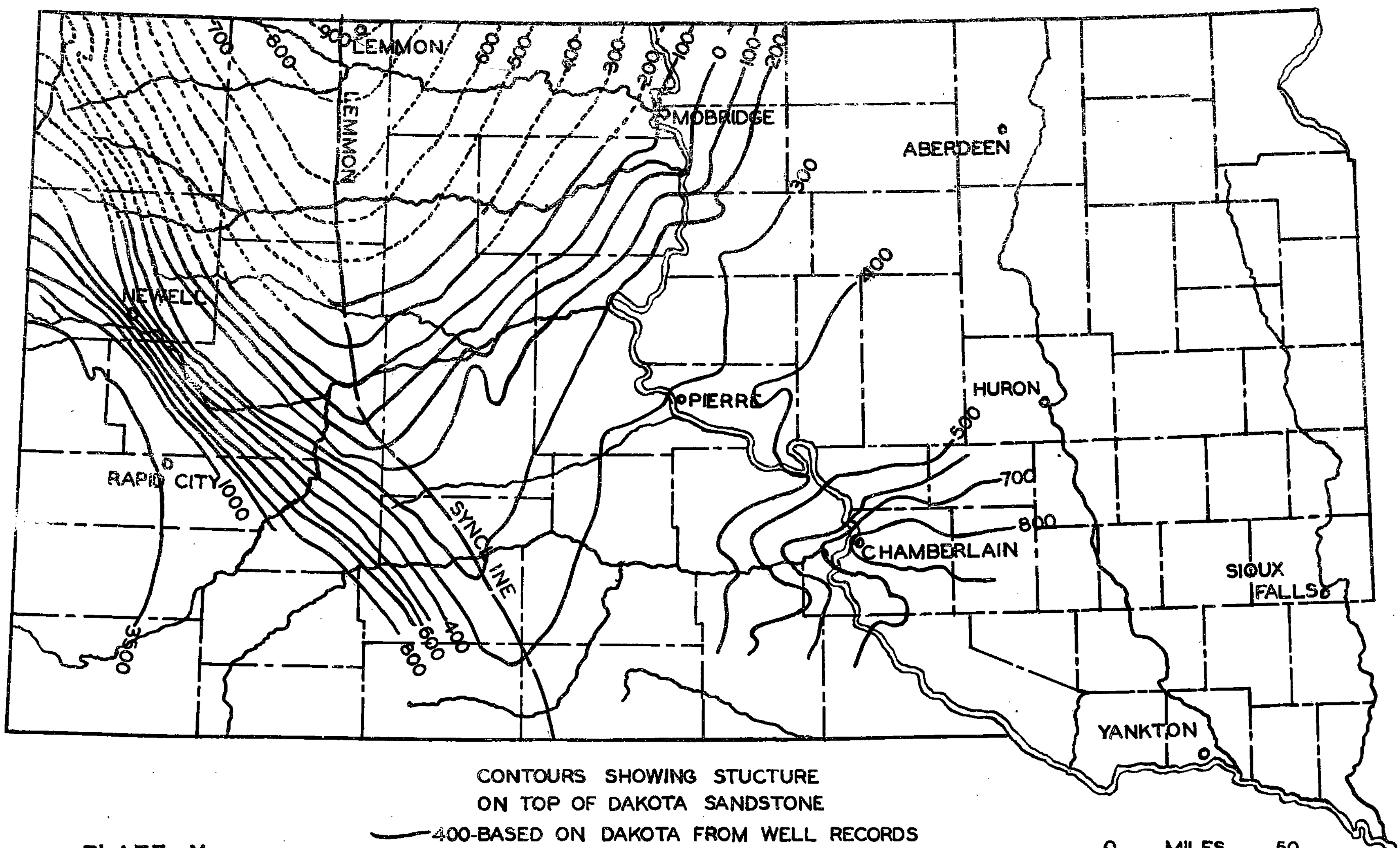
Absence of detailed information as to the variation in thickness of the rocks lying between the Dakota sandstone and a lower key horizon such as the Mississippian limestone, makes it possible that the structure of the deeper formations is somewhat different from that on the Dakota sandstone. Comparison of the logs of the Hunter #1 (Gypsy) and Standing Butte wells suggests only a slight thickening of these lower formations toward the west. (See Plate II) Evidence outside the area indicates that they may also thicken somewhat to the northwest. Any thickening of these beds to the north or west would serve to accentuate the steepness of the east flank of the syncline and reduce the dip on the west flank. Any steepening of the dip with depth is of utmost importance in interpreting the significance of the structures observed in the surface rocks.

DETAILED LOCAL STRUCTURE

The detailed structure of this area is shown on the accompanying map, contoured on the base of the Oacoma bentonite zone. The micaceous bentonite which served as the key horizon was chosen because it is the lowest easily recognized bed in the area. By its choice, the effect of variations in thickness of the overlying beds is eliminated, and because of its position low in the breaks, it is less prone to slumping than are the higher horizons.

Due to the linear nature of the outcrops, contouring has been possible only close to the Missouri and Cheyenne rivers. Elevations and trends of the minor structural features are thus shown, but it has not been possible to close the structures in many cases. Elevations on the base of the Oacoma range from less

STRUCTURE OF WESTERN SOUTH DAKOTA



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

PLATE V

than 1500 feet in the southeastern corner of the area to over 1590 feet just southwest of the mouth of the Cheyenne. Over much of the area the elevation ranges between 1550 and 1575 feet. The former figures compare with a range between 1520 and 1560 feet for a comparable horizon[1] in the region south of Pierre, and adjoining this area in the southeast. Following the practice adopted in previous reports, the contour interval used is 10 feet. This serves to outline the important structures, but is large enough to iron out minor variations in elevation of the key bed.

Because of the strong topographical relief developed along the Missouri and Cheyenne rivers, there has been considerable slumping of the Pierre shale. The slumps are usually easily recognized because of their characteristic "slump" topography, and the lack of covering vegetation in the area; and the greatest care has been taken to obtain elevations on unslumped outcrops. The degree of success in selecting exposures may be judged from the concordance of elevations on both sides of the rivers, and from the uniform trend of the structures mapped.

Considering the very low regional dip in this area, the trend of the local structural features is surprisingly uniform. The northwest-southeast trend of these features is at right angles to the regional strike, and roughly parallel to the axis of the Lemmon syncline. Because these lie oblique to the rivers, the contour lines cross and recross the major valleys in a series of troughs and noses. Absence of data on either side of the breaks makes it difficult to determine the pitch of these folds in many instances.

Although all the structures outlined are low, the most conspicuous feature is the broad band of partly outlined high areas extending northwest-southeast across the region from north of the Camp Creek Buttes, south of Fort Bennett, and on through the southeast corner of Township 7 North, Range 29 East. Elevations in this belt are consistently above 1570, and reach

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1. As has been previously mentioned, the Pierre Gas Field was mapped on a concretion zone about 20 feet above the Lower Micaceous bed which was used as the key horizon in this area.

nearly to 1600 feet in the upper part of Brush Creek. The highest elevations found anywhere in the area lie a short distance south and west of the mouth of the Cheyenne. Considerable displacement of beds was noticed in the upper ends of both Mission and Brush Creeks, but whether this is due to slumping or minor faulting was not determined. The displacement is small in either case, and undoubtedly dies out with depth.

The high area located in the bend of the river in the southeastern part of Township 7 North, Range 29 East is better defined, but not as high as areas to the north and west. This may not close on the west side of the river as indicated, but may be part of a larger area lying partly east of the river in the extreme southwestern corner of Sully County.

The elevations at the extreme northern edge of the area mapped suggest that another high area may lie immediately to the north of this region. On the other hand, the elevation on the top of the Agency shale in the extreme northeast corner of Armstrong County, as determined during the survey in Dewey and Potter counties, is in the neighborhood of 1520 feet.

The pronounced syncline at the southeastern corner of the area, south and west of Oahe Mission, is due in part to structure, and in part to slumping. Measurement up from the big bentonites in the Agency to the base of the Oacoma zone suggest that up to 30 feet of slumping may have occurred in that general area. Although elevations as low as 1470 were recorded on the base of Oacoma south of the Mission and at the mouth of Chantier Creek, nothing less than 1500 has been contoured on the accompanying map.

Another feature which may be of considerable importance in this area is an apparent reversal of regional dip in the surface rocks. The fact that the highest elevations are encountered in the north central part of the area, and the lowest along the southeastern edge is supported by the fact that the average structural elevation determined in northeastern Stanley County is perhaps 30 feet higher than that in the area south of Pierre. The rapid drop-off in elevation of the key horizon in the northwestern corner of the area would suggest that the line of reversal of dip may lie within this area. It would, however, be necessary to carry the survey farther west on a higher key bed to determine this more certainly. Whether this reversal is present as deep as the Dakota sandstone is not known, but a study of the none too accurate logs of the deep wells in this region suggests that local reversals may be found in the Dakota.

There has not been sufficient careful mapping combined with drilling in the northern Great Plains states to enable definite conclusions to be drawn as to the possible changes in these structures with depth. The two most likely possibilities are either that they retain about their same magnitude with depth, or that they increase in sharpness below, and become flattened in the soft Cretaceous shales. It is not likely that they die out with depth.

If they retain the same magnitude, any increase in regional dip at the horizon of the Dakota is important. An increase in dip of even 10 feet to the mile would tilt the smaller structures so that they would lose their closure and appear only as noses. On the terrace included in this area, this is of no particular importance, but the northwest regional dip of the Dakota is believed to increase sharply just west of this area. If, on the other hand, as is quite common in areas overlain by thick shales, the structures increase in intensity with depth, the closure in the lower beds may be several times as great as it appears on the surface. Only test drilling in a carefully mapped area will give the final answer.

V. GAS AND OIL POSSIBILITIES

GAS

The Central South Dakota gas field, as determined by the location of artesian wells yielding natural gas, lies along the Missouri River, and comprises parts of Lyman, Jones, Stanley, Hughes, Sully, Armstrong, Potter, Dewey, and Walworth counties. The area under consideration lies near the southwestern corner of the field.

Although relatively few artesian wells have been drilled in northeastern Stanley County, nearly all of them produce gas. One of these wells is located at Old Lacy, in the valley of Chantier Creek, about seven miles above its junction with the Missouri. It is the only well whose gas has been utilized (see page 2). Gas, and a reported oil show from the Dakota sandstone in the Ike Geyer well, about 10 miles northwest of Old Lacy, is said to have inspired the drilling of the Standing Butte test well. A recently drilled well in the Missouri river bottoms in extreme southwestern Sully County is also producing considerable gas.

During drilling operations, gas is frequently encountered in the formations lying between the Pierre shale and the Dakota sandstone, but wells which are cased to the Dakota continue to give off gas. In the Standing Butte test, gas was also reported from several horizons in the Minnelusa formation.

The source of this gas has not definitely been established. If it is shale gas, as has generally been supposed[1], it is disseminated through the shale and small quantities should be yielded almost indefinitely. The finding of gas in sandy or limy zones in the shale during drilling has led to this belief, although this does not preclude the idea that all the gas has come up from a deeper source and has been trapped in such porous zones.

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1. For a more detailed discussion of the possible sources of this gas, see Roy A. Wilson, The Possibilities of Oil in South Dakota, Bull. S. D. Geol. and Nat. Hist. Survey, 1922, pp. 83-86.

The fact that in some instances gas has not been noticed until the newly drilled well starts flowing has suggested that the gas may be chiefly in the sandstone, and that it is only brought to the foot of the well by the movement of the water in that direction. Reports from other parts of the field that gas is no longer noticed in some wells that have ceased to flow have supported this theory. If this is correct, it offers another strong argument for control of flowing wells; that is, to conserve the gas as well as the water supply.

The fact that the field is located on the large structural terrace referred to, and that even within that area the gas-producing wells are more or less closely grouped, has suggested a third hypothesis, namely that the accumulation of gas may be due at least in part to structural control. Whichever theory is correct for the gas encountered in or above the Dakota sandstone, it is nevertheless true that the most favorable areas for development of deeper supplies are on the structurally high areas superimposed on this terrace.

Natural gas is said to be either wet or dry. Wet gas is that normally associated with oil, and contains some of the more volatile constituents of the oil. Gas not associated directly with oil does not contain these elements, and is said to be dry. Gas from the Pierre field is of the latter type, so that it does not necessarily indicate the presence of oil in the area.

Analyses of gas from the central South Dakota field show it to be largely methane, but with a somewhat larger percentage of ethane and propane than is usually found in dry gas. The following analyses are typical.

City Gas, Pierre, South Dakota
Sampled June 12, 1939
Low temperature fractional analysis

Air	10.62%
Carbon dioxide	.74%

Fractional analysis on air and carbon dioxide free basis:

	Gas volume per cent	G.P.M.
Methane	74.8	
Ethane	13.2	
Propane	10.7	2.62
Iso-Butane	.4	.13
N-Butane	.9	.25
	100.0	3.00

Gas from artesian well at Old Lacy
NW¼, Sec. 35, T. 7 N., R. 28 E., Stanley County
Analysis by U.S. Bureau of Mines

Carbon dioxide	3.1%
Oxygen	0.6
Methane	88.7
Ethane	0.0
Nitrogen and helium by difference	7.6
Total	100.0
Helium content	0.04%

It appears likely that sufficient gas for domestic use may be secured from wells drilled anywhere in this area, and that larger quantities might be encountered by drilling on any of the structural highs, as indicated on the accompanying structure map. The possibilities of gas, possibly associated with oil in deeper rocks depends upon the factors discussed in the following paragraphs.

OIL

In determining the oil and gas possibilities of any area, it is necessary to consider four questions. First, are the source rocks present from which oil or gas could be derived; secondly, are suitable reservoir rocks available to receive these products; third, are structures present which would collect them in small areas within the reservoir rocks; and fourth, have the reservoir rocks been flushed out by circulating artesian water.

It is generally believed that oil originates in marine sediments containing bituminous material. Black shales are probably the most common source rocks, but frequently sandstone or limestone may carry much disseminated bituminous material. Wilson[1] and Russell (page 10) have suggested that the thin black shales in the Pennsylvanian and Permian rocks of this region might serve as source rocks.

There are several possible reservoir rocks in the local geologic section. It is possible that gas or even oil may be trapped in some of the structures in the Dakota group, but these formations have been so thoroughly drilled for water in this general region, that the chance of their containing any material amount of oil seems remote. The next possible oil reservoir is in the sands of the Sundance formation.

The most promising reservoir rocks in the state belong to the upper Paleozoic system. The Minnelusa formation contains thin sands in this region. As these are likely to be more or less discontinuous, the formation offers more promise than it does farther west where the thick sandstone offers opportunity for more complete artesian circulation. The underlying Pahasapa limestone, which is over 500 feet thick in this area, should be thoroughly tested on a local structure. Although it is the oldest Paleozoic formation of which we have record in the central part of the state, it seems possible the older limestones may be present. Any test should be planned to continue into the Cambrian beds unless pre-Cambrian rocks are encountered immediately below the Mississippian limestone. The total thickness of sediments to be tested is estimated at between 3600 and 4200 feet. (Plate I)

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1. Wilson, Roy A., The Possibilities of Oil in South Dakota, S.D. Geol. and Nat. Hist. Survey, Bull. 10, 1922, page 52.

The structures which have been mapped on the top of the Agency shale appear to have closures as great as 20 or 30 feet, but whether this continues with depth is not known. It has already been suggested (page 38) that because of the increased dip at the elevation of the Dakota sandstone, these high areas may appear at that horizon only as small noses or terraces on the flank of the broad Lemmon syncline. On the other hand, it is possible that the structures are sharper at greater depths, and flatten out somewhat in the thick Cretaceous shales. In either event, they appear to be the most favorable locations for gas and oil accumulation within the area under consideration, and therefore offer the best locations for test wells.

Water associated with oil is always highly mineralized. In areas where the circulation of underground water is sufficiently vigorous to flush out the salt water, it is apparently also capable of either flushing out the oil or preventing its accumulation. For this reason, the exact nature of the sands in the Dakota group is significant. If the Dakota and the Lakota are always two separate and continuous sandstones underlying much of the state, they should be well flushed out by circulating ground water entering them at their outcrops around the Black Hills and beneath the glacial drift in the eastern part of the state. But as previously mentioned, study of records of many artesian wells has suggested that the sands in this group may be lenticular in nature, so that circulation is restricted, and perhaps nearly negligible in some zones and areas. The mineralized nature of the water from many of the wells also suggests that the flushing process is very slow and certainly not complete. The following analysis from the Lacy well is typical of the artesian water in this area.

Water Analysis of Old Lacy Well
NW¼, Sec.35, T.7 N., R.28 E., Stanley County
State Chemical Laboratory, Vermillion
Guy G. Frary, State Chemist

	P.P.M.	G.P.G.
Total solids	5094.0	297.0
Silica	16.0	0.93
Sulphate	3.0	0.18
Chloride	2530.0	147.5
Calcium	32.0	1.87
Magnesium	20.0	1.17
Alkalinity as $CaCO_3$		
Phenolphthalein	None	
Methyl Orange	890.0	51.90
Hardness as $CaCO_3$	164.0	9.56
Iron	0.2	
Fluoride	0.4	

Water under artesian head is encountered in the Sundance sands farther west, and even in the Standing Butte well, two water sands, one with "great water flow", were noted. The Sundance formation is so variable in nature that the oil possibilities of the formation should not be ruled out because of the above report.

The Minnelusa is an important water sand in the vicinity of the Black Hills. As the formation becomes much more shaly and limy to the east, however, it seems to carry much less water. In the Standing Butte well, water was reported from near the base of the formation. Although no report was made of the fact, it seems likely that the water was highly mineralized.

This same well had no report of water from the Pahasapa limestone. At the outcrop, this formation is very cavernous, and an important aquifer, but the extent to which this is true under the plains is not definitely established. The Hunter No. 1 (Gypsy) well north of Wall, Pennington County, reported fresh water from two "porous zones" in the upper 200 feet of the formation, but that well is within 55 miles of the outcrop of the Pahasapa. Circulation of water through solution channels would not be as likely to prevent or remove oil accumulation as the uniform circulation through a porous sandstone. It is not believed likely that artesian water will be encountered in the Pahasapa in this area.

The possibility of finding strong artesian flow in any of the formations underlying the Pahasapa appears to be remote.

Discussion of oil shows in the various wells in the region can be nothing more than a reiteration of reports, some verified, others more or less doubtful. The Dakota is frequently reported as carrying some gas, and unverified reports are at hand of oil appearing periodically in some of the artesian farm wells scattered throughout the gas field. The Standing Butte well also reported an oil show at this horizon.

Oil shows are reported at the top of the Minnekahta, and both gas and tar in the Minnelusa formation in the Standing Butte well.

VI. CONSIDERATIONS FOR DRILLING

FAVORABLE AREAS

The most favorable locations for test drilling in the area covered by this survey lie along the low northwest trending structure previously described. On the evidence at hand, this appears to consist of a series of small irregular domes superimposed on a gentle anticline.

The high elevations encountered in Mission and Brush creeks suggest that a large high, possibly several miles across, may lie in the north central part of the area. Because the structure could not be closed with the data obtained, it is not possible to point out any location as being superior to others. It seems doubtful if such a high area would have a closure of over 20 or 30 feet. It is possible that this structure could be outlined more definitely by use of a key bed in the Virgin Creek member, although the tendency of those beds to slump might render the task difficult and the results of doubtful value.

The high points present two to five miles south of old Fort Bennett lie on the low anticline, but because outcrops were available on only one side of the river, the structure could not be outlined. It seems quite probable that a high is located just east of the river, in the southwest half of Lewellyn Park township (T. 113 N., R. 81 N.), Sully County.

The structure outlined in T. 7 N., R. 29 E. may also be part of a larger area, for it is not definitely closed on the west and north. Low elevations to the northeast and southwest show the anticline to be narrow and well defined at this point.

Elevations above 1570 were found at the extreme north edge of the area, but further work around the Little Bend would be necessary to define the high area indicated.

DEPTH

The necessary depth for a test hole at any specific point will obviously be dependent upon the surface elevation at the chosen location, and the structure and thickness of the bedrock formations. The elevation of the top of the Agency shale varies roughly from 1470 to 1600 feet within the area. Of considerable importance in estimating the depth to a given formation is the surface relief, which in this area varies about 650 feet. Since the present topography is only slightly influenced by the underground structure in this region, there is no geological advantage in locating a test on high ground, and several hundred feet of drilling may easily be saved by locating a test hole on low ground. In some parts of the area, a higher elevation may be sufficiently more accessible to justify drilling the additional footage.

By using the table of estimated thicknesses for this area (Plate I), it may be seen that a well started in the river bottoms, considerably below the top of the Agency shale zone, and encountering only a minimum of perhaps 250 feet of the Dakota group, might be expected to strike the top of the Pahasapa limestone at about 2600 feet.

At the other extreme, a test hole on the upland starting in the upper Virgin Creek member and encountering a maximum of 400 feet of Dakota-Fuson-Lakota beds, would probably enter the top of the Pahasapa at somewhat over 3200 feet. Allowing at least 500 feet for the thickness of the Pahasapa limestone, and another 500 feet for any earlier Paleozoic formations which might be encountered, the total thickness of formations to be tested in this area is probably between 3600 and 4200 feet. Anyone planning test drilling should therefore be prepared to drill to at least the maximum figure, and should start with a large enough hole to drill to that depth after the necessary casing and liners have been set.

TRANSPORTATION AND COMMUNICATION

Stanley County is served by the Chicago and Northwestern Railroad, which crosses the Missouri River at Fort Pierre, and continues southwest down the valley of Bad River to Philip, and thence to Rapid City. The closest rail shipping point, therefore, is Fort Pierre, which lies somewhat southeast of the area under consideration.

U. S. Highway 14 continues west from Fort Pierre, and passes just below the southern edge of the area mapped. This through route across the state is all improved, either gravel or blacktop. A graded and drained road, part gravel and part dirt, leaves route 14 about nine miles west of Fort Pierre, and cuts northwest across the southwestern edge of the area, toward Lacy, Sansarc, and the Carlin bridge across the Cheyenne River. The rest of the area is served by an abundance of partly graded dirt roads and trails branching off the Sansarc road. Trails leading down into the river bottoms are few, and many of the river flats are accessible only by foot.

There are no telephone or power lines in the northeastern part of Stanley County. The area is served by R.F.D. three times a week.

Although many trails lead north to the Cheyenne River, there is no bridge across that stream in Stanley County, and it can seldom be forded by a car even in times of lowest water. North of the Cheyenne in Armstrong County few trails are found.

East of the Missouri River in Sully and Hughes counties, all-weather roads approach to within a few miles of the river at many points. Dirt roads and trails reach nearly all parts of the river bottoms.

WATER

Water will likely be needed for drilling until the Dakota sandstone is encountered. Water from this formation will flow unless the well is located on the higher parts of the upland. There is a possibility that some water may be encountered in joints in the Agency shale. In any case, the Agency may "take" considerable water during drilling operations.

Water for drilling can be secured from either the Missouri or Cheyenne rivers, or possibly from one of the flowing wells in the area. It could also be impounded in advance in many of the normally dry tributary creeks. Some of the larger of these, such as Chantier, Mission or Brush creeks, carry flash floods after heavy rains which might wash out temporary dams built in their lower ends.

Dug wells or sandpoints driven in many places in the Missouri or Cheyenne bottoms will furnish large quantities of potable water. Dug wells on the upland seldom collect much water, and it is usually highly alkaline.

APPENDIX

A. Well Records

STANDING BUTTE WELL[1]

Location: NW$\frac{1}{4}$, Sec. 9, T. 7 N., R. 27 E., 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, shall	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

1. (p. vii)

	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, conglomerage 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

PIERRE CITY WELL NO. 3

Location: T. 110 N., R. 79 W., Hughes County, South Dakota
Drilled: Lewis Greenough, 1910
Source: E. C. Perisho, 1910
Elevation: 1441

	Thickness	Depth
Pierre and alluvium		
"Soft material, sand, mud, boulder clay, etc.	300	300
Niobrara, Carlile, Greenhorn (?)		
"Upper shale"	50	350
"Pierre" shale; rubber-like substance which looked like asphaltum, burned with black smoke; odor like asphaltum-25 feet, water greasy	300	650
Graneros		
"Benton" shale	310	960
Dakota-Fuson-Lakota		
"Dakota" sandstone; first flow	320	1280
Soft sandstone; main flow, large volume of water	20	1300

PIERRE CITY WELL

Location: NW ¼, SE ¼, Sec. 4, T. 110 N., R. 79 E., Hughes County.
Drilled: Norbeck Company, 1929.
Source: Norbeck Company
Elevation: 1440 (Approx.)

	Thickness	Depth
Alluvium		
Silt, or yellow sandy clay	60	60
Pierre (?)		
Gray shale	150	210
Niobrara, Carlile, Greenhorn (?)		
Dark shale; at 850 feet, a two gallon flow and a little gas	640	850
Graneros		
Dark to gray shale with scattered streaks of sandstone	310	1160
Dakota-Fuson-Lakota		
Sandstone	5	1165
Unrecorded	145	1310
Good sandstone	6	1316
Gray shale and small layers of sandstone.... Perforated from 1159 to 1341 feet	25	1341

STATE CAPITOL WELL

Location: State Capitol Grounds, Pierre, Hughes County, South Dakota
Drilled: 1909-1910, Norbeck Company
Source: Sample drill cuttings on file at S.D. State School of Mines; studied and correlated by J.P. Gries
Elevation: 1474
Remarks: These cuttings are obviously taken at too great an interval to represent all the beds. Contacts between formations are correspondingly inexact, but they do tally fairly well with those selected from the drillers' logs on the preceding page.

	Thickness	Depth
Pierre		
Shale, light brownish-grey, silty, non-calcareous. Contains fragments of iron-manganese concretions and caved surface materials. (Verendrye zone?)	40	40
Shale, very light gray, fine, slightly calcareous	50	90
Shale, very light gray, flaky, slightly calcareous	60	150
Shale, mixtures, very light and medium gray, pyritic, very calcareous	75	225
Shale, similar to above, some yellow pieces, non-calcareous	125	350
Niobrara		
Shale, mixture, light and medium gray, speckled, very calcareous	50	400
Shale, as above	75	475
Carlile		
Shale, medium gray, very slightly calcareous	130	605
Shale, light gray, fine, uniform, non-calcareous	70	675
Shale, medium to light gray, flaky, non-calcareous	75	750
Shale, medium gray, fine, flaky, slightly calcareous	50	800
Shale, same, very slightly calcareous	75	875
Greenhorn and Graneros		
Shale, medium gray, fine, flaky, calcareous	75	950
Shale, as above, speckled, calcareous	100	1050
Shale, mixture light and medium gray, speckled, much silt and fine sand, calcareous	50	1100
Shale, as above, more sand, calcareous	50	1150
Shale, as above, still more sand, calcareous	50	1200

HUNTER #1 (GYPSY) WELL

Location: NE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 28, T. 3 N., R. 16 E., Pennington County.
Drilled: Gypsy Oil Company, 1931.
Source: Bull. Amer. Assoc. Petrol. Geol., Vol. 23, No. 8, 1939.
Elevation: 2956.8 (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
<u>Dakota Sandstone</u>		
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
<u>Fuson Shale</u>		
Shales, gray, drab, and maroon, in part sandy....................................	72	3154
<u>Minnewasta Limestone</u>		
Interbedded shales and limestone. Limestones range from brown and sideritic to gray and crystalline...............................	24	3178
<u>Lakota Sandstone</u>		
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	3323
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	3407
Conglomeratic sand, poorly sorted..........	13	3420
<u>Morrison Shale</u>		
Clay shales, red, brown, yellow, green, gray and black................................	40	3460
<u>Unkpapa Sand</u>		
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	3488
Shales, gray to green, sandy; grading down into fine sand with green, pink, white, and brown clay..........................	42	3530
<u>Sundance Series</u>		
Clay and shale, green, glauconitic, sandy..	32	3562
Limestone, gray-brown, dense...............	3	3565
Interbedded green shales, shaly glauconitic siltstones and sand with interstitial green clay..............................	202	3767

	Thickness	Depth
Spearfish Shale		
Sand and siltstone, white to pink, with interbedded red clay and shale..................	69	3836
Shale, red, gypsiferous........................	114	3950
Minnekahta Limestone		
Limestone, light brown, cream-colored, and pink; somewhat porous.......................	30	3980
Opeche Shale		
Shale, red, in part silty; with a few thin beds of anhydrite..........................	102	4082
Pennsylvanian Series		
Limestone, dense, white to pink...............	39	4121
Shale, pink, calcareous.......................	15	4136
Interbedded pink limestones, anhydrites; sands; and red and green shales....................	68	4204
Anhydrite; with interbedded dense brown limestone..................................	16	4220
Shale, red and green..........................	7	4227
Anhydrite, white..............................	13	4240
Sands and shales, red and green, anhydritic...	11	4251
Anhydrite, white..............................	25	4276
Interbedded pink and brown limestones; red sand; and red and green shales..............	39	4315
Limestone, dense, pink, anhydritic............	22	4337
Interbedded red and green shales, clayey sands, and anhydrite..............................	53	4390
Interbedded pink limestone and anhydrite......	15	4405
Shale, red and green, silty...................	10	4415
Limestone, red, and limy fine sand............	9	4424
Interbedded limestones, brown to pink, anhydrite..................................	26	4450
Sand, poorly sorted, calcareous...............	5	4455
Interbedded brown limestone, white anhydrite and thin layers of sandy green shale........	23	4478
Interbedded green shale, gray sand, and thin brown limestones............................	39	4517
Limestone, brown, dense; with chalcedony......	15	4532
Interbedded brown limestone, sand, dark shales, and anhydrite. Some fragments of sand and limestone showed oil stain..................	20	4552
Limestone, brown; with interbedded dark shales. Some limestone fragments showed oil stain...	8	4560
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	4573
Limestone, brown to gray, silty, sandy; with interbedded thin dark shales and rare spots of anhydrite...............................	55	4628
Interbedded clayey sand and siltstone and varigated shales............................	65	4693

	Thickness	Depth
Limestones, dense, white to pink.........	32	4725
Shales, variegated.........................	9	4734
Shales, dark gray, with thin brown crystalline limestones.................	18	4752
Limestone, dense, white, brown and pink, with partings of variegated shale......	60	4812
Interbedded sands and shales. Sands poorly sorted, fine to coarse, hematitic. Shales variegated.......................	18	4830
Mississippian Series		
Limestone, light brown, dense, cherty....	20	4850
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	4859
Limestone, dense, white to light gray, cherty..................................	65	4924
Pre-Mississippian (?) Dolomite		
Dolomite, brown to pinkish, finely crystalline; with porosity between crystals and in small vugs. Seven inch casing was at 4930 feet and fresh water rose 4000 feet in the hole from 4934 feet................................	77	5001
Total depth. Dry and abandoned at		5001

Note: Another correlation of formation thicknesses in this well from study of cuttings is given in Baker, C. L., Report of Investigations No. 57, 1947, South Dakota Geological Survey.

ARTESIAN WELL DATA

Compiled largely from R. I. No. 26, S.D. Geol. Survey

Northeastern Stanley County				
Name	Date	Depth	Elev.	Remarks
Sioux City Stock Yrds. (Ike Geyer) SE ¼, Sec. 17, T. 7 N., R. 27 E.	1918	2000		Flowed when first drilled; gas reported.
Standing Butte Test Well. NW¼, Sec. 10, T. 7 N., R. 27 E.	1926	3508	1958	Flows; both gas and oil show reported.
E. J. Lacy Sec. 35, T. 7 N., R. 28 E.	1918	1500	1711	Flows wild; considerable gas.
W. C. Lewis SE¼, Sec. 20, T. 6 N., R. 29 E.	1910	1760	1888 est.	Flowed two years after drilling.
Mrs. George Huston NW ¼, Sec. 8, T. 5 N., R. 29 E.	1909	1980		Flowed 2 years after drilling.
Rural Credits Board NE ¼, Sec. 10, T. 5 N., R. 29 E.	1908	1489		Flowed 45 GPM when drilled.
Rural Credit Board SE ¼, Sec. 22, T. 5 N., R. 29 E.	1911	1768	1934	Waterlevel 6 feet below surface when drilled.
Northwestern Hughes County				
State of S. Dak. SW¼, Sec. 22 T. 113 N., R. 81 W.	1936		*1576	Flowing; much gas

*Top of casing, 1½" above ground level

APPENDIX

B. HISTORY AND CHRONOLOGY OF GAS PRODUCTION IN PIERRE

The following history has been compiled by Mr. R. B. Hipple, Managing Editor of the Daily Capital Journal, Pierre, from newspaper files, interviews with old residents of Pierre, and the references listed in the footnotes.

Nov. 1889 The city of Pierre granted a franchise to Tams W. Bixby of St. Paul for the sale of gas in Pierre. A producing plant and complete system of mains was installed, and served the city until 1894.

1892-93 The U. S. Indiana Service caused an artesian well to be drilled at the Pierre Indian School, on the eastern edge of the city, which resulted in the discovery of a large flow of natural gas with the artesian water. The gas was never used, but was allowed to burn as an open torch above the well for many years. The well was cemented off in October, 1939, and was still producing a small quantity of gas.

1893 Private adventurers, well drillers from Pennsylvania, drilled a well at the foot of Pierre street to a depth of 1100 feet, without encountering artesian flow or gas. They abandoned the hole, claiming to have encountered "granite."

1894 The Locke Hotel company drilled a well in the rear of their building one block west of the above mentioned well to a depth of about 1300 feet and encountered a strong flow of water and natural gas. The gas was separated and used in cooking, heating, and lighting the hotel. A surplus was piped across the street to the State Publishing Company where it was used to operate an internal combustion engine.

1894 The City of Pierre drilled a well a few feet from the large expansion tank which had been built by Bixby for his producer plant. This well produced water and natural gas in quantity. The city bought out Bixby's franchise, mains, and business as a whole and took over the business. The natural gas was separated in an expansion tank of about 25,000 cubic feet capacity, and then run into Bixby's tank of about 50,000 cubic feet capacity, whence it was generally distributed throughout the city, serving practically every home and business house in the city for cooking, heating and lighting. All streets in the city were lighted by gas lights atop iron posts. One of these posts still stands on the J. E. Hipple residence property. As an incident to the capitol location fight then in progress the citizens tapped a main on the principal street and set an open torch ablaze, which blazed day and night for months. During the next year or two additional wells were drilled in the same general location, all of which added to the gas supply in the expansion chamber. The second well came in with the largest pressure ever noted at Pierre, shooting a solid stream approximately 100 feet in the air.[1] (See picture page 6 Kingsbury).

1898 C. L. Hyde drilled a well in the adjoining block to operate a flour mill. The gas was used to run a thirty-four horsepower internal combustion engine.[1] (See page 55, Kingsbury).

A few years later two additional wells were sunk approximately six blocks west of the gas plant, but neither produced gas in quantity, although both produced artesian water. Both wells were cemented off in 1924.

1910 A well was sunk at the state capitol, about two blocks north of the gas plant, to provide water for an artificial lake. The report of the state engineer[2] for 1915-16 (pages 225-227) says, "This is an 8 inch well. The flow at the time was 5.9 cubic feet of water per second, the equivalent of 2,648 gallons per minute. The pressure is reported to have been about 165 pounds per square inch, although at the present time it has fallen to about 30 pounds. This well yielded about 59 cubic feet of natural gas per minute, equivalent to 84,960 cubic feet per 24 hours. The flow of both water and natural gas has diminished until the latter averages very nearly 15,100 cubic feet per 24 hours."

1928 The city drilled a fifth well near the original location which produced only a small flow of gas.

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1. Kingsbury, George W., History of Dakota Territory, Vol. 3, edited by George Martin Smith, published by S. J. Clarke Company, 1915.
2. Report State Engineer 1915-1916.

1930 The Norbeck company drilled a well for the city about six blocks east of the original plant under an agreement that the company was to receive 75 cents per thousand cubic feet of gas used in the mains for one year. Under this arrangement the company received $10,472, indicating a total production by this well of approximately 14,000,000 cubic feet for the year.[3]

3. Financial Reports, City of Pierre, 1932-1936, particularly City auditor's financial report Jan. 1, 1932.