STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 8

THE CASCADE ANTICLINE

by

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A REPORT

ON

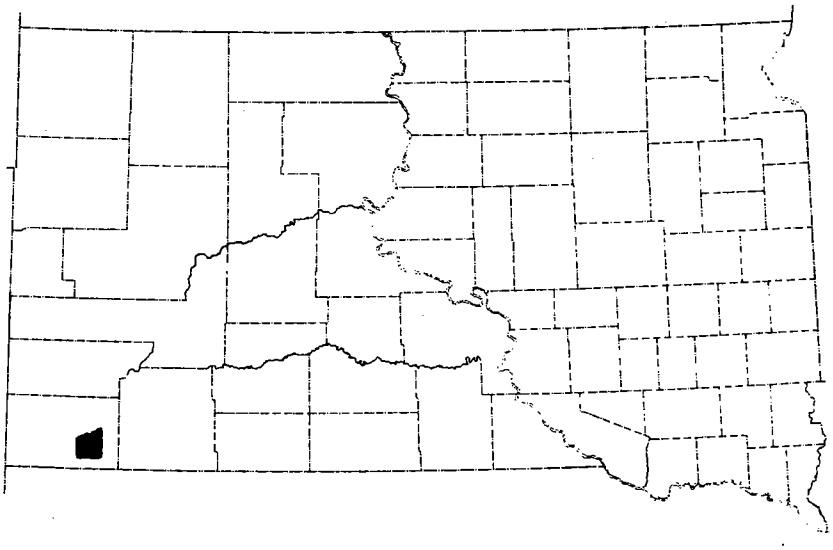
THE CASCADE ANTICLINE

BY

E. P. ROTHROCK

1930

INDEX MAP



■ Location of Cascade Anticline

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INTRODUCTION

PURPOSE OF THE SURVEY

It has long been known that the folds of the Black Hills extend under the Great Plains to the southward. It has also been known that these folds finger out like a great turkey track from the mountains proper. Reconnaissance maps have even been made of them (Darton, U.S.G.S. Folio 108 and 85, Oelrichs and Edgemont, Annual Report). The persistent demand for petroleum has led searchers into South Dakota, and many inquiries have been received by the State Geological Survey about the oil possibilities of these structures. The information available was of too generalized a nature to give satisfactory answers to most of these inquiries. This report and one on the Chilson Anticline have been prepared as an answer to these inquiries. It is the result of two months field work by a party consisting of the State Geologist and four advanced students from the Department of Geology of the University of South Dakota. It is hoped that the information contained herein will be of aid to producers in testing out the possibilities of these structures.

METHOD OF WORK

Mapping for both horizontal and vertical control was done with plane table, the elevations being run from bench marks set by the U. S. Geological Survey. The intervals between key beds were computed at favorable places from the width of the outcrops and the angle of dip of the formations, as very few places offered sections of sufficient length to be measured directly.

ACKNOWLEDGEMENTS

The Survey was especially fortunate in securing the services of Messrs. M. E. Kirby, B. W. Heiss, R. W. Parrott, and L. K. Olson, whose painstaking work both on plane table and in the preparation of this report, maps, text and plates, made this report possible.

A word of appreciation is also due to the people of Fall River County who in many ways assisted in the progress of the work, by giving information and by numerous other courtesies.

LOCATION

The Cascade Anticline lies entirely in Fall River County. It is recognizable as a distinct fold almost directly west of Hot Springs and can be traced southward for some 20 miles. It lies in townships 7, 8, 9 and 10 south, of ranges 5 and 6 east. Its western flank crosses Cascade Creek at Cascade Springs, hence the name by which the structure is usually designated.

The present survey was concerned only with the southern end of the structure, namely that which lies south of the Cheyenne River, because this part allows for a greater number of possible oil sands than does that in the mountains. The Cretaceous rocks have been eroded from the top of the structure north of the Cheyenne River but have been preserved in nearly all of the part south. The area mapped covers about 40 square miles and contains the entire part of the structure underlying the Plains.

THE STRUCTURE

The part of the Cascade Anticline covered by this report is only a portion of the entire structure. From the Cheyenne River the fold can be followed northward into the mountains at least as far as Hot Springs. In the south it is lost under the thick shales of the Pierre Formation, for lack of conspicuous key horizons. The dips seen at the southern end of the area mapped, however, indicates that the structure should continue for some distance.

SHAPE OF STRUCTURE

As shown in the accompanying map, this portion of the structure is a plunging, assymetrical 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°. This steep dip is very persistent along the entire western flank of the structure. It flattens out little where the structure is lost under the Pierre Formation at the southern end. The following dips were measured:

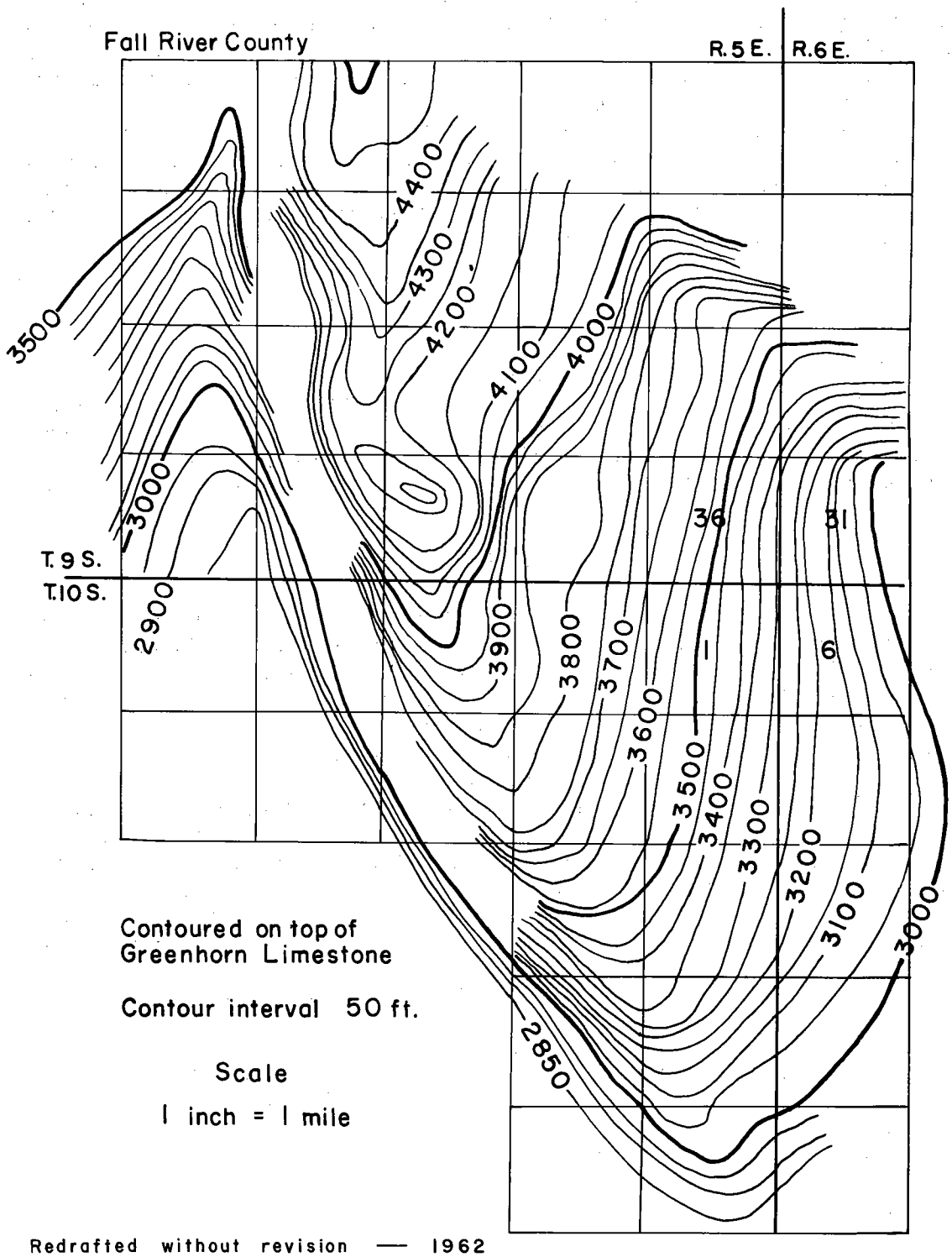
NW¼ sec. 28, T. 9 S., R. 5 E.	Dip 34°, West
SE¼ sec. 33, T. 9 S., R. 5 E.	Dip 33°, South 80° West
NW¼ sec. 23, T. 10 S., R. 5 E.	Dip 28°, South 65° West

On the eastern flank of the anticline the dip is more gentle. This dip, averaging about 3°, 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, T. 10 S., R. 5 E.	Dip 3°, South 65° East
SW¼ sec. 30, T. 9 S., R. 16 E.	Dip 4°, South 82° East

The axis of the fold at a point four miles south of the Cheyenne River, Sec. 34, T. 9 S., R. 5 E., 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 of it 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 the 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 which 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 the larger structure of an area of about a square mile.

STRUCTURE MAP OF THE CASCADE ANTICLINE.



Contoured on top of
Greenhorn Limestone

Contour interval 50 ft.

Scale

1 inch = 1 mile

Redrafted without revision — 1962
Beth Garnos, Draftsman

DRILLING SITES

Although many factors other than structure affect the location of oil and gas pools, it is the practice to locate tests on the tops of anticlines or domes in untried country. It has been found that the chances of success in such a location are far superior to that in any other part of the structure.

If such procedure is followed in testing the Cascade Structure, the best location should be on the dome which has just been described. Though this area is a small part of the structure, it has a fair closure and a large collecting area. The dips over the rest of the structure are too steep and too regular to make structural traps such as those in which oil and gas are usually found.

EXPOSED FORMATIONS

The formations exposed in the part of the anticline covered by this report all belong to the Cretaceous System. Underneath these, however, lie a series of Paleozoic formations which have been the source of oil in some Wyoming fields and have given showings in South Dakota. The generalized section is shown in the accompanying columnar section.

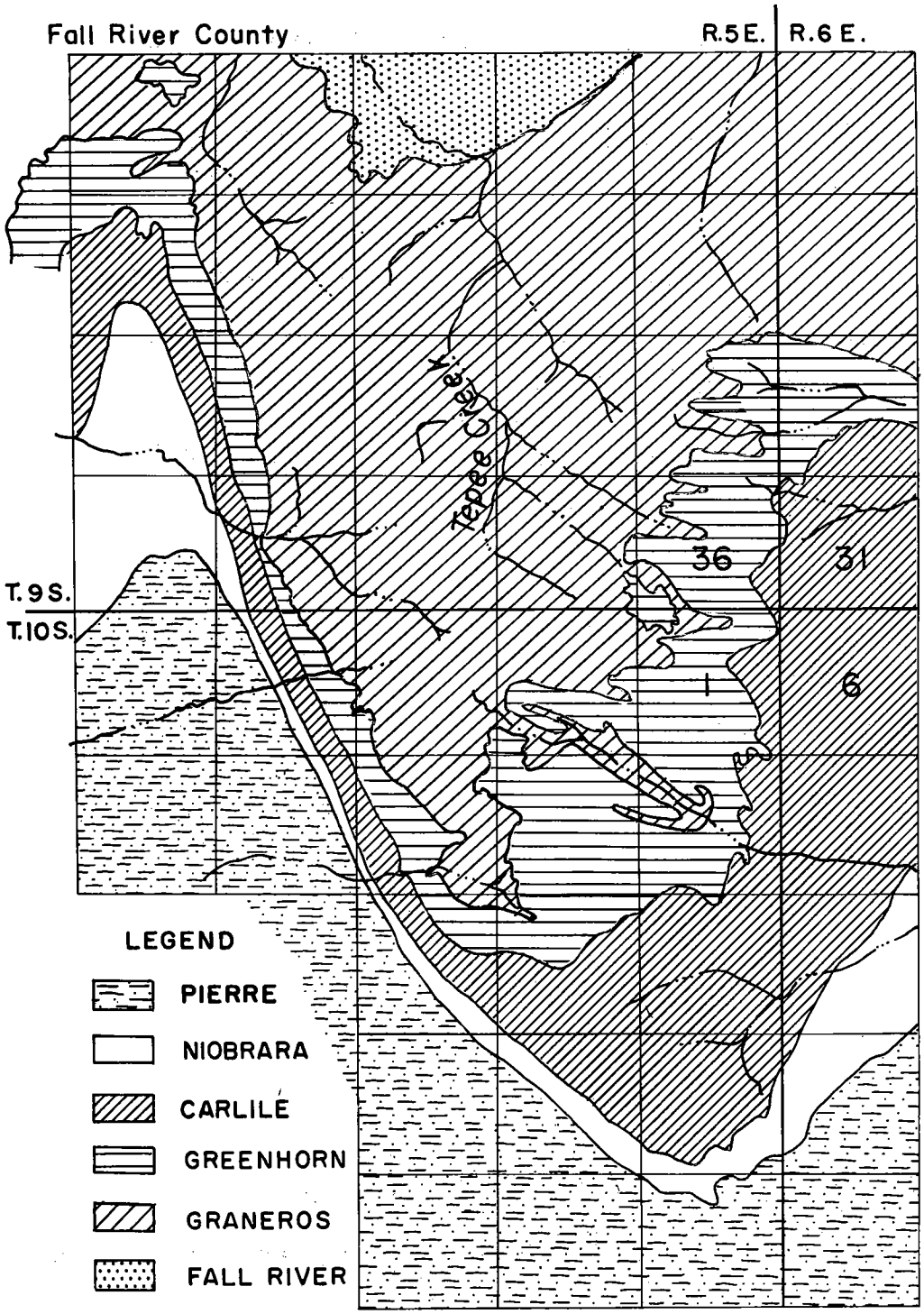
PIERRE

The Pierre Shale is the youngest formation exposed on the part of the structure mapped. It is a very thick formation (1500-2500 feet) composed for the most part of black shale which is well known for the stiff gumbo it makes when wet. This formation is so thick and of such a uniform character that it has been impossible to separate it into recognizable stratigraphic horizons. It completely surrounds the structure on the east, west, and south sides. The dips on the flanks and end of the anticline are concealed in the grassy slopes which it forms.

The lower 200 feet, however, contained bentonite beds and concretionary zones which could be easily followed and which enabled the mapping to be carried considerably farther than the top of the chalk rock. The following section taken in the S. E. $\frac{1}{4}$ of Section 33, T. 9 S., R. 5 E., gives a good idea of the character of the base of the formation.

7	ft.	Shale zone containing 3 ft. cone in cone concretions. Good horizon
80		Good Black shale
18		Black shale with 1-3 ft. concretions of lime. Dense, smooth, light gray limestone
0.6		Bentonite
2.6		Black shale
.9		Bentonite
6.1		Black shale
.8		Bentonite
.9		Black shale
1.3		Bentonite
.7		Black shale
.45		Bentonite
.7		Black shale

GEOLOGIC MAP OF THE CASCADE ANTICLINE



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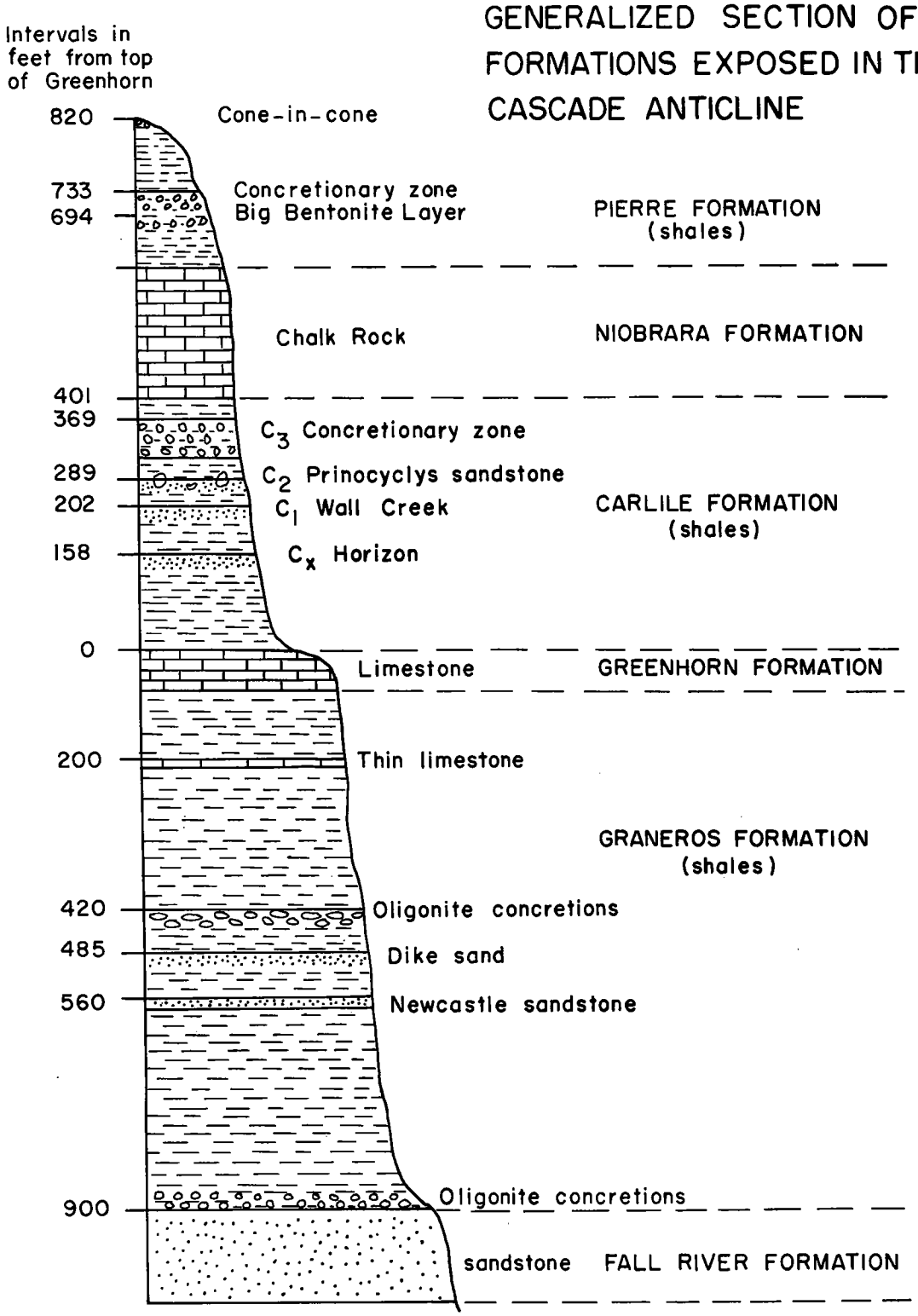
GENERALIZED SECTION OF FORMATIONS EXPOSED IN THE CASCADE ANTICLINE



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	.4	Bentonite
	1.4	Black shale
	.1	Bentonite
	.3	Black shale
	.35	Bentonite
	.3	Black shale
	.6	Bentonite
	2.6	Black shale
	3.8	"Big" Bentonite layer. One layer of concretions. Below this Bentonite bed marks bottom of the zone.
	33.0	Black shale
	.9	Bentonite
	16.0	Black shale
	.6	Bentonite
	11.0	Black shale
	.1	Bentonite
	1.0	Black shale
	.1	Bentonite
	3.0	Black shale
	.2	Bentonite
Pierre	8.0	Shale
Niobrara		Chalk

The zone of bentonite (ardmorite) is of interest because this clay has been used for many purposes. A plant for manufacturing it into a water softener has been in operation at Ardmore for several years.

Key Horizons

Though the Pierre Formation is notably lacking in key horizons in most places, four horizons were found in the lower 200 feet which could be traced with certainty.

The base of the formation lies on the Niobrara Chalk with little transition from one formation to the other. This makes a horizon which is easy to find because of the marked contrast between the black shales of the Pierre and the gray to white chalk of the Niobrara. The contact, however, is usually found in the lowlands for both formations are easily eroded into smooth slopes.

The Big Bentonite layer, as it was called by the field party, made an excellent key horizon. It is about four feet thick and exceedingly white or creamy in color, so that it is readily separated from the surrounding shales. It is considerably thicker than the other bentonite seams in this zone and could be followed wherever the Pierre was exposed in the area mapped. The top of this bed lies 79 feet above the base of the Pierre where measured in the S. E. $\frac{1}{4}$, Sec. 33, T. 9 S., R. 5 E., and this interval was used in contouring.

A third zone which was recognized but not used in this investigation was the top of a concretionary horizon 33 feet above the Big Bentonite layer. The shale in this zone differs little if any in general appearance from that of the rest of the formation. The distinguishing character is the presence of large irregular shaped but roughly rounded, concretions of light gray limestone. These concretions reach diameters of three or more feet though the average concretion is somewhat smaller.

The lowest concretions occur in a single layer immediately below the big bentonite bed and they are abundant from this layer to the top of the zone, 39 feet above. Most of the concretions lie in definite layers parallel to the bedding so that the impression of beds of concretions is very pronounced. Stray concretions above the top layer are very few.

The highest horizon marker that might serve as a key bed for this area is a zone of cone-in-cone concretions, which lies 46 feet above the top of the concretionary zone just described. It is not a thick zone and comprises only one or two layers of concretions. They are tan colored, as they appear on the surface and about two feet in diameter. The marked cone-in-cone structure and the color, which contrasts sharply with the surrounding black of the shales, makes this zone easy to trace. This zone can be used as a key bed, but some confusion may arise at certain places where the same kind of concretion occurs in short layers below it. Where exposed in the high bluffs at the south end of the structure the layer is easily traceable and can be followed with the eye for several miles toward the north and east.

NIOBRARA FORMATION

The Niobrara Formation lies in the valleys which surround the structure. It outcrops only in small areas and though its position can be easily traced, it does not make a very good key horizon because of its uniformity and covered contacts. Its character is much like that which is to be seen in the Niobrara of the Missouri Valley. The rock is predominantly if not entirely chalk of a light gray to white color. It weathers readily leaving a very white or a light yellow powdery residue.

There are no ledge-makers or other horizon marking features, in this formation. Its color, however, contrasts so sharply with the black of the shales of the overlying Pierre and the underlying Carlile that its top and bottom could be used for horizon markers where contacts could be found. As the thickness is 217 feet in this region it serves to give elevations at points where they are much needed.

CARLILE FORMATION

Darton (Darton, N. H., Artesian Waters in the Vicinity of the Black Hills, South Dakota), describes the Carlile Formation as follows: "The Carlile Shale, the uppermost of Benton age, consists of dark fissile shale that contains concretions, thin sandstones, and impure limestone layers lying between the Greenhorn Limestone and the Niobrara Formation. Near the top of the formation, numerous oval concretions contain Prionotropsis, Prionocyclus, and other fossils." A study of the formation shows that these generalizations hold for this region. The black shale, forming the bulk of the formation, is not unlike the shales of the overlying Pierre Formation and concretions and limy sand layers occur. The striking features of the formation are the black shales which form a matrix, three thin sandy ledge-making zones near the middle of the formation, and a thick zone of large round concretions in the upper part.

The sandy zones carry a fauna which is very prolific in places. In fact it is possible to find some kind of a fossil in them almost any place. They are most abundant, however, in calcareous patches in the sandstones. These are not typical concretions but are places where the formation of limestone exceeded the formation of sand. This process made slabs of nearly pure limestone in the sand.

The concretionary zone in the upper part of the formation carries large spherical concretions of lime, which are usually cracked, the cracks being drused with calcite crystals which look like veins until the concretions are broken open. No fossils were observed in the concretions or surrounding shales. This zone is very thick, measuring 53 feet in one section. In it the concretions are arranged in rows parallel to the bedding, much as were those of the concretionary zone in the Pierre. Four such zones were recorded from one section while but three were noted in another.

The following typical section will give an idea of the details of this formation:

Section of the Greenhorn-Niobrara, taken at the NW¼ sec. 28, T. 9 S., R. 5 E.

	Bottom of Niobrara
44 feet	Shale
53 feet	C_3 (upper) Note: C_3 is a concretionary zone with large (3') rounded lime concretions in black shale. Four distinct beds of these concretions occur at this place with a very few scattered concretions above the top layer.
35 feet	Shale
2-3 feet	C_2 (upper) Note: C_2 is a sandy horizon which is easily traceable. The sand is a dark tan to brownish color and is often limy. In the limy parts thin masses of limestone occur which carry an abundant fauna the most striking of which is a large Prionotropsis.
7 feet	Shale
2 feet	C_2 (lower--slump) Like upper ledge
46 feet	Shale
9 feet	C_1--Detailed section: 0.5' Coarse sandstone in 1 bed 6.0' Black shale 0.5-1' Coarse sandstone like above. 20-30 mesh, 1 bed ripple marks Black shale (couple feet) 2.0' Slabby buff sandstone mapped as C_1 Black shale
58 feet	Shale
1-3 feet	C_x Sand
158 feet	Shale
	Greenhorn

Key Horizons

Four horizons which could be used as key horizons were found in the Carlile. The three lower were ledges made by the sandy zones shown in the sections above. The fourth is the top of the concretionary zone in the upper part of the formation.

The lowest sand ledge-maker used, lies about 160 feet above the top of the Greenhorn Formation. It is local in occurrence or at least does not make sufficiently prominent ledges to be identified in many

places. Therefore, it does not make a very satisfactory key bed. The low ledges in the shoulders of the divides with a rubble of soft, white, to light-gray sandstone are its most common indication. In some places considerable numbers of small Prionocyclus from the size of a dime to the size of a quarter were to be found. The color of the sandstone and the presence of the fossils are the best indicators of this horizon. It is only a few inches to a foot thick, so far as could be ascertained.

The second horizon lies about 50 feet above the first. It is also a sandstone but weathers characteristically to a brown color. In this region it carries one and in some places two six-inch layers of a coarse sandstone near its top. It is quite conspicuous and serves to identify the horizon locally. It can be differentiated from a ledge of similar appearance which lies above it by the fact that it carries very few fossils. In most places exposed it is entirely devoid of them. This ledge and the one below it have the stratigraphic position of the Wall Creek Sands which produce in the Wyoming oil fields.

The third ledge-maker which might be called the Prionocyclus ledge is a thin brown sand which weathers characteristically into thin slabby layers. In thickness it varies from a foot to three or four. At no place is it very thick. The striking feature of this sand is the abundant fauna which it carries in all outcrops. The large Prionocyclus are abundant enough to form a good means of identification though there are also Scaphites, Inoceramus, and gastropods in abundance. These fossils occur in limy parts of the sandstone. In places the sandstone contains only a little lime with a few fossils embedded in it while in others, the lime increases until it forms a mass several feet across which is composed entirely of shells. This layer is remarkably uniform in color and thickness over the entire area mapped. Its chief variation is in the fossil content which varies from place to place. At some places the ledge must be followed for as much as 100 feet before the fossils can be found while in other places fossils abound nearly the entire length of the outcrop.

Where it has been folded into steep dips and on narrow stream divides it forms good, easily traceable outcrops but in other places it tends to weather easily into the slopes. Even with this handicap, however, it is the most reliable of the Carlile ledge-makers for mapping, for it is persistent and can be easily recognized. It was known as C_2 during the course of mapping.

The highest of the Carlile ledge-makers is a zone of large round limestone concretions from one foot to five or six feet in diameter. The concretions lie in rows or layers in a matrix of black shale which has the same appearance as the shale of the rest of the Carlile. There is a general tendency for the concretions in the lower part of the zone to be gray in color while those in the upper layers may be buff. On the western side of the Chilson Anticline the top is composed of small gray concretions one foot or less in diameter. All the concretions have been cracked and the cracks carry druses of calcite with an occasional barite crystal. The calcite may be white, yellow, or brown and often lines the cavities in geode-like fashion.

The number of layers of concretions in the zone varies. In some places as few as three distinct layers were observed while in others four were very evident. Few concretions strayed from the layers. The zone is thick and its thickness varies considerably. It is, therefore,

not a good horizon to use as a key unless others cannot be found. When the zone forms the surface of a slope or top of a ridge, it is then a difficult matter to determine which part of the zone is exposed. The variations in thickness and number of layers is well brought out in the Carlile section given above. This zone was indicated as C_3 in mapping.

THE GREENHORN FORMATION

The Greenhorn Formation is the most prominent formation in the section exposed, for it surrounds the structure in the form of a horseshoe. It stands up as high hogbacks on both flanks and at the south end. The pitch of the fold is so great that the hogbacks trend away to the east and west, leaving the north end of the horseshoe open. Because of its uniformity and the fact that it is so conspicuous, the Greenhorn was used as the datum in contouring the structure.

The Greenhorn displays the same general characters in this region as it does in other regions in the Black Hills from which it has been described. It is composed almost entirely of slabby limestone, gray on fresh surface, but weathering to a buff 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.

Perhaps the most notable characteristic aside from the composition of the rock is the abundance of fossils. The beds are full of shells of the pelecypods Inoceramus Labiatus. In fact some beds are made entirely of these shells. This fossil occurs in other Cretaceous formations in the vicinity but no where in such striking abundance as in the Greenhorn. Some shales are to be found near the base of the formation which must be included in it because they separate limestone sections which are identical in character of rock and fossil content. These are well shown in the following section:

Section of the Lower Greenhorn Limestone

Location: Sec. 14, T. 9 S., R. 5 E., Fall River County, South Dakota

9 feet	Shelly limestone which has the typical bedding and Inoceramus fossils. Beds 1/16--1 inch thick but bedding planes are irregular. This makes rock break into slabs $\frac{1}{2}$ - 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 inches	Massive limestone like above
1 ft. 3 in.	Limy shale, same buff color on weathering but is streaked with blue. Also contains shells
3 inches	Massive limestone with fossils
8 inches	Lime shells like top
4 inches	Massive limestone like top
2 ft. 3 in.	Limy shale of bluish cast
6 inches	Massive limestone
1 foot	Shelly limestone like above
3 feet	Blue shale, probably Carlile, bottom of exposure

The thickness of the Greenhorn in this region is about 60 or 65 feet.

THE GRANEROS FORMATION

The Graneros Formation underlies the Greenhorn in the slopes of the hogbacks mentioned above, and is exposed over much of the territory included in the center of the anticline in the region covered by this report. It occupies the hollow inside the horseshoe of the Greenhorn hogbacks. Striking topography is not developed on this formation, though some of its members make minor hogbacks and ridges. There are enough of these, however, to make topography on the Graneros quite rough. Deep valleys are easily cut in the shale unless the shales are protected by hard sands or concretionary layers.

The Graneros is another black shale formation, much like the Pierre and Carlile in general appearance. It can be divided, however, into three distinct zones, and contains several layers of limestone and sandstone, which make good horizon markers. The upper and lower zones are composed of black sticky shale, and between these lies a dark-gray siliceous shale, which sometimes has a silvery cast. This middle zone is usually correlated with the Mowry Member of the Graneros in the Rocky Mountain District. According to Russell (Russell, W. L., "The Origin of the Sandstone Dikes of the Black Hills Region", American Journal of Science XIV, 1927), the top member is 420 feet thick, the Mowry 150 feet thick, and the lower shale member 300 feet thick.

Both top and bottom limits of the upper zone are easily identified. The upper limit is marked by an abrupt change from the typical black shale to the buff or gray, very fossiliferous limestone of the Greenhorn Formation. The bottom is marked by a zone of oligonite concretions. These are large rather flattish concretions of manganese-bearing iron carbonate anywhere from a few inches to two or three feet in thickness, and ranging up to 10 or 20 feet across. In some places they make small pavements, while in others they are separated by several feet of shale. They disintegrate readily upon exposure, forming a black rubble of small angular pieces. Good exposures showing the thickness of this zone are very rare, though the top was easily found. The best information at hand indicates that it is at least 20 feet thick.

A limestone ledge-maker occurs about 250 feet from the top of the Greenhorn, which can be traced over a large area in the middle of the structure. The limestone is never more than five or six inches thick, and weathers out in smooth brown slabs four or five inches across and one-half to an inch in thickness. It resembles very much a limestone ledge found at about the same horizon on the Chilson Anticline farther west. In the southern end of the Graneros outcrop a second bed very similar to the limestone just described is found 50 feet higher. This limestone, however, contains numerous fossil oysters and though it weathers to about the same color, the slabs are not nearly so smooth on the surface. Its outcrop was not followed for more than about one mile, and consequently it was not used as a horizon marker. A section measured at the U.S.G.S. Triangulation Station gives the relation of these beds:

Section from the SE¼ section 3, T. 10 S., R. 5 E.

Feet	
	Greenhorn Limestone
202	Dark shale
1	Oyster-bearing limestone, weathers brown; layer of 2 feet, light gray, limestone concretions in shale beneath it
50	Dark shale
1	Gray limestone, weathers brown Horizon marker
254	

The Mowry member of the Graneros is characterized by siliceous shales, which often have a silvery cast and do not become muddy in wet weather. Its outcrop is marked by a growth of evergreen trees, which for some reason do not grow on the surrounding formations. The fish scales so prominent in this member in many localities are not so abundant here, though a search in almost any locality will reveal some. Its top is immediately below the base of the oligonite zone mentioned above, and its base lies at the top of a 30-foot sandstone member, which is evidently the Newcastle Sandstone of Wyoming. About the middle of the Mowry member is a soft yellow or white sand, which has been largely forced into cracks in the shale in the form of sandstone dikes. While the position of these dikes can be readily followed, they occupy too wide a zone in the formation to make this sand usable as a horizon marker. The Newcastle Sandstone is a gray or buff, loosely cemented rock. Good outcrops are rare, though the sandstone makes a very definite horizon. It occupies the floor of the structure over a considerable area. This sandstone is not a good marker, but can be used in the absence of better horizons.

The lower zone of the Graneros is exposed only in the extreme northern part of the area mapped. It is much like the upper zone in composition, but contains very few markers. Two layers of oligonite concretions were found in this zone in the Cheyenne Valley, the lower about 15 feet above the base of the formation. The following section shows their position:

Section from SE¼ of Section 22, T. 9 S., R. 5 E., Fall River County, South Dakota

Feet	
1	Layer of oligonite concretions in black shale Concretions flattened or biscuit-shaped
9	Black shale
1	Lower layer of oligonite concretions. Looks just like above but makes a definite horizon across structure
13	Black shale

6	Brown shelly sandstone. Beds 1/8 to 1/4 inch thick. Probably the top of the Fall River but makes horizon across this structure
28 feet	

The Graneros Formation is about 900 feet thick.

FALL RIVER SANDSTONE

(Dakota Sandstone)

As shown in the foregoing section the black shales of the Graneros Formation give way abruptly to the sands of the Fall River Formation. Six feet of shelly sandstone form a transition from the black shales to the typical thick-bedded buff to brown sandstones of the Fall River. As this formation was exposed only in the Cheyenne Valley at the extreme northern edge of the area mapped, and as only its top was used in mapping, no sections of the formation were measured. Darton (Darton, N. H., U.S.G.S. Folio No. 85, Oelrichs Folio, page 3) gives 150 feet as the maximum thickness of the formation.

FORMATIONS UNDERGROUND

About 3000 feet of sedimentary rock lie between the Newcastle Sand zone of the Graneros Formation and the barren Precambrian Rock, the "granite" of the drillers. The Newcastle zone is taken as the starting point because it outcrops on the highest part of the structure in the vicinity of Section 34, T. 9 S., R. 5 E. Wells drilled north of this section encounter a lesser thickness of sediments while wells drilled east, west or south will encounter a greater thickness, the amount depending upon the formation in which the well is started.

There are at least six formations carrying sands which might be reservoirs for oil or gas. Information concerning these formations, however, must be gleaned entirely from their outcrops in the upturned edges of Black Hills north of this structure. Descriptions of these outcrops can be found in the Oelrichs, Edgemont, and Central Black Hills Folios, published by the U. S. Geological Survey as Folios Nos. 85, 108, 219 respectively. The following brief descriptions may be useful as guides to the operator in locating horizons, but it must be remembered that the thicknesses given are estimates based on outcrops several miles from the structure. In this distance many changes in thickness may occur, especially in sandy formations. The thicker limestone beds, however, are so persistent and easily recognized that it should not be difficult to correlate the log of a well drilled on the structure with the section here given.

GRANEROS AND FALL RIVER FORMATIONS

These formations have been described above since they outcrop in the northern end of the structure.

Fuson Formation

The Fuson Formation is described as fine grained deposit consisting of fine grained sandstones and clays. The latter is usually massively bedded and weathers out in small cyclindrical fragments like dry starch. Some of the sands are coarse, but these constitute only thin shells. A section 132 feet thick at Cheyenne Falls, in T. 8 S., R. 6 E., gives thirteen divisions of sands and clays, averaging about six feet in thickness. One clay and the bottom sandstone member reach thicknesses of twenty-five feet. Most of the formation is gray in color, but there are conspicuous sections showing maroon and purple.

About 130 feet of this formation should be encountered.

Minnewaste Formation

In the outcrops from Buffalo Gap and Hot Springs to Cascade Springs, a dense limestone underlies the Fuson Formation. Traces of lime are found at this horizon as far west as Edgemont. It is very probable, therefore, that the same limestone will be encountered in drilling the Cascade Anticline.

It is described as a nearly pure, light gray limestone, very uniform in character throughout its outcrop. Careful search has been made for fossils, but no fossils have been found in it. Thicknesses up to 25 feet have been measured. This figure, however, seems to be about an average for the thicker part of the formation, and can be used as the approximate thickness which should be encountered under the Cascade Anticline.

Lakota Formation

The Lakota Formation is a thick sand formation, and like the overlying Fall River, carries an abundance of water in many parts of the State. Water may be expected, therefore, in one or both of these formations on the Cascade Anticline. The Lakota Formation is described as being composed of hard, coarse-grained, mostly cross-bedded and massive sandstone, with occasional thin partings of shale. Streaks of conglomerate occur in the lower part. This portion of the formation also contains scattered coal beds, varying from thin streaks to seams four or five feet in thickness.

On the outcrop the color of the sands is usually buff, but cuttings from this formation will probably appear as a light gray or white sand because of the absence of weathering underground.

This formation contains an abundance of fossils, particularly petrified wood. On the outcrop entire logs of this wood are often seen. In some places fossil cycads occur in great abundance and bones have been reported from the vicinity of Buffalo Gap. It is doubtful whether such material will always be struck in penetrating this formation, and if encountered it may be destroyed beyond recognition by the drill bit. If recognizable pieces of these materials are found, however, it may aid in identifying the formation.

A thickness of 250 feet should be encountered on the Cascade Anticline.

MORRISON FORMATION

The Morrison Formation is supposed to thin out and disappear in the southeastern part of the Black Hills. There is in the vicinity of Hot Springs, however, a few feet of "blocky" shale, characteristic of the Morrison Formation lying directly beneath the Lakota. It is questionable, therefore, whether this formation will be encountered or not on the Cascade Anticline. If it occurs at all it is probably very thin, and may go unnoticed in the drilling.

The formation is described as being composed of "massive shales or hard clays, mainly of light-gray or pale greenish-gray color, but generally in part also red or maroon, with occasional layers of fine grained sandstone".

It is not very fossiliferous but bones and shells of fresh water mollusks have been found in it in the vicinity of the Black Hills.

UNKPAPA FORMATION

If the Morrison Formation is missing, a well penetrating the Lakota will immediately enter another sand called the Unkpapa Formation. The sand in this formation is fine-grained but is easily recognizable, because of its striking color. Much of it is very pure white, but purple and buff or even yellow colors are common. The brilliancy of these colors is in sharp contrast to the ordinary coloring of rocks, and should make the sand an easy one to recognize. In the vicinity of Buffalo Gap this formation produces the famous "calico" sandstone.

In the outcrop of the southeastern part of the Black Hills, the formation is very thick, measured sections running between 100 and 225 feet. It is not unreasonable, therefore, to expect 150 feet of this formation under the Cascade Anticline.

SUNDANCE FORMATION

Leaving the sands of the Unkpapa Formation, a well will encounter the sands and shales of the Sundance Formation. This formation is divided roughly into two sections, the upper half being predominantly of shale, with here and there streaks of limestone, which will probably appear as shells in the drillers log. These lime shells carry abundant fossils in places, perhaps the most easily recognized of which are the quills of the fossil Belemnites. The shales are greenish or reddish, the former color being predominant in most places.

The lower half of the formation is predominantly sand. Sections in the southwestern part of the Black Hills show cliffs of sandstone 75 feet in height. In the southeastern part, however, the sands were much thinner, and separated by shales, and this is probably the condition which will be encountered in the Cascade Anticline. These sands are in general soft, sometimes slabby, and on the outcrop show abundant ripple marks, and other evidences of shallow water deposition. Part of them, especially near the upper part of this member, are buff or even red, resembling the red beds, somewhat, in color.

The outcrops in the nearby part of the Black Hills show thicknesses varying from 220 to 330 feet. Like most sand formations there is apt to be considerable variation in thickness, but an estimated figure of 250 feet is used for the thickness under the Cascade Anticline.

No oil has been produced from this formation in the vicinity of the Black Hills. An outcrop in the northwestern side of the Hills, however, shows a bituminous residue indicating that oil once existed in this sand. It is possible, therefore, that it may occur in this formation in the Cascade Anticline.

SPEARFISH FORMATION

The Spearfish is perhaps the most easily recognized formation in this series, because of its brick red color. This color shows not only on the outcrop, but very characteristically in well cuttings. The character of the material is also of aid in distinguishing it because it is almost uniformly a fine shaly sandstone. This character and the great thickness of the formation serves amply to distinguish it from all other red rocks of the series. A further distinguishing character, however, is available in the presence of gypsum beds, notably abundant at the top and the bottom of the formation. The white of the gypsum stands out in startling contrast to the red of the sandy shales. Gypsum beds occur in all thicknesses from that of tiny stringers up to 20 feet, though most of them are not over four or five feet in thickness.

These might be known as the big red beds on account of their great and uniform thickness. In the northern flanks of the Black Hills it is nearly 700 feet in places. The thicknesses measured in the vicinity of the Cascade Anticline, however, are much less, averaging about 400 feet. Since these beds are so wide spread and thick, there is no question but what they will be encountered in drilling the Cascade Anticline. About 400 feet should be expected.

MINNEKAHTA LIMESTONE

The Minnekahta Limestone acts as a parting between two red bed formations. Over it lies the thick Spearfish red beds, and beneath it the thinner red beds of the Opeche Formation. It is a very dense limestone where unweathered, and can be distinguished on the outcrop by its very thin beds. Upon weathering these beds break into slabs two or three inches in thickness. Although this bedding is of considerable assistance in quarrying the rock, it will probably not help when this rock is struck in the drill hole, and the formation will undoubtedly be recognized as one which is difficult to drill.

This has been called the "purple limestone" because of the purplish tinge which is common to the fresh rock in all places. Even where the general appearance is gray, a purplish or a pinkish tinge is always noticeable.

As this rock is not porous it would not act as a reservoir for oil pools. It is interesting, however, to note that when broken it frequently gives off a bituminous odor. In the outcrops it averages between 40 and 50 feet in thickness and as there is no sign of its thinning toward the southeast, about this thickness may be expected beneath the Cascade Anticline.

OPECHE FORMATION

The lower red beds, or the Opeche Formation, lie immediately below the Minnekahta Limestone. In color and general appearance it is much like the overlying Spearfish red beds, but differs in that gypsum is not reported from it. It consists primarily of soft red sandstone, containing variable amounts of clay. Most of it is thin-bedded. A zone of purple shale marks its upper limit, and the base is made of layers of red sandstone. A section reported from Cold Brook, four miles northwest of Hot Springs (Oelrichs Folio, p. 3) gives the following:

5 feet	Purple shale
50 feet	Red sandy clay
60 feet	Deep red sandstone, in beds one to four feet thick, with red clay partings

This formation averages somewhere near 100 feet in all of its exposures about the Black Hills. It is safe, therefore, to assume that about 100 feet will be encountered in drilling the Cascade Anticline.

MINNELUSA FORMATION

The Minnelusa Formation is of particular interest because it has given encouraging shows of oil in a number of places in western South Dakota.

It is a thick formation composed of alternating sands and shales, with some beds of limestone. In the vicinity of Hot Springs, the top is marked by a 10-foot layer of gray limestone. In other outcrops, however, the top is composed of a gray or sometimes salmon color sandstone. Probably the chief distinction noted in drilling will be the change in color from the red of the Opeche to the gray of the Minnelusa.

There are two striking divisions in this formation, an upper one 150 to 200 feet thick made of massive sandstone, and a lower one 250 to 300 feet thick of alternating layers of sandstone, limestone and shale. The limestone and sandstone stand out notably as ledges separated by covered slopes underlaid with shale. In the vicinity of Hot Springs, there are several beds of limestone in the upper member, however, and it is possible that they will be encountered in this part of the formation under the Cascade Anticline. The base of the formation is marked by a few feet of red shale in many localities. It is not necessary to seek this red shale to locate the base for there is little chance of mistaking the underlying Pahasapa Limestone.

Section of Minnelusa Sandstone on Hot Brook, South Dakota
(Darton, Oelrichs Folio, U.S.G.S. Folio 85)

	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 sandstones	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

The measured sections reported vary from 376 to 500 feet in thickness. It is probably, therefore, that 400 to 450 feet of the formation may be encountered under the Cascade Anticline.

PAHASAPA FORMATION

The Pahasapa Formation is a dense massive limestone. The color of the fresh rock is a light gray, but on weathering it often darkens to a dove color or buff, or even to a white. A little chert is reported from the upper parts of the formation in some places, but is not sufficiently abundant to be an important part of the formation.

A feature of this formation which makes it of interest to oil prospectors is the cavernous character of much of it. Many large caves are found in the formation in the outcrops in the Black Hills and smaller openings including cracks and holes as small as a small fraction of an inch in diameter make the rock very porous in many sections. This character is conspicuous in all the outcrops of the formation, and it may occur underground in the area mapped. If this is true the limestone might serve as an oil reservoir. Oil is produced from similar limestones in many fields.

The maximum measured section of this formation gives 630 feet as its thickness. In the outcrops on the eastern side of the Hills, most of the thicknesses recorded are between 300 and 350 feet. The sections on the western side of the mountains, however, average 500 feet. It is probable, therefore, that 500 feet would be about a maximum for the thickness of this formation under the Cascade Anticline.

ENGLEWOOD FORMATION

Beneath the Pahasapa Limestone lies the Englewpod Formation, which is another limestone formation some 30 to 60 feet thick. It is a slabby limestone of buff color, which has a decidedly purplish tinge in most places. So far as is known it will be of no interest to oil drillers, except that it must be penetrated to reach the underlying Deadwood Sandstone.

DEADWOOD FORMATION

The Deadwood Formation is the lowest of the sedimentary series, and the last one worth testing for oil. Below it lies Precambrian schists or granites, which never carry oil. It is impossible to say how much of this formation lies beneath the Cascade Anticline. The nearest outcrop gives the probable thickness as about 56 or 60 feet.

The formation in this area consists entirely of sandstone of a very dark buff or red color. Some portions of this sandstone are described as being shaly, and near the base it nearly always carries some conglomerate. Its dark color, the presence of conglomerate, or coarse sand, and its position beneath the thick limestones of the Pahasapa or possibly the purple limestones of the Englewood, make it an easy formation to recognize from well cuttings.

DRILLING CONDITIONS

The Cascade Anticline lies 15 miles west of Oelrichs and can be reached by a good graded road, which crosses the northern end of the structure. It is about 25 miles from Hot Springs, which can also be reached by a fair road. Grades and the difficulties in reaching crossings on the Cheyenne River will probably make trucking more expensive from Hot Springs than from Oelrichs. Both these places are served by the C. and N. W. Railroad. Provo and Rumford on the C. B. & Q. Railroad lie about the same distance to the west and can also be reached by good roads.

There is no large surface supply of water south of the Cheyenne River. Tepee Creek which flows northward, paralleling the axis of the structure, has water in it except in dry seasons. Even in such seasons there is sufficient water for stock. It might be a source of a sufficient supply for drilling, as most of the streams in the region have cut gorges, it should not be difficult to impound water with small, inexpensive dams.

There is no fuel in the immediate vicinity. The nearest coal would have to come from the lignite fields of northern South Dakota or from Wyoming, and the nearest bituminous coal from the Rocky Mountain fields. The cost of cutting and hauling wood from the Black Hills would be prohibitive. All fuel used in drilling operations, therefore, would have to be hauled in from the railroad.