

South Dakota
Geological and Natural History
Survey

Freeman Ward, State Geologist

CIRCULAR 28

Structures

in

Western Haakon and Eastern
Pennington Counties

By

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INTRODUCTORY

LOCATION

The region described in this circular is almost equally divided between Haakon and Pennington counties, and is in the west central part of South Dakota. It lies approximately ten miles south of the Cheyenne River, and includes all or parts of T. 3 and 4 N., R. 17 and 18 E. The area covered in detail is about fifty square miles. (See Figure 1.)

PURPOSE OF THE WORK

The chief object of the investigation was to make a thorough study of the peculiar blocks of highly tilted strata which occur in the northern part of the area, especially on Ash Creek and Mix-His-Food Creek. It appeared that an examination of these remarkable structures might throw light not only on the structure and oil possibilities of the region in which they occur, but on the general nature of similar structures throughout western South Dakota.

FIELD WORK

Owing to the extremely complicated nature both of the structure and stratigraphy in the area, the field work was of necessity slow and detailed. The sea level elevations used are based on differences in elevation between the area and the Chicago and North Western Railway station at Philip, as given by aneroid readings. The whole

EXPLANATION

The Survey issues two series of publications as follows:

BULLETINS.—Some subjects have been investigated a longer time, full data have been gathered, such preparatory or experimental work as was necessary has been entirely or nearly finished. In other words, the study of the subject is actually completed or so nearly so that the results can be relied on and published with a degree of confidence as to their value; and the treatment is full and thorough. In such a case the matter is published as a bulletin.

CIRCULARS.—But, often, during the progress of the work enough information is at hand to be of value to those interested, yet not enough for a complete treatise. A part of a county or a part of a certain subject may be finished, perhaps, and publication waiting for the complete investigation of the whole county or the whole subject. There may be a demand for statistical matter, or lists of references, or current information, etc., which would hardly do for a formal bulletin. Such partial reports, summary reports, reports of progress, lists, or unit fragments of larger subjects, etc., are handled in circulars.

It is planned to publish the circulars frequently and the bulletins at longer intervals. With this arrangement much information will reach the public with a minimum of delay.

Inquiries may be addressed to the State Geologist, Vermillion, S. D.



Figure 1. Index Map

Black portion shows area covered by this report.

Shaded portions give locations of other reports already published.

region was plane tabled on a scale of 2,500 feet per inch, and a large scale map of one of the areas of tilted blocks was constructed on a scale of 1,000 feet per inch. Most of the elevations within the area were obtained by the use of the telescopic alidade and the Beaman stadia arc. In order to obtain a better idea of the general structure, a few points were located by taking sights, and their elevations obtained by aneroid.

TOPOGRAPHY AND FIELD CONDITIONS

One of the most conspicuous topographic features of the area is the gently rolling plain which covers an extensive area between the larger valleys. It is doubtless the remnant of a former peneplain which extended over the whole area. The plain slopes gently to the northeast, and in the southwestern portion of the area several points on it attain an elevation of about 2,850 feet. These elevations are the highest in the area. The larger streams have carved broad, flat-bottomed valleys about 200 feet deep in this old peneplain, and a comparatively recent rejuvenation has caused these streams to cut deep, narrow trenches and badlands several hundred feet deep in the flat-bottomed valleys. The channels of the rejuvenated streams have a rather steep gradient, and descend to an elevation of about 2,000 feet a few miles north of the area. The southern boundary of the region examined is close to the divide between the Cheyenne River and Bad River.

The nearest railroad stations are Cottonwood and Wall on the Chicago and North Western Railway. Cottonwood is slightly nearer than the others, but the road to Philip is in better condition. The distance by road to Philip varies from thirty to forty miles. Hauling would be comparatively easy in the area except in the badlands in the western part of the area near Deep Creek. Water for drilling would probably have to be obtained from the larger creeks, either from the surface flow or from shallow wells in the alluvium alongside the watercourses.

STRATIGRAPHY

EXPOSED ROCKS

Many difficult and interesting problems are connected with the stratigraphy of the area. As already mentioned, working out the relations of the various strata in the area is a slow and laborious process. Several of the important key horizons of the Fox Hills are identified by the peculiar types of concretions associated with them, and in many cases it is necessary to make a long search on each outcrop in order to identify the stratum. The Lingula Shale member, which contains the fibrous calcite concretionary horizon, the best key bed, must be identified in part by finding the minute lingulae. As these tiny shells are easily destroyed by weathering, it is often necessary to dig innumerable holes in order to find them.

In the area of faulted and highly tilted blocks on Ash Creek and Mix-His-Food Creek the structure is so complex that the detailed

sequence of the strata could not be worked out. The general relations of the various key horizons were established on the east side of the Deep Creek valley, where the rocks are comparatively undisturbed. Owing to the great amount of work necessary for an understanding of the detailed relations of the various beds of concretions even in a small area, it did not seem advisable to spend the time for the thorough examination of these beds in the Fox Hills formation in T. 3 N., R. 17 E.

The following tabulation indicates the character of the exposed rocks of the area; Figure 2 shows their areal distribution.

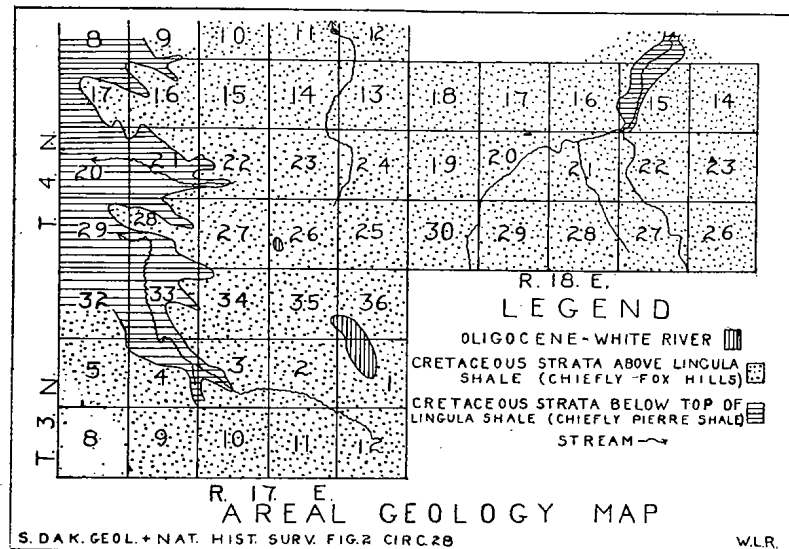


Figure 2. Areal Geology Map
SUMMARY OF THE FORMATIONS OF THE AREA

Top

Younger gravels, occurring on the benches, or old flood plains of the Cheyenne River. Consist of sand with pebbles of many different kinds of rocks, especially igneous and metamorphic rocks probably derived from the Black Hills. Late Pleistocene?

Unconformity

Older gravels, at elevations above 2,600 ft., and capping the highest plain or peneplain. Consist almost entirely of gray and greenish sandstones, gray and pinkish limestones and white, gray or translucent cherts, all derived from the White River formation, together with sandstone fragments from the Fox Hills, and loose sand. Early Pleistocene?

Unconformity

White River Formation. Oligocene. Pink, green and gray clay, thirty to forty feet.

Unconformity

Fox Hills Formation, Cretaceous

Upper Member.—Shales of a light grey, yellowish or pinkish color, with thin gray sandstones, weathering brown, some of which have pitted, grooved or roughened surfaces. The rocks of this member have marked banding, the bands being often 4 to 8 inches in width, much wider than the bands in the lower Fox Hills. Thickness, 50 feet or more. The base of this member is 250 to 260 feet above the fibrous calcite key bed.

Middle Sandstone Member.—Upper Portion. Shales, similar to those in the member just above, replaced in many localities by sandstone. Near the top of this member there is in many places, a sandstone containing large concretions of calcareous sandstone, which are gray inside but weather brown. Towards the south these concretions are oval in shape, and quite regular and symmetrical in outline. Towards the north they are much rarer and, when found, frequently have a twisted or contorted appearance. In many places a ledge of hard, gray calcareous sandstone weathering brown, containing ripple marks, and minutely cross-bedded, occurs in association with these concretions. Just below the large twisted concretions, smaller, oval concretions of grayish or yellowish, impure limestones are often developed. These crack into angular fragments. About 8 feet below the upper twisted sandstone concretions there is in a few places a layer containing cone-in-cone concretions. About 10 feet below the twisted sandstone layer there are in many places limonite concretions which often have a concentric structure and mammillary surfaces. Thickness of this portion of middle sandstone member, 60 feet.

Middle Sandstone Member.—Lower Portion. Bluish gray shales, interbedded with layers of soft, yellowish sandstone or silt, and in places replaced by soft, yellowish or gray fine grained sandstones, which in the faulted regions are cemented into hard, brown ledges. About 60 feet below the twisted sandstone concretions just mentioned, and about 180 feet above the fibrous calcite key bed, is another horizon containing large twisted sandstone concretions which are so similar to the upper ones that they can only be distinguished by the other concretions which are associated with them. This lower ledge is also associated with ripple marked and minutely cross-bedded sandstones. About 30 feet below this lower twisted ledge is a horizon containing thin, flat, disc-like concretions, which are composed of hard, calcareous sandstone and are generally 1 to 3 feet in diameter and 1 to 3 or 4 inches thick. They are gray or bluish gray inside and weather brown. A few feet above these flat disc concretions is a horizon containing thick disc concretions, which are more nearly pure lime than the others. They are a darker bluish gray color inside, weather browner and in shape are much thicker, being 6 to 14 inches in

diameter and 3 to 9 inches thick. Some of them are so thick that they are nearly spherical. Occasionally they are dumb-bell shaped, owing to two of them growing together. These concretions are found on Deep Creek, Mix-His-Food Creek and the southwest branches of Ash Creek, but not farther northeast. On the southeast branches of Ash Creek, these concretions are not found, and there is a horizon or horizons of huge, rounded or irregular masses of sandstone, often twisted, containing rounded and angular fragments of gray, impure limestone. The horizon of this may be the same as the horizon of the lower contorted ledge, which also contains numerous angular fragments of limestone. These fragments are sometimes angular, sometimes rounded and sometimes cut by minute faults. This lower twisted ledge also contains many minute folds, often 2 to 4 inches across, and many contorted zones. It contains in some places numerous bits of carbonized and petrified wood, which cause it to look like the Lance. One ledge of sandstone was found just above it, which contained numerous small clamlike pelecypods. This was the highest occurrence of invertebrate fossils in the Fox Hills. Clam shells occur sparingly below this in the Middle Sandy member. About 50 feet below the lower twisted sandstone ledge, and 130 feet above the fibrous calcite key bed, is a ledge of hard, calcareous sandstone, gray inside, weathering brown, generally wholly or partly very thin bedded. It is about 2 feet thick and in places contains bits of carbonized wood or other carbonaceous matter, and in places a few clam shells. The thickness of this portion of the Middle Sandy member is about 100 feet, sometimes possibly 150 feet.

Basal Banded Member of the Fox Hills.—Shales with thin interbedded layers of sandstone or silt, which are generally yellowish in color. The bands are about one inch or less in thickness. The fine sand or silt is much more abundant, and the layers of it are thicker towards the top. The concretions in this member are composed of fairly pure lime, and are flat, and generally not very large. Minute specks of carbonaceous matter occur scattered very sparsely through it, and assist in distinguishing it from the Pierre shale. The fossils are small clam shells which occur fairly abundantly, but are scattered individually through the formation, and generally not in groups or beds. No lingulae are present. Thickness generally about 100 feet, ranging from 50 to possibly 150 feet.

Base of Fox Hills

Total Thickness of Fox Hills, about 275 to 300 feet.

Pierre Shale?

Uniform Shale Member.—Massive or thin bedded shale with no sand or silt and no banding; this absence of banding gives it a highly uniform appearance, when contrasted with the shales above and below it. No lingulae, ammonites or baculites are present. Thickness, 10 to 100 feet or more; grows much thicker to southeast.

Lingula Shale Member.—Massive, silty shale, containing the silt as lumps or specks, and scattered uniformly in the shale. Numerous lingulae, especially in the silty portions. Grows thicker and more silty towards the northwest. Probably a few ammonites in base. Contains numerous, large round concretions of calcium carbonate, which generally do not show any trace of the lamination of the shale they replace. In this respect they are unlike the concretions in the banded beds both above and below them. They are also much larger than these concretions. About 5 feet below the top of this shale is a layer of cone-in-cone concretions, and also small limestone concretions, 6 inches to 1 foot thick, and 1 to 2 or 3 feet long. About 25 to 30 feet below the top is a horizon of large limestone concretions, generally 1 to 1½ feet thick and 3 to 13 feet long. Immediately below is a horizon of fibrous calcite concretions. These are associated with cone-in-cone, but contain masses of fibrous calcite in which the fibers are 2 to 4 inches long and nearly straight and parallel. To the northeast, on Lower Ash Creek and Mix-His-Food Creek, there are other beds of fibrous calcite which cannot be distinguished from this, but this is outside of the area mapped. In the area mapped and for some distance to the south this bed is an excellent key bed. About 8 feet below it there is another horizon containing fairly large concretions of limestone, though not so large as those associated with the fibrous calcite. The fibrous calcite bed is generally 5 to 10 feet above the base of the lingula shale. To the southeast the lingula shale grows thinner and becomes interbedded with massive or thin bedded shale without silt or lingulae. It contains no specks of carbonaceous matter and no fissiles but the lingulae and a few small ammonites. Thickness, 10 to 40 feet, generally about 30 feet.

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Banded Member of the Pierre Shale.—This member consists of thin bedded shale, dark bluish gray in color, in thin bands 1-10 to ½ inch thick, separated from each other by thin streaks of silt, which are 1-40 to 1-10 or 1-5 inch thick. It contains thin and rather small concretions, which show the traces of the banding. A few lingulae are scattered through it, but not as abundantly as in the lingula shale above. The fossils consist of small ammonites, numerous pelecypods of various types and a few lingulae. Baculites are either absent or very rare. Thickness, 150 to 200 feet.

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Intermediate Member.—Shale with streaks of silt, as in the member above, interbedded with shale which has no silt. The fossils consist of minute baculites and small ammonites. Bands of dark yellowish material occur in the weathered shale. Several thin beds of limestone associated with a band of fibrous calcite are scattered through the member. This fibrous calcite differs from the fibrous calcite key bed in the lingula shale in being in thin layers and not in oval concretions. The thickness of this member was not measured accurately, but is probably 50 to 150 feet.

Baculite Member.—This member consists of shale with very little sand or silt. Baculites are very abundant, and large ammonites and pelecypods of various types are also present. At the top are sandy streaks containing bright yellowish material, a few feet below which is a zone of large limestone concretions, 2 to 8 feet long and 1 to 2 feet thick, containing cracks and hollows which are often lined with a coating of white calcite containing minute pits. Below this is 90 feet of bluish gray shale without sand or silt, and containing innumerable concretions composed partly of iron carbonate.

Total thickness of exposed Pierre, 340 to 500 feet.

Total thickness of exposed Cretaceous rocks, 600 to 900 feet.

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The thickness and character of the rocks below the Banded member of the Pierre shale are very imperfectly known, knowledge being based on a few hastily measured sections. Also, the Baculite member was not observed within several miles of the fibrous calcite key bed in the Lingula shale. As the dips are sharp and irregular, considerable uncertainty was introduced into the measurements.

One of the most striking characteristics of the Fox Hills in this area is the lenticularity and non-persistence of its strata. Though it contains layers of concretions which can be used as key beds over limited areas, there does not appear to be any widespread stratum that can readily be identified. As the various key beds of the Fox Hills usually extend over only a few square miles; it is necessary to use many different key beds in mapping the structure of a large area, and as the relations of these to one another are difficult or impossible to determine, it is evident that the Fox Hills in this immediate area is as a whole an unsatisfactory formation for use in working out the structure.

By far the best key bed of the region is the fibrous calcite bed in the Lingula shale, which is apparently near the top of the Pierre shale. The long, parallel fibers of calcite, their occurrence in oval concretions, the presence of a stratum of large limestone concretions immediately above, and the occurrence of the whole in a peculiar massive silty shale, with lingulae, all help to mark this key bed off from all the strata above and below. In the area covered by the structure map, Figure 3, the fibrous calcite stratum may be distinguished from the other concretions in the Lingula shale. Farther north, however, along lower Ash Creek, there are several layers of fibrous calcite concretions in the Lingula shale. Even here, however, the top and base of the Lingula shale serve as approximate horizon markers.

The Lingula shale is apparently not simply a transition phase from one type of rock to another, but a definite stratum, due to a change in the conditions of deposition. It does not lie at the horizon where shale merges into sandstone, or where marine deposits merge into shore deposits, but is a distinct horizon in a series of off-shore deposits. In its massive character, and in the occurrence of silt scattered irregularly through it, rather than in bands, as well as in the occurrence of lingulae, it differs from the formations above and below. It appears to owe its origin to an agitation of the waters, which re-

sulted in the introduction of the large amount of silt, and in the interruption of the rhythmic alteration in conditions, which produced the banding in the strata above and below.

The area in which the Lingula shale was found extends from Grindstone Post Office in Section 17, T. 2 N., R. 18 E. to old Dowling Post Office in Section 18, T. 5 N., R. 18 E., a north-south distance of eighteen miles, and its extent in an east-west direction is at least eight miles. The Lingula shale and the fibrous calcite horizon may be traced almost continuously along the east side of the Deep Creek badlands, and here it is fairly certain that they always occur at the same horizon. It is possible that the lingula shale and fibrous calcite observed in some of the widely scattered localities beyond the area covered by the structure map, as at Grindstone and old Dowling Post Office, are at a different horizon, but there is no indication of this.

The variations in the character of the Lingula shale and of the formations immediately above and below it, particularly the Massive Shale member, suggest a source from the northwest. In this direction the Lingula shale becomes thicker and more silty, while to the southeast it is replaced by shale without silt. The Massive Shale member just above the Lingula shale becomes replaced towards the northwest by the banded shales and sandstones of the Basal Banded member of the Fox Hills. Its thickness increases from about 10 feet on the northwest to 100 or 150 feet on the southeast. In other words, the proportion of shale and sandstone in the formation as a whole varies in a northwest and southeast direction, the proportion of sand and silt to clay increasing towards the northwest and decreasing towards the southeast. This evidence of a northwesterly source is in agreement with the indications of the direction of the source obtained by the writer from a study of the cross bedding in an area about a hundred miles north¹. The general conditions in the Rocky Mountain region indicate a westerly source for the Fox Hills, and in northeastern Meade County, S. D., Wilson² found evidence of a source from this direction.

One of the important stratigraphic problems of the region is to determine which of the various members should constitute the top of the Pierre. This question is complicated by the transitional character of the Pierre-Fox Hills contact. If the source of these formations was to the west or northwest, the shore line at any given time presumably extended in a north-south or southwest-northeast direction. Hence if a definite horizon were traced from southeast or east in the opposite direction, it should pass from the marine formations of the Pierre to the shore deposits of the Fox Hills.

Another important stratigraphic problem is the question of whether or not there is any Lance in the area. If the dividing line between the Fox Hills and Lance is placed at the horizon where littoral deposits give place to fresh water formations, then it is quite likely that some Lance is present. No marine fossils were discovered in the

¹ W. L. Russell, The Possibilities of Oil in Western Ziebach County: S. D. Geol. and Nat. Hist. Surv., Circ. 20, 1925.

² R. A. Wilson, Oil and Gas Possibilities in Northeastern Meade County: S. D. Geol. and Nat. Hist. Surv., Circ. 23, 1925.

upper 100 feet of the Cretaceous section, and the presence of bands of pink shale suggests deposits of continental origin. Many of the strata in the upper part of the section contain numerous bits of carbonized wood, and these are in places so abundant that the rocks in which they occur look locally very much like the Lance.

It does not appear, however, that the presence of bits of coal or carbonized wood, or even the occurrence of terrestrial deposits can be used by themselves to separate the Lance from the Fox Hills. Thin streaks of coal and bits of carbonized wood occur throughout the Fox Hills in some areas, and in certain places Fox Hills strata with marine fossils may be found above beds of continental origin. The general characteristics of the various members would seem to be the most reliable criteria. Though the Upper member and Middle Sandstone member of the Cretaceous rocks contain pink shale and occasional bits of wood, their banding and the concretions and general appearance of the thick sandstones in them are typical of the Fox Hills. As the banding in particular is one of the most important of the features used to identify the Fox Hills, it seems advisable to include these upper strata provisionally in the Fox Hills.

The occurrence of bands of pink shale is such a peculiar feature that it calls for some explanation. The bands of the Upper member which contains the pink shale are similar to the bands in the lower marine portion of the Fox Hills, except that they are thicker and that some of them are pink. The explanation of the pink color is tied up with the origin of the bands in general. While no exact statement of the origin of the bands is possible at present, it appears that the sea in which the banded strata of the lower Fox Hills were deposited was very shallow, and that there were either frequent alternations of quiet waters with agitated waters, or else that the rivers and currents carried in mud and sand alternately. If we imagine a broad mud flat, alternately submerged and allowed to dry, at the landward margin of this shallow sea, it is possible to conceive of the pink bands in the shale being formed during the times of drying and oxidation, to be covered by bands of gray shale or sandstone during the times of submergence.

UNEXPOSED ROCKS

The information regarding the subsurface formations is derived largely from the exposures in the Black Hills seventy miles west, from the log of the well at Conata, nearly fifty miles south-southwest, from the log of the Standing Butte well northwest of Fort Pierre, about seventy miles east, and the log of the Irish Creek well southwest of Isabel, about seventy miles north of the area under discussion. In spite of this information, there is still much that is uncertain about the underlying strata, particularly those below the top of the Dakota, and very little at all is known about the Paleozoic rocks. The character and thickness of the formations which would be encountered by a well starting in the Lingula Shale member are estimated in Table 1.

TABLE OF THE UNEXPOSED ROCK FORMATIONS

Name	Thickness	Character
Pierre Shale	300	Bluish gray shales with thin bands of silt.
	900	Bluish gray shale, with practically no sand or silt.
	200	Dark bluish gray or grayish black bituminous shale.
Niobrara	200	Gray impure chalk and chalky shale, with shaly limestone.
Carlile Shale	400	Bluish gray, brown and black shale with possibly two limy sandstones, each 0-40 feet thick, about 100 and 300 feet below top.
Greenhorn Limestone	0-50	Limestone and shale interbedded.
Upper Graneros Shale	400	Bluish gray or black shale.
Dakota Sandstones	300	Sandstones interbedded with dark bluish gray shales, probably in part bituminous, which are equivalent to lower Graneros shale of Black Hills; Newcastle sandstone near top.
Fuson, Lakota and Morrison	100-300	Gray, pink and greenish shales with sandstones or conglomerates.
Unkpapa and Sundance	100-200	Greenish gray shales, with possibly a white sandstone at top.
Spearfish Redbeds	600	Red, sandy shale with some gypsum.
Paleozoic	Unknown	Interbedded shales, limestones and sandstones above, with thick series of limestones below.

Table 1

The top of the Dakota sandstones would probably be reached at about 2,400 feet, and the top of the Minnelusa sandstones, if present, should be encountered around 3,500 to 4,000 feet.

It seems likely that bituminous material such as is supposed to be the original source of oil and gas occurs in the basal portion of the Pierre shale, the Niobrara, the Carlile, the Graneros, and probably also in the marine shales interbedded with the Dakota sandstones. The lower Cretaceous and Spearfish Redbeds are presumably barren of this material, but it is reasonable to suppose that some of the Paleozoic limestones and shales would be bituminous, since they were formed under different conditions and at different geologic periods.

It should be recognized that all the estimates of the characteristics of the unexposed rocks which have been discussed above are exceedingly uncertain, owing to the absence of deep wells in the vicinity. The interpretation of the Dakota formation given in Table 1 is based on a study of the surface exposures and well logs made by the writer, and the evidence for it will be given in a later publication.

STRUCTURE

REGIONAL STRUCTURAL RELATIONS

The map showing the general structure of the top of the Pierre in western South Dakota, which was recently completed by Ward³, indicates that the area under discussion is on an extensive regional arch or anticline which lies along the divide between the Cheyenne River and Bad River. Its axis runs in an east-west direction near the southern border of the area mapped, but turns near the southwestern corner of the region and extends in a southerly direction, still following the divide between the Cheyenne and Bad rivers. The apex of this regional anticline, which is one of the largest in South Dakota outside of the Black Hills, is near the southern boundary of the area mapped, and the southwestern portion of the area as shown in Figure 3, is within its closed area. Near its crest is a smaller, sharper anticline, which extends into the southwestern part of the area mapped.

The direction of the regional dip in the region covered by Figure 3 is northeast, away from the regional arch and the anticline on its crest, and its amount averages about ten feet a mile.

STRUCTURAL TYPES AND DETAILS.

Different types of structure are present in different portions of the area. The northern half is characterized by small, sharp folds in the shales, many of which dip as much as four degrees and are only a few hundred feet across, by numerous small faults, and by the presence of small, highly tilted blocks of hard Fox Hills sandstones, some of which dip as much as 60 degrees. In the southern portion the sharp dips and tilted blocks are, in general, absent, though there are a few dips of several degrees along some of the faults. In the extreme southwestern portion of the region there is a larger, gentler anticline, situated on top of the regional arch already mentioned. Though its crest lies south of the southern boundary of the area mapped, it extends for several miles into this area from Section 9, T. 3 N., R. 17 E., to the southeastern portion of Section 27, T. 4 N., R. 17 E., where it flattens out and disappears. Its axis extends in a direction slightly east of north and plunges northward.

The structure of the portion of Figure 3 which lies in T. 3 N., R. 17 E., was mapped rather hurriedly in order to determine the general nature of the structure in that section. Consequently the details shown on the structure map there are not as reliable as elsewhere.

³ Freeman Ward, The Structure of Western South Dakota: S. D. Geol. and Nat. Hist. Surv., Circ. 25, 1925.

⁴ W. L. Russell, The Possibilities of Oil in Western Corson County: S. D. Geol. and Nat. Hist. Surv., Circ. 27, 1926. (See also 1.)

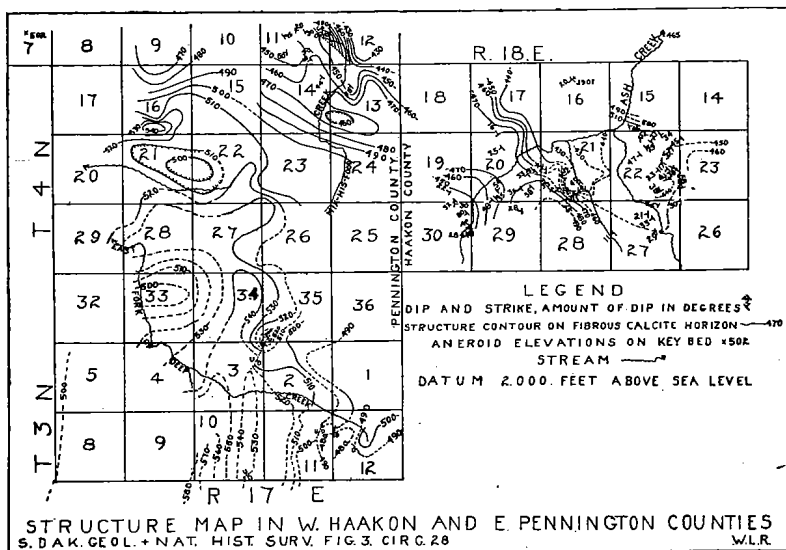


Figure 3. Structure Map

The western portion of the area, on the east side of Deep Creek Valley, is characterized by a series of small folds in the Pierre shales. The structure of this region is actually much more complex than is shown on Figure 3, for many of the folds are only about a thousand feet across, and the dips run as high as several degrees.

The chief object of the survey of this area was, as already stated, the examination of the ridges of tilted sandstones which occur conspicuously on Ash Creek and on Mix-His-Food Creek. These ridges are generally less than a thousand feet in length, but some of them rise nearly a hundred feet above the surrounding prairies. The dips of the strata forming these ridges are generally from 15 to 60 degrees, and are fairly constant on the same ridge, though varying in minor amounts. The majority of the ridges, especially the larger ones, extend in a northwest or north-northwest direction. In addition to the ridges, there are smaller exposures of hard, tilted sandstones, which are not large enough to form distinct elevations. The strike of these smaller exposures is prevailingly northwest also, though by no means as regularly so as in the case of the large ridges. The dips of these tilted strata may be either northeast or southwest, though those towards the southwest predominate, as is indicated by Figure 5, B, in which the dips of the exposures having a northerly or northwesterly strike are shown, the dips of the few which strike in other directions being omitted. The angle of dip averages about 35 degrees.

Generally the rock formation exposed on the tilted ridges and outcrops is hard, calcareous Fox Hill sandstone, usually thin bedded, though in some places massive. In many of the tilted exposures sys-

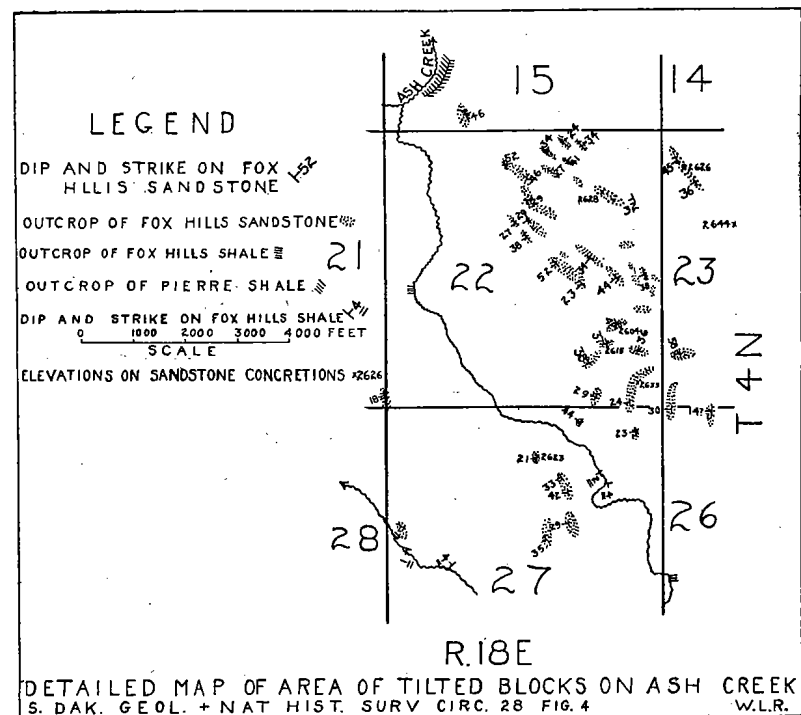


Figure 4

tems of joints are well developed, while in some of them none can be detected. The best developed joint system is at right angles to the strike of the strata in which it occurs, and another, less conspicuous system is parallel to the strike. Other joints are usually present, but form no well defined system. Occasionally there is shearing along some of the joint planes, and in some places the laminae of the sandstone have been contorted and cut by small faults. The rocks of the tilted outcrops differ from the normal Fox Hills in being much more cemented by calcium carbonate, in the greater development of joints and in the presence of small faults and contorted zones. Otherwise they present no unusual features.

Occasionally semi-consolidated sands are found interbedded with the hard calcareous sandstones on the tilted ridges, and these dip the same as the more resistant strata. On the other hand, the shales of the lower Fox Hills and Pierre, which outcrop in the valleys below the tilted ridges, are either horizontal or dip very gently, less than five degrees. Figure 4 shows how these gently dipping shale outcrops are scattered among the highly tilted blocks on Ash Creek. These comparatively flat-lying shale outcrops may be found scattered among the highly dipping sandstones in other parts of the region. The dips

of the shale exposures are highly irregular, showing no similarity to one another in either the amount or the direction of the dip. In places these shales are thrown into folds twenty or thirty feet across.

The general structure of the areas in which the tilted blocks occur is shown in Figure 3, but in interpreting this structure, allowances should be made for several factors. In the first place it should be

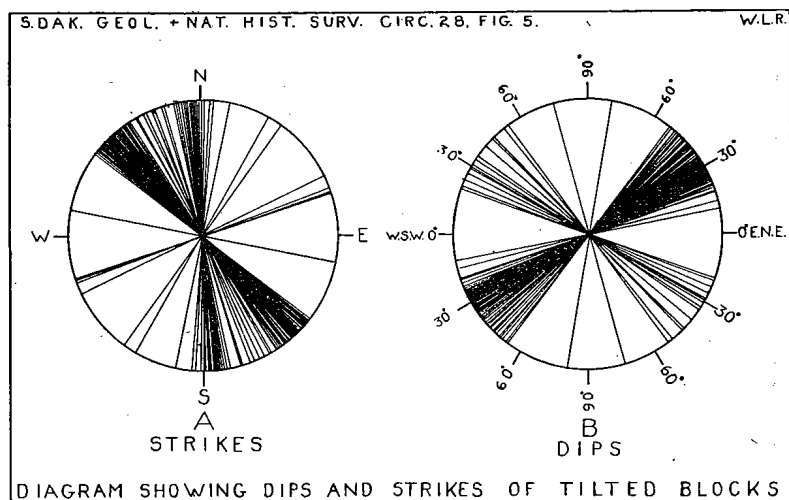


Figure 5

remembered that in the eastern part of the area, on the southeastern branches of Ash Creek, there is some uncertainty as to whether the structure contours are drawn on exactly the same horizon as they are farther west. The stratum used for contouring in Sections 22, 23 and 27, T. 4 N., R. 18 E., is characterized by huge, rounded or irregular concretions of calcareous sandstone, containing contorted laminae, angular fragments of impure, yellowish limestone, and occasionally deep, gash-like cracks. Farther west this horizon is associated with the disc-like concretions which underlie the horizon used for contouring there; hence it is quite likely that it is really the same stratum, and no indications of the contrary were encountered. However, the structure among the tilted blocks is so confused that if the concretions occurred at different horizons the fact might readily remain undetected.

As some of the tilted blocks are over a hundred feet in width, and as they dip at angles of over 30 degrees, it is obvious that elevations taken on outcrops of any key bed would be greatly influenced by the altitude of the surface. The size and steep dips of the tilted blocks indicate that the elevations of the same stratum in different parts of the same block would vary at least 50 or 100 feet, and consequently the outcrops of the key bed would tend to be higher where the surface intersected it at higher elevations. That something of this nature does take place is suggested by the fact that there are

apparent synclines in the valleys, and anticlines on the intervening hills, in the areas in which these tilted blocks occur. In the same way the apparent structure may be influenced by the altitude of the surface in the areas in which the shales are thrown into small, sharp folds.

In at least two places, in Section 22, T. 4 N., R. 18 E., and on Mix-His-Food Creek in Section 11, T. 4 N., R. 18 E., the dips of the tilted blocks are such as to suggest a fairly large anticline. In Section 22, T. 4 N., R. 18 E., a number of sandstone exposures, as is shown in Figure 4, all dip in a uniform northeast direction at angles averaging over 30 degrees for a distance of over 1,200 feet, and on the southeast side of the axis of the apparent anticline the apparent dip is at the same angle in the opposite direction for a distance of over 500 feet. If these dips were genuine and continuous the strata would be expected to rise over 700 feet to the northeast side of the anticline, and over 300 feet on the southwest. The mere fact that Fox Hills sandstones are exposed on all these tilted blocks indicates that no folds of this order of magnitude are present. The occurrence of the same stratum at nearly the same elevation throughout these anticlinal areas also shows that they are not true anticlines. In fact the strata are found at lower elevations in these anticlinal areas than in the surrounding region. Even making allowances for the influence of the altitude of the surface on the elevation of the outcrops, and for possible errors in identifying the key beds, it is apparent that there is no anticline of even moderate size in these apparent anticlines, and that the dips of the tilted blocks are absolutely unreliable for mapping structure.

Though the hard sandstone ledges in these tilted blocks are well exposed, their relations to the rocks beneath them and beside them can rarely be seen. On the southeast branch of Ash Creek, in Section 22, T. 4 N., R. 18 E., all the sandstone exposures dip at high angles. On the southeast branch of Ash Creek, however, as well as on Mix-His-Food Creek, some of the tilted exposures are associated with ledges of sandstone which are horizontal or dip very gently. On Stony Butte in the southern half of Section 16, T. 4 N., R. 18 E., the ledges of gently dipping, hard Fox Hills sandstones are in several places tilted at angles of 10 to 30 degrees. The strikes of these tilted strips are northwest, parallel to the strikes of the other tilted blocks, and they are cut by a similar system of joints parallel to the dip. Some of these tilted exposures on Stony Butte are in small valleys or hollows which run parallel to their strike. In the southern part of the area, in T. 3 N., R. 17 E., there are several exposures of gently tilted sandstone along faults. These dips are generally less than five degrees, and those close to the faults are usually in a direction opposite to the drag. They appear to be similar in origin to the other occurrences of reversed drag described by the writer⁴. Very few faults are actually exposed in the area. The few which may be seen are normal faults, dipping at angles of 50 to 70 degrees.

ORIGIN OF TILTED SANDSTONE BLOCKS

The origin of the tilted blocks is important to determine not only because of its bearing on the interpretation of the structure of the area, but because it may give the key to other similar structures in western South Dakota outside the region under discussion. The various explanations which may be suggested to account for them may be grouped under the following headings:

1. Slumping
2. Cross-bedding
3. Forces of crystallization
4. Swelling of the shales due to absorption of water or chemical changes at the surface.
5. Folding and faulting.

At first thought the most plausible hypothesis for the origin of these steep dips is that they are due to slumping. Under this heading it is necessary to consider the possibility not only of recent slumping, but of slumping during any time since the Fox Hills sandstones were laid down. It seems fairly obvious that the tilted blocks are not due to any slumping when the topography was essentially the same as it is now, for they do not show the slightest relation to any existing hills or valleys, and in places their dips are practically continuous across several hills and valleys.

A careful consideration of the evidence indicates that they are not likely to have been formed by slumping during the geologic past. If valleys large enough for blocks a thousand feet in length and several hundred feet across to slump into, ever existed in this region, ample traces of them should still remain. Yet there is not the slightest indication of any such features. That no such valley formed and was filled during Fox Hills times is indicated by the total absence of any evidence of extensive cutting and channel filling in that formation. If the valleys into which the blocks may be imagined to have slumped formed after Fox Hills time, the deposits with which they would have been filled would differ from the Fox Hills, and no indications of any such differences could be found by an examination of the surrounding exposures. The exposures of tilted blocks occur over such large areas that improbably large topographic features must be postulated to account for slumping over such an extensive area. Certainly if such large and steeply tilted blocks are due to slumping, they must have descended a considerable distance. Yet the structure map indicates that the elevations of the strata on these tilted blocks average no more than 50 feet lower than the elevations of similar strata in the surrounding undisturbed areas, and in no case were they found to be over 100 feet lower.

The high angle of dip of these blocks is also contrary to what would be expected if they were slumps. As shown by Figure 5, B, the majority of these exposures dip over 30 degrees. On the other hand, the majority of the large slump blocks which may be found in western South Dakota dip less than 20 degrees. The regularity of the strike of the tilted blocks, as shown by Figure 5, A, is also against

the hypothesis that they are due to slumping. If they were found in a long, narrow area which extended parallel to their strike, they might possibly be supposed to be slumps in a long, narrow valley, for the strikes of the large slumps are generally parallel to the walls of the valley in which they occur. The area in which the tilted blocks are found apparently extends in a west-northwesterly direction, however, while their strikes are usually north-northwest, as is shown in Figure 5, A. In order to explain this uniformity in strike it would be necessary to postulate several valleys extending in a north-northwesterly direction, but, as already stated, there is every reason to believe that no such valleys existed.

Another feature which suggests that the tilting of the blocks is not due to slumping is their occurrence among horizontal strata. On the southeast branch of Ash Creek, in the area covered by Figure 4, practically all the ledges of hard Fox Hills sandstone are tilted, but on the southwest branch and on Mix-His-Food Creek outcrops of highly dipping strata are scattered among nearly horizontal ledges, and the few steep dips on Stony Butte in Section 16, T. 4 N., R. 17 E., are also in areas of comparatively flat strata. In some of these cases there is no room for a valley large enough to have occasioned a slump ever to have existed between the tilted and flat strata.

The evidence to show that the tilted blocks are not due to cross-bedding is still more convincing. Quite a number of the dips are over 45 degrees, which is too steep for cross-bedding. Moreover, in the numerous excellent exposures of the Fox Hills formation on the east side of the Deep Creek valley, to the west and southwest of the tilted blocks, cross-bedding is unusually inconspicuous for this formation, and there is no large scale cross bedding. The very size of these blocks and the height of the exposures of tilted strata render it improbable that they could have been formed by this process. If cross bedding on such a tremendous scale had occurred in the Fox Hills formation, some evidence of channeling and other effects of violent currents should be seen, while as a matter of fact their characteristics suggest the opposite. Ripple marks, of the same type as are found in the horizontal exposures, may be seen in the tilted exposures on bedding planes dipping 40 to 50 degrees. The strikes and dips of these tilted exposures are not what would be expected if they were due to cross-bedding; in that case one would expect them to dip prevalently southeast or east, away from the direction of the source of the materials. It would be strange if so many cases of cross-bedding at such different elevations could occur without any evidence of the horizontal bedding planes above and below the oblique laminae, and there is no sign of these. Moreover, the explanation that the dips are due to cross-bedding does not account for their association with contorted strata, shearing and jointing, or for the folding of the shales beneath and other evidences of deformation.

As the sandstones of the tilted blocks are nearly always firmly cemented by calcite, it might be suggested that the force of crystallization of the calcite had caused the upheaval of the strata. However, though small anticlines owing their origin to the force of crys-

tallization developed during the deposition of a calcareous cement have been described, it does not appear that the expansion produced by the cement could be sufficient to tilt the strata at such high angles.

While small folds due to the expansion of shales near the surface may be observed in western South Dakota, they may generally be recognized by the fact that they diminish rapidly downward. Though the folds in the shales dip at lower angles than the tilted sandstone blocks above them, these folds give no indication of dying out without depth, and similar folds exposed on the high bluffs over the channel of Deep Creek also apparently persist to considerable depths. Moreover, there is every gradation between the small folds associated with the tilted blocks and larger folds shown on the structure map, Figure 3, which are undoubtedly due to true deformation.

It becomes apparent, therefore, that some structural disturbance, such as folding or faulting, must have caused the steep dips. Yet the lack of conformity between the sandstones and shales and the manner in which the strata lie nearly level across the apparent anticlines, indicate that the deformation in this region is of an unusual type. While it does not at present seem possible to state exactly how the tilted blocks originated, a number of circumstances and factors which may have a bearing on the problem may be mentioned. In the first place, it appears likely that the soft and plastic character of the rocks at the surface and for considerable depths, and the fact that the strata were close to the surface when deformed, have influenced the character of the deformation. Under such circumstances, formations would be likely to buckle up into small folds, and, as strong lateral pressure could not be transmitted, tensional faults would be produced along with the anticlines. If there were some rigid rocks among these incompetent strata, the pressure could be transmitted for a greater distance through this harder material, and thus their effects might be concentrated at a few points which were weak, or in which deformation had already begun. If this is the case, it is possible that the numerous small folds of the shales were concentrated into a few steep dips in the hard sandstones.

Where the majority of the strata are of a plastic nature, unable to transmit great pressures, folds in deeper, more rigid strata are apt to be marked near the surface by tension and normal faulting. Collapsed anticlines of this nature have been described by the writer, (see footnotes 1 and 4,) from two other areas in western South Dakota. In one of these areas an apparent anticlinal fold ⁵ was found, in which the normal faults dropped the strata down towards the axis to such an extent that it was no higher than the flanks. Some such process may be at work in the apparent anticlines in this region. In the two areas just mentioned, the strata along the faults were frequently bent in a manner opposite to the drag, and something of this nature appears to have taken place along the faults on the east fork of Deep Creek in this area. It is not known exactly how this reversed drag originated, but it may be due to the elastic rebound. If this feature were devel-

⁵ Circ. 20, p. 14, Fig. 4, Section No. 1.

oped to an extreme degree, features similar to the tilted blocks might be formed.

Whatever the exact process which caused the tilted blocks, it seems safe to say that both folding and faulting have played a part in their formation. Small folds are actually exposed in the shales beneath them, and the fact that in places they dip in the same direction without any corresponding rise in the strata indicates that they are fault blocks.

RELATION BETWEEN STRUCTURE AND TOPOGRAPHY

A relation between the structure and the topography may be detected in this region in three different sets of phenomena. Owing to their great resistance to erosion the hard sandstones of the Fox Hills form sharp ridges where highly tilted. The branches of Ash Creek and possibly Mix-His-Food Creek run in apparent synclines. This may be caused by the surface intersecting the fault blocks at a lower elevation in the valleys, as already explained, or it may mean that the valley has been produced by the syncline, as has happened in a number of cases in the areas just mentioned in northern Ziebach County and western Corson County.

The most striking relationship between the structure and the topography is exhibited in the manner in which the dissected plain that lies between the main valleys conforms to the regional structure. To the north of the axis of the regional arch, which runs east from the southern border of the area mapped, this plain dips gently to the north, while to the south of this axis it dips gently to the south, still conforming to the structure. This plain also rises over the anticline in the southwestern corner of the area. A few remnants of the White River formation lie scattered over this plain, and remnants of the older gravel deposits are also found on it. These patches of White River suggest that the plain lies at the position of the contact of the Fox Hills and the White River, and that after the regional arch had been uplifted, the White River, which is easily eroded, was stripped off of the Fox Hills. This would account for the manner in which the topography of the plain reflects the structure.

SUMMARY OF REASONS WHY STRUCTURE CANNOT BE MAPPED BY TAKING LOCAL DIPS

Since efforts are still being made to map oil structures in western South Dakota by taking local dips with a clinometer, and since some of the fault blocks which are tilted in opposite directions have an extraordinary resemblance to genuine anticlines, it may be advisable to give a summary of the reasons why such methods are unsuited for this region.

1. Owing to the crumpling and the presence of innumerable small folds, such dips often show no prevailing directions, and have no relation to the underlying structures.

2. The chance arrangement of such local dips, especially when the exposures are scattering, may suggest folds which do not exist at all.

3. Even when folds may be actually mapped by such methods, they are generally so small that they are not likely to persist down to the level of the strata which may be oil bearing.

4. Such methods do not indicate the faults, which may neutralize or overcome the rise of the strata indicated by the dips.

5. The larger folds, which are the most promising for oil production, are too gentle to be mapped by this method.

OIL AND GAS POSSIBILITIES

It is obvious from what has been said that the tilted fault blocks and other steep dips in the region are not indicative of promising oil structures. In fact, these features appear to occur in areas which are lower structurally than the surrounding territory, and thus unusually unfavorable for oil production. They do, however, indicate that a certain amount of deformation has affected the area, and in that respect they may be considered favorable for the oil possibilities of the region as a whole, since a certain amount of deformation is considered necessary for the formation and accumulation of oil.

The most promising structure of the region is the large anticline which extends into the southwestern portion of the area mapped, running from the southeastern portion of Section 9, T. 3 N., R. 17 E., to the northeastern portion of Section 34, T. 4 N., R. 17 E. The highest part of this anticline is south-southwest or south of the southwestern corner of Section 9, T. 3 N., R. 17 E. Hence before doing any drilling it would be necessary to map the region immediately south of the western portion of the area mapped, in order to locate the apex of this anticline.

Although this territory has not been examined by the writer, Ward's structure map of western South Dakota (see foot note 3) indicated that this structure is closed to the south. If the size and closure are as large as they appear to be from the present indications, it would be well worth testing. Its position on the apex of a large closed regional anticline makes it the most promising structure in this portion of South Dakota. It should be noted also that the thickening of the Upper Cretaceous section towards the northwest, and the general northward dips, make the depths of the Upper Cretaceous oil sands shallower than they are under the structures farther north.

The smaller anticlines in the area should not be drilled until the larger structure has been tested, for they are not nearly as promising. If the latter is productive, they would deserve consideration.

From what has been said about the characteristics of the unexposed rocks it appears that the main conditions for the occurrence of oil are present under this area. There is the anticlinal trap for the accumulation of the oil, and reservoir rocks, and probably also source rocks underlie the region. One unfavorable feature is the artesian circulation and the occurrence of fresh water in some of the sandstones in which production might be expected. Investigations of the Dakota, Fuson and Lakota formations made by the writer indicate that these are composed largely of sandstone and conglomerate lenses

interbedded with shales and clays, and that the sandstone lenses which are found in the upper part of the Dakota formation towards the east, which is the direction of their source, become replaced by the Graneros shale towards the west. If these suppositions are correct, artesian circulation may be weak or wanting in some of these lenses, and in the westward extension of the upper sandstone members of the Dakota, near the locality where they give place to the Graneros shale.

From the records of the wells and other considerations it seems likely that the water in the sandstones of the Dakota formation will be fresh or slightly salty, and that the water in the lower Cretaceous sandstones will either be fresh or will contain sulphates and other mineral substances in solution, which will give it a "hard" or bitter taste. The probable occurrence of fresh waters in these horizons is unfavorable, for fresh water is not generally associated with oil in the same sand, but it should not be considered as condemning the area.

The most promising horizons for production are the Dakota sandstones and the Paleozoic sandstones. The sandstones in the Carlile shale are favorable if they are sufficiently porous, but the lower Cretaceous sandstones are probably not closely associated with bituminous matter from which the oil could form, and are not so promising.

It appears to the writer that the Paleozoic sandstones should be thoroughly tested, for they hold out the greatest hope of production. The large anticline and the other smaller ones of the area, which are not as steep as the majority of the productive oil structures in Cretaceous rocks, are fully as pronounced as many of those which contain oil pools in Paleozoic rocks. It cannot be positively asserted that the stratigraphic conditions in the Paleozoic strata are suitable for oil production, but there is no good reason for thinking that they are not, and the point can never be settled without drilling.

As a well passing through the Paleozoic sandstones would presumably give the sole clues to the subsurface conditions over a wide area, and as it would probably be a difficult matter to identify the various formations, it appears to the writer that it should be bored with a diamond drill, in order that a continuous core might be obtained. The diamond drill would also have the advantage of being cheaper. Whatever method is used, drillers should be prepared to encounter cavy shales in the Upper Cretaceous rocks and large flows of water in the Upper and Lower Cretaceous sandstones, possibly also the Unkpapa sandstone.

While a consideration of the oil and gas possibilities shows that this region is of some promise, it should be remembered that only about one out of three of the best oil structures is expected to be productive, and that the chances become still less in areas far removed from production.

SUMMARY OF CONCLUSIONS

1. In this area local dips are thoroughly unreliable as an indication of oil and gas structures.

2. The tilted sandstone blocks are due to faulting and folding, probably influenced by the rigid character of the sandstones and the plastic nature of the surrounding strata. The tension produced by stretching in the anticlines, and the forces which produce the reversed drag along faults may possibly have also played a part.

3. These tilted blocks are not indications of oil and gas structures.

4. A large and promising oil and gas structure lies near the southwestern corner of the area.