STATE OF SOUTH DAKOTA
George T. Mickelson, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS
No. 62

STRUCTURES SOUTH OF THE BLACK HILLS

by

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University of South Dakota
Vermillion, South Dakota
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ERRATA

Page	Paragraph	Line	
1	2	11	30° west of south, not 70°.
6	3	1	Coarse grained, not cross grained.
17	2	10	Carbonaceous, not carbonatious.
19	2	4	Trapezoidal, not trapizoidal.
19	2	14	Stratum, not strata.
27	4	9	Dolomite, not dolmite.
28	3	7	Underlie, not underly.
38	2	6	Schmitt, not Schmidt.
39	(Bottom of page)		The following dips were omitted:

NW¼ Sec 28, T 9S, R5E; dip 40°, W.
SE¼ Sec 33, T 9S, R5E; dip 33°, S80°W.
NW¼ Sec 23, T10S, R5E; dip 28°, S65°W.

"Subsurface Cross Sections in Fall River County", (back pocket) altitude on Ordnance well should read 3664, not 3364.

"Structures in Fall River County", (back pocket) "Childer No. 1" should read "Childers No. 1".

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by

E. P. Rothrock

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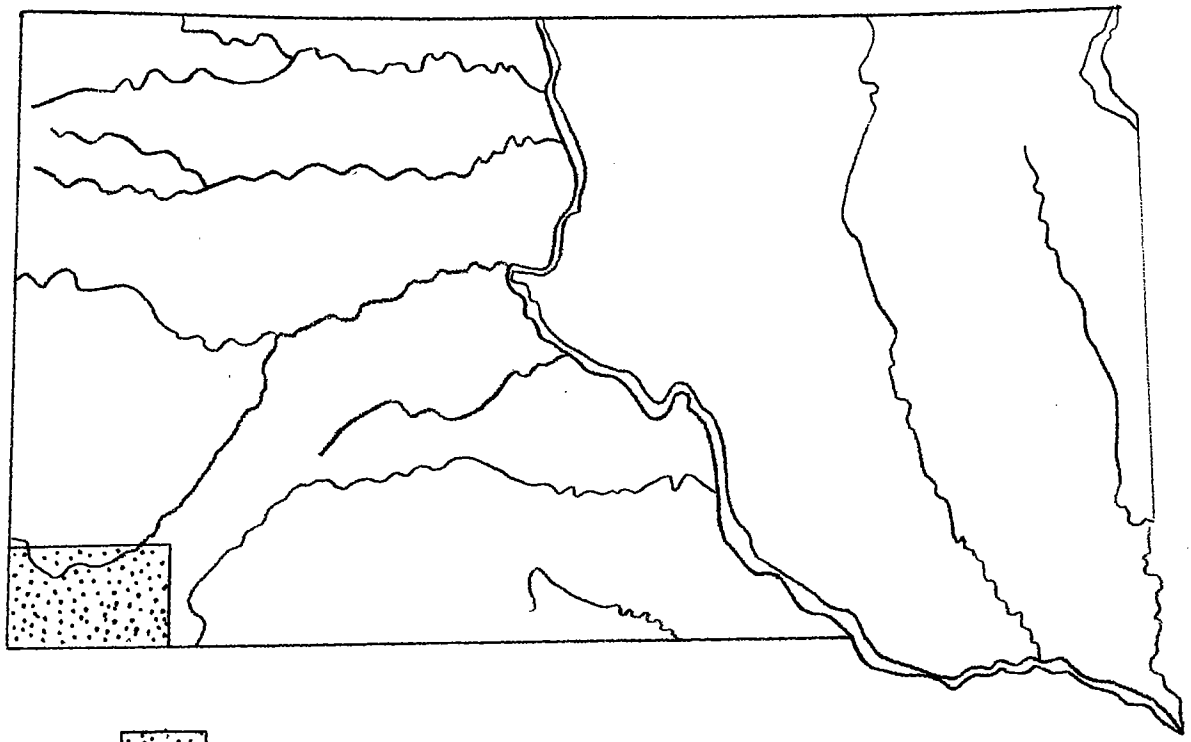

Area covered in this report.

ABSTRACT

South of the topographic mountains, the folding of the Black Hills continues through Fall River county, South Dakota and into Nebraska in three plunging anticlines whose axes fan out from the southern end of the mountains like a rough turkey track. Though the folds are sharp they have not made sufficient impress on the topography to differentiate them from the surrounding plains.

The longest fold points directly south from the mountains and can be followed entirely across Fall River county and into Nebraska. This is known as the Chilson or Hat Creek Anticline. A second fold lies east of the Chilson anticline, and its axis trends slightly east of south. It is very prominent near the mountains but plunges rapidly beneath the plains and is lost 10 miles south of the Cheyenne river. This fold has been designated as the Cascade anticline from Cascade Springs which lie at its northern end. A third fold lies west of the Chilson structure whose axis lies roughly along Cottonwood Creek. This axis trends 70° west of south and can be followed nearly to the Wyoming line.

Beneath these folds lies a stratigraphic section of Mesozoic and Paleozoic rocks similar to that found in Wyoming and outcropping in the Black Hills. A total of about 5,000 feet of sediments is available for prospecting in the southern parts of the county and 3,000 in the northern. In this section the Jurassic Sundance formation and the Pennsylvanian Minnelusa formation have given shows of oil and gas in wells drilled on and near these structures. One small gas field has been obtained from the Graneros formation.

Though a number of wells have been drilled in the county, most of the structures described in this report have not been tested. In view of this and because of the shows that have been encountered, Fall River county still should hold considerable interest to oil and gas prospectors.

INTRODUCTION

Purpose of the Report

Fall River county has been interesting as an oil prospect for a great many years. This is due in large measure to the fact that oil pools have been discovered not far across the state line in Wyoming. In fact the Mule Creek field misses the South Dakota line by only three miles. Since geological conditions are not limited by state boundaries, it has been reasoned that the factors which produced oil in Wyoming should also make accumulation in South Dakota.

A few shallow wells had been drilled in the county giving indifferent results. In the 1920's a well was promoted west of Provo by a promoter named Dillon. One or two other wells were drilled about the same time not too far away from this one by the Norbeck Company. Another well was drilled at Rumford where shallow wells near the railroad station had given shows of gas. So far as records are available, however, it appears that these wells never reached below the upper artesian sands and their poor results discouraged the promoters.

On January 11, 1929 a charge exploded in a well near the mouth of Red Canyon about four miles northeast of the city of Edgemont, filled the well with oil. Because of litigation this well had been standing since 1925. This aroused considerable excitement at the time and there was much talk of more drilling. The title was not cleared, however, and no further wells were drilled until 1931, when a test known as the Shiloh well was finished by the Lakota Development Company on the top of the Chilson anticline.

In the summer of 1930 the State Geological Survey sent a party into Fall River county for the purpose of mapping these structures with the hope of finding favorable places for oil accumulation on them. This party succeeded in mapping the Cascade structure (Rothrock 1), and the Chilson structure (Rothrock 2).

Opportunity to finish the mapping in Fall River county was not offered until the summer of 1948 when a party was then sent to Edgemont to complete the mapping

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(Names in parentheses refer to publications in the bibliography at the back of this report.)

of the Cottonwood Creek structure and surrounding areas.

This report, therefore, covers the work accomplished by the two surveys and presents the results of surface mapping which covers all the area in Fall River county where reliable key beds are available. It is an attempt to present, in a single picture, the structural features of the plains south of the Black Hills.

As will be noted, the northern boundary of the area is marked by the valley of the Cheyenne river which skirts the outer part of the so-called "Dakota Hogbacks" which make the outside wall of the Black Hills. There is no sharp southern boundary as the southern limit was marked by the southernmost key beds which could be followed. These were in the base of the Pierre formation and above them lies a great thickness of uniform dark shale which gave poor outcrops and no key beds between the mapped area and the Nebraska state boundary.

This report, therefore, does not cover the entire area of Fall River county but does cover that part of the county between the outer Black Hills and the Nebraska state line which could be mapped from surface outcrops. It is certain that the structures here described continue in the unmapped areas beneath the surface of the plains, and it is expected that the mapping here recorded will serve as a guide to prospecting beyond its limits. It should also be noted that a large area in the eastern part of the county is not covered. Some of this can be mapped from the surface.

The purpose of this report is to describe only the three big folds which occupy most of the county south of the Cheyenne river.

Methods of Work

The results presented herein were obtained by plane table mapping. Three parties were used on each survey, thereby allowing a large area to be covered in a fairly short field season. Horizontal control was obtained by checking the survey against corners of the land survey, and by the use of prominent land marks as reference points. This was necessary especially on the Cottonwood Creek structure since for some unknown reason the magnetic needle is unreliable over a large part of that area.

Vertical control was carried from bench marks of the U. S. Geological Survey and the U. S. Coast and Geodetic Survey. These are scattered over the county sufficiently

close together to keep accurate checks on the levels obtained by the plane table. The structures are so large that it was necessary to use a 50 foot contour interval. Since the limit of traverse error was held to one or two feet, the plane table obtained better accuracy than could be shown on the map.

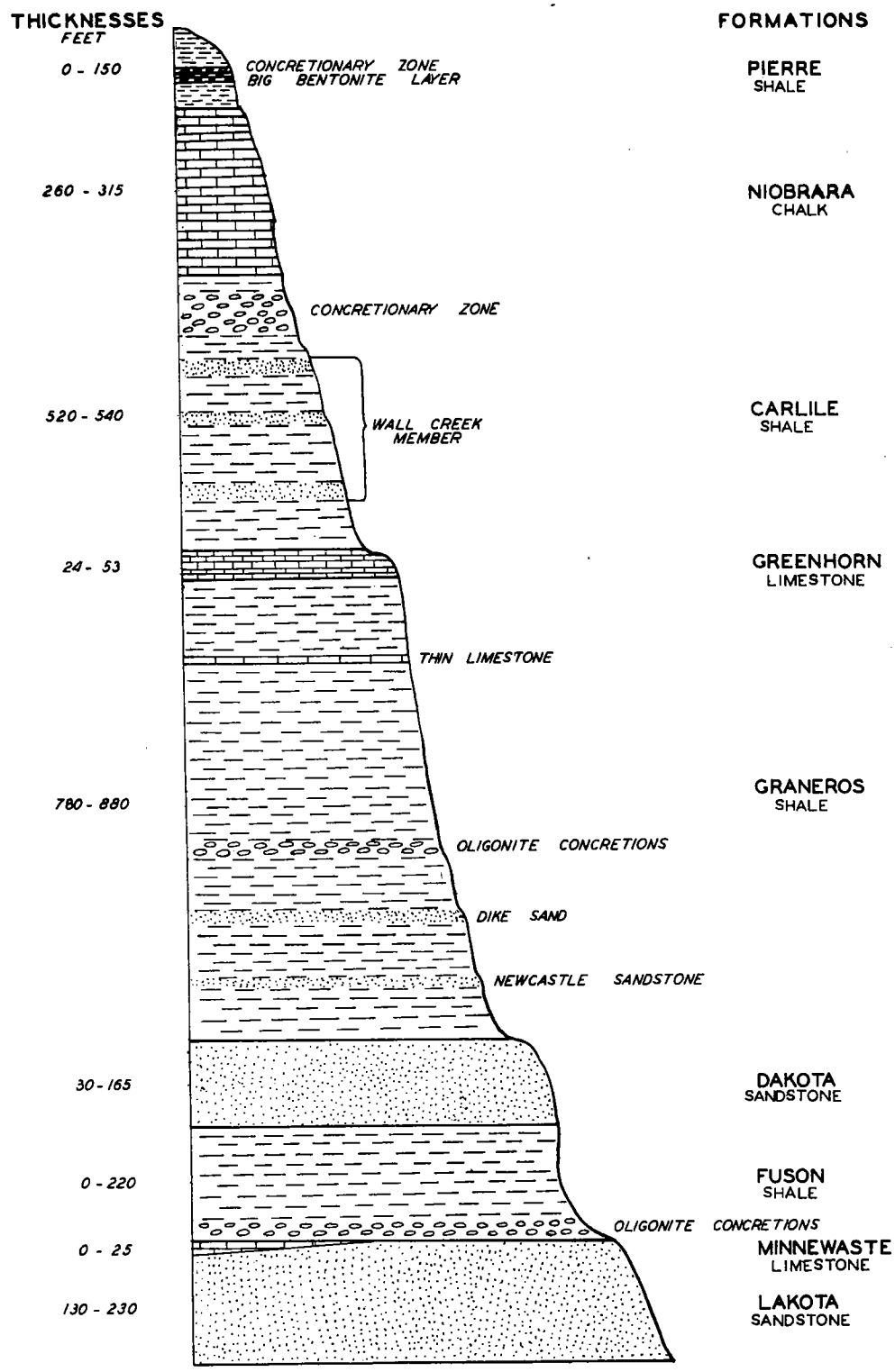
Acknowledgements

The compilation of the field maps into the unified picture here presented is the work of Mr. Bruno Petsch, Staff Geologist of the State Geological Survey. His careful work in bringing together the data from the many field maps and his skillful drafting has made this presentation possible.

On both surveys the State Geologist was especially fortunate in securing the services of competent assistants and wishes here to acknowledge the work of Messrs. M. E. Kirby, B. W. Heiss, W. R. Parrott, and L. K. Olson on the 1930 survey. On the 1947 survey he was assisted by Messrs. Robert E. Curtiss, Marion G. Glass, Amos F. Klein Jr., and Donald F. Rothrock. Without the painstaking work of these gentlemen both on the plane table and in the collection of the geological data this report could not have been written.

The correlation of the well logs which has given the subsurface data here presented, is the work of Mr. C. L. Baker of the State Geologiacl Survey Staff. The courtesy of local residents and drillers in supplying information on these wells added much to the accuracy of the information obtained. Recognition is also made of the courtesy of the oil prospectors in supplying cuttings for this correlation. Much of this was over and beyond the requirements of the State's regulations and has given a clear picture of what can be expected underground in this area. Among these should be mentioned Mr. Harry L. Hollingsworth, Mr. James Bell, The Amerada Petroleum Corporation, the Continental Oil Company, and the Woodward Oil Company.

FORMATIONS EXPOSED IN FALL RIVER COUNTY



PLM

EXPOSED FORMATIONS

The area mapped is underlain with sedimentary strata to depths ranging from 2400 to 4200 feet. These strata are underlain by the so-called "granite". This granite is composed of the volcanic and metamorphic rocks of the pre-Cambrian group which are of no interest as oil prospects. The sedimentary section is thinnest near the mountains, where the older strata outcrop, and thickens southward. Some of the thickest sections have been found well toward the Nebraska state line. They are also thinner along the axis of the folds which traverse the area than they are on the flanks and in the troughs between them.

The sedimentary strata include rocks of both the Paleozoic and Mesozoic groups. More than half of the formations belonging to these groups lie underground in the entire area. In fact, the only rocks outcropping in the area mapped are those belonging to the Cretaceous system. Most of the older formations outcrop somewhere in the mountains to the north, though the characters of some of them have been changed considerably where exposed.

The formations on which the structures were mapped are given in the following list. It should be noted that they are arranged in the order of their deposition, the oldest at the bottom of the column and the youngest at the top.

Mesozoic Group

Cretaceous System

Pierre Formation	shales
Niobrara Formation	chalkrock
Carlile Formation	shale
Greenhorn Formation	limestone
Graneros Formation	shale
Dakota Formation	sandstone
Fuson Formation	shale
Minnewasta Formation	limestone
Lakota Formation	sandstone

A more detailed description follows starting with the oldest.

LAKOTA FORMATION

The Lakota formation outcrops only in Red Canyon which lies at the extreme northern part of the map and extends southward well toward the valley of the Cheyenne before it disappears underground. The outcrop area is wider at the north end and tapers to a point at the south due to the dip of the beds in that direction.

No detailed study was made of this formation. It has been described as follows, however:

"The Lakota is composed of hard, cross-grained, mostly cross-bedded and massive sandstone, with occasional thin partings of shale. Streaks of conglomerate often appear especially in the lower portions. Small basins of coal occur in it east and north of Edgemont." (Darton p.4)

Studies in other parts of the Black Hills have shown that the Lakota is made of two or three massive sandstones separated by shale, some of them rather highly colored. The exact number of sands and shales seems to vary from place to place but in most that have been made, two or three sandstones were readily discernible.

In the Red Canyon a very white sugary bed 10 or 15 feet thick was used as a horizon for mapping. It is the only distinctive bed readily available for use as a key bed in this vicinity.

Lakota sandstone has been recognized in cuttings of all the wells drilled in Fall River county. It, therefore, is safe to assume that it underlies the entire county. Its thickness, however, varies considerably. In the vicinity of Ardmore, near the Nebraska line, 150 feet was penetrated in the Gertrude Schmitt #4 well. Nine miles to the north, in the Shiloh well on top of the Chilson structure, 130 feet were recorded. This thickness seems to carry east for a long way as the Lakota in the Vorhees well near Oelrichs gave a similar thickness. At about the same latitude but to the west of the Shiloh, the formation seems to thin considerably. Only 100 feet were definitely recognized as Lakota. The thickest sections were found in wells drilled on or near the hogbacks in the north end of the area. A well drilled three miles north of Edgemont and known as the Childers#1 showed 230 feet of Lakota formation, and a similar thickness was found in a well drilled on top of the Chilson structure by the Continental Oil Company.

MINNEWASTA FORMATION

A thin limestone which seems to be local lies at the top of the Lakota formation and outcrops in the bluffs of the Cheyenne east of Coffee Flats. It is missing in the vicinity of Hot Springs. Its outcrops run from the old town of Cascade Springs to Buffalo Gap where its thickness is about 25 feet. It is a nearly pure, light gray limestone, quite uniform throughout. It was recognized in only three wells drilled in Fall River county, namely: the State Agricultural College well south of Hot Springs, the Vorhees well near Oelrichs, and the Schmitt well at Ardmore. In the first well it had a thickness of 125 feet, the second 70 feet, and in the third 20 feet. It would appear, therefore, that this lies as a large lens occupying less than the eastern half of the county. It might be a horizon marker in wells drilled in the eastern part of the county but should not be expected in wells drilled in the west. The wells in which it occurs indicate a general southwest trend for the western edge of the formation.

FUSON FORMATION

This formation is exposed on the inside of the hogbacks in the northeastern part of the county. Like the Lakota, it also appears to underlie the entire area mapped. It is a persistent clay zone between the Lakota sandstone and the overlying Dakota which has been assigned to this formation.

A great many descriptions have been given this formation and it is seldom that those from two localities agree. The only generalization that can be made is that it is predominantly a "clay or sandy clay of gray color with conspicuous maroon and purple portions. Thin beds of buff sandstone and one or two layers of characteristic dark green sandstone are usually included". (Darton p.5)

At the southern end of the area, near Ardmore, 250 feet of sediments have been assigned to this formation. In the Shiloh well, 9 miles to the north, 100 feet is recognized as Fuson. Farther north on the same structure the Continental Oil Company's well also recorded 100 feet.

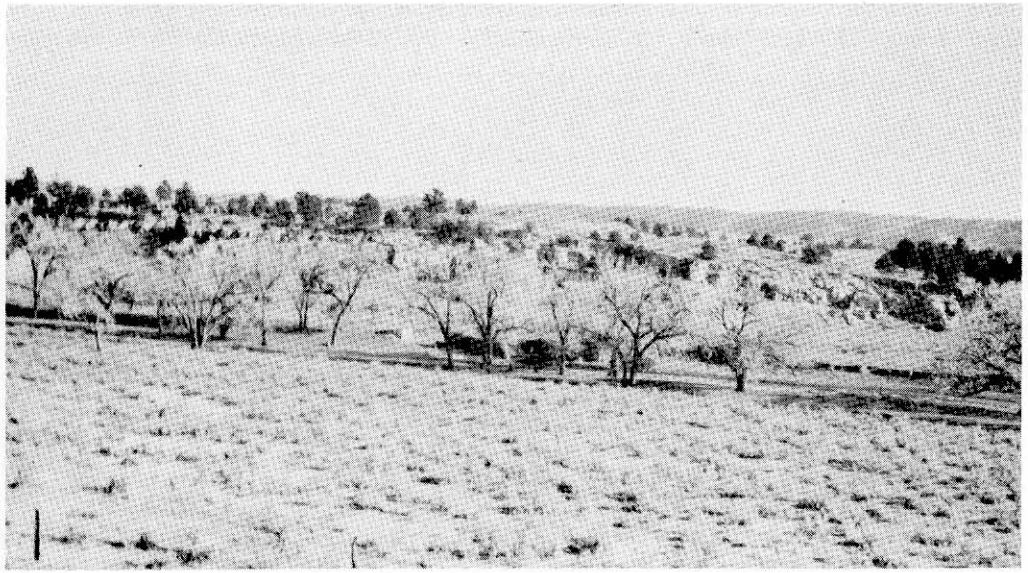
DAKOTA FORMATION

The Dakota formation is a sandstone unit which is quite persistent though it differs considerably in thickness from place to place. It is variously described in the outcrops as a massive sandstone or a shelly sandstone, and both descriptions are right. In most places the top appears as an alternation of thin sand and shale layers which grade through a short interval into the overlying Graneros shale. The gradation is so narrow that the contact between the two formations is fairly distinct. In some outcrops the upper half of the formation is made of this shelly sand and the lower half of a massive buff sandstone. In other places the shelly material seems to be nearly missing and a short gradation carries the massive sandstone into the Graneros shale. This character has made some difficulty in recognizing the top of the Dakota in drilling. It has doubtless made more variation in the recorded thicknesses of the formation than actually exists.

In the area mapped, the Dakota sandstone is readily visible north of the Cheyenne river where it makes the slope of the hogbacks. It crosses the Cheyenne river on the axis of the Chilson and Cascade anticlines, and makes steep walls on the western flanks of these flexures.

The thickness of this formation varies from 30 feet to 165 feet in the wells drilled in Fall River county. The thinnest sections were recorded from the Vorhees, Government, and Schmitt wells where 30, 75, and 40 feet, respectively, were encountered. The thickest section was in the Red Eagle well just east of the county line where 165 feet was measured. The Ordnance well at Provo gave nearly the same thickness, namely: 162 feet. The other wells drilled gave figures between these extremes. The Agricultural College well encountered 115 feet, the Shiloh 120 feet, but the Moody 107 feet. There does not seem to be any order in this thickening and thinning and while it is probable that part of it is due to uncertainty of the upper contact, it seems to follow the pattern of this formation in the outcrops where the thickness changes rapidly from place to place.

In most wells this formation gives abundant water which is under artesian head in this area. It is of interest to note, however, that the thinnest section, at the Government well, gave no water. This, however, is the only well where such a condition was reported, though the Schmitt wells at Ardmore had a minimum of water trouble from this formation.



DAKOTA SANDSTONE OUTCROP
at the
MOUTH OF RED CANYON

Old Cleveland Stone Company Quarry
in center of picture

GRANEROS FORMATION

Overlying the Dakota sandstone is a thick formation composed largely of dark colored shale. It outcrops over a wide area in the Cheyenne Valley and is exposed for several miles along the axis of the three anticlines. It makes the bedrock along the crest of the Cascade structure for five miles, and is exposed on the axis of the Chilson structure at least half way from the Cheyenne to the state line. It also is exposed on the axis of the Cottonwood Creek structure extending up Cottonwood Creek for five miles from Edgemont.

Measurements on the outcrop gave the Graneros formation a thickness of about 680 feet. Thicknesses in wells farther away from the Black Hills, however, were considerably more. The thickest sections were at the southern end of the area. Here the Red Eagle well, in Shannon county, gave 880 feet; the Moody well, 12 miles west of Ardmore, 860 feet; and the Schmitt well at Ardmore 810 feet. Two wells drilled about halfway between the Cheyenne river and the south state line show a thinning of the formation toward the Black Hills. The Vorhees well near Oelrichs showed 820 feet and the well at Provo 810 feet. A well drilled near Hot Springs, the State Agricultural College well, showed 780 feet. Apparently this formation thickens south and southeast from the outcrop.

The formation is usually described as a black shale. There are persistent horizons of other rocks, however, some of which serve as excellent key horizons for mapping structure. The Newcastle sandstone and the Mowry shale zone differ markedly from the rest of the formation. Bentonite beds scattered through the formation add to the stickiness of the gumbo which is formed when the shale disintegrates on weathering. A thin limestone, very much like the overlying Greenhorn occurs in the upper part of the formation.

Thermopolis Shale

In Wyoming it is customary to separate the formation into three members using the Newcastle sand as the middle member. The lower member, between the Dakota and Newcastle sand, is known as the Thermopolis or Skull Creek Member. In this area it is a uniform black shale. A zone of clay ironstone concretions bearing a small percentage of manganese occurs at its base. An outcrop of this member in the southeast corner of Sec. 22, T. 9 S., R. 5 E., Fall River county, gave the following succession of beds:

Section of Concretionary zone in the base of the Skull Creek Member of the Graneros formation; Sec. 22, T. 9 S., R. 5 E., Fall River county.

Graneros Formation	Feet
Lower layer of manganese bearing clay-ironstone concretions in black shale, concretions flattened and biscuit shaped.....	9
Black Shale.....	1
Lower layer of manganese bearing concretions. Looks just like above, but makes a definite horizon that can be followed across the structure.....	13
Black Shale.....	
Dakota Formation	
Six foot brown shelly sandstone beds 1/8 to 1/4 inch thick forms well marked horizon.....	

The thickness of the Thermopolis or the Skull Creek Member in wells is from 230 to 370 feet.

Newcastle Sandstone

A soft white sandstone separates the Skull Creek shale from the overlying Belle Fourche Member. On the eastern side of the Black Hills it appears to be rather patchy, forming a very thick, prominent ridge in front of the Dakota, in some localities, and in others being entirely missing. It seems to be fairly continuous in the area covered by this report, however, as it was encountered in all wells drilled through the Graneros formation, and was found outcropping along the Cheyenne river. Its thickness varies considerably but seems to average about 20 feet. In some well cuttings it showed as a ten foot layer while in others it appeared to be 100 feet thick. However, most of the wells showed between 20 to 50 feet. This is the sand that carries gas in the vicinity of Ardmore and has furnished gas and oil in Wyoming. Where it occurs underground, therefore, it is always well to watch for production. It also furnishes the material for the famous sandstone dikes which occur throughout the area and which will be described later.

Belle Fourche Member

The Belle Fourche Member of the Graneros formation is composed primarily of dark clayey shale. There are certain zones into which it can be readily divided, and some thick bentonites, and a limestone horizon which can be used as key beds for mapping.

The Mowry Zone--Immediately above the Newcastle sandstone there lies about 150 feet of colored shale which dries to a silvery gray and forms little chips which will rattle in the hand. This shale does not break down to mud upon being wet. It is usually marked on the outcrop by a growth of evergreen trees.

Fish scales, spines, and vertebrae occur very abundantly in the typical Mowry. South of the Black Hills they are to be found but are not nearly so abundant as they are farther north and west. The physical properties of the shale, however, are exactly the same.

Near the middle of the Mowry there is a light gray to brown sandstone which appears to have been forced into cracks and bedding planes in the shale so that it is now in the form of dikes and sills. In many places the dikes and sills are uniform in thickness and weathering has cracked them into even-sized blocks so that they resemble man-made walls and pavements. Many dikes are less than four inches across while others may be six to ten feet thick. This zone of sandstone dikes is variable in thickness and apparently does not always mark precisely the same horizon in the Mowry.

Oligonite Zone--Immediately above the Mowry is a zone of black shales verying from 20 to 80 feet in thickness which is characterized by the presence of numerous large and small clay-ironstone concretions bearing a small amount of manganese. This has been called Oligonite in former reports (R. I. #8, 9, and 36).

Bentonites are scattered through the upper Mowry and the Oligonite zone. One fairly persistent bed is found in many outcrops about 20 feet below the top of the Mowry, and another about the same distance above. A four foot bed is usually found about 40 feet above the contact. This bentonite and the abundance of black concretions make a zone which is readily recognized.

The Graneros Limestone--A prominent bed of limestone occurs in the upper part of the Belle Fourche Member about halfway between the top of the formation and the zone of

Oligonite concretions and is so persistent that it makes an excellent key bed. It is never more than six or eight inches thick and weathers out in smooth brown slabs four or five inches across and about an inch in thickness. It resembles the Greenhorn limestone and there has been some tendency to put it and the part of Belle Fourche shale above it in the Greenhorn formation. However, the lack of similar beds in the shale anywhere in the area that might suggest a transition does not favor this correlation; and this ledge, therefore, will be considered as a bed in the Graneros formation.

A similar limestone in the same position in the Graneros north of the Black Hills has been called the Orman Lake limestone.

GREENHORN FORMATION

The Greenhorn formation is the prominent ledge-maker in the area. Imposing bluffs are capped by it all along the south side of the Cheyenne river valley.

Over most of its outcrop area it makes large cuestas. The Greenhorn formation forms the cap rock of these cuestas which recedes from bold cliffs facing the Cheyenne drainage in dips varying from one to five degrees. On the west side of the Chilson structure near Rumford and on the west side of the Cascade structure about 12 miles to the northeast of Rumford the formation has been tipped so steeply that it forms very striking hogbacks which can be seen for a long distance.

The Greenhorn formation is primarily a shelly limestone, gray on fresh surfaces and weathering to a buff color wherever exposed. The slabby character of the limestone allows weathering to penetrate deeply into the formation so that all surfaces of the slab show the weathered color. In some quarries that have been opened in the formation, the fresh rock seems quite solid but weathering soon separates the beds into flakes and slabs from a quarter of an inch to two inches in thickness and varying from the size of the hand to a foot or so in diameter. The separation between beds seems to be caused by very thin layers of silt or clay.

Perhaps the most notable character aside from the composition of the rock is the abundance of fossils. The beds are full of fragments of a large pelecypod Inoceramus labiatus. In fact, some of the beds are made entirely of

these shells making a coquina. The aragonite prisms from the shells make a good means of identifying the formations in well cuttings. This fossil or its near relatives occur in other Cretaceous formations in the vicinity, but nowhere in such striking abundance as in the Greenhorn.

Some shales are to be found in the base of the formation which must be included in it because they separate limestone sections which are identical in character with typical Greenhorn in rock and fossil content. At the base of the formation lies a chalky marl which is overlain by an eight inch bentonite in the western part of the area. In some places it is rather thin but they reach thicknesses of two or three feet. Five and six inch bentonites occur in some sections of the formation. No such beds have been recorded above the base, however. Nowhere in the area was the top well exposed.

The following sections taken from opposite sides of the area will give an idea of the character of the formation:

Section of the Lower Greenhorn Limestone

Feet	Inches	Location: Section 14, T. 9 S., R. 5 E., Fall River county, So. Dakota
9		Shelly limestone which has the typical bedding and Inoceramus fossils. Beds 1/16 to one inch but bedding planes are irregular. This makes rock break into slabs ½ to 12 inches in diameter.
		Limestone probably impure, feels gritty to hand when fresh, but leaves only fine clay residue when weathered.
		A very few limonite concretions.
		Inoceramus shells much broken as though broken at time of deposition. Might be by compacting of mud.
	5	Massive limestone like above.
1	3	Limy shale, same buff color on weathering but is streaked with blue. Also contains shells.
	3	Massive limestone with fossils.

Feet	Inches	
	8	Lime shells like top.
	4	Massive limestone like top.
2	3	Limy shale of bluish cast.
	6	Massive limestone.
1		Shelly limestone like above.
3		Blue shale, probably Carlile, bottom of exposure.

Section of Greenhorn Formation

Location: On highway 2 miles south of Edgemont, W. quarter Sec. 19, T. 9 S., R. 3 E., Fall River county, So. Dakota

12		Shelly gray limestone weathering buff with abundant Inoceramus shells.
12		Alternating limestone and dark shale in thin beds in one and two foot beds.
	8	Bentonite.
11.9		Dark shale.
1.3		Shelly limestone with abundant Inoceramus shells.
1		Black shale.
	4	Concretion-like bed of limestone with Inoceramus shells.
7		Blue-black marl weathering brown.
	1	Bentonite.
4		Marl like above.
____	____	Graneros, blue black shale.

Section of Greenhorn Formation

Feet	Inches	Location: Along highway 2½ miles S. of Edgemont, NW quarter Sec. 13, T. 9 S., R. 2 E.
12		Shelly limestone.
13		Alternating limestone and dark shale.
	8	Bentonite.
12		Dark shale with marl near the base.
1.3		Shelly limestone with abundant Inoceramus fragments.
1		Black shale.
.3		Concretion-like beds of limestone with abundant Inoceramus.
	1	Bentonite.
13		Brown marl.

The thickness of the Greenhorn is given in the Edgemont Folio as about 50 feet. Two sections measured in T. 10 S., R. 4 E., however, did not give as great a thickness. One which did not quite reach the top of the formation gave 24 feet, and the second 34 feet. The section directly south of Edgemont indicated 53 feet. This is in part due to the character of the outcrop of the formation. If the marly shales and marls are included in the formation a greater thickness had to be allowed than if only the slabby limestone is used. The typical limestone, however, occurs in a transition zone with the marls at the base of the formation making it difficult to locate the exact contact with the Graneros. Even the thin limestone in the Graneros formation described above looks very much like the typical Greenhorn limestone. Because of this transition the base has to be set more or less arbitrarily. In this report the 53 foot interval is included as Greenhorn, about one half being made of solid mass of slabby limestone and the other half, the transition zone carrying the marls and chalkstones.

CARLILE FORMATION

Above the Greenhorn limestone lies another thick section of dark shales much like those of the underlying Graneros in character. It was named the Carlile formation by G. K. Gilbert in 1896 from outcrops he studied near Carlile station 21 miles west of Pueblo, Colorado.

This formation occupies the flanks of all three structures that were mapped and large areas of the intervening synclines. It shows on the map as a crenulated belt from two to five miles wide festooning around the structures across the middle of the map.

Two zones of different material break the monotony of the dark shales of the section. The lowest is a zone of sand and sandy shales which occupies the stratigraphic position of the Wall Creek sand in Wyoming. It makes prominent ledges and cuestas and is of interest as an oil-bearing horizon where it is buried. Some distance above this sand is a thick zone of round concretions in which concretions are sufficiently numerous and persistent to hold up important ledges which could be used as mapping horizons. The topographic prominence of these two members is all out of proportion to their actual importance in the formation as they represent only a small fraction of its thickness. The rest of the formation, however, is usually lost in the cuesta slopes below and above these ledges. Since most of the cuestas face northward, the lower half of the formation makes the steep escarpment faces of the cuestas. The upper half of the formation makes the gentle slopes far to the rear of the cuesta edge and the base of the cuesta slopes of the next ledgemaker to the south. About 73% of the thickness of the formation is occupied by the black shale, 10% by the Wall Creek sandstone, and 17% by the zone of concretions. As the shale holds little interest as a mapping horizon, it will be described no farther. The Wall Creek sandstone and the concretionary zone, however, will be given a short description.

The Wall Creek Sand

As stated above the Wall Creek Member of the Carlile formation lies about 250 feet above its base. It is characterized as a sandy zone and in Wyoming is often indicated as several different sands. It is a sandy zone with several very different ledgemakers. These are fairly well cemented sands and between them lie soft sands or, typically, alternating sand and shale. On good exposures the typical Wall Creek appears to be made of beds perhaps a quarter of an inch thick of alternating sand and black shale or carbonatious matter.

The formation becomes more sandy from the east to the west, but the ledgemakers persist at about the same intervals throughout the area. The top of the member is characterized by two thin persistent beds of fine sand which are brown on the outcrop and quite shelly. These ledges are about two feet thick and separated by ten feet of sandy shale and fine-grained sandstone. The cement for these ledges contains considerable lime, and in a great

many places it increases until it is a limy lens which carries a very prolific fauna. The most striking fossil in the fauna is a large cephalopod with a highly ornamented surface. These vary all the way from a few inches to a foot and half across, and belong to the two genus Prionotropis and Prionocyclus. With these are a host of other cephalopods, particularly scaphites, and a great many other mollusks particularly Inoceramus. The following list of fossils was identified from this horizon:

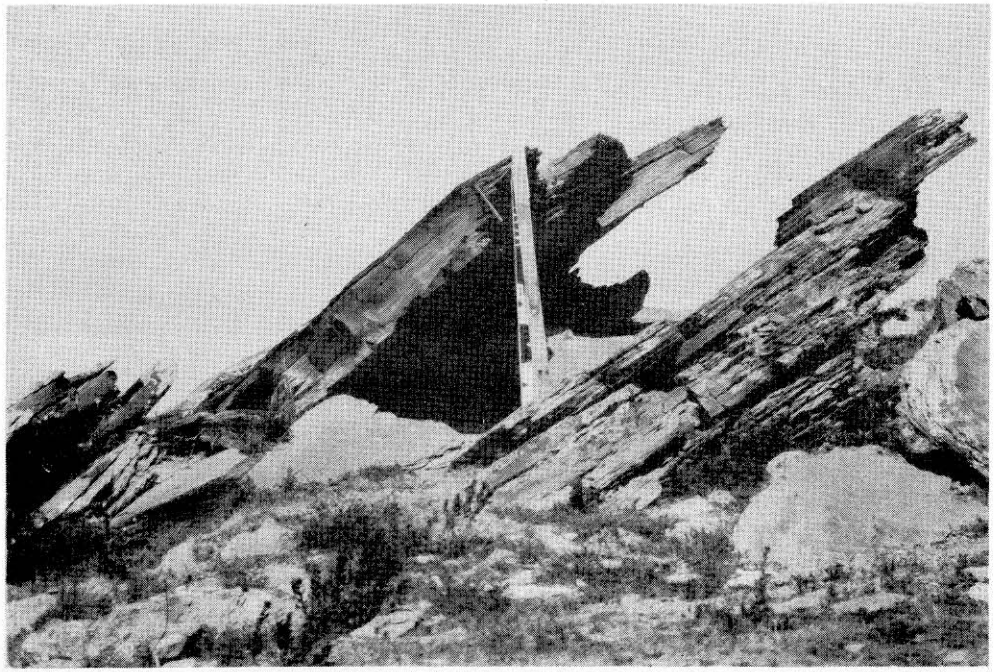
Prionotropis woolgari (Mantell)
Prionotropis woolgari var.
Prionotropis sp.
Prionocyclus wyominginsis, Meek
Acanthoceras sp.
Scaphites warreni, var. wyominginsis, Meek
Scaphites warreni, Meek and Hayden
Gyrodes depressa, Meek
Inoceramus fragilis, Hall and Meek
Fusus shumardi, Whitfield
Radiolaria, undet

(Identified by C. W. Espe, in the laboratories of the Dept. of Geology, University of So. Dakota)

The smooth shelly surfaces and the brown color together with the prolific fauna make these two ledges unmistakable in the outcrop.

Below the lower of the ledgemakers just described comes about 45 feet of sediments which in the eastern part of the area are largely black shales. Toward the west, however, they become sandy and in the westernmost outcrops they are largely fine sandstones with alternations of dark shale. This part of the member is composed of extremely thin beds of fine-grained gray sand which is separated by layers of black clay or loam. These beds are so thin (1/16 to 1/32 of an inch) that it gives the outcrop the appearance of lamination. The black clay partings are evidently colored by organic matter and suggest an origin for the oil found in the Wall Creek farther west. This offers a possible oil horizon for wells drilled in southern parts of the structures to be described.

Below the zone just described comes another pair of ledgemakers. The upper one is always present and the lower one is sometimes visible. These ledges are again from six inches to two feet in thickness and are made of



UPPER LEDGE MAKER OF WALL CREEK SAND
NEAR RUMFORD

Photo by W. L. Russell

very coarse sandstone which is in marked contrast to the very fine sandstone of the upper ledgemakers. The grains become so coarse that spots in the lower ledge can be called conglomerate. Where two ledgemakers occur they are separated by from six to ten feet of poorly cemented sand. Sometimes it is slabby and sometimes in beds several inches thick. Some thin shales occur in this zone also. A few of the cephalopods and other mollusks of the upper ledges occur in this zone, but there is no such abundance of them as was noted above. In the western part of the area, at least, sharks teeth are abundant and make a good distinction between the fauna of this ledge and that of the upper ledge. The coarseness of the sandstone and the fish teeth are the chief characters which identify the lower ledge.

Concretionary Zone

A second zone of ledgemakers lies above the Wall Creek sand and is characterized by layers of large, round concretions which tend to weather to a rubble of small, trapizoidal pieces on long exposure. The concretions are made of lime and most of them are cracked, at least in the center. These cracks are drused with calcite. Individual calcite crystals an inch or more in diameter have been found in these druses. Much of the calcite is white, but much of it is also colored in shades of dark brown and even red. This crystallization has in some cases filled the cracks with calcite veins and, in others, has drused the walls making geodes. The total thickness of the concretionary zone is about 60 feet; but, as with all concretions, they are not confined to a single bed or strata though they occur at approximately the same stratigraphic horizon. Often two beds occur with an interval of five to ten feet between them while only one is found at the same horizon not far away, and stray concretions occur throughout the zone.

The lowest concretionary bed lies between 25 and 45 feet above the top of the Wall Creek Zone, and is characterized by large, three-foot concretions which weather to a striking yellow. The yellow character seems to be confined to this particular horizon and can be traced over most of the area covered in this report. They are especially prominent in the vicinity of Provo. The highest bed of concretions lies from 56 to 66 feet above the yellow concretions and is characterized by large, gray or white concretions which weather to a lighter color. The drusing and cracking is especially noticeable in these concretions, and they are sufficiently numerous to make dip slopes on prominent cuestas in the vicinity of Provo

and eastward. They can also be followed westward to the state line. The matrix in which these concretions lie is a gray shale much like the rest of the Carlile formation.

This horizon is easy to trace because of its topographic expression on the cuestas. It is not a first class key bed for structural mapping, however, but occurs in intervals where other key beds are absent and, therefore, can be used with the proper precautions. The yellow color in the lower bed is sufficiently continuous and is sufficiently confined to make it a useful zone. Gray concretions, however, are scattered through a larger interval and, therefore, are not so reliable unless a very good outcrop is available. Single concretions roll down the escarpment slopes for considerable distances, and blocks of them are often slumped far out of place. New horizons of gray concretions which can be followed for only a short distance are to be found below the uppermost ledge here and there about the area. Because of their advantageous position in the section and the large contour interval that had to be used in mapping this territory, it was possible to use this concretionary zone to good advantage in spite of the difficulties just mentioned.

Upper Shale Member

Between the topmost gray concretions and the base of the overlying Niobrara formation is a section of dark shale which is very poorly exposed in this area. The best measurement on it was obtained west of Edgemont and on the Black Hills Ordnance Depot where a thickness of 162 feet is indicated. The weak character of these shales combined with a similar weakness in the overlying Niobrara formation causes the contact between the two to be found in the valleys and at the bases of the slopes where it is not well exposed. These contacts were seen only on the extreme western part of the map in the Black Hills Ordnance depot. Even these contacts were so poorly exposed that they could not be used satisfactorily in determining intervals or in mapping structure.

Thickness

The total thickness of the Carlile formation was not easily obtained for reasons that have been stated. Intervals from the top of the Greenhorn formation to the top of the Niobrara formation, however, were available, and by the process of subtraction it was possible to obtain a figure for the total thickness of the formation. These figures vary somewhat, but average around 520 feet. In

the Vorhees well near Oelrichs, 540 feet were assigned to the formation.

NIOBRARA FORMATION

The Niobrara formation is the most easily identified of the Cretaceous formations because it is made entirely of chalk or marl. It is gray in color when fresh, and weathers to an orange, yellow, or light tan color. There are some ash layers in it which are white, and thin bentonite partings occur at a good many places.

In the area under discussion, however, it is not possible to give a good description of the formation because its weakness prevents its making exposures of sufficient size and thickness to allow a good inspection. It occurs in the bottoms of valleys where it makes swampy sloughs that cannot be cultivated, and in the lower parts of inter-cuesta valleys where it is usually covered by talus from above. Glimpses of the top of the formation are to be had on the long bluff capped by Pierre shale which lies south of Provo and extends between Provo and Rumford. This shows 20 to 40 feet of solid chalk above which lies a gradational zone of black shale and chalky marls which grade off into the black shales of the Pierre formation.

It is impossible to get a good measurement of the thickness on the outcrops since the base of the formation was so hard to locate accurately. However, by subtracting the interval obtained in the western part of the area from the upper Wall Creek to the top of the Niobrara, a figure of approximately 220 feet is left for the thickness of the formation.

In checking well cuttings where Niobrara was penetrated, a variety of figures is obtained. The lowest is 60 feet in the Vorhees well and the highest 315 feet in the Moody well. Wells nearer the structures here mapped, namely; the Schmitt #2 and the Amerada Moody, penetrated 260 and 200 feet, respectively.

It must be remembered, however, that such figures are not too accurate as the Niobrara cuttings are usually mixed and carried down below their actual base. In most cases well cuttings in the formation appear as a speckled shale and that adds to the difficulty in accurately locating the contacts of the formation.

There are no key beds that can be used in this formation. The top, however, was traced for a short way between Provo and Rumford. Since better key beds were available a short distance above, no great effort was made to use it as a key horizon. If time were available and the detail necessary, it might be possible to use both the top and bottom of the Niobrara to better advantage than was done on this survey. The formation has no members within it which can be identified on the surface and so far none have been discovered in the examination of well cuttings.

PIERRE FORMATION

The youngest formation exposed in the area covered by this report is the Pierre formation. Its lower part makes cuestas in the central and western parts of the area which can be easily followed since they have bold north facing escarpments with well-defined back slopes. They are the outermost cuestas of the Black Hills folding.

South of these cuestas the entire topography is carved on Pierre bedrock. It is nothing but a jumble of hills separated by a dentritic network of stream valleys which give little or no hint of underlying structures. The portion of the formation exposed in these hills is so uniform that it is impossible to distinguish different members or to find beds or zones which can be used as key horizons.

The top of the Niobrara formation is exposed in the lower part of the Pierre cuestas in many outcrops. Above this contact it was possible to measure about 150 feet of the lower Pierre formation.

Sharon Springs Member

According to Gries and Spivey, this entire thickness belongs to the Sharon Springs member of the Pierre formation. This member was first described from a locality in Kansas (Elias) and first recognized in South Dakota along the Missouri river (Searight). The member is much thicker in western South Dakota than along the Missouri. Gries (p.8) assigns a mixiumum thickness of 28 feet to it in the Missouri valley, but measured 175 to 200 feet of it in Fall River county. Similar thicknesses have been encountered in the wells drilled in the vicinity.

Three characteristics distinguish the Sharon Springs member. First, the fact that it is a bituminous shale; second, that most outcrops are marked by an abundance of fish remains, scales, fragments of spines and plates; third, it carries a very conspicuous zone of bentonite which is thick enough to be commercially important. All these characters are present in the Fall River county section. The fish fragments, however, are not so abundant as they are in the Missouri valley outcrops. The bentonites, on the other hand, are thicker and possibly a little more numerous. At Ardmore they have been quarried and used commercially for a good many years.

Spivey describes the Sharon Springs member as follows:

"The shale of the lower Pierre is dark gray in color but may be brownish-gray to silvery-gray when weathered. It is thinly laminated and frequently the thin sheets are separated by thin layers of small, selenite crystals which are often stained brown by iron oxide. Although the shale is usually hard and brittle, it forms a sticky gumbo when weathered. Fish scales and vertebrae are quite common in the shales of the lower Pierre, and reptile remains occur in some places."

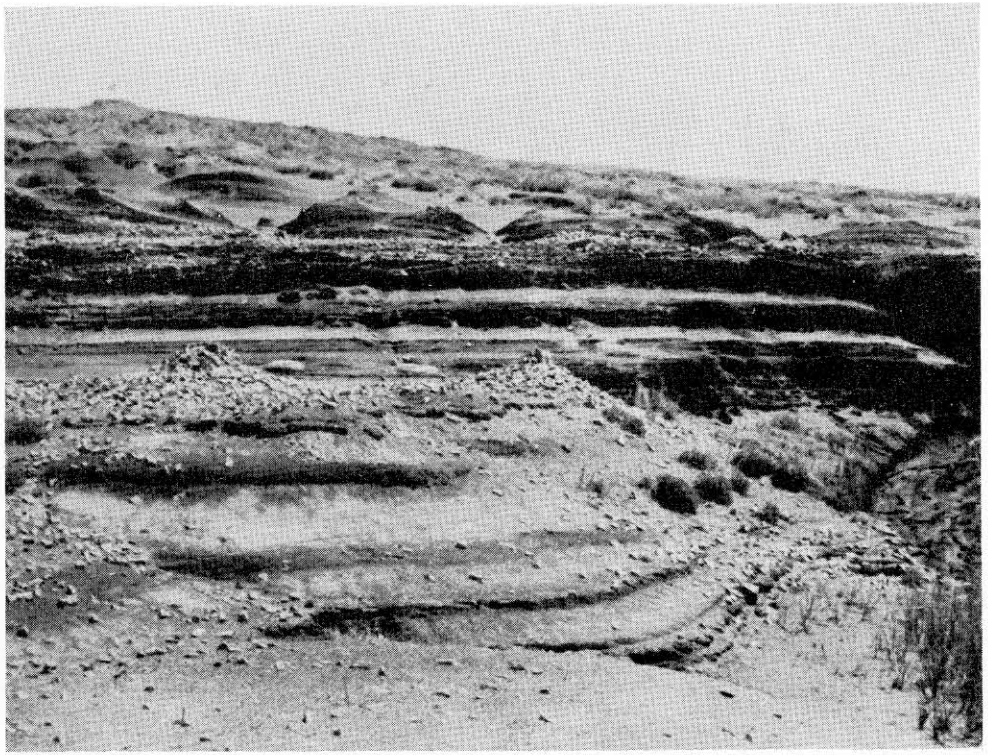
The most striking zone in the member is the Ardmore bentonite zone which lies 50 to 70 feet above the base of the formation. Between 10 to 15 beds lie in this zone and are a white or cream color. Where the bentonite beds are exposed, they are so closely spaced that they can be seen and recognized from a distance of several miles. Since the bentonites are very plastic they form a lubricant which will cause slumping of blocks of shale wherever slopes are steep, so that it is common to find large bare outcrops exposing a considerable thickness of the zone.

The whiteness of the outcrops is accented by an abundance of large, gray lime concretions which lie in and about the bentonites. These concretions weather out of the dark shales as large spheres which average two or three feet in diameter and which turn almost white on exposure. Upon long exposure they break down into small fragments an inch or so in diameter which lie strewn over most of the outcrop.

Unfortunately, these big concretions cannot be used as key horizons as they are not confined to a single bed. In one part of the area they may overlie recognized bentonite beds, while in others they may underly the same bentonite. They are useful, however, in recognizing the Ardmore zone since it is the only zone in which such

concretions occur. Above it, all concretions are darker in color. Some are dark red to maroon when fresh and on weathering turn a tan or yellow.

Moreover, the Ardmore zone concretions are smooth-surfaced while those above them are either shelly, breaking down into cardboard-thin laminae, or are covered with a shell of cone-in-cone which presents a rough or dimpled surface.



BENTONITE ZONE
BASE OF PIERRE FORMATION

Photo by R. C. Spivey

SUBSURFACE FORMATIONS

SUMMARY

Since the early reports on this region were written, several deep tests have penetrated the sedimentary series to, or nearly to, the "granite". These wells have shown that there are about 5000 feet of sedimentary rocks lying between the pre-Cambrian group and the surface. The formations encountered belong to the Mesozoic and late Paleozoic systems and correspond in general to those formations which are outcropping in the southern part of the Black Hills. Minor changes, however, are noted in the formations as the distance from the mountains increases.

The lower Paleozoic systems, Cambrian, Ordovician, Silurian, and Devonian are missing. The large unconformity also represents part of the late Paleozoic since Mississippian formations lie on the pre-Cambrian granite in some wells while others went directly into it from Pennsylvanian. This, together with the fact that the formations plunge southward rather steeply, make any general statement on the thickness of sedimentaries in this area impossible. A well starting in the Cheyenne valley will penetrate only those rocks lying below the Dakota or lower Graneros formation, while one drilled toward the state line will have to penetrate everything below and including the Sharon Springs Member of the Pierre formation.

In general, the subsurface formations near the surface south of Provo and Igloo are those which outcrop north of this latitude, while those that lie beneath the northern half of Fall River county are those which are outcropping behind the hogbacks in the Black Hills. The following descriptions, therefore, will include only those formations lying below the Lakota sandstone.

The formations which will be encountered are herewith listed. The youngest and, therefore, highest in the section is represented at the top of the column and the oldest at its base.

Jurassic System
- Morrison Formation
- Unkpapa Formation
- Sundance Formation

Triassic System
- Spearfish Formation (Redbeds)

Permian System
- Minnekahta Formation (Limestone)
- Opeche Formation (Redbeds)

Pennsylvanian System
- Minnelusa Formation

Mississippian System
- Pahasapa Formation (Limestone)

Pre-Cambrian Rocks
- Schists

A brief description of each of these formations follows beginning with the oldest and proceeding to the youngest in the order of their deposition.

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks which are exposed in the southern part of the Black Hills are largely schists in which muscovite is a predominating mineral. Some fine-grained slates are also encountered and a few dikes of granitic rock injected from volcanic sources.

Four wells drilled in the county furnished samples from the top of the pre-Cambrian group. None of them entered these rocks more than a couple of feet as they were drilled for oil or water.

The most westerly of the four was drilled for the army ordnance depot near Provo, (T. 10 S., R.2 E.). Here the pre-Cambrian rock was a biotite granite. About 24 miles southeast of the Ordnance Depot well, the Amerada Petroleum Company drilled the Moody well into the pre-Cambrian in T. 12 S., R. 6 E. A core from these rocks showed them to be granite of volcanic origin. About 24 miles straight east of the Moody well, the Amerada Company drilled another well to the pre-Cambrian on land owned by Red Eagle. This well is just east of the Fall

River county line. Again volcanic granite was encountered. A third well drilled by the Amerada Company about five miles east of Oelrichs encountered mica schists which were cut by granitic intrusions.

From these four wells it is evident that the pre-Cambrian rocks underlying Fall River county are much like those exposed in the core of the Black Hills. The volcanics encountered appear to be like those injected into the schists in the area south of Custer. It is not certain, however, whether these granites indicate a single large mass of granite underlying a large part of Fall River county or a number of smaller injections like the dikes which intrude the schists in the outcrops near Custer.

Encountering either schist or granite in drilling, however, is an indication that the pre-Cambrian rocks have been reached. This marks an important horizon since all sedimentary rocks lie above this horizon and it is inadvisable to search below it for either oil or water.

THE PAHASAPA FORMATION

Of the eleven wells shown on the subsurface cross-section plate, three showed the Pahasapa formation lying directly on the pre-Cambrian. In three others the Pahasapa was penetrated and three were not drilled to a sufficient depth to reach it. In two southeasterly wells the Pennsylvanian Minnelusa formation rested directly on the pre-Cambrian showing that the Pahasapa was missing in this part of the county. This evidence is sufficient to make the assertion that it will be encountered beneath the entire county except the extreme southeastern corner.

In the outcrops it is a dense massive limestone. The color of the fresh rock is light gray but on weathering it often darkens to a dove color, a buff, or even a white. A little chert is reported from the upper part of the formation in some places, but it is not in sufficient quantities to be an important part of the formation. In the well at the Black Hills Ordnance Depot, the cuttings showed a white and pink limestone, partly recrystallized, and also some dolmite. The Moody well gave Pahasapa cuttings that showed a cream-colored lithographic limestone much blotched with pink dolomite and calcite (Baker, pp. 75 and 86). It is evident, therefore, that the character of the rock is not much changed in various parts of Fall River county.

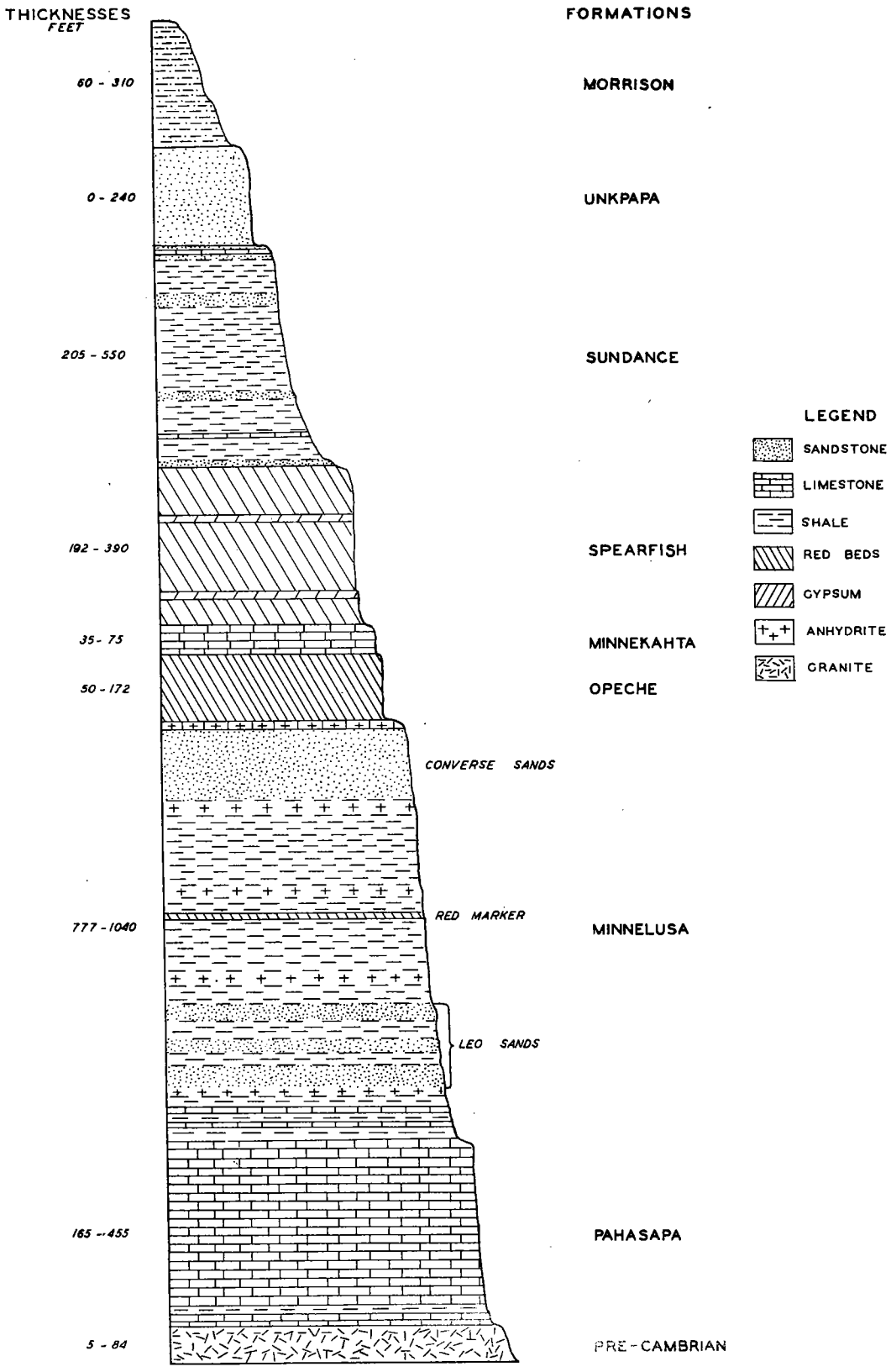
A feature of this formation which makes it of interest to all prospectors is the cavernous character of much of it. Many large caves are found in the outcrops in the Black Hills including such caverns as Wind Cave. Smaller openings, including holes a fraction of an inch in diameter and small cracks, make the rock very porous in many sections. The Continental Oil Company's State #1 encountered a cavern into which the drilling tools fell and which could not be filled with cement or other materials sufficiently to allow drilling to continue. Most of the wells drilled into this formation in Fall River county had trouble because of lost circulation. The drilling mud was forced into the holes in the formation instead of rising to the surface around the drill stem. In some cases this amounted to only a small annoyance while in others it made serious interludes on drilling time or even stopped the well entirely as in the case of the State well mentioned above. It is interesting to note that this porosity was found in the Moody well at the extreme southern end of the county at least 30 miles from the place where the formation outcrops in the Black Hills. Apparently depth of burial and distance from outcrops have nothing to do with this character.

In the descriptions of the formation in the Black Hills, thicknesses of 400 to 600 feet are given for the Pahasapa (Darton). No such thicknesses seem to exist in the formations beneath Fall River county, however. Three wells which penetrated to the underlying pre-Cambrian rocks gave the following thicknesses:

Moody # 1.....165 Ft.
Black Hills Ordnance Depot.....275 Ft.
Shiloh Well.....465 Ft.

The formation is cut out entirely in the southeastern corner of Fall River county. In the Vorhees and Red Eagle wells the Pennsylvanian-Minnelusa formation rests directly on the pre-Cambrian granite. With the exception of these two wells, however, the Pahasapa appears in all wells drilled in Fall River county to a sufficient depth. It must, therefore, underly the entire remainder of the county. In general, it appears to thicken to the west and north. The unusual thickness listed above in the Shiloh well, however, is not as reliable a figure as those in the others quoted because the Shiloh was drilled many years ago and cuttings were not collected as carefully as in more recent wells. The other wells mentioned were carefully logged and are, therefore, a much more accurate record of the thickness of the formation.

SUBSURFACE FORMATIONS IN FALL RIVER COUNTY



PLM

MINNELUSA FORMATION

In Fall River county the Minnelusa formation is exposed in a small area west of Hot Springs. In the older reports of this area (Darton) the formation is called the Minnelusa sandstone because a large part of the outcropping formation is sandstone separated by beds of shale. Some thin limestones occur in the upper part. The following section was taken in the bluffs of Hot Brook canyon.

Section of Minnelusa Sandstone
on Hot Brook, South Dakota
(Darton p.3)

	Feet
Red Opeche sandstone at top.....	
Gray limestone.....	10
Soft red sandstone.....	20
Limestone breccia, red to buff matrix.....	15
Yellow arenaceous limestone.....	15
Red limestone.....	5
Yellow arenaceous limestone.....	5
Red arenaceous limestone.....	5
Gray limestone breccia, red matrix.....	15
Red sandstone.....	25
Greenish-gray limestone.....	5
Soft red sandstone.....	50
Gray limestone.....	10
Red sandstone.....	10
Gray sandstone.....	10
Red sandstone.....	6
Red shale.....	30
Pale-red sandstone, thin coaly shale partings.....	20
Light-buff and gray sandstone.....	15
Breccia.....	3
Reddish-gray sandstone.....	25
Green shale.....	1
Gray to buff sandstone.....	12
Black shale.....	2
Light-buff, soft sandstone.....	15
Dark shale.....	2
Soft white sandstone.....	15
Gray calcareous sandstone with coaly shale partings	30
Total.....	376

Underground, however, in all wells that have penetrated it, both north and south of the mountains, the formation has been found to contain considerable beds of anhydrite.

In most of the outcrops this anhydrite has been leached out leaving only a brecciated zone between sandstones to indicate its position. From the well records it appears that sandstone makes only about half of the formation. Limestone and dolomite and shale make the largest part of the other half while anhydrite occupies the rest of the interval. This formation has the typical alternations of sand, lime, and shale which is so characteristic of the Pennsylvanian system. Certain horizons have been recognized, however, and are important in oil prospecting in this region since they have given shows of oil and gas here and elsewhere.

Converse Sand Horizon

The Converse sand lies near the top of the formation. It is usually designated as the one which is first encountered after leaving the Opeche redbeds. Its thickest sections appeared in the Childers well where about 18 feet were measured. In the Ordnance well only about half that amount was encountered.

The Red Marker

The Red Marker is a zone of red shales lying about 500 feet below the top of the formation. It is usually not very thick, but serves to indicate that Leo sands are being approached.

Leo Sand Horizon

The Leo sands are a series of thin sandstones three or four of which are prominent enough to be noted and given numbers by drillers. In most well logs these have been separated by anhydrite beds. Oil was found in the anhydrite at the Ordnance well and the sands have given shows of oil at several other wells drilled in the county. To date these Leo sands are the most promising oil horizons in the formation. The thickness of the Leo sand zone is not well defined. In the Ordnance Depot well, which gave the most accurate record, a thickness of 170 feet was found.

Basal Laterite

The Basal Red shale zone is a good marker for the base of the formation. It is not everywhere present, however. Where it does occur in the outcrops, it is some 25 feet in thickness. Where it is not present, it is sometimes difficult to determine the lower contact of the formation because of the numerous lime beds in the base of

the Minnelusa. The shale beds become rather thin and the formation appears to grade into the underlying Pahasapa limestone. The thickest section of these lateritic beds in Fall River county was recorded from the Moody well where 100 feet was assigned to this zone. It is described as red clay, cream and red-colored sandstone, and some chert. The thinnest section is recorded from the Ordnance Depot well where thirty feet of pink limestone, pink and red sandstone, and mudstone are assigned to it.

On the outcrops it is usually a smooth red shale which is supposed to have been deeply weathered and leached. This process produced a laterite, a clay high in iron which accounts for the red color. The persistance of this zone makes it a very useful marker.

OPECHE FORMATION

Above the Minnelusa formation lie two redbed formations separated by a dense, thin limestone in the outcrops in the Black Hills. This redbed series is extremely useful in drilling in Fall River county as it forms a horizon which is impossible to miss. Not only the cuttings but the drilling mud becomes red and the formations are so thick that it is impossible for other materials to mask the red color.

The lowest and thinnest of the two redbeds is known as the Opeche formation. It and the dense limestone formation overlying it, the Minnekahta formation, have been assigned with some question to the Permian system.

The Opeche formation is characterized by red sands and sandy shales which on the outcrops show a dark maroon shade. Beds of gypsum or anhydrite may be encountered, but they are not abundant.

In the outcrops near Hot Springs the formation is assigned a thickness of 115 feet. Thicknesses encountered in Fall River county wells, however, vary somewhat from this figure. In the Moody well at the south end of the county, it measures 120 feet. The greatest thickness was encountered in the Black Hills Ordnance Depot well where 173 feet was penetrated. The most northerly well in the county, the James Bell #1, showed 130 feet of this formation. The thinnest section appears to be in the Shiloh well where only 75 feet could be assigned to the Opeche. This rather uniform thickness, however, seems to persist,

as the most easterly well, the Vorhees, shows 135 feet as does also the Red Eagle well, a short distance east of the county line.

THE MINNEKAHTA FORMATION

This is a solid gray limestone which is about 50 feet thick on the outcrops and which is very persistent in the Black Hills region. It has been encountered in all wells drilled in Fall River county. An outcrop of fresh rock appears to be massive, but weathering brings out a fine bedding which is almost laminated in places. It breaks, characteristically, into slabs along these bedding planes. When freshly broken, it gives a strong petroleum odor. The density and gray color make cuttings of this formation easily recognizable.

The 50 foot average thickness given on the outcrops is uniform over all of Fall River county. The thinnest section was encountered in the Vorhees well where only 35 feet penetrated the formation. The Moody and Ordnance wells give 50 and 54 foot thicknesses, respectively, and in the northern part of the county in the Childers well, it measured 45 feet. The thickest section was encountered in the Bell well where 75 feet was measured.

Unlike the underlying Pahasapa formation, this is not a cavernous limestone. Caves are found in it on the outcrops near Hot Springs where solution seems to be active. However, no trouble with loss of circulation was encountered in the wells drilled through the Minnekahta in Fall River county.

THE SPEARFISH FORMATION

The uppermost of the two redbed formations that are encountered in drilling this county is the big Spearfish formation. It is well exposed in the Red Valley north of the Dakota hogbacks. Its outcrops encircle the entire Black Hills. It is ordinarily assigned to the Triassic system though there is some question as to where the line between the Permian and the Triassic beds should come. Some would like to place it in the Spearfish formation. It correlates with the Chugwater Redbeds in Wyoming and is much like them in appearance.

The formation is composed of sandstones and shales of a brick red color which distinguishes it from the underlying maroon Opeche formation. A prominent feature of the outcrop is gypsum which, because of its white color, stands out in sharp contrast to the red sands and shales. Gypsum occurs in many beds varying from less than an inch to ten feet in thickness. There are also many stringers and veinlets of gypsum which cut across the bedding.

Just how these outcrop characters carry underground is not known, but the color is very readily identified in well cuttings, and beds of anhydrite show through the entire formation. No attempt has yet been made to correlate individual anhydrite beds, however.

In the Edgemont folio the thickness of the Spearfish is given as 400 feet. The thicknesses obtained from well cuttings in Fall River county, however, are not so great. The thickest one registered is in the Childers well where 375 feet was penetrated. This is nearest the mountains and it may be that the formation thickens northward toward the Red Valley. The Bell well nearby showed 390 feet of the same formation.

The formation apparently thins toward the south since the three wells drilled near the southern boundary of the county showed about 200 feet less of the formation. The Gertrude Schmitt well near Ardmore encountered 200 feet; the Moody, 12 miles east, 192 feet; and the Red Eagle outside the county line, 240 feet.

The east-west line of four wells crossing the center of the county gave thicknesses similar to those along the southern edge. The thickest of these was found in the Ordnance well which is the farthest west. There 337 feet were penetrated. The Government and Shiloh wells gave 235 and 265 feet, respectively, and the Vorhees well near the

east county line, 290 feet.

These beds have been very important as horizon markers, but have never given any indication of either oil or gas in any of the wells drilled in Fall River county.

THE SUNDANCE FORMATION

The Jurassic system is represented by three formations in Fall River county. In order of their deposition they are: the Sundance, the Unkpapa, and the Morrison. Of these the Sundance is the thickest and the most interesting as it has been a source of oil and gas in neighboring states. It is characterized by an alternation of thin limestones and sandstones with thick beds of green shale intervening. The green color is a very diagnostic feature of this formation and some of it, at least, is due to the presence of glauconite.

This is a shallow water marine formation and, therefore, is characterized by numerous beds of oysters and other mollusks. Some of the sandy layers are calcareous and carry a rather abundant fauna. On the outcrops the sands are characterized by an abundance of belemnite quills. Fragments of these fossils, glauconite pellets, and green shales are the chief indicators of this formation in well cuttings.

The Sundance formstion outcrops on the escarpment faces of the hogbacks, in the vicinity of Hot Springs and westward. The outcrops cut a large "V" in the north central part of the county, nearly reaching the Cheyenne river at the old town of Cascade Springs not far from the Continental Oil Company's well. It is found underground in all the wells that have been drilled thus far.

A typical section of the outcrop near Minnekahta was published in the Edgemont folio.

Section of Sundance Formation
Near Minnekahta Station, South Dakota
(Darton, p.4)

	Feet
Morrison shale at top.....	
Limestone with many fossils.....	3
Buff to gray sandstone.....	5
Dark grayish-green shales with thin fossiliferous layers and a four foot bed of buff sandstone near its base.....	100
Red sandstones, mostly soft, partly massive, with a thin mass of gray shales in middle.....	75
Pale greenish-buff, thin-bedded sandstone, ripple-marked.....	10
Pale grayish-green shales.....	10
Buff sandstone, flaggy and ripple-marked above, massive below.....	35
Fissile gray shale.....	45
Red sandstone, coarse, massive, fossiliferous.....	20
Buff, brown, and red sandstones, thin-bedded above, lying unconformably on Spearfish redbeds..	5
Total.....	308

The thickness of the Sundance given in the Edgemont Folio is 308 feet. In the wells drilled in Fall River county, however, thicknesses vary considerably from this figure. Wells to the west and south give the thickest sections and those on the east, the thinnest. The thickest section recorded was in the Schmitt well north of Ardmore where 550 feet of sediments were assigned to this formation. The Moody well 12 miles east of the Schmitt gives only 423 feet. The Ordnance well at Provo and the Childers north of Edgemont give 437 and 425 feet, respectively. In the extreme east the Vorhees well near Oelrichs gave 260 feet and the Red Eagle, just east of the Fall River county line, 255. The State Agricultural well about 15 miles south-east of Hot Springs gave only 305 feet.

THE UNKPAPA FORMATION

Probably the showiest formation in the section is the Unkpapa sand. This is always light-colored running from snow-white and pastel grays to light yellow and lavender. The famous calico sand quarried at Buffalo Gap belongs to this formation.

The Unkpapa is patchy both on the outcrops and in wells. In some outcrops it cuts through the Morrison until it nearly obliterates it, while in other places it is missing entirely. It has been interpreted as a dune formation and this may account for its rapid thickening and thinning. It will also account for the cleanness of the sand which composes it. It is always poorly cemented and disintegrates easily upon exposure.

The maximum thickness on the outcrops in the Edgemont Folio is 100 feet. In the 11 wells drilled only five showed this formation. Those in which it was identified showed considerable variation: the Moody well, 28 feet; State Agricultural College well, 25 feet; the Vorhees well at Oelrichs, 95 feet; the Childers well at Edgemont, 30 feet. The thickest section was in the Government well drilled in the Piney Hills 20 miles west of Edgemont where 240 feet were assigned to this formation. Part of this, however, may be Morrison.

Because of the variability of the thickness and position of this formation, it is not possible to say where it might be encountered in drilling Fall River county. Spots of it have been found at various places over the entire county, but it has also been absent in enough wells to show that its presence at any location is unpredictable.

THE MORRISON FORMATION

The Morrison formation is a wide-spread set of sediments lying unconformably on the Unkpapa and Sundance and under the Lakota. It is terrestrial in origin and in some places in the Rocky Mountains is famous for its dinosaur remains. Some reptilian remains have been collected from it north of Rapid City, but so far as is known, none have appeared in the southern end of the Black Hills. The formation is described as being "massive shales or hard clay, mainly of light gray or pale greenish-gray color, but, generally, also red or maroon with occasional layers of fine-grained sandstone." (Darton) In the Ordnance Depot well at Provo it is described as light gray, brown, and lavender clays; gray silt; light gray, green, and brown bentonite; and some light gray fine sandstone. In the State Agricultural College well, near Hot Springs, light yellow and leek-green mudstones, brown-red siltstones, and buff and cream sandstones were added. (Baker)

This formation is much more persistent than the underlying Unkpapa and is found in all the wells drilled in the county. In the Edgemont Folio (Darton) its thickness is listed as 0 to 125 feet. Cuttings from the wells, however, show thicknesses up to 310 feet, and a minimum thickness of 60 feet, with the exception of the Government well in which it was not possible to distinguish Morrison and Unkpapa.

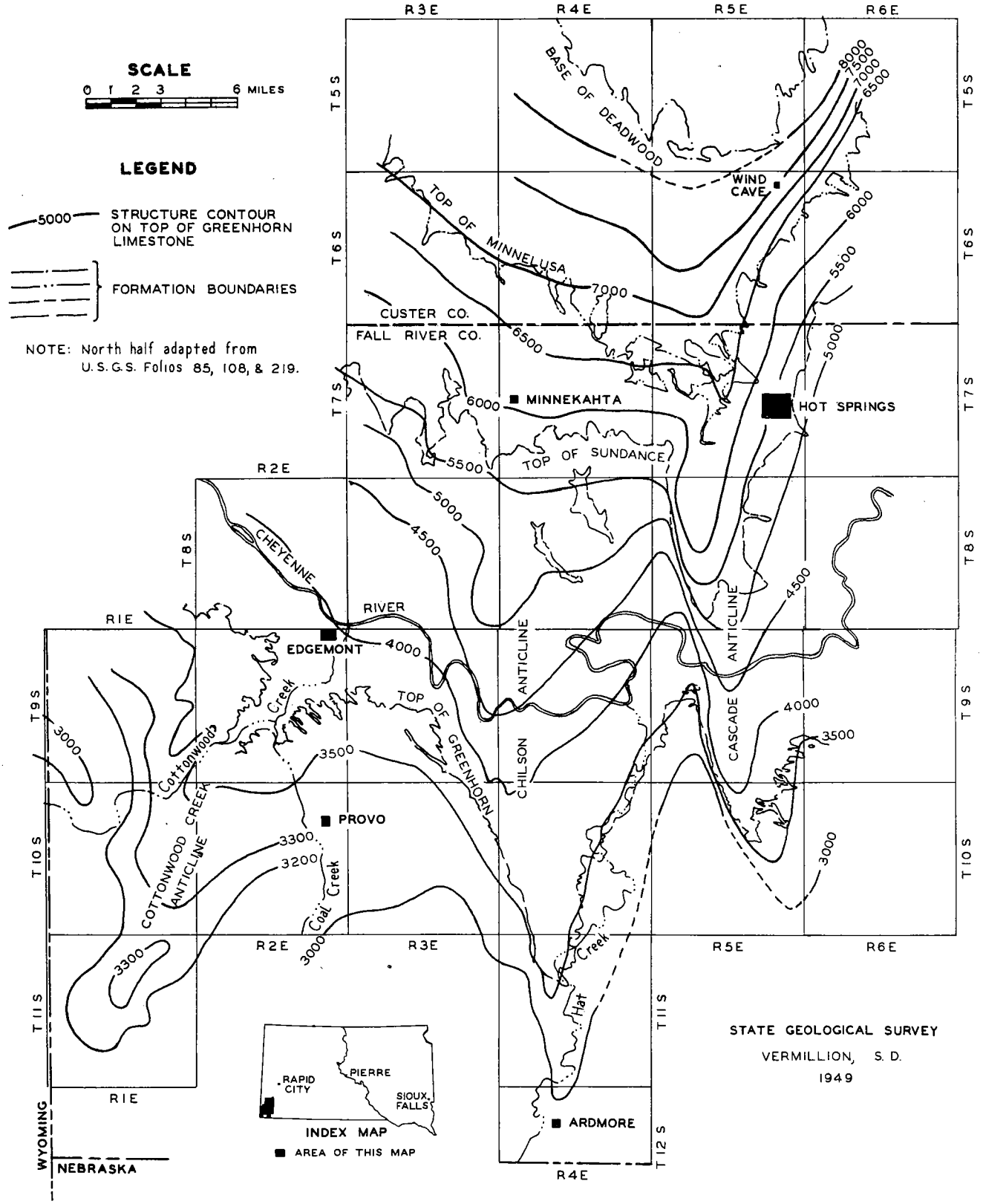
In the northern part of the county the Bell well gave 310 feet, the State Agricultural College well, 290. The State #1 drilled by the Continental Oil Company and located between these wells, however, showed only 80 feet. Farther south, at Provo, the Ordnance Depot well showed 150 feet, yet the Shiloh well immediately east of it showed only 60, while the Vorhees well at Oelrichs gave 220 feet. In the southern tier of wells, near the state boundary, the Schmitt well gave 60 feet, 12 miles east the Moody gave 240 feet, and 40 miles east of it the Red Eagle showed 105 feet.

THE LAKOTA FORMATION

Though the Lakota is underground in nearly all the wells drilled except the Bell and State wells, it was described above as a surface formation since it outcrops in the hogbacks surrounding the mountains.

Its underground thickness in Fall River county varies from 100 to 230 feet, the thinnest section being in the Ordnance well at Provo and the thickest in the Childers well north of Edgemont. The most easterly well, the Vorhees, showed 120 feet while across the county border the Red Eagle gave 135 feet. At Ardmore the Schmidt well gave 150 feet.

STRUCTURE
OF THE
SOUTH END OF THE BLACK HILLS



STRUCTURE

The dominant structure in Fall River county is a strong southward dip of all beds off the southern end of the Black Hills. Imposed on this dip are three plunging anticlines which spread away from the southern end of the mountains like a great turkey track. The most easterly is known as the Cascade, the central and longest as the Chilson, and the western as the Cottonwood Creek Anticline. Outside of the mountains the axis of the first two structures trend north and south. That of the third, however, extends southwestward.

CASCADE ANTICLINE

Only part of the Cascade Anticline is included in the map accompanying this report. North of the Cheyenne river the structure can be followed into the mountains at least as far as Hot Springs. This portion, however, was not of interest in the present investigation. South of the area mapped, the structure is lost in the thick shales of the Pierre formation in which key beds are not sufficiently conspicuous to allow surface mapping. The dips seen at the southern end of the area mapped indicate that the structure should continue southward for some distance.

As shown in the accompanying map, this portion of the structure is a plunging, asymmetrical fold approximately nine miles in length and five miles in width. The axis lies near the western flank and trends directly south from the Cheyenne river for three miles, then turns to a southeasterly direction. The southeast trend was followed for five miles before it was lost in the shales of the Pierre formation.

The steeper side of the fold is on the west where the formations have a dip averaging about 30 degrees. This dip is very persistent along the entire western flank of the structure. It flattens but little where the structure is lost under the Pierre formation at the southern end and is much steeper north of the Cheyenne river in the vicinity of Cascade Springs where it approaches 90 degrees. The following dips were measured on this flank:

On the eastern flank of the anticline the dip is more gentle. This dip, averaging about three degrees, starts directly over the top of the fold. The direction of the dip is east and southeast. The following dips were recorded on this flank:

SE¼ Sec 3, T10S, R5E; dip 3°, S65°E.
SW¼ Sec 30, T9S, R16E; dip 4°, S82°E.

At one point four miles south of the Cheyenne river (Sec. 34, T. 9 S., R. 5 E.) the axis of the fold rises 1450 feet above the lowest portion of the syncline which separates the Cascade from the Chilson Anticline. The horizontal distance between the bottom of this syncline and the axis of the Cascade Anticline to the east is a mile and a quarter. Although the dip on the east flank is more gentle, it continues until the high point of the structure is more than 1200 feet above the lowest part of syncline mapped. To the south there is a slope of 1450 feet in the direction of the plunge of the anticline.

The uniform plunge of the axis is broken by a pinch at the northern end which forms a saddle in the structure. North of this saddle a bulge occurs. Unfortunately, an area of poor outcrops made it impossible to map the structure with extreme accuracy at this point, but sufficient information is available to be assured of a closure of at least 50 feet. This makes a dome on a larger structure with an area of about a square mile.

This part of the Cascade structure, therefore, presents a fold with a very sharp west flank, a small reversal on the top, and a large collecting area to the south and east. A shallow well was once drilled near the top of it but the record is lost.

CHILSON ANTICLINE

The central fold lies along Hat Creek and is usually designated as the Chilson Anticline. Because Hat, or War Bonnet Creek, lies just east of its crest, it also has been called the Hat Creek Anticline. Its axis runs directly north and south through the city of Ardmore. It starts in the mountains, at least as far north as the Red Valley, and appears in the outer "hogbacks" of the Black Hills. The axis proceeds southward in a series of steps.

South of the Cheyenne river the axis plunges 500 feet in less than four miles, then flattens out on the first tread to a plunge of only 100 feet in the next four miles. At the southern end of this tread is a dome covering about two and a-half sections and having a reverse (north) dip of at least 100 feet. South of this closure, a steeper plunge of 150 to 250 feet to the mile carries the axis of the fold down to the second tread which occupies parts of sections 32 and 33, T. 10 S., R. 4 E., and sections 4 and 5 of T. 11 S., R. 4 E. The plunge of the axis on this tread is about 80 feet per mile. Below this tread another riser extends for about a mile in which distance the axis drops 100 feet to a third tread which is about three miles long, extending from the middle of section 16 to the middle of section 32 of T. 11 S., R. 4 E. The plunge of the axis on this tread is about 65 feet per mile. Below the third tread the axial plunge again steepens to about 160 feet per mile and maintains this plunge at least as far as Ardmore where mapping was discontinued.

The Dakota sandstone, which outcrops at the Cheyenne river, lies 1310 feet below the surface in the Schmitt #5 well, a mile north of Ardmore. The average plunge of the axis of the Chilson structure, therefore, is 100 to 110 feet per mile. The axial plunge of the treads is considerably below this average and that on the risers considerably above it.

Like the Cascade structure, the Chilson Anticline is notably asymmetrical. All the dips on the west side are much steeper than those on the east except in the vicinity of Ardmore. These dips are easily seen in the Greenhorn formation which outcrops on the west side as a series of very sharp hogbacks, while on the east side there is a very gentle dip and no such topographic expression on the outcrop. The most striking of these hogbacks are in T. 10 S. where they have been well developed for a distance of more than five miles. North and south of this stretch the dips on both sides are more nearly alike, though the difference still persists in the north and can be seen in the

Dakota sandstone along the north-south reach of the Cheyenne river and the east side of Red Canyon. This flank can be seen extending northward almost as steep as the west flank of the Cascade structure and is finally lost in the hogbacks surrounding the Red Valley. Dips measured on the Greenhorn hogback showed the following:

NE¼ Sec 23, T9S, R3E, 7°
SE¼ Sec 18, T10S, R4E, 22°
NE¼ Sec 8, T12S, R4E, 6°

The dips on the eastern flank are much less steep. They have a tendency to steepen, however, toward the south so that in the vicinity of Ardmore the dips on both sides of the structure are nearly the same. The southern end is much more like the textbook type of anticline than the northern end. The following dips were measured on the east flank of the structure, two near the middle, and two at the southern end:

Sec 9, T10S, R4E, 3°
E side Sec 21, T10S, R4E, 3°
SE¼ Sec 16, T11S, R4E, 4°
SE¼ Sec 4, T12S, R4E, 6°

A small bulge on the west side of this anticline in the vicinity of Rumford is of interest since gas shows were encountered on it in the lower part of the Niobrara formation. A 3500 foot slope lies to the west of it, and behind it lies a steep flank of the Chilson Anticline. The flat top of the structure is a half mile to three-quarters of a mile across. Its area is about a square mile.

COTTONWOOD CREEK ANTICLINE

The Cottonwood Creek Anticline is the westernmost structure in Fall River county and is unlike the two described above both in axial direction and shape. The axis extends in a slight arc from the city of Edgemont toward the southwestern corner of Fall River county and its flanks slope gently in both directions. It covers a more extensive area than the two structures just described, occupying a large portion of three townships.

The northern end of the structure is well-marked in the Greenhorn cuestas along Cottonwood Creek. South and west of the point where this formation goes underground, however, it is not so readily seen. Elevations on the Niobrara formation and the big bentonite zone of the Pierre formation, however, outline the structure in this area.

It has two features which are worth the attention of oil prospectors. The first is a long shoulder extending up Cottonwood Creek along the axis of the anticline for five miles southwest of Edgemont. The Greenhorn limestone outlines this shoulder very nicely. It should be noted, however, that there are some small sharp faults on the western side which make that flank appear steeper than the eastern. These faults apparently are not of great extent as their length is less than a mile and their displacement less than 50 feet.

The second feature to be noted is a closure on the divide between Alum and Alkali Creeks. This part of the structure was mapped on the big bentonite bed in the base of the Pierre formation and its dips were sufficiently steep and persistent to rule out any great inaccuracy from slumping. A closure of at least 100 feet is indicated. The structure has a elongate top trending in a northeast-southwest direction. It starts in Sec. 2, T. 11 S., R. 1 E., crosses Sec. 10, and ends in the NE. quarter of Sec. 21.

It is not clear why the Cottonwood structure lacks the asymmetry so conspicuous in the Cascade and Chilson structures. The very steep western dips on these latter structures is missing from the entire length of the Cottonwood structure. It may be significant that the southern end of the Chilson structure is symmetrical and corresponds in that respect to the southern end of the Cottonwood structure. This would seem to indicate that a strong thrust was applied to the Black Hills north of the

Edgemont region probably causing a shearing thrust from the west, its intensity lessening toward the south. Such a force would not only explain the steep western flanks of the Cascade and Chilson structures, but also the direction of the axis at the Cottonwood Creek structure.

DRILLING FACTORS

RESULTS OF PREVIOUS DRILLING

Though a number of wells have been drilled in Fall River county, most of the structures here described are untested. In spite of the fact that they have not been on the best structural locations, however, nearly all the wells in Fall River county have given at least a show of oil or gas.

Oil excitement occurred in 1929 when a well near the mouth of Red Canyon in Sec. 17, T. 8 S., R. 9 E., four miles northeast of Edgemont, gave a show of oil. This well had been drilled four years before but had not been touched due to litigation in which it was involved. When workers exploded a shot in the hole preparatory to pulling the casing, the well filled with oil. Nothing came of it, however.

Interest was again aroused when the Woodward Oil Company of Denver, using the State Geological Survey's map of the Chilson structure as a guide, discovered a gas field in the vicinity of Ardmore in 1943. The gas was encountered in the Newcastle sand and was traced for at least four miles along the crest of the anticline. One well, the Gertrude Schmitt #4, was drilled into the Minnelusa formation but encountered no more oil or gas. Additional impetus was given to drilling by the discovery of a show of oil in a well drilled the same year to supply water for the Black Hills Ordnance Depot at Provo.

The well known as the Shiloh #1 was drilled on top of the Chilson Anticline in Sec. 20, T. 10 S., R. 4 E., about the time the Red Canyon well was causing excitement (1929). This well gave a few colors and finally reached the pre-Cambrian as shown on the well log sheet accompanying this report. Whether the axis of the structure at the oil horizon has shifted sufficiently far east to prevent a show in the Shiloh well is not known. However that may be, the Shiloh was drilled on top of the axis as indicated by surface mapping.

The Bell #1 well was started by a local company one mile north of the old Red Canyon well in Sec. 8, T. 8 S., R. 3 E., in 1944. This well eventually got into financial difficulty and was abandoned. A show of oil was reported from the Minnelusa formation.

Shortly after the Bell well was started, a well was drilled on the Childers ranch three miles north of Edgemont (1945). This well gave a show of oil and some gas from the Leo sands of the Minnelusa formation. It was never completely tested, however, so that its potential production is not known. Indications were, however, that the well was producing only a good show.

While the gas field was being developed at Ardmore, (in 1946), a well was drilled in what is known as the Piney Hills about 13 miles due north of Ardmore by Woodward and Morton. It appears to be on the east flank of the Chilson structure as shown by surface mapping. This well also gave a show of oil and gas from the Leo sands but swabbing failed to bring production and the well was abandoned as a water well.

The State #1 is the only well that has been drilled on these structures by a major oil company. This was drilled in 1942 by the Continental Oil Company near the crest of the Chilson Anticline north of the Cheyenne river, in Sec. 36, T. 8 S., R. 3 E. This location is six miles east and one-half mile north of the city of Edgemont. The well was drilled into the Pahasapa formation where the bit struck a cavern which allowed the tools to fall 30 feet. All efforts to plug the cavern failed and drilling had to be abandoned. No shows of oil or gas were reported.

The Nina #1 in Sec. 2, T. 10 S., R. 2 E., one mile northwest of Provo was drilled by a local company on the strength of the oil show in the Ordnance Depot water well. The Nina was located across the creek from the Ordnance well. Oil was encountered in the cuttings in the Minnelusa formation. Most of it, however, appeared to be within the anhydrite beds and it was impossible to make a producer out of it.

Two wells should be mentioned on which records are not clear. These were drilled many years ago and neither went to any great depth. The Conroth test, drilled about 1920 by the Norbeck Company in Sec. 3, T. 11 S., R. 1 E., lies 8 miles southwest of Provo and on the north flank of the closure described at the southern end of the Cottonwood Creek Anticline. This well is of interest as it is now making a little gas. No log has been available, but since it starts near the top of the Niobrara, it is assumed that the gas is coming from that formation.

The Dillon oil test, named after its promoter, was drilled between July, 1929, and May, 1930. It is located three miles north and one mile east of the Conroth test or six miles west and one and one-half miles south of Provo. It was drilled near the axis of the Cottonwood Creek Anticline, but went only 1568 feet ending in the Lakota sandstone or top of the Sundance. No oil or gas had been reported from this well.

POSSIBLE OIL HORIZONS

From the experience of these wells and the other deep wells drilled in the county farther east, it appears that two formations offer the best chance for oil production. The uppermost is the Sundance formation which is reported to have given a show in the Childers well. Other wells, however, failed to encounter either oil or gas in this horizon.

The second productive formation appears to be the Minnelusa. Two horizons in this formation should be watched for shows. The shallowest is a sand near the top of the formation which is correlated with the Converse sand of Wyoming. The horizon that has given the best shows in drilling so far, however, is the Leo horizon. This consists of several sands separated by shales and anhydrite beds and lies but a short distance below the Red Marker mentioned in the description of this formation.

The Pahasapa limestone, which should be a good reservoir rock because of its porosity, has thus given very little encouragement. Usually troubles with lost circulation have been sufficient to discourage penetrating it. It should be noted, however, that the wells that have been drilled through it were drilled with rotary equipment. It is possible that oil and gas may have been under low pressure and, therefore, mudded off by the drilling operations.

POSSIBLE DRILLING SITES

The usual practice of drilling tests on the top of structures in wildcat country will have to be practiced in prospecting Fall River county until enough drilling has taken place to disclose other controls for accumulation. In the case of the Ardmore gas field this seems to have worked out satisfactorily. The Shiloh well, however, was not so fortunate though its structural location appears to be considerably better. Neither the Cascade Anticline nor the Cottonwood Creek Anticline has been drilled with the exception of the Conroth well. It is, therefore, impossible to use experience as a guide there.

The asymmetry of the two eastern structures suggests that the axis may shift eastward with depth. The most logical location for wells on these folds, therefore, would seem to be on the highest part of the structures or on terraces indicated at the surface but slightly east of the surface axis, the distance depending on the depth at which the sands may lie.

The Cottonwood structure, on the other hand, does not show this asymmetry and wells could be placed with profit along the axis. The long shoulder three miles south of Edgemont in the bottom of Cottonwood Creek would seem to offer feasible prospecting sites. The closure at the south end of the structure in T. 11 S., R. 1 E. is symmetrical and an initial well could be located somewhere in Sec. 10 as that appears to be the top of the dome.

As pointed out above, with the exception of the drilling on the Chilson Anticline, none of these sites have been tested. The wells southwest of Provo did not go to a sufficient depth to constitute a test and no attempt to drill the Cascade Anticline has ever been made. Due to the shows of oil in the wells that have been drilled and the pronounced structures available, this county would appear to offer some interesting and profitable prospecting ground.

ACCESS AND WATER

Most parts of Fall River county can be reached over good dirt grades, and a trunk system of highways radiates from Edgemont. The Chilson and Cascade Anticlines are, therefore, very easily accessible over good roads.

The northern end of the Cottonwood Creek Anticline is also well supplied with dirt grades. The southern end is largely pasture land and can be reached only by traveling ranch trails which are in various stages of repair. In dry weather, however, this country is easily traversed over these roads, and tote roads can be made to almost any point in the area. Transportation is not a major problem.

Railroad access is available to the region over the Chicago, Burlington, and Quincy lines which run north and south through the central part of the county, reaching Ardmore, Provo, and Edgemont. From Edgemont the main line runs northwestward around the western edge of the Black Hills while a branch goes up Red Canyon to Deadwood.

Water for drilling is a more serious problem since water sources are few. Even the Cheyenne river, the master stream, is dry much of the time especially in summer. All the tributaries are likewise dry. However, small pools remain in most of them during much of the year. North of the Cheyenne and in the Cheyenne Valley it is possible to reach the Dakota sandstone without excessive drilling. This will furnish a sufficient supply of water for drilling purposes. The rapid plunge of the formation to the south soon carries it below the depth of practical drilling for water wells. Most drilling will have to depend on water impounded by dams in the smaller stream valleys.

DRILLING MUD

It should be pointed out that all the Cretaceous formations contain considerable bentonite. The bentonite zone in the base of the Pierre has been described and the bentonites in the Graneros have been mentioned. Most of the formations carry numerous thin bentonite beds and bentonitic material is incorporated in most of the shales. Until the Dakota formation is reached, therefore, there is little need for making a mud for rotary drilling. The formations themselves are sufficiently bentonitic to make their own mud.

From the Dakota down, however, the situation changes considerably and it may be necessary to add commercial thickeners in order to handle artesian water in the Dakota and Lakota formations and in the underlying Morrison and Sundance. Bentonites appear to be missing from the Paleozoic rocks entirely, and the driller should be prepared to thicken his drilling mud throughout the drilling of this group. It is well to be especially cautious in drilling the Pahasapa as this is a formation that has given the most trouble with loss of circulation.

CONCLUSION

This report has attempted to show that there is in Fall River county a considerable area that offers good prospecting at moderate depths. Enough drilling has been done so that it is not necessary to work in the dark. The stratigraphy is sufficiently well known to permit a tentative log to be made for almost any portion of the county. The surface structure is very pronounced and has been mapped in sufficient detail to locate the better prospecting areas. It may be possible to uncover other sites with more detailed mapping as terraces must exist in the flanks of these big folds, and small reversals may have been missed because of the large contour interval used. It would appear, however, that prospecting for oil and gas in this part of Fall River county has reached the stage where drilling can be carried on with considerable assurance and the area tested with a minimum number of wells.

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