STATE OF SOUTH DAKOTA
M. Q. Sharpe, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 49

A GEOLOGICAL SURVEY

in

DEWEY AND CORSON COUNTIES, SOUTH DAKOTA

by

Ray E. Morgan

and

Bruno C. Petsch

University of South Dakota
Vermillion, S. Dak.
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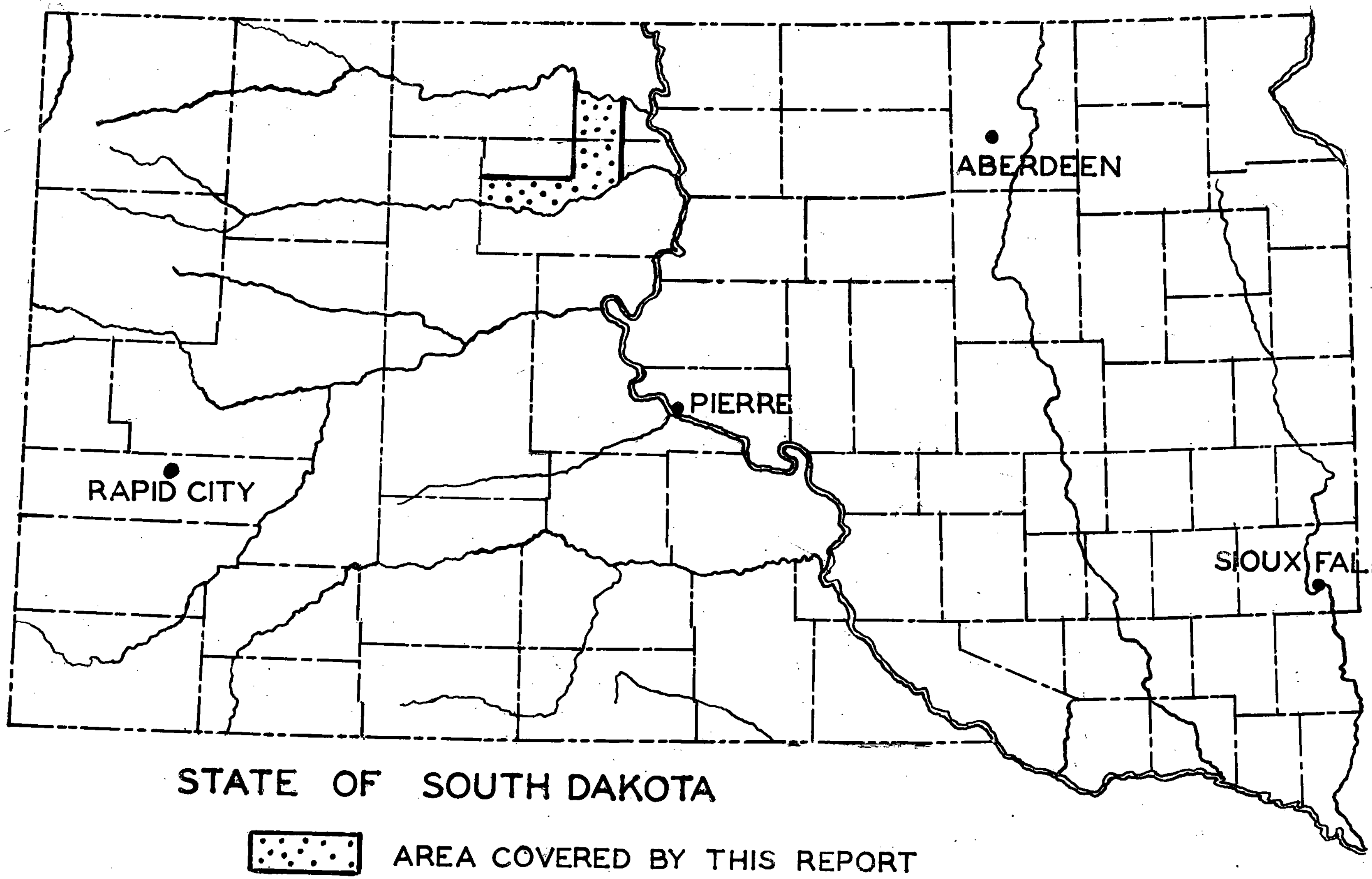
ABERDEEN
PIERRE
RAPID CITY
SIOUX FALLS
STATE OF SOUTH DAKOTA
AREA COVERED BY THIS REPORT

FIGURE 1

A GEOLOGICAL SURVEY

in

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INTRODUCTION

PURPOSE OF THE REPORT

In recent years residents of South Dakota and exploration departments of various oil companies have shown considerable interest in the petroleum possibilities of South Dakota.

In view of this interest, the State Geological Survey made a study of the stratigraphy of the surface formations of an area in north central South Dakota in the summer of 1944. The broad structural features, as indicated by the attitude of surface formations, were also mapped and a columnar section prepared to show not only surface formations but also the sub-surface rocks. The latter shows all formations likely to be encountered by the drill in testing for oil down to the top of the Pre-Cambrian granite. Below this drilling would be futile. (See Fig. 6.)

Studies of this sort are a necessary prelude to detailed mapping of local structures which may be used as drilling sites. Favorable local structures are, of course, anticlines or upfolds in the rocks. (Fig. 8A) Test wells located upon anticlines are much more apt to produce oil than are random wildcats located without regard to favorable geological conditions. By describing possible key beds and giving their stratigraphic position, it is hoped that this report will encourage the detailed geological or geophysical mapping necessary to outline favorable structures in plains type folds where the dips are ordinarily very low.

Potential host rocks or producing horizons are also discussed and estimates made as to the depths at which they probably occur. These considerations are very important to anyone contemplating drilling a test well, as cost is very largely a function of depth.

The structural and geological map accompanying this report employs a contour interval of 25 feet. This interval is larger than would be most advantageous for detailed local mapping designed to outline drilling sites in plains type folds. In view of the rapidity with which the area was mapped, it was not possible to establish enough control points in all parts to justify the employment of a smaller contour interval. The purpose of this preliminary survey, however, was to establish the regional structure and general stratigraphy in a rather large area and thus lay the groundwork for detailed mapping. However, the swinging of the 25 foot contours in several parts of the structure map suggests the possibility of local closures and indicates promising spots for more detailed mapping.

It will be noted that buttes are spotted on the geological map and that elevations have been established on many of these. These points of known elevations will be valuable as check points for geologists running plane table or barometer traverses and also for geophysical parties carrying sea-level datum elevations on their surveys.

DESCRIPTIONS OF ILLUSTRATIONS--PLATE 1

Figure 1.
Plane Table in Use--The instrument man lines up the alidade on the stadia rod held by the geologist in order to plot on the map points selected by the geologist. The telescopic alidade contains horizontal cross hairs or stadia hairs as well as a single vertical hair which bisects the circular field of the telescope and which is superimposed upon the stadia rod or any other target selected for locating or positioning on the map. The instrument man or engineer reads the intercept in feet between the bottom stadia hair and the top stadia hair on the stadia rod. Multiplying this reading by the stadia constant of the alidade (very close to 100 feet) the horizontal distance from the plane table to the stadia rod may be calculated. For example an intercept of 2½ feet will indicate a horizontal distance of 250 feet from the table to the rod. As the plotting edge or fiducial edge of the alidade always passes through the point on the map representing the position of the plane table, the position of the stadia rod may be plotted by scaling off 250 feet from the plane table point along the edge of the alidade. Vertical angles may be read with the telescopic alidade, and therefore the elevation of points may be determined according to trigonometric laws. In actual practice vertical differences are read from stadia tables. When vertical angles are large a horizontal correction may be required but for small vertical differences this correction is negligible.

Figure 2.
Sketching--The geologist sketches in details such as stream courses and formation boundaries, using as control the points plotted on the plane table sheet by the instrument man. Later he will draw in structural contour lines which are based on data carried in his field notebook, and elevations recorded in his engineer's notebook.

Figure 3.
Typical topography in which concretionary key beds usually show only as grassy shoulders and knoll tops, with fragments of concretions, often fossiliferous, weathering out at the grass roots. Trees grow only along water courses. It is possible to drive over much of this terrain without regard to roads. Sec. 11, T 15 N, R 22 E.

Figure 4.
Roads--Typical road or trail over Pierre shale in valley bottom and winding steeply to the plateau which is capped by Fox Hills concretions. Sec. 30, T 15 N, R 23 E.

PLATE 1

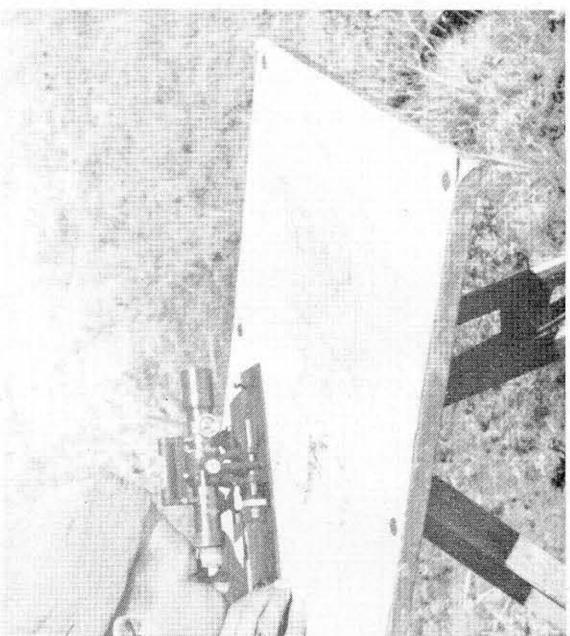


Fig. 1

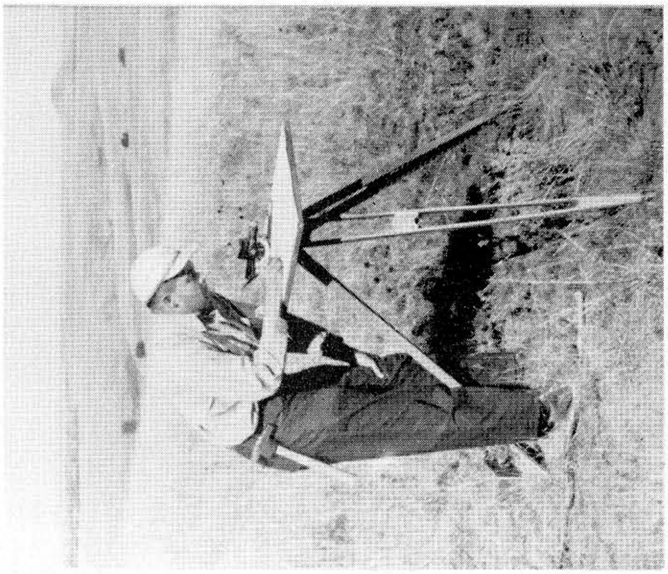


Fig. 2

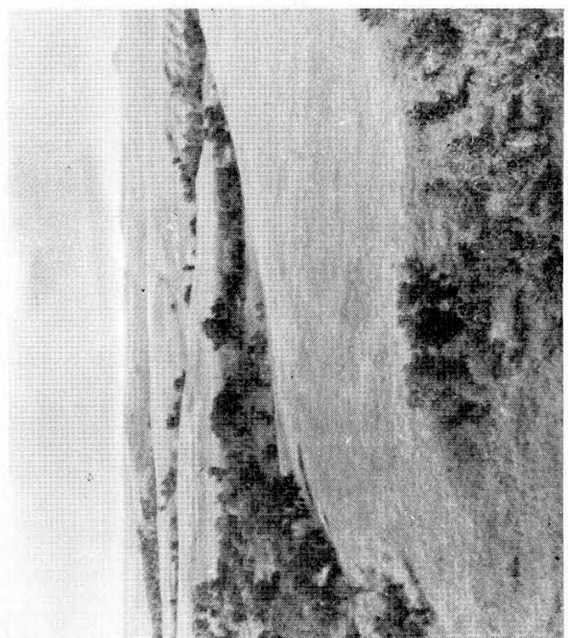


Fig. 3

Fig. 4

LOCATION AND AREA

The area covered by this report lies in north central South Dakota (Fig. 1). It includes portions of south central Corson County, western Dewey County and a small area in eastern Ziebach County. The city of Timber Lake is centrally located in the area; henceforth the region may be referred to as the Timber Lake area. Isabel, Firesteel and Trail City are also located in the district. (See map at back of report.) In general, the survey was confined to the "breaks" on the north bluffs of the Moreau River Valley and the south bluffs of the Grand River Valley. It also included portions of the divide separating the two.

The area extends about 46 miles from east to west, and 25 miles from north to south. A total of approximately 360 square miles was mapped in the following townships:

Township 19 N, Ranges 27 & 28 E
Township 18 N, Ranges 28 & 29 E
Township 17 N, Ranges 26, 27, 28 & 29 E
Township 16 N, Ranges 25, 26 & 27 E
Township 15 N, Ranges 21, 22, 23, 24 & 25 E
Township 14 N, Range 21 E

METHODS OF WORK

To accumulate field data for this report, a plane table survey was carried on during the months of July and August, 1944, from headquarters in Timber Lake. The party consisted of three plane table units, the geological work being done by Messrs. E.P. Rothrock, Bruno E. Petsch and Ray E. Morgan. The instrument work was done by Messrs. R.G. Arthur, H.R. Fossler and Robert Lawton.

Horizontal control was maintained by plotting stadia readings to scale (Fig. 1, Plate 1). Telescopic alidades and 18-foot stadia rods were used and the plotting done on a horizontal scale of 2500 feet to the inch. Horizontal position was checked at section corners and Indian allotment markers. In some cases it was possible to check horizontal position by triangulating on sheep herders' cairns on butte tops, or on other prominent markers previously accurately located on the plane table sheets.

Vertical control was maintained by the usual combination of stadia readings and vertical angles. Sea level datum was carried throughout the area. The stadia read distances and vertical angles were referred to stadia tables to get differences in elevations. The tables employed were those published by the United States Geological Survey in 1937, compiled by C.G. Anderson. In some cases differences in elevation were checked by trigonometric computation.

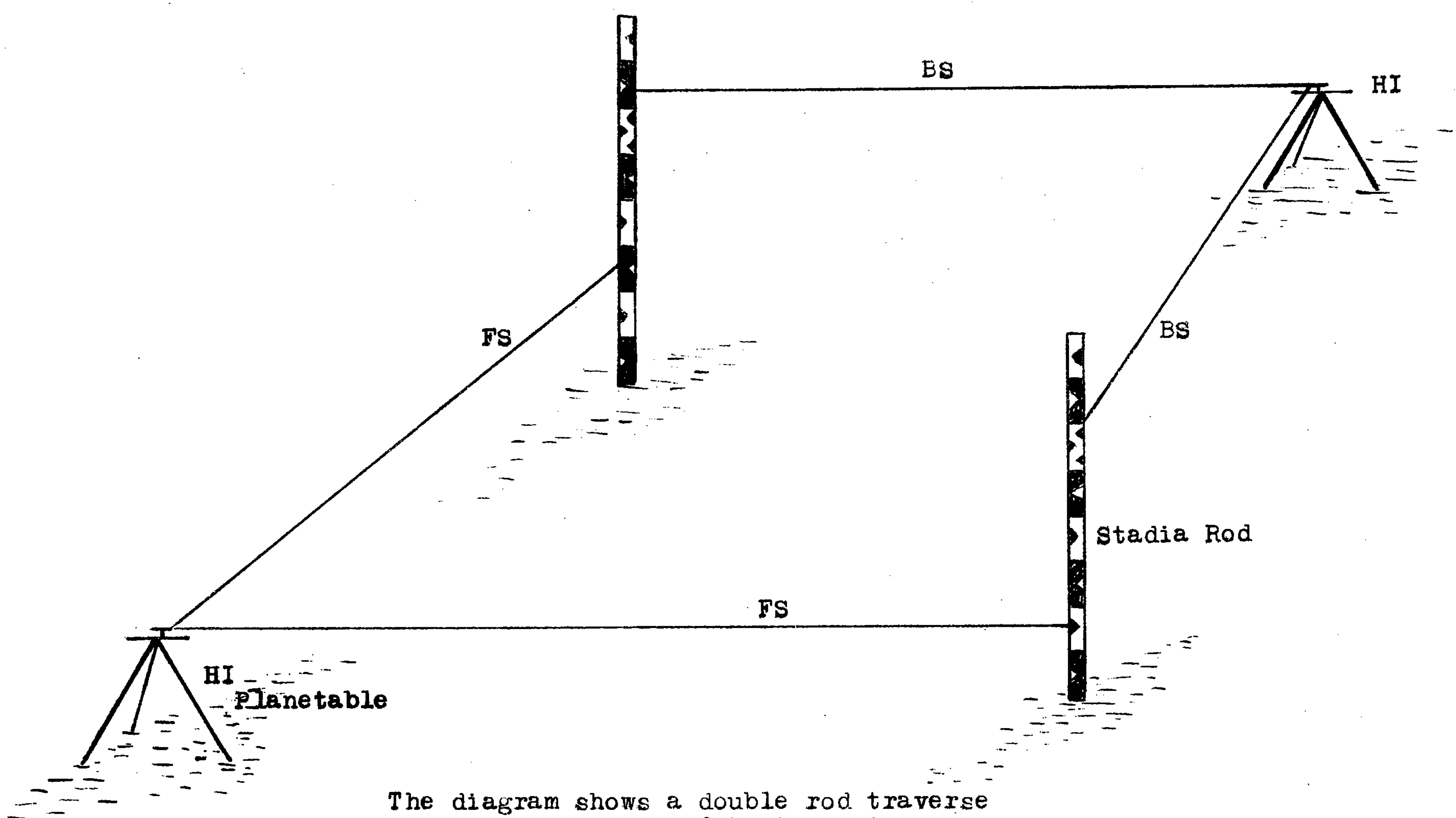
A number of buttes with summit elevations are shown on the map in the back of this report. Not all of these were located by stadia readings. In some cases the buttes were positioned by triangulation, the method by which objects are located at the intersection of alidade sights taken at them from several positions. In such cases a prominent sheep herder's cairn or bush was chosen as a sighting point so that the triangulation would be accurate. To get elevations on these summits angle shots and <u>scaled</u> distances were referred to tables or computed. Angle shots from several positions were read to lessen the chances of error.

BENCH MARKS

Elevations were carried from bench marks established by the United States Coast and Geodetic Survey. These bench marks are usually about two miles apart along two precise level lines which cross the area. One line follows the right-of-way of the Chicago, Milwaukee, St. Paul and Pacific Railroad east and west through the area. The second follows Highway 65 north and south near the western margin of the area (See map at back).

DOUBLE ROD TRAVERSING

Where practicable, traverses were run from one U. S. bench mark to another, or traverses from different bench marks were joined. Frequently however, this procedure would have entailed an unwarranted expenditure of time in traversing areas where mappable rocks do not outcrop. An alternative method of checking vertical control was the double rod technique, which was frequently employed when traverses were not to be closed at the starting bench mark or checked at some other point of known elevation. In the double rod method, two separate traverses are carried simultaneously on the same plane table. From each instrument station the rod-



The diagram shows a double rod traverse
closing at the Height of Instrument.

Figure 2

man establishes two turning points instead of one, and spaces them far enough apart so that the separate foresight and back sight lines will, obviously, converge at the plane table position when the traverse is plotted. To insure greater accuracy, the rodman tries to select rod positions of differing elevations for each pair of turning points. Thus, in effect, one traverse serves as a check on the other. If the two traverses do not show approximately the same difference in elevation between any plane table station and the last previous station, the instrument man knows that one of the traverses is in error and may then find the error by checking through his computations relating only to the last pair of foresights and the last pair of backsights, or if the error was made in reading angles or stadia distances, these shots may be retaken immediately while the positions of the last pair of turning points are freshly marked. The double rod method of traversing also guards against gross errors in horizontal control due to misreading or misplotting of backsight stadia distances as the plane table position is checked by resecting on the last pair of turning points (See Figs. 2 and 3). In running long traverses, even where the intent is to close the traverse or to check the elevations at some distant point, the double rod method may prove a time saver by eliminating the need for checking over a multitude of notes or re-running the traverse to discover an error.

The trace of the contact of the Pierre and Fox Hills formations was sketched from control points, as was also the drainage which largely controlled the shape of this contact. (See map in back of this report and Fig. 2, Plate 1.)

METHODS OF ESTABLISHING STRUCTURAL CONTROL

To establish structural control the top of a series of yellow bentonites was chosen as a datum plane or horizon. Elevations were taken on this horizon wherever it appeared to be in place. (Fig. 2, Plate 4) The most important key beds other than the bentonites were layers of fossiliferous concretions in the basal Fox Hills. (Plate 2 and Fig. 3, Plate 4)

Sections were measured at various exposures, largely by stadia methods, and intervals established between the bentonite and the concretionary layers. (See Figs. 4 and 5) Where the datum horizon was not exposed, elevations were taken on the concretionary key beds. These elevations were reduced to the datum horizon for structural mapping.

TRANSPORTATION

Transportation was by automobile. The flat or gently rolling upland between stream courses is sectionized and generally some sort of road or trail follows the section lines. Some of these are interrupted by washed out bridges. Where no formal roads exist it is often possible to drive across range land. Interstream divides are usually capped by Fox Hills rock which is more or less sandy. Even during wet weather it is usually possible to drive on the tough prairie sod and follow these ridges until they nose off into the breaks of the Moreau or Grand Rivers (Fig 3; Plate 1).

The valley bottoms are underlaid by the Pierre shale. Trails here are generally good in dry weather, but wheels become "balled up" with gumbo if the unimproved valley roads are driven on shortly after rains. (Fig. 4, Plate 1)

State Highway 8 is an all-weather road traversing the area from east to west. State Highway 65, a "black top" (tar surfaced) road, skirts the western edge of the area. (See map at back.)

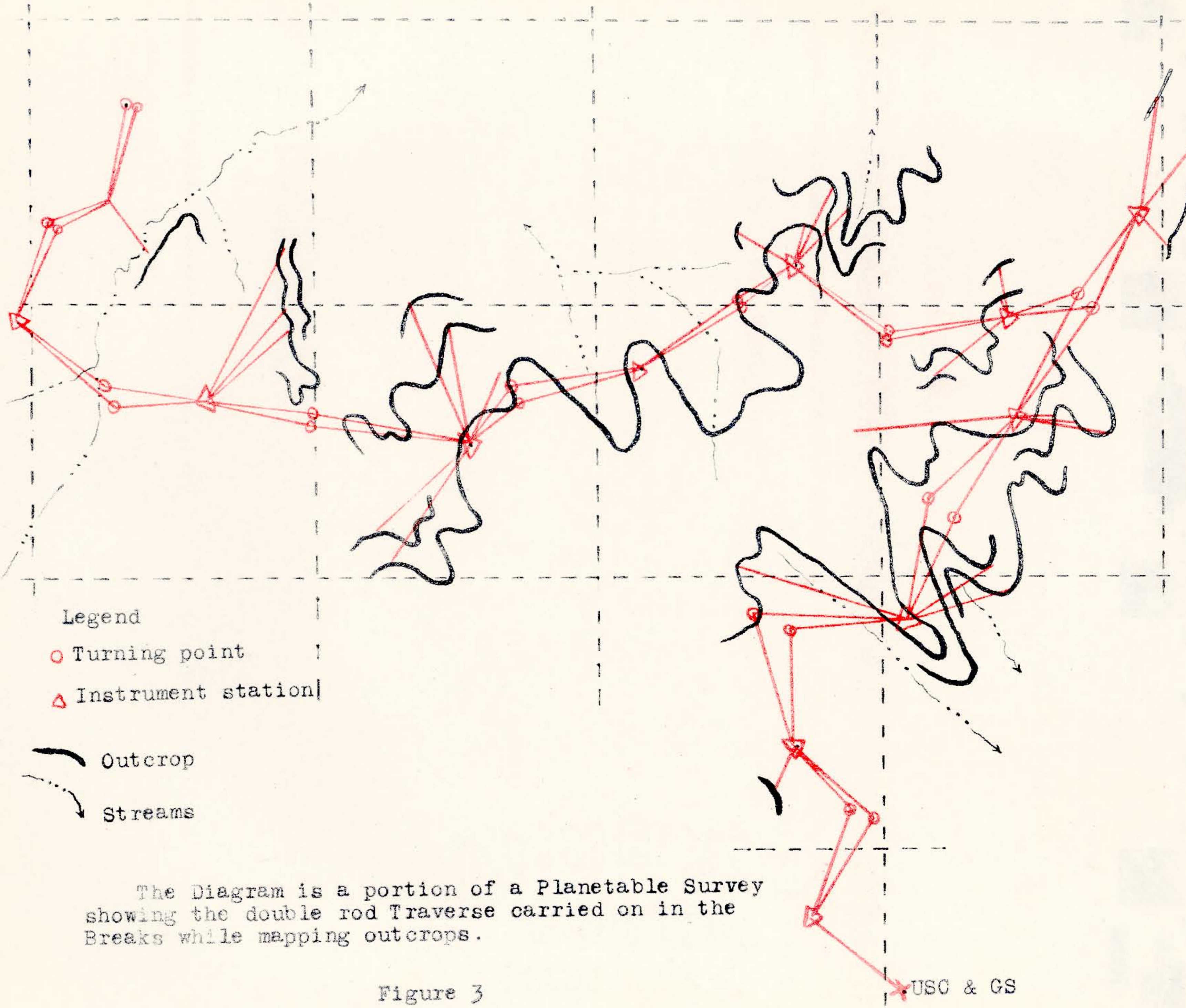
Railroad transportation is supplied by the Chicago, Milwaukee, St. Paul and Pacific Railroad mentioned in connection with bench marks. (See map at back.)

PREVIOUS WORK

Geological work has been done on this area by federal, state and commercial geologists. Most of it has been of a reconnaissance nature, though some attempts have been made to map detailed structure of small portions of it. The results of most of this work have been published in federal and state reports.

The following publications of the Federal government are concerned with the earlier work in this area:

1. Report of the United States Geological Survey of the Territories, Vol. IX, by Meek and Hayden, published by the Government Printing Office, Washington, 1876.



The Diagram is a portion of a Planetable Survey showing the double rod Traverse carried on in the Breaks while mapping outcrops.

Figure 3

2. Bulletin 575 of the United States Geological Survey, Geology of the Standing Rock and Cheyenne River Indian Reservations North and South Dakota, by W.R. Calvert, A.L. Beekly, V.H. Barnett, and M.A. Pichel, published by the Government Printing Office, Washington, 1914.

The following reports, which have been published by the South Dakota State Geological Survey, cover parts of the area here described:

Report of Investigation 10-The Isabel-Firesteel Coal Area, by W.V. Searight, 1931.

Circular 9--The Possibilities of Oil in Western Dewey County, by Freeman Ward and Roy A. Wilson, 1922.

Circular 10-The Possibilities of Oil in Northern Dewey County, by Roy A. Wilson, 1922.

Circular 13-The Possibilities of Oil in Northern Ziebach County, by Freeman Ward and Roy A. Wilson, 1923.

Circular 18-Well Log in Northern Ziebach County, by W.L. Russell and T.W. Stanton, 1925.

Circular 24-The Ragged Butte Structure, Southwestern Dewey County, by Roy A. Wilson, 1925.

Circular 27-The Possibilities of Oil in Western Corson County, by W.L. Russell, 1926.

In addition to the foregoing, a detailed log of an oil test drilled into the Spearfish formation in central Ziebach County appeared in The Journal of Paleontology titled "A Micro-Fossiliferous Upper Cretaceous Section from South Dakota," Vol. VII, No. 2, June, 1933. The description was written by E.R. Applin and includes lists of micro-fossils.

With few exceptions the publications cited above give only a general idea of the stratigraphy of the area. Some are concerned with the detailed mapping of small areas and include structural maps showing surface closures that suggest drilling sites. However, detailed sections with workable key beds indicated are usually omitted from the reports, and it is often not clear exactly what stratigraphic horizon was used as datum. In some cases aneroid barometers were used for vertical control. It is not apparent that frequent returns to a bench mark were made to observe changes in the diurnal curve. Nor is there any reference to temperature corrections. These considerations, influenced by difficulties of transportation, may have rendered barometric elevations insufficiently accurate to outline structures of small closure on some of the older surveys. It is likely that some local structures, mapped in the older publications, should be checked by careful surface work, and possibly by core drilling or geophysical work.

The Meek and Hayden report, although old, is still the chief paleontological reference for identification of Fox Hills fossils, and was used largely in classifying the fossils collected during the summer's field work. (See Plates 5 and 6.)

ACKNOWLEDGMENTS

The South Dakota Geological Survey is much indebted to Dr. Clinton R. Stauffer, of Sierra Madre, California, retired professor of paleontology of the University of Minnesota, for his great kindness in checking the identification of the Fox Hills fossils listed in this report. Dr. Stauffer's experience in surface mapping and collecting in areas of Fox Hills rocks has eminently qualified him for this service.

Many residents of the Timber Lake area offered hospitality to Survey members and aided the prosecution of the geological survey by acting as guides and furnishing information relative to roads.

The kindness of Messrs. Frank Cundill, Frank O'Leary, Jim O'Leary and Jess Tucker in rescuing members of the party temporarily stranded on the "lone prairie" by a refractory automobile was and is appreciated greatly.

SURFACE FORMATIONS

Their Characteristics and Possibilities For Structural Mapping

PIERRE FORMATION

Figure 4 is a generalized section of formations exposed at the surface. The lowest or oldest formation exposed is the Pierre formation, which has a total thickness of about 1400 feet. (Fig. 6) However, a maximum of only 200 feet or thereabouts of upper Pierre is exposed in the area. Of this exposure the upper 30 or 40 feet are the most significant for structural mapping. The Pierre is called a shale and, in general, the sombre exposures of massive appearing soft rock do have the appearance of a typical uniform shale. The color is usually medium to dark gray when dry and black when wet, but may be buff, brown or mottled gray and brown near the top of the formation. Close inspection reveals that the upper Pierre contains considerable silt and becomes more silty toward its top. At some exposures the rock consists largely of very thin streaks of clay shale intercalated with very thin streaks of silt.

The Pierre-Fox Hills Contact It has been pointed out in previous publications of the Survey that the contact between the Pierre and Fox Hills formations is conformable.* The graduation from typical shales of the Pierre to the typical sands of the Fox Hills was said to take place in a vertical interval of 50 feet or more. As the basal Fox Hills is often silty or composed of fine sand and the upper Pierre contains considerable silt, this is probably true in many places. The fact that the lower member of the Fox Hills over much of the eastern half of the Timber Lake area is a sandy shale with interbedded shales that often resemble the typical

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*Ward, Freeman, and Wilson, Roy A., The Possibilities of Oil in Western Dewey County, Circular 9, S. Dak. Geo. Sur., 1922.

Pierre makes it difficult to pick the contact on the basis of general lithological characteristics. In the western part of the area, however, the lithological distinction is usually much sharper on the basis of both color and texture. Here the gray silty Pierre shale is usually in sharp contact with bright yellow, well bonded Fox Hills sandstone.

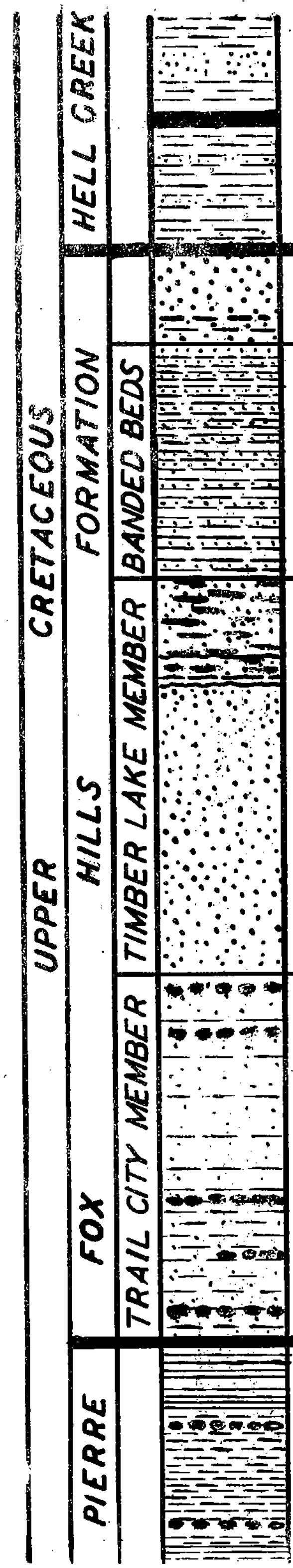
Taking the area as a whole, however, a sharp contact between the two formations cannot be drawn on the basis of color alone. For example, the exposure on Highway 63 (Fig. 3, Plate 4) reveals a color band in the upper Pierre which is lighter in shade and more yellow in tone than the basal Fox Hills immediately above. This local reversal of color is due to masking of the typical gray Pierre by the washing down of weathering yellow bentonite. In other cases, the inclusion of a fairly small amount of silt or fine sand in the Upper Pierre may give a color band on the outcrop very similar to the typical Fox Hills.

The contact, therefore, must be chosen arbitrarily. The exposures in this area showed bentonite beds which were confined to the lower and more shaly portions of the exposed sections and conspicuous fossiliferous concretions in the beds above them. It was, therefore, assumed that all the bentonites were in the Pierre formation and all the fossiliferous concretions in the Fox Hills. The contact, therefore, was taken below the first prominent zone of fossiliferous concretions and above the highest of the bentonites.

The interval between the top bentonite and the lowest concretionary layer varies from 3 to 25 feet averaging about 12 to 14 feet in the eastern part of the area and nearer the maximum figure in the western part. When a decided lithological or color change appeared in this interval (usually an upward change from predominantly gray shale to more sandy material of yellow or buff tone) the Pierre Fox Hills contact was placed at this point. Where no apparent lithological change occurred in this interval the contact was assumed to be about intermediate between the topmost bentonite and the overlying concretionary layer. This contact, however, is not a sufficiently well marked horizon to be used for mapping. Therefore, the top bentonite had to be used as a key bed.

GENERALIZED SECTION OF THE FOX HILLS FORMATION AND UPPER PORTION OF THE PIERRE AND LOWER PORTION OF THE HELL CREEK IN THE AREA BETWEEN FIRESTEEL AND TRAIL CITY

Vertical Scale, 1 inch = 40 feet



The Hell Creek formation is non-marine and consists of clays, lignitic and carbonaceous shale, sandstone, lignite coal, and thin beds of limonite. Total thickness: 150 to 300 feet.

A gray sandstone often caps buttes. Thickness: 20 feet plus or minus.

Usually composed of thin bedded fine grained sandstones and shales. Not well exposed in the area. Thickness: 50 feet or less.

The lower portion is usually soft or uncemented uniform sand. The upper portion contains calcareous, lens-shaped concretionary masses, thin limonitic claystones, and soft, mottled sandstone. Thickness: about 90 feet.

Usually a brown or buff sandy shale, becoming more sandy toward its top. Contains 3 to 5 locally persistent, fossiliferous zones of concretions. Thickness: 50 to 90 feet.

The upper Pierre is usually a dark gray, silty shale containing calcareous concretions and thin layers of yellow "bentonite."

Figure 4

Bentonites A number of very thin layers of "bentonite" or volcanic ash are exposed at many places at the top or near the top of the Pierre formation, and on this basis a separation is not difficult. (Fig. 4 and 5) This material is bright yellow on exposures, probably from contained limonite. It is very unctuous or greasy when wet but dried material does not swell markedly in water as does "text book" bentonite. In the eastern part of the area covered by this report recent slides or fresh exposures are not common and the "bentonite" is usually found weathering out at the grass roots as yellow nodular limonite pebbles below benches or knolls capped by lower Fox Hills concretions. (See Fig. 6, illustrating stratigraphic and topographic relations.)

Pierre Concretions The upper Pierre contains calcareous concretions, many of them arranged in nearly horizontal lines, and others scattered at random. Upper Pierre concretions generally exhibit fine grained gray limestone when freshly broken. They frequently weather white on the surface, or in some cases maroon. The concretions of the exposed portion of the Pierre were not fossiliferous in this area. However, T.W. Stanton wrote, "The genus Sphenodiscus and the various Scaphites species of the section Discoscaphites are essentially guide fossils for the Fox Hills sandstone, and yet in South Dakota and Wyoming they are all found in the upper 200 feet of the Pierre shale."* In contrast to the concretions of the lower Fox Hills, the concretions of the exposed portion of the Pierre were not found to be of much value for structural mapping.

Green Shale A rather unique local development in the upper Pierre is a bright green shale which averages about 2 feet thick. This shale is exposed in parts of Sections 19, 30 and 31, T 15 N, R 23 E, and Sections 24, 25 and 36, T 15 N, R 22 E, where it serves as an aid in structural mapping. This shale or other markers in the Pierre must be used with caution as a key horizon for mapping local structures of small closure because many slumps or local faults occur in steep slopes of Pierre shale. The green shale is ordinarily waxy in appearance when not dessicated. When well moistened it becomes very plastic. It probably contains bentonite and

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*Stanton, T.W., Well Log in Northern Ziebach County, Circular 18, S. Dak. Geo. Sur., 1925.

often has fresh biotite at its base. It seems to darken in color on strike and lose its identity away from the area indicated above. The green shale is exposed or may easily be dug out: (1) In the ditch on the west side of the road in the center of the north half of Sec. 19, T 15 N, R 23 E; (2) On the cliff facing Red Earth Creek and forming the north boundary of a Fox Hills outlier near the center of the east half of the south line of Sec. 19, T 15 N, R 23 E; (3) On a cliff below an escarpment capped by lower Fox Hills concretions 1250 feet north of the south line and 2000 feet east of the west line of Sec. 31, T 15 N, R 23 E.

Slumping of the Pierre along Slip Planes or Local Fault Planes At the latter exposure a slip or local fault has dropped the green shale about 16 feet on the west side of the fault. The slip plane is nearly vertical and contains post-slip selenite gypsum. There is no evidence that the fault is of considerable horizontal or vertical extent, nor does it displace the Fox Hills concretions which cap the escarpment.

Local faults or slips in steep slopes of Pierre shale are common. A good example occurs in the southwest corner of Sec. 14, T 15 N, R 23 E, on the east bank of Meadow Creek. Here the slip or local fault block has rotated so that strong dip is simulated by the inclined planes of yellow bentonites and also the inclined lines of concretions. Here too, selenite gypsum may be found in the fault plane.

THE FOX HILLS FORMATION

In most descriptions the Fox Hills formation is called the Fox Hills sandstone. In the area described in this report, however, the Fox Hills formation contains two identifiable units of almost pure sandstone, but also includes two others that, over a considerable portion of the area, are much less sandy in character. (See Fig. 4) Over most of the area described in this report these lithological units are distinctive in character and readily recognized where exposed. They are, therefore, considered to be members of the Fox Hills formation.

DESCRIPTIONS OF ILLUSTRATIONS--PLATE 2

Figure 1.
Concretionary Ledge--Nearly horizontal fossiliferous lower Fox Hills concretions (foreground) form the rim rock along a steep sided gorge tributary to Red Earth Creek. Distant Buttes capped by Upper Fox Hills sandstone appear on the horizon in the right background. Sec. 13, T 15 N, R 22 E, looking eastward.

Figure 2.
Sandstone Concretions--Large sandstone concretions of the Upper Fox Hills capping Ragged Butte in Sec. 26, T 15 N, R 22 E, Eastern Ziebach County.

Figure 3.
Concretions as Cap Rock--Lower Fox Hills (Trail City member) concretions form cap rock and influence the shape of these butte-like topographic forms along Meadow Creek in Sec. 22, T 15 N, R 23 E.

Figure 4.
Concretions as Ledge Makers--A zone of lower Fox Hills (Trail City Member) concretions forms the distant skyline in figure 4, and another zone which is 10 or 20 feet lower, stratigraphically, forms the shoulder in the far middle distance. Sec. 31, T 15 N, R 23 E, looking southward.

PLATE 2

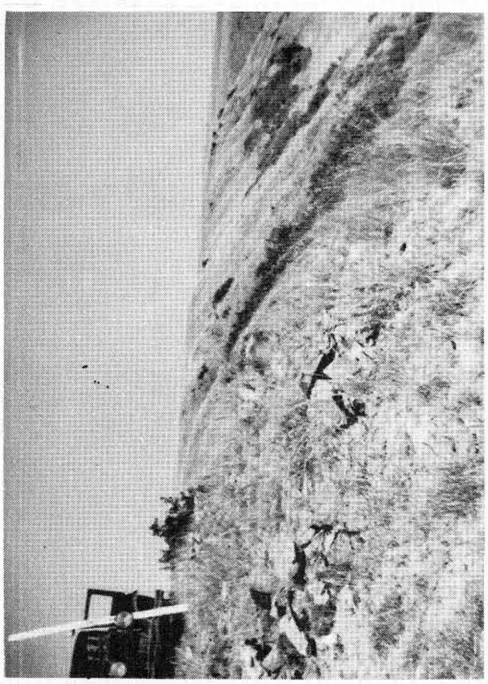

Fig. 1

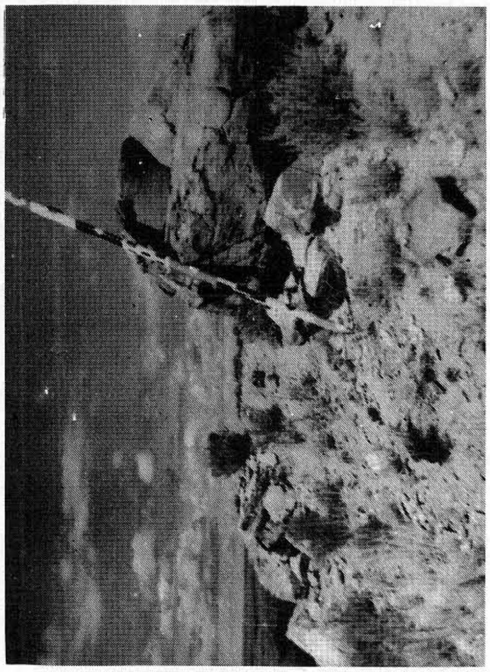

Fig. 2

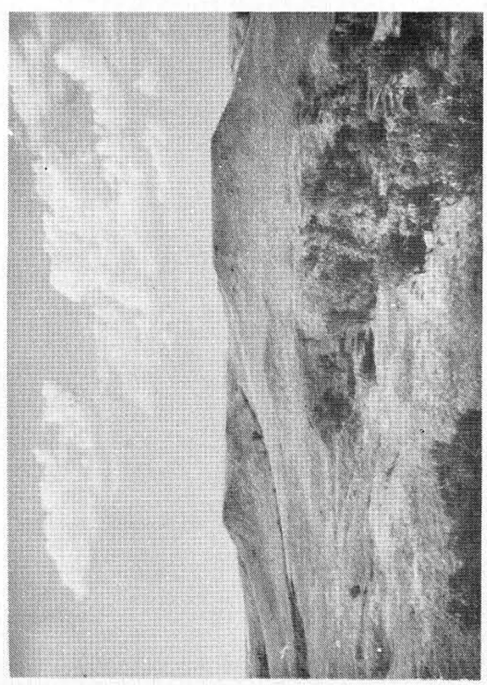

Fig. 3

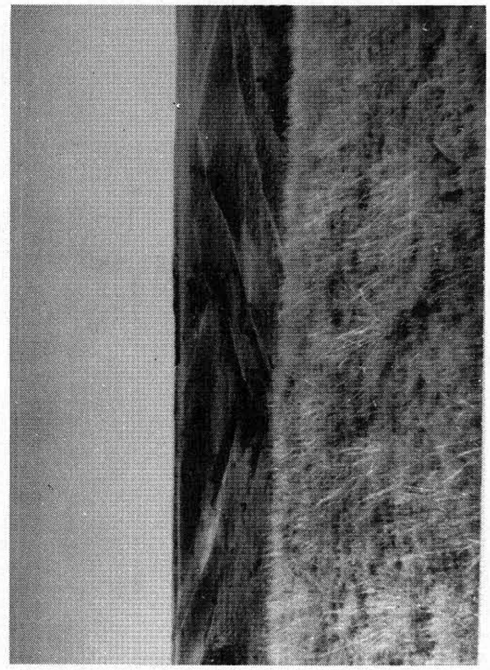

Fig. 4

TRAIL CITY MEMBER

The Trail City is stratigraphically the lowest member of the Fox Hills. It is named because of its excellent development in the area around Trail City near the eastern edge of the region studied and mapped for this report. It is also readily recognized for at least 12 miles north of Trail City along the edge of the breaks of the Grand River and also for a distance of about 50 miles in a direction about 25 degrees south of due west from Trail City along the edge of the breaks of the Moreau River. The Trail City member is also exposed for some distance up the courses of various tributaries to the Moreau, notably Little Moreau River, Red Water Creek, Meadow Creek, and Red Earth Creek. (See map at back.)

The nature of the Pierre-Trail City contact is indicated above in the description of the exposed portion of the Pierre. In the eastern part of the area the Trail City is usually a sandy brown or buff clay near its base, becoming more sandy in its upper parts near the contact with the overlying Timber Lake sandstone member. The base of the Trail City becomes more sandy on strike toward the west until in extreme western Dewey County (along the Moreau River) there is a sharp color change where the gray silty Pierre shale underlies the bright yellow ferrugenous concretionary sand of the lowermost Fox Hills.

Concretions of the Trail City The Trail City member contains 3 to 5 zones of characteristic concretions which are locally persistent. The concretions have cores of dense limestone but often have sandy jackets which spall off on exposure to weathering. The concretions are usually gray or blue on fresh fracture, but weather to shades of brown. Trail City concretions are often more or less spherical in shape and some resemble cannonballs in form. Others may be lenticular in outline. They average from about 1 to 2 feet through. Like upper Pierre concretions, they may contain yellow or golden calcite in shrinkage cracks.

Locally in the eastern part of the Timber Lake area the basal concretionary zone of the Trail City exhibits a peculiarity that is of some significance in correlation. This consists of black carbonaceous matter in the jacket or outer shell enclosing many of the concretions. In some cases, this material is black selenite gypsum, probably carbonaceous. In other cases a selenite gypsum jacket may enclose an inner shell resembling mineral charcoal, which is very black and soft and soils the fingers. The origin of this material is debatable, but it may represent carbonized sea weed.

Fossils Unlike Pierre concretions observed in the area, the Trail City variety are frequently highly fossiliferous. The common fossils are illustrated and described in Plates 5 and 6. In the eastern part of the area the large, heavy shelled pelecypod, Cucullea nebrascensis, Owen (Fig. 1, Plate 5 and Figs. 3 and 4, Plate 6) is locally abundant in the higher concretionary layers and appeared to be nearly or quite absent in the lower layers. Also "colonies" of the small pelecypods, including Limopsis striatopunctata, E. and S., (Fig. 2, Plate 5) seemed locally to characterize the lowermost Trail City concretionary layer. However, toward the western part of the district these fossils appear in any part of the Trail City member and even in the eastern portion of the area there was some mixing. In general it may be said that fossils appear to be of some value in correlating the various concretionary horizons in the area to the east of a north-south line through the town of Timber Lake, but that even here they are not entirely reliable.

Key Beds The Trail City member varies from about 50 to about 90 feet in thickness (Fig. 4). Its concretionary horizons are locally persistent and in many areas maintain constant intervals for sufficient distances to enable them to be correlated for structural mapping purposes. However, accurate sections should be measured wherever they are exposed and the intervals between the various concretionary layers noted as well as the interval down to the uppermost bentonite of the Pierre.

The concretionary layers of the Trail City and the top of the bentonite layers in the upper Pierre are probably the best key horizons or markers to be found in the area. They were used largely for structural control in the preparation of the map at the back of this report. (See Plate 2 and Fig. 5.) Ancient creep, slumps or slip offs along the edge of escarpments complicate the interpretation of structure from surface geology. (Fig. 4, Plate 4)

THE TIMBER LAKE SANDSTONE MEMBER

Area of Outcrop The Timber Lake member is the surface rock over most of the area shown on the map in the back of this report and covers the Trail City member over much of upland away from the larger stream depressions. The member is named because of its exposures in and near the town of Timber Lake.

Timber Lake Capped Buttes Many buttes are capped by Timber Lake sandstone, where it has become case-hardened or otherwise indurated. (Fig. 5) An interesting cluster of four Timber Lake capped buttes appear conspicuously in Sec. 24, T 15 N, R 23 E, and Sec. 19, T 15 N, R 24 E, where they stand about 100 feet above the surrounding terrain. Here the characteristic mottled sand of the Upper Timber Lake (Fig. 3, Plate 3) has become indurated, but together with limonitic claystones it is readily recognizable and especially in the sandstone capping the butte in the NE ¼ of Sec. 19, T 15 N, R 24 E, near Jim O'Leary's ranch house. Other buttes capped by Timber Lake sandstone include those in Sections 2, 6, 11, 12 and 27, T 15 N, R 24 E; Sec. 7, T 15 N, R 25 E; Sec. 1, T 15 N, R 22 E; and Sec. 31, T 16 N, R 23 E. These and other buttes are shown on the map in the back of this report, some with summit elevations.

Simulated Dip Slope on Butte Tops Some of these buttes have flat tops which slope interestingly with rather high dips. Interpretation of all or any of these apparent dip slopes as reflecting true subsurface conditions should be done with caution. The cap rock of Castle Butte in the NW corner of Sec. 25, T 15 N, R 23 E, has a strong northeasterly slant, as has the cap rock of the butte in the SE corner of Sec. 11. The top of the large butte in the NE ¼ of Sec. 24 slopes toward the east. However, the long butte in the NE ¼ of adjoining Sec. 19, T 15 N, R 24 E, is nearly horizontal on top.

It is probable that the slanting of these butte tops is due largely to slow creep in the clayey portions of the Trail City member and the bentonitic upper Pierre. The action is probably most rapid during seasons of heavy rainfall or during the spring when melt waters serve to lubricate the clayey portions of the sediments and permit them to move sideward in directions of least confining pressure and in response to the loading pressure of the Timber Lake sandstone. Mr. Cundill, local rancher, reported that portions of the cap rock of Castle Butte are undermined and thunder down the steep sides of the butte every spring. Of course, some of this disruption is due to frost wedging rather than to the movement of underlying beds. However, Mr. Cundill also reported that in the summer of 1944 a barbed wire stock fence some distance down the side of Castle Butte was completely separated and that the severed strands tapered toward the point of rupture as though they had been pulled slowly apart. The evidence suggests that forces causing local inclinations of butte tops probably are not related to deep subsurface movements.

This is not to assert that favorable local structure does not exist in the cited area but is merely to point out that the evidence provided by markedly tilting butte tops, whether favorable or otherwise, is probably untrustworthy. As a matter of fact, dips in plains type folds are generally so small that they would not usually be apparent by mere inspection of butte tops, even though reflected in them.

<u>General Character on Fresh Exposure</u> Where the Timber Lake formation is revealed in fresh exposures as in road cuts or the steep walls of valleys (Plate 3), the lower part is usually a greenish-yellow medium grain soft or uncemented quartz sand. The upper portion contains thin bands of fine grained orange to brown, well cemented limonite claystone, which also appears as isolated pieces or pebbles. The limonitic claystone occurs most abundantly toward the base of a series of lense-like masses formed by concretionary cementation of the otherwise soft sand.

The cement is calcite and the concretionary lenses, being relatively hard, weather out as resistant brownish ledges in exposures of the upper Timber Lake member. The soft sand between the concretions is often marked or mottled in a vermicular pattern. (Fig. 3, Plate 3)

DESCRIPTIONS OF ILLUSTRATIONS--PLATE 3

Figure 1.
Timber Lake Member of the Fox Hills--Closeup of lenticular masses weathering from a road-cut exposure of the Timber Lake member. The resistant lenticular masses are sandstone well cemented with calcite and embedded in a matrix of friable sandstone. (See Figure 3, Plate 3) NW corner of Sec. 7, T 16 N, R 24 E.

Figure 2.
Timber Lake Member of the Fox Hills Formation--
NW corner Sec. 7, T 16 N, R 24 E.

Figure 3.
Mottled Sand of the Timber Lake Member--Closeup of the mottled friable sand which is peculiar to much of the unindurated or soft sand of the Timber Lake member. The light colored areas are almost white and the darker background is a greenish-yellow. This mottled sand may be found in exposures of the Timber Lake member in the NW corner of Sec. 7, T 16 N, R 24 E, on the east side of the road skirting the Timber Lake golf course; in the NW corner of the NE$\frac{1}{4}$ of Sec. 21, T 17 N, R 24 E, on the south side of Highway 8, between Timber Lake and Firesteel; in a road-cut 5 miles north of Timber Lake; in the ditch on the west side of 63, in the center of the west line of Sec. 19, T 15 N, R 24 E; and at other places in the Timber Lake area.

Figure 4.
Timber Lake Member of the Fox Hills--Exposed along Little Moreau River in the SW $\frac{1}{2}$ of Sec. 7, T 16 N, R 24 E.

PLATE 3

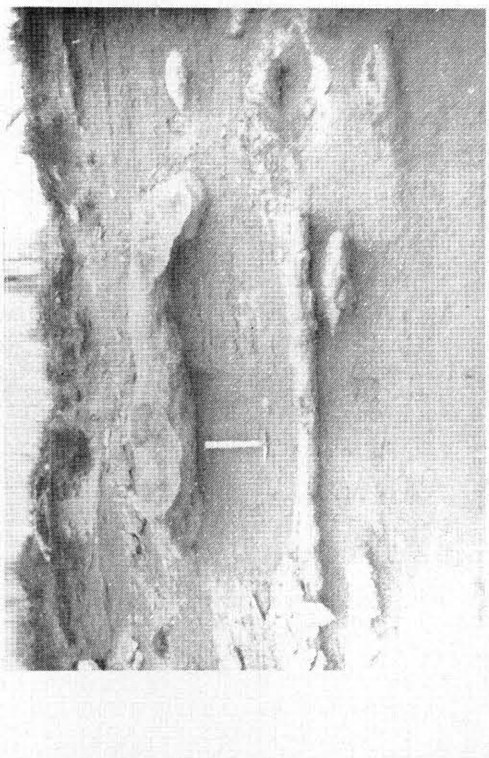

Fig. 1

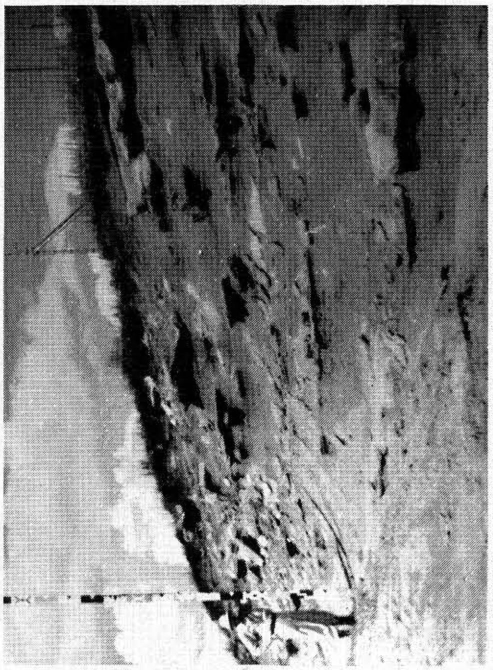

Fig.2

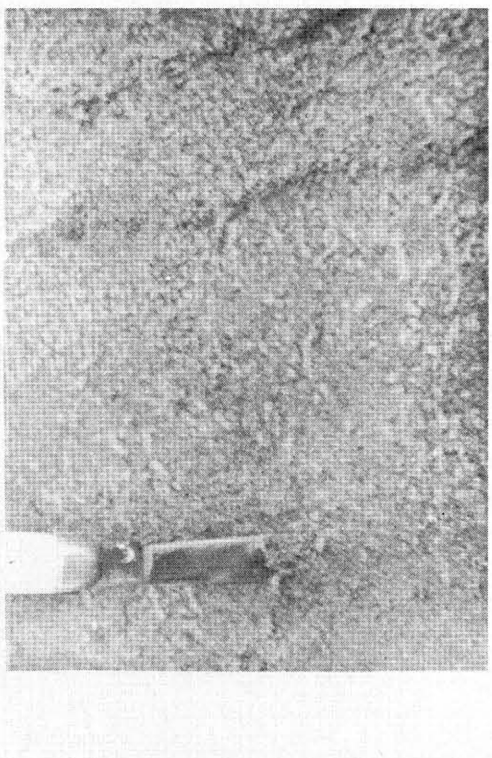

Fig. 3

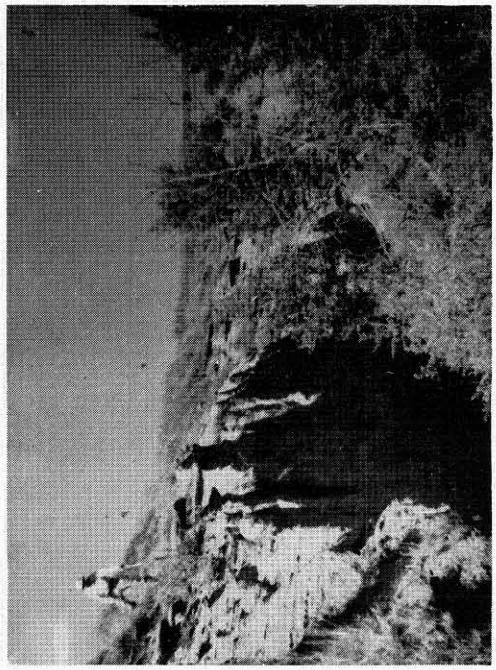

Fig. 4

DESCRIPTIONS OF ILLISTRATIONS--PLATE 4

Figure 1.
Color Change Near the Pierre-Fox Hills Contact--A color change, dark gray below and buff above is at this point somewhat below the contact of the Pierre shale and the basal portion or Trail City member of the overlying Fox Hills formation. Along Red Earth Creek in the SE $\frac{1}{4}$ of Sec. 19, T 15 N, R 23 E, looking southward.

Figure 2.
"Bentonites"--Thin bands of yellow "bentonite" with concretions containing selenite gypsum occur close to the Pierre-Fox Hills contact in the SE $\frac{1}{4}$ of Sec. 19, T 15 N, R 23 E, on the south side of Red Earth Creek and near French's ranch house. See Fig. 1, Plate 4.

Figure 3.
Key Beds and Other Mappable Horizons--In this view a recent slide has exposed part of the Pierre-Fox Hills section. The man is standing upon a concretionary layer near the top of the Pierre formation. Concretionary layers such as this also are present in the lower Fox Hills and make short pavements which are locally sufficiently resistant to make shoulders or to cap knolls in otherwise featureless grassy areas.

About six feet below the human figure the light colored band indicates the presence of bright yellow thin limonitic layers of volcanic ash or "bentonite." The top of a higher zone of "bentonites" occurs at the level of the man's shoulders. These do not show in the photograph but may easily be dug out of the bank. The upper limit of this "bentonite" is close to the Pierre-Fox Hills contact and was used as a datum horizon or key bed for structural mapping of the area. Elevations taken on other beds or concretionary layers were reduced to this zone of "bentonites." NW $\frac{1}{4}$ of Sec. 32, T 15 N, R 24 E, on the west side of Highway 63.

Figure 4.
Slumping--Recent slumping has occurred along the west bank of a steep sided gorge in the SE $\frac{1}{4}$ of the NE $\frac{1}{4}$ of Sec. 34, T 15 N, R 22 E. In part, blocks have sunk almost vertically with little tilting. Other blocks are somewhat tilted. Further valleyward the grassed-over lower Fox Hills has been undermined and has cascaded over the Pierre shale like Alpine snow drifts. Fresh subsidence like this is easy to detect but in cases where advanced weathering and masking by vegetation has taken place it is difficult to ascertain whether or not certain concretionary layers are in place or whether they have been "repeated" at various levels by ancient slumping. These considerations add to the difficulty of mapping the relatively incompetent Cretaceous formations.

PLATE 4

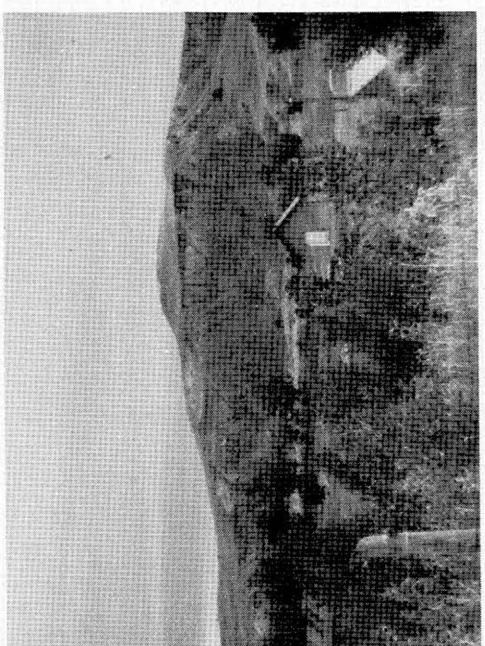

Fig. 1

Fig. 2

Fig. 3

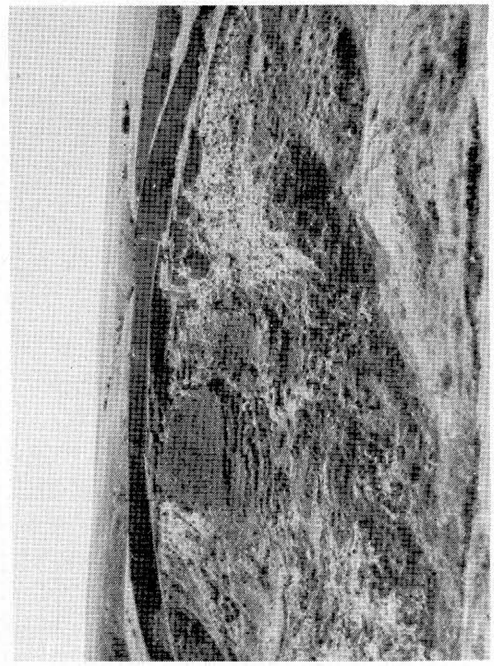

Fig. 4

Possibilities for Structural Mapping The possibilities of utilizing one or more horizons of the Timber Lake member for structural control have not been fully investigated. Sandstones are often lenticular and change rapidly on strike, both as to thickness and lithological character. Because of the apparently greater possibilities of correlating a number of horizons in the underlying Trail City member and the upper Pierre, the field party spent most of the available time in mapping them.

The Timber Lake has a total thickness of about 90 feet, but because of the apparent lack of very definite key horizons below the top of the member, it would appear difficult to use it for detailed mapping to discover local structures of small closure. In many cases too, the sides of buttes capped by Timber Lake sandstone are mantled by talus and vegetation. However, careful study may reveal usable horizons in the Timber Lake which will permit surface structural mapping on the uplands where the Trail City and Pierre are buried. This would provide a valuable aid to the mapping of the central part of the divide between the Grand and the Little Moreau Rivers.

THE BANDED BEDS

A series of very thin bedded olive-drab shales intercalated with equally thin sands appears in a road cut on Highway 8 between Timber Lake and Firesteel. The exposure is in the center of the south line of Sec. 18, T 17 N, R 24 E. Elevations indicate that these beds occur stratigraphically higher than an exposure of upper Timber Lake in the NW corner of the NE $\frac{1}{4}$ of Sec. 21, T 17 N, R 24 E, on the same road. Topographic relations suggest that these banded beds or a lithologically similar unit probably occur between the uppermost Timber Lake and a sandstone which caps some buttes in the Timber Lake area. The Banded Beds may be equivalent to a "banded member" described by W.V. Searight in the SE $\frac{1}{4}$ of Sec. 21 and the SW $\frac{1}{4}$ of Sec. 22, T 16 N, R 22 E.* Because they are not well exposed in the area, the banded beds are of doubtful value as an aid to structural control. (See Figs. 4 and 5)

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*Searight, W.V., The Isabel-Firesteel Coal Area, Report of Investigations #10, S. Dak. Geo. Sur., 1931.

UPPER FOX HILLS SANDSTONE

A gray flaggy sandstone caps several buttes in the vicinity of Timber Lake and at an elevation higher than nearby exposures of the upper part of the Timber Lake member. This sandstone is believed to constitute the uppermost Fox Hills member in the Timber Lake area. At Dog Butte, five miles east of Timber Lake, the sandstone contains an abundant brackish water fauna composed mainly of the large oyster, Ostrea glabra (Fig. 2, Plate 6). As in the case of the Timber Lake member, the upper Fox Hills sandstone was little used for structural mapping, but it may, however, have potential value.

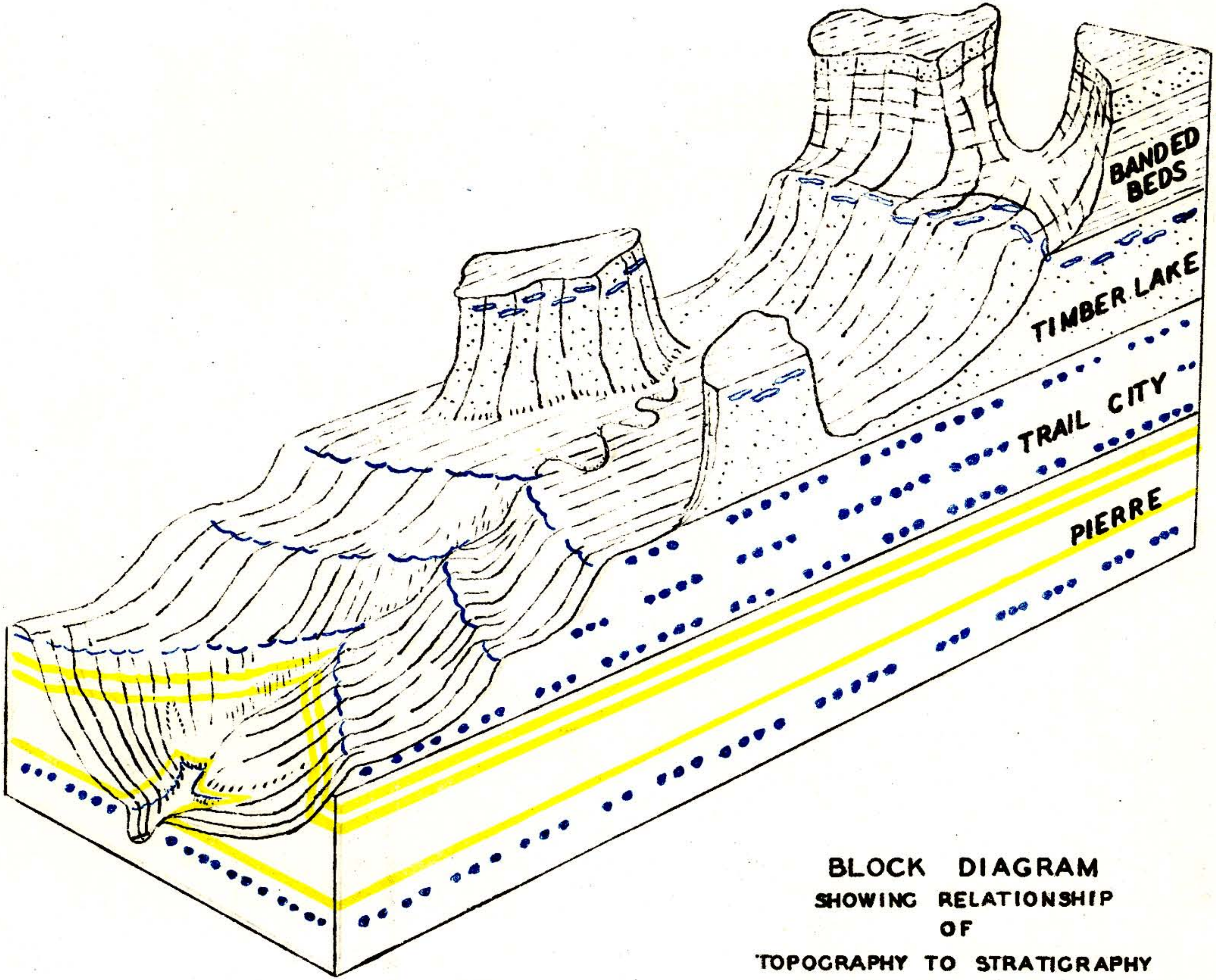
THE HELL CREEK FORMATION

General Characters The Hell Creek is the youngest formation exposed in the area. It is composed largely of fresh water clays and sands which are dominantly gray in color. The sands of the Hell Creek are usually banded with gumbo or colloidal clay and consequently, are characteristically tough and resistant to fracture. The Twin Buttes in Sec. 34, T 17 N, R 23 E, are capped with Hell Creek sandstone. The buttes are two miles south of Firesteel near the Fox Hills-Hell Creek contact.

The fauna of the Hell Creek is, of course, non-marine and fragments of fossilized bones are not uncommon. Some whole or nearly whole skeletons of Ceratops, one of the last of the great quadrupedal dinosaurs, have been found.

Coal Lignite and carbonaceous shale occur in the Hell Creek. Limonite is also abundant. The lignite is exploited by strip mining in several places and especially at Firesteel where accumulated waste from the stripping operation resembles a low butte from a distance.

Possible Key Horizons The Hell Creek formation is confined to the western portion of the area considered in this report and was not utilized for structural mapping purposes. However, certain horizons hold promise as mappable key beds, notably the lignite and carbonaceous shale.



BLOCK DIAGRAM
SHOWING RELATIONSHIP
OF
TOPOGRAPHY TO STRATIGRAPHY

R.E.M.

FIGURE 5

SELECTED STRATIGRAPHIC SECTIONS

The following descriptive sections of the Upper Pierre and Fox Hills formations are representative of the mapped area and probably are the best to be seen. They were measured largely by stadia methods with portions of some sections filled in by hand-level.

As indicated heretofore, recent exposures are rare in the eastern part of the area and the section making is limited mostly to taking elevations on concretionary benches in the Trail City member and on the upper limit of yellow pebbly material which is the weathered product of the upper Pierre bentonites (Fig. 5).

Section Number 1

Succession of beds exposed along a wagon road
2½ miles southeast of Trail City.
NW ¼ Sec. 9, T 17 N, R 29 E, Dewey County

Total Thickness: 51 feet

Elev.	Intervals in feet	
2163		Concretionary rimrock. Below to 2149, buff sandy shale.
	14	
2149		Concretionary ledge. Below to 2126, buff sandy shale.
	23	
2126		Concretionary ledge. Below to 2119, buff sandy shale.
	7	
2119		Single concretion. Below to 2113, buff sandy shale.
	6	
2113		Base of Fox Hills. Below to 2112, gray shale.
	1	
2112		Laminated thin yellow bentonite and yellow bentonite pebbles. Below to 2111, gray shale.
	1	
2111		Gray shale, base of exposure.

Section Number 2

Succession of beds exposed in north bluffs of the Moreau Valley along graveled road to White Horse. SW corner Sec. 24, T 16 N, R 25 E, Dewey County

Total Thickness: 34 feet

Elev.	Intervals in feet	
2182		Top of exposure. Below to 2180, gray limey shale.
	2	
2180		Top of red-brown shale. Below to 2179, red-brown shale.
	1	
2179		Base of red-brown shale. Below to 2174, gray shale similar to Pierre shale.
	5	
2174		Ledge-making concretionary layer. Concretions are blue inside but weather red. They occur in gray, limey mud jackets. A pearly scaphite with golden drusy calcite inside broke out of one concretion. Below to 2165, gray shale.
	9	
2165		Top of covered zone. Below to 2158, no exposure.
	7	
2158		Base of covered zone. Below to 2156, gray shale.
	2	
2156		Top of Number 1 or basal concretionary zone of the Trail City. Concretions, blue but weather reddish. Some in mud jackets. Some "peanut brittle" (See Fig. 2, Plate 5.) Below to 2153, gray shale.
	3	
2153		Top of brown shale. Below to 2151, brown shale.
	2	
2151		Top of dark gray shale. Below to 2048, dark gray shale.
	3	
2048		Base of measured section.

DESCRIPTIONS OF ILLUSTRATIONS--PLATE 5

Figure 1.
Fox Hills Fossils--"Colony" of Cucullea nebrascensis, Owen weathering out of a concretion in the Trail City member of the Fox Hills formation.

The Cucullea is a large fat pelecypod or clam with a very thick shell. Many specimens are not unlike a peach in point of size and general proportions. In the eastern part of the area described in this report the Cucullea appeared to be largely restricted to the upper portion of the Trail City member but as the Trail City became more sandy toward the west the Cucullea was found also in the lower portion.

Very often a zone of concretions is highly fossiliferous in places, but with intervening portions almost barren of fossils. Individual concretions (as in Fig. 1 and Fig. 2 of Plate 5 and Fig. 3 of Plate 6) may be composed largely of fossils from a single species. In others, several forms may be mixed in about equal proportions.

Figure 2.
Fox Hills Fossils--Small pelecypods such as these are very abundant in certain places in the Trail City member of the Fox Hills. The small clams average about the size of a navy bean and weather out white, whereas their enclosing calcareous matrix often weathers to a limonite brown. For obvious reasons the aggregates (which include many Limopsis striatopunctata, Evans and Shumard) were sometimes called "peanut brittle."

In the eastern part of the area described in this report, "colonies" of small pelecypods make up the greater part of many concretions, especially in the lowest concretionary zone of the Trail City member where they helped locally in the correlation of the several concretionary layers.

Figure 3.
Fox Hills Fossils--The large fossil pictured here is Sphenodiscus lenticularis, Owen. It has a complex suture pattern characteristic of ammonites. A smaller sphenodiscus is shown edgewise in order to illustrate the characteristic cross-section which resembles that of a double-bitted axe.

Figure 4.
Fox Hills Fossils--The fossils here pictured are found in Trail City concretions. They include the following pelecypods: numbers 3 and 6 Pteria linguiformis, Evans and Shumard; number 1, Cucullea shumardi, Meek and Hayden; number 2 the "chevron clam" Goniomya americana, M and H; number 5 Gervillia recta, M and H. Number 4 is the gastropod, Fusus dakotensis, M and H.

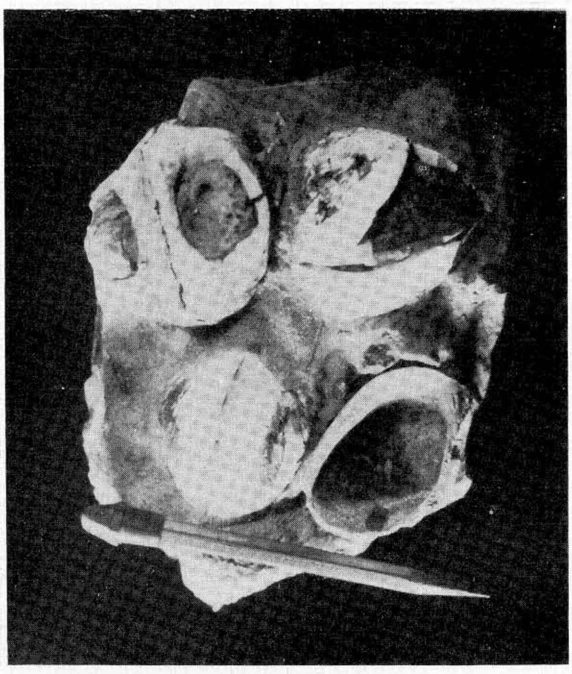


Fig. 1

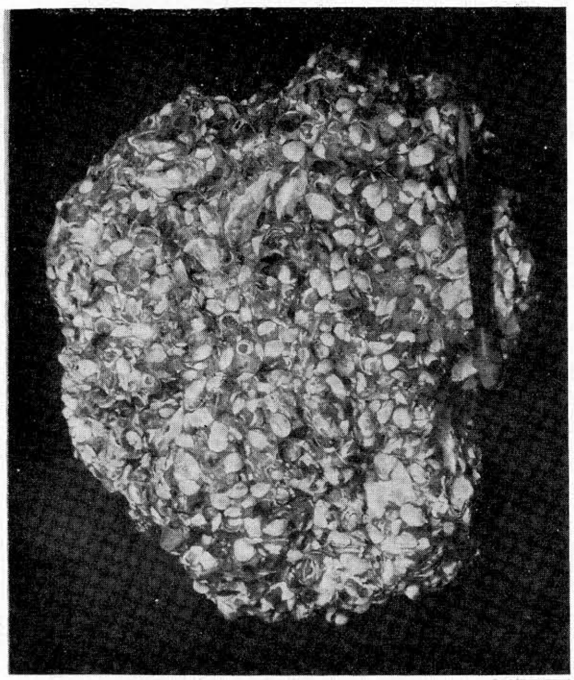


Fig. 2

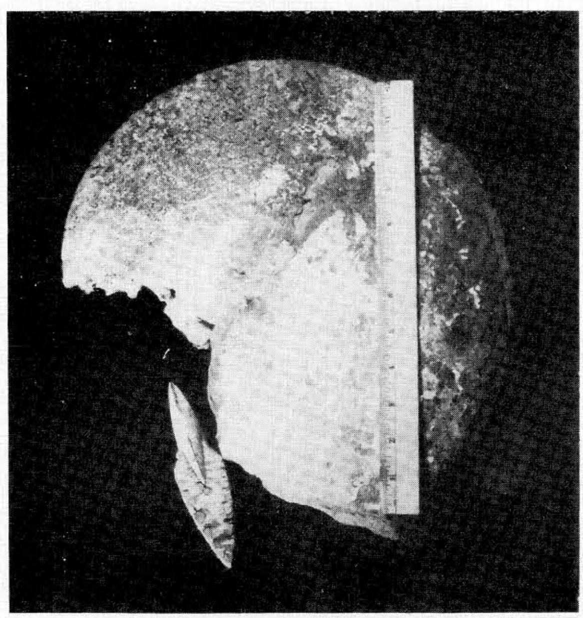


Fig. 3

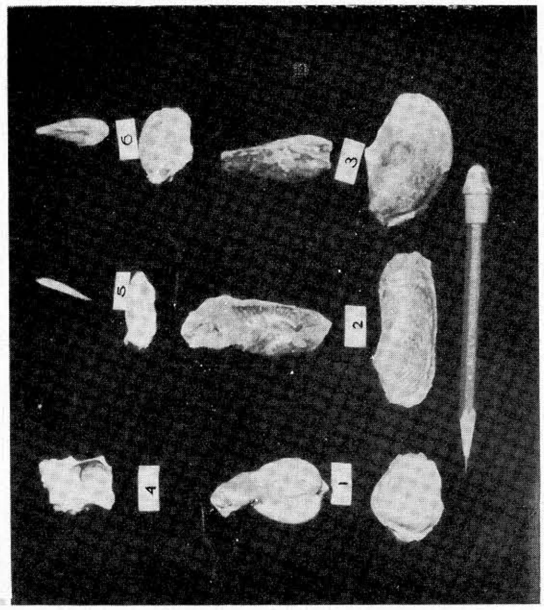


Fig. 4

Section Number 3

Succession of beds exposed in road cut
A half mile east of Little Moreau Lake.
E ½ Sec. 17, T 16 N, R 25 E, Dewey County

Total Thickness: 173 feet

Elev.	Intervals in feet	
2222		Top of section. Below to 2221, large sandy lenticular concretions of the upper Timber Lake.
	1	
2221		Below to 2220, greenish, angular, friable sand
	1	
2220		Below to 2216, orange limonitic claystones in part sandy and ledgelike, and intercalated with soft sand.
	4	
2216		Below to 2206, soft, greenish sand.
	10	
2206		6-inch concretionary ledge, limonitic claystone on outside, blue calcareous material inside. Below to 2205, greenish yellow sand.
	1	
2205		Think yellow limonitic claystone in part conglomeratic. Below to 2201, greenish sand.
	4	
2201		1 foot thick, fine grained blue limestone concretions weathering buff and maroon. Below to 2199, soft greenish sand.
	2	
2199		Thin orange limonitic layer, below to 2195, greenish sand.
	2	
2197		Thin orange limonitic layer, below to 2195, greenish sand.
	2	
2195		Thin orange limonitic layer, below to 2159, greenish sand.
	36	
2159		Top of covered zone. Below to 2138, no exposure.

Elev.	Intervals in feet	
	21	
2138		Base of covered zone-probable base of Timber Lake and top of Trail City. 1 foot concretionary layer with Cucullea nebrascensis (Fig. 1, Plate 5). Below to 2134, buff clayey silt.
	4	
2134		1 foot thick, concretions (containing Cucullea) in sandy clay jackets, weathering buff. Below to 2124, buff clayey silt mottled with white calcite.
	10	
2124		1 foot thick single concretion weathering maroon. Below to 2115 grayish clayey silt.
	9	
2115		Ocherous, fossiliferous, soft, concretionary band, 1 foot thick. Below to 2112, buff silty shale.
	3	
2112		Ocherous concretionary band, 2 feet thick. Below to 2107, buff silty shale.
	5	
2107		Slightly resistant, yellow concretionary streak. Below to 2096, yellow-brown shale.
	11	
2096		Large concretions $1\frac{1}{2}$ feet thick, blue in center, weather red and yellow, white calcite in cracks. Below to 2085, yellow-brown sandy shale.
	11	
2085		Color change. Below to 2080, shale, mottled dark brown and gray.
	5	
2080		1 foot to 2 foot concretions, blue inside, weathering white, golden calcite in partings. Below to $2077\frac{1}{2}$, reddish fossiliferous sand.
	3	
2077		Thin irregular limonitic streaking. Reddish clayey silt starts 6 inches higher and continues below to 2074.
	3	
2074		Below to 2067, gray to buff clayey silt.

Elev.	Intervals in feet	
	7	
2067		6 inch silty fossiliferous concretions, blue core, gray on outside. Below to 2061, clayey buff silt.
	6	
2061		1 foot thick concretions, blue inside with jackets of silty gypsiferous material which includes black carbonaceous matter, probably the remains of seaweed or other marine life. Below to 2056, clayey buff silt.
	1	
2060		Base of Fox Hills.
	4	
2056		Thin yellow streaks of bentonite and yellow limonitic "pebbles." Below to 2049, mottled buff and gray slightly sandy shale is jointed and selenite appears in the joint planes. Occasional random concretions in the shale consist of fine grained blue limestone which weathers buff.
	7	
2049		Base of exposure--bottom of section.

The lower portion of this section is rather difficult to correlate because of the unusual number of concretionary layers in this exposure. It has been suggested that the lower part of the section has been repeated by faulting and that the color change at 2085 represents the true base of the Fox Hills formation.

Section Number 4

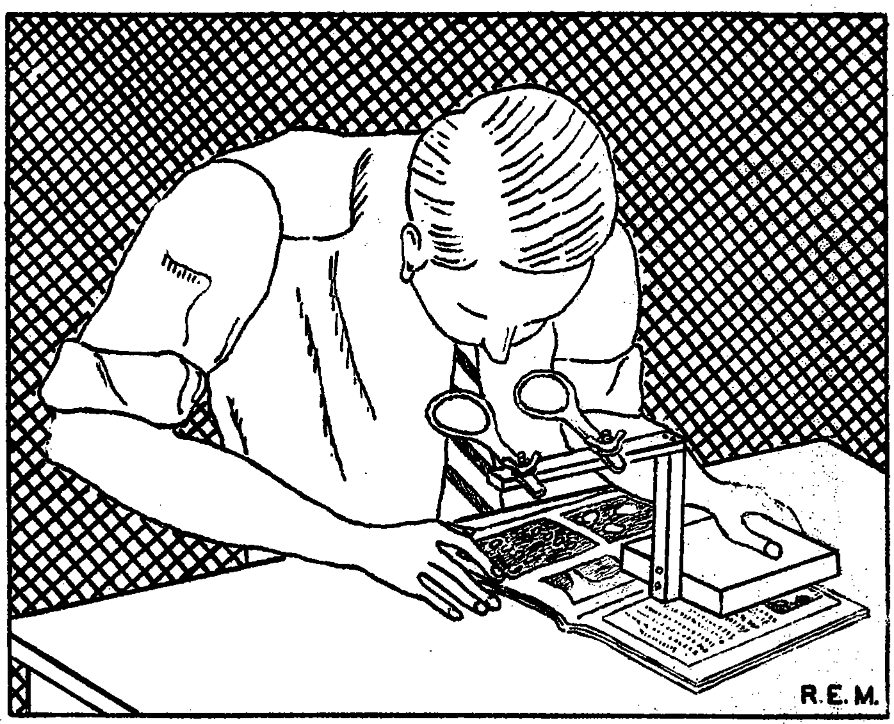
Succession of beds on the north bluffs of the Moreau Valley in road cuts along State Highway 63. NW corner Sec. 32, T 15 N, R 24 E, Dewey County

Total Thickness: 146 feet

Elev.	Intervals in feet	
2297		Top of exposure-Rimrock formed by layer of calcareous concretions which weathers to brown sandy rubble. Fossils include casts of Cucullea shumardi which are dark blue in color (No. 1, Fig. 4, Plate 5), and one Sphenodiscus (Fig. 3, Plate 5). Below to 2278, somewhat clayey yellow-brown sand.
	19	
2278		Layer of concretions over 2 feet thick. Cores of blue limestone encased in sandy calcareous jackets which weather to sandy rubble. Some shrinkage cracks show drusy golden calcite and others are colored dark blue. Some concretions are fossiliferous. Below to 2158, yellow-brown sandy clays and argillaceous sands.
	20	
2158		Calcareous concretions of clayey sand weathering to sandy rubble. Some fossils. Below to 2255, yellow sandy clay.
	3	
2255		Below to 2228, buff to brown sandy shale.
	20	
2235		About the base of the Fox Hills. Below to 2228, brown silty shale.
	7	
2228		Top of a 2 foot band of 4 or 5 thin but distinct yellow bentonitic streaks. Below to 2223, darker shale with indistinct yellow streaks.
	5	
2223		Prominent layer of lenticular concretions 8 inches thick and 2 to 6 feet long makes short pavements. Concretions have sandy jackets and show golden calcite in shrinkage cracks. Below to 2215, buff to brown silty shale.

perception of the true shape of the specimens than can be realized by inspecting the ordinary "one-eyed" photograph. The effect is much as though the actual specimens were viewed by both eyes from a distance of 30 inches, but with centers of the eyes spaced five inches apart instead of the average interpupillary spread of about 2 and 5/8 inches.

The right and left hand views in Fig. 4 are spaced conveniently for inspection by a folding pocket stereoscope. An ordinary "parlor-type" stereoscope also may be adapted by sliding the picture carrier from its guide and substituting Figure 4. This may be done without damage to the report by folding back the preceding pages and holding Figure 4 in front of the lenses and moving it back until the two lines of images fuse into one. It may be necessary to rotate the page or the stereoscope slightly in order to superimpose the images. It is not difficult to construct a simple lens-type stereoscope from inexpensive magnifying lenses frequently available in drug stores or five-and-ten-cent stores. (See illustration below). Some people master unaided stereoscopic vision by focusing their eyes on a distant object so that the lines of vision become nearly parallel and then transferring the gaze to a stereoscopic pair spaced so that the right eye looks at the right hand view and the left eye at the left hand view; the two images fusing. Fig. 4 is arranged so that this is possible for persons who have learned the technique.



DESCRIPTIONS OF ILLUSTRATIONS--PLATE 6

Figure 1.
<u>Fox Hills Fossils</u>--In this illustration all the forms except number 5 are cephalapods, which, in life, extruded fleshy tentacles for procuring food and in some cases for walking along the sea bottom. Number 1 is Eutrephoceras dekayi, Morton, a nautiloid with a comparatively smooth shell and a simple suture pattern. Numbers 2 and 3 are Scaphites conradi, Morton. Number 4 is Scaphites nicolletii, Meek and Hayden. Scaphites are ammonites with transverse ribs and nodes on the shell and the usual comples suture pattern caused by folding of the septa which separate the shell chambers.

Number 5 is Ostrea glabra, M. and H. a brackish water oyster, which occurs abundantly at various places in the upper Fox Hills sandstone (See Fig. 2, Plate 6) but which is not found in concretions of the Trail City member as are the other specimens in this Figure.

Figure 2.
<u>Brackish Water Deposit</u>--Dog Butte, five miles due east of Timber Lake, is capped with upper Fox Hills sandstone, which is literally loaded with a brackish water fauna including much Ostrea glabra (See number 5, Fig. 1, Plate 6). There is also abundant fossil wood and it is likely that a stream or streams entered the sea at this place in late Fox Hills time. These conditions were duplicated at other places in the Timber Lake area.

Figure 3.
<u>Fox Hills Fossils</u>--Number 1, The heart-shaped figure is a natural cross-section of a Cucullea nebrascensis , Owen weathering from a fragment of a Trail City member concretion. Number 2 is a portion of a concretion composed largly of Gervillia recta, M. and H. (See number 5, Fig. 4 , Plate 5). Number 3 is principally Pteria linguiformis, E and S. (See bottom fossil, Fig. 4, Plate 6).

Figure 4.
<u>Stereoscoped Fossils</u>--A stereoscopic view of four common Fox Hills fossils was prepared in order to show their forms in three dimensions. From top to bottom these fossils are Cucullea nebrascensis, Owen; Fusus dakotensis, M. and H.; Scaphites nicolletii, Morton; and Pteria linguiformis, E. and S. They are shown one-third natural size.

The stereoscopic pair was made by photographing the same fossils from two slightly different positions at a distance of about 30 inches. The camera lens was moved about five inches toward the left after exposing the right hand view and before taking the left hand view. When the right hand picture is viewed by the right eye and the left hand picture by the left eye in such a manner that the two images fuse into one, a marked impression of relief or three dimension prospective is experienced and a much keener

PLATE 6

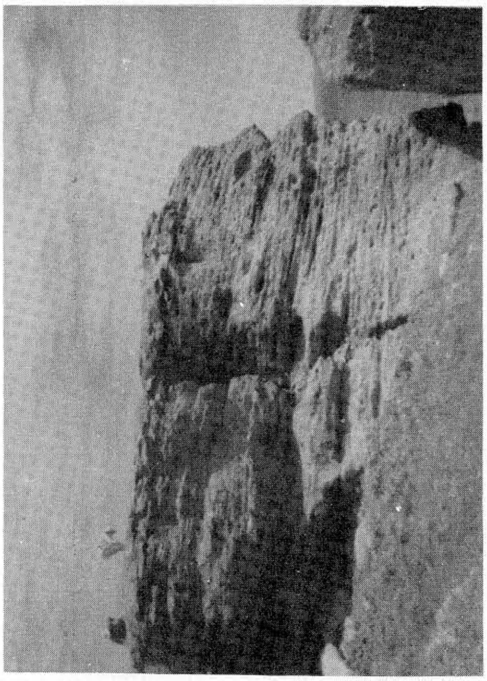


Fig. 2

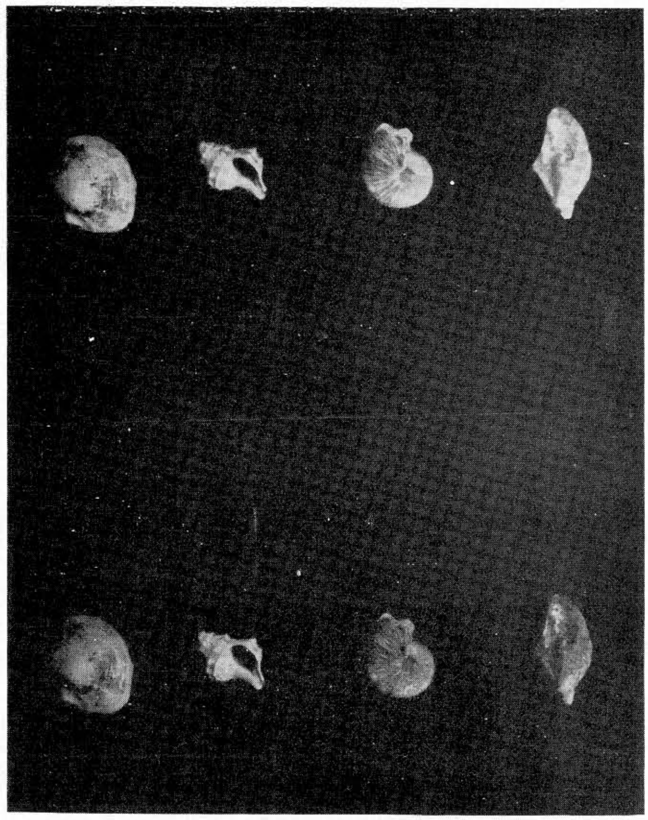


Fig. 4

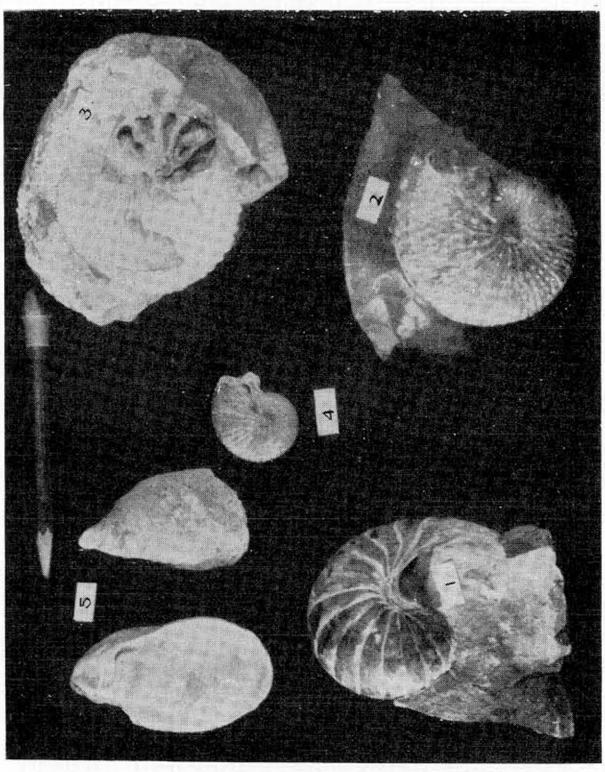


Fig. 1

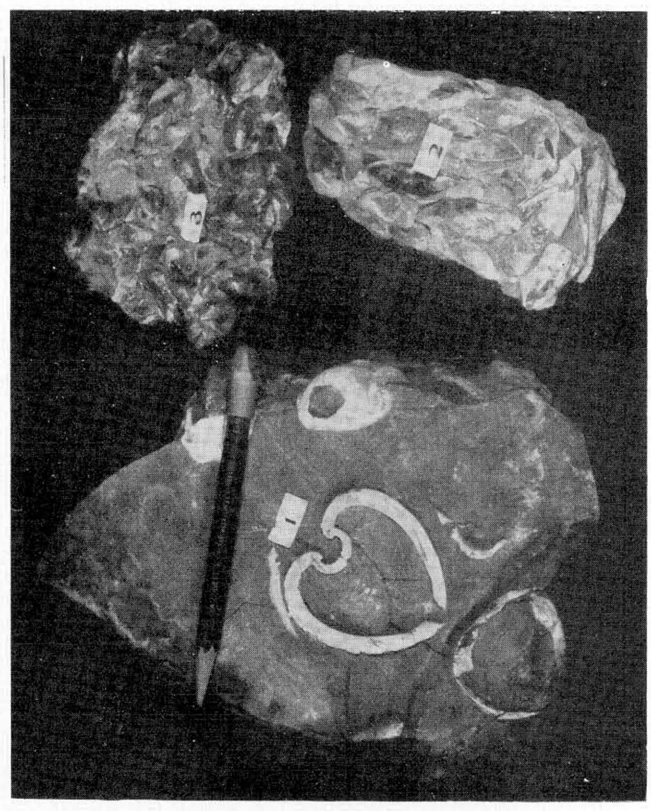


Fig. 3

Elev.	Intervals in feet	
	8	
2215		Thin yellow bentonite--occasional concretion. Below to 2212, buff to brown silty shale.
	3	
2212		Thin yellow bentonite--occasional concretion. Below to 2208, buff to brown silty shale.
	4	
2208		Thin yellow bentonite--occasional concretion. Below to 2205, buff to brown silty shale.
	3	
2205		Thin yellow bentonite. Below to 2200, buff to brown silty shale.
	5	
2200		Knobby concretions 1 or 2 feet thick. Below to 2192, brown silty shale.
	8	
2192		Thin yellow bentonite. Below to 2185, buff silty shale.
	7	
2185		Below to 2179, gray silty shale.
	6	
2179		Rubbly concretions in sandy mud jackets. Below to 2151, gray silty shale.
	28	
2151		Thin yellow bentonite, base of measured section.

Section Number 5

Succession of beds on the south side
of a conical butte.
SW ¼ Sec. 27, T 15 N, R 23 E

This is the best continuous exposure of upper Pierre, Trail City, and Timber Lake strata to be found in the area mapped for this report.

Total Thickness: 125 feet

Elev.	Intervals in feet	
2349		Top of butte. Below to 2321, yellow sand of the Timber Lake member.
	28	
2321		Fine yellow sand above. Below to 2317, dark green, glauconitic fine silty sand which weathers orange. There are also thin ocherous limonitic claystones and small concretions which make short pavements at a few places.
	4	
2317		Below to 2310--same glauconitic sand as 2321 to 2317, but without the concretions or ocherous claystones.
	7	
2310		Below to 2298, fine yellow sand.
	12	
2298		Below to 2293, reddish sandy zone.
	5	
2293		Top of Trail City. Concretions 1 foot thick in sandy mud jackets. Below to 2287, random concretions weathering white in yellow clayey sand.
	6	
2287		2-foot thick concretions in gray and buff sandy mud jackets. Below to 2280, buff clayey sand.
	7	
2280		Below to 2275, clayey, buff, banded sand with a few small random concretions.
	5	

Elev.	Intervals in feet	
2275		2-foot thick concretions in gray, sandy mud jackets. The limestone cores are dark blue when freshly exposed and contain golden calcite in cracks. The cores are fossiliferous and weather red. Below to 2243, silty shale, mostly medium to dark gray with a trace of buff color.
	32	
2243		2-foot thick concretions in gray sandy mud jackets. Cores are bluish gray and contain golden calcite in cracks. The cores weather red. Below to 2235, medium gray to brownish shale.
	3	
2240		Base of Fox Hills.
	5	
2235		Thin yellow bentonite streak. Below to 2224, gray-buff silty shale.
	11	
2224		Thin yellow bentonite streak. Base of measured section.

Section Number 6

Succession of beds exposed in the North scarp of the Moreau Valley. SW corner Sec. 31, T 15 N, R 22 E

Total Thickness: 73 feet

Elev.	Intervals in feet	
2215		Top of exposure. Below to 2208, yellow firmly bonded sand.
	7	
2208		Concretions 1½ feet thick in sandy mud jackets. One Sphenodiscus noted. Below to 2185, yellow well-banded sand.
	23	
2185		Concretions 2½ feet thick in sandy mud jackets. Below to 2181, yellow slightly clayey sand.

Elev.	Intervals in feet	
	4	
2181		Small concretions less than 1 foot thick. Below to 2178, yellow slightly clayey sand.
	3	
2178		Base of the Fox Hills. Below to 2158, gray sandy or silty shale.
	20	
2158		Thin yellow bentonite. Below to 2154, gray silty shale.
	4	
2154		Thin yellow bentonite. Below to 2149, gray silty shale.
	5	
2149		Thin yellow bentonite. Below to 2146, gray silty shale.
	3	
2146		Thin yellow bentonite. Below to 2145, gray silty shale.
	1	
2145		Thin yellow bentonite. Below to 2142, gray silty shale.
	3	
2142		Base of measured section.

OTHER GOOD EXPOSURES

In addition to the detailed sections given above and outcrops referred to heretofore, good exposures may be seen at the following locations:

1. The NE corner of Sec. 18, T 16 N, R 25 E, on the south bank of the Little Moreau River.
2. The SE corner of Sec. 7, T 16 N, R 25 E, on the north bank of the Little Moreau River.
3. 1500 feet from the N line, 2300 feet from the W line of Sec. 15, T 15 N, R 23 E, on the north bank of Meadow Creek.
4. The SE $\frac{1}{4}$ of the NW $\frac{1}{4}$ of Sec. 13, T 15 N, R 22 E, on the south bank of Red Earth Creek.
5. The center of the N $\frac{1}{2}$ of the W line of Sec. 13, T 15 N, R 22 E, on the south bank of Red Earth Creek.

6. The center of Sec. 13, T 15 N, R 22 E, on the west bank of Red Earth Creek.
7. 1000 feet from the S line, 2000 feet from the E line of Sec. 24, T 15 N, R 22 E, on the south bank of a tributary to Red Earth Creek.
8. 200 feet from the E line, 2500 feet from the N line of Sec. 36, T 15 N, R 22 E, on the edge of the Moreau River valley.
9. Center of the N $\frac{1}{2}$ of Sec. 5, T 14 N, R 22 E, on the edge of the Moreau River valley.
10. The SE corner, NW $\frac{1}{4}$, NW $\frac{1}{4}$ of Sec. 29, T 15 N, R 22 E, on the east bank of a tributary to the Moreau River.
11. 750 feet north of the center of Sec. 26, T 15 N, R 21 E, at Ragged Butte near the north scarp of the Moreau River valley in Ziebach County.
12. 1750 feet west of the NE corner of Sec. 26, on the north scarp of the Moreau River valley in Ziebach County.

County road maps on the scale of one inch to the mile are available from the South Dakota State Highway Commission in Pierre. These maps are of value in indicating the best routes to drive to or close to the exposures listed above.

SUB-SURFACE STRATIGRAPHY AND POSSIBLE OIL RESERVOIRS

No deep wells have been drilled in the area mapped for this report. Therefore, information relating to probable sub-surface conditions has to be gleaned largely from studies of wells outside the area. A list of the wells which give the most pertinent information is given below. It will be noted (Fig. 7, Map) that they represent conditions to the east, west and south of the area and that they lie within 35 miles of the boundaries of the mapped area.

1. White Horse water well. Sec. 13, T 15 N, R 26 E, Dewey County.
2. Irish Creek oil test. SE $\frac{1}{4}$ Sec. 17, T 15 N, R 20 E, Ziebach County.
3. Ole Tanberg, oil test. Sec. 9, T 11 N, R 19 E, Ziebach County.
4. Red Scaffold water well. SW $\frac{1}{4}$ Sec. 6, T 9 N, R 19 E, Ziebach County.
5. Carter Oil Co. stratigraphic test #1. Center NW $\frac{1}{4}$, NE $\frac{1}{4}$ Sec. 34, T 118 N, R 78 W, Potter County.
6. Carter Oil Co. stratigraphic test #2. Center SE $\frac{1}{4}$ Sec. 12, T 9 N, R 27 E, Stanley County.
7. Cheyenne Agency water well. Sec. 2, T 12 N, R 31 E, Dewey County.
8. Lincoln Park water well at Mobridge. T 124 N, R 79 W, Walworth County.

From these wells it is evident that the sub-surface section in this part of South Dakota includes representatives of both the Paleozoic and Mesozoic groups of sediments. In the wells cited formations belonging to the Cambrian, Ordovician, Mississippian, Triassic, Jurassic and Cretaceous systems have been identified. Neneteen formations have been reported in the correlation of the logs of these wells. The list is recorded on the columnar section, Fig. 6, to which the reader is referred.

1. The White Horse well was drilled to furnish water for the Indian school at White Horse. It started in curb lines at a sea level elevation of 1720 in the Pierre formation. The top of the Niobrara formation was encountered at a depth of 1467 feet, the Dakota at 1821 feet and the Lakota at 1980 feet.

2. The Irish Creek well was a cored oil test drilled by a local company, 36 miles W-SW of Timber Lake. Its curb elevation is approximately 2150 feet above sea level. According to W.L. Russell,* the well started in the Fox Hills. The Pierre was topped at 139, the Niobrara at a depth of 1875 feet, and the Greenhorn at 2350. The well reached a total depth of 2680 and was abandoned before encountering the sands of the Dakota-Lakota series. No show of oil or gas was reported.

3. The Ole Tanberg oil test was drilled by the J.S. Cosden Company 8 miles south of the post office at Red Elm in the fall of 1928. It was drilled with a rotary rig and carefully sampled by Mr. Paul L. Applin, the company geologist. A sample log including the microfauna was published by E. R. Applin.* This well lies about 40 miles southwest of Timber Lake. Its curb lies in the Hell Creek beds at an elevation of 2327.5 feet. It has been correlated by Mr. and Mrs. Applin as follows:

Fox Hills	40 - 280	
Pierre	280 - 1640	
Niobrara	1640 - 1840	
Carlile	1840 - 2177	
Greenhorn	2177 - 2380	
Graneros	2380 - 2745	
Dakota	2745 - 2765	
Fuson	2765 - 2971	
Lakota	2971 - 3039	
Morrison	3039 - 3220	
Sundance	3220 - 3505	
Spearfish	3505 - 3581	Total depth

4. The Red Scaffold well was drilled to supply water for Red Scaffold Indian school and lies 50 miles SW of Timber Lake. It started in the Pierre formation, its curb lying at an elevation of 1996 feet sea level. A formation identified by the driller as "85 feet harder shale" and topped at a depth of 1240 feet probably represents the Niobrara formation. The Greenhorn lime is indicated at 1640 feet and the Dakota at 2250. The total depth of the well is 2380. It produced abundant water and some gas.

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*Russell, W.L., The Possibilities of Oil in Western Corson County, Circular 27, S. Dak. Geo. Sur., 1926.
**Applin, E.R., "A Micro-Fossiliferous Upper Cretaceous Section from South Dakota," The Journal of Paleontology, Vol. VII, No. 2, June, 1933.

5. Carter Company Stratigraphic test #2 was drilled in the northeastern part of Stanley County and about 50 miles S-SE from Timber Lake. This was a "slim hole" test and samples were carefully collected and studied. It started in the Pierre formation with a curb elevation of 1786 feet. The following correlation was determined from a study of the cuttings:

Pierre	0 - 770	feet	
Niobrara	770 - 970	"	
Greenhorn	1230 - 1290	"	
Top Dakota	1560	"	
Sundance	1925 - 2125	"	
Minnelusa	2125 - 2300	"	
Charles	2300 - 2820	"	
Pahasapa	2820 - 3260	"	
Whitewood	3260 - 3780	"	
Deadwood	3780 - 3880	"	Total depth

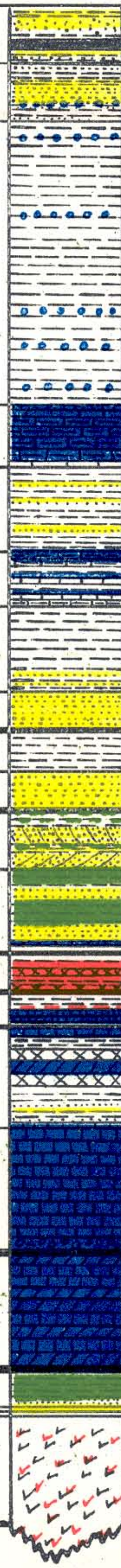
6. Carter Company Stratigraphic test #1 was drilled east of the Missouri River opposite the Cheyenne Indian Agency. It lies about 35 miles SE of Timber Lake. Its curb elevation is 1865 feet sea level datum. This well was a "slim hole" test and samples were carefully collected and studied. The following correlation was made from sample studies:

Pierre	0 - 800	feet	
Niobrara	800 - 900	"	
Greenhorn	1250 - 1310	"	
Top Dakota	1590	"	
Minnelusa	2065 - 2245	"	
Charles	2245 - 2400	"	
Pahasapa	2400 - 2970	"	
Whitewood	2970 - 3465	"	
Deadwood			
(green shale)	3465 - 3560	"	
(sandstone)	3560 - 3580	"	
Pre-Cambrian			
(granite)	3580 - 3611	"	Total depth

7. The Cheyenne Agency well was drilled to supply water for the Agency in the early 1900's. It lies about 30 miles SE of Timber Lake and about 4 or 5 miles north of the location of Carter #1 stratigraphic test. It started about the

GENERALIZED COLUMNAR SECTION
of
NORTH CENTRAL SOUTH DAKOTA

COLOR KEY...Blue, limestone, dolomite or chalk. Yellow, sandstone. Red, red beds (mostly shale). Green, green shale. Black, coal.



UPPER CRETACEOUS	HELL CREEK	Non-marine clays and sands, carbonaceous shale and lignite. About 200'
	FOX HILLS	Concretionary shale, sandstone and intercalated sands and clays. 250'
	PIERRE	Mainly a soft gray shale. The bottom 100 feet is darker than that above. Inoceramus fragments are abundant. There are several zones of hard limestone concretions, and several zones of volcanic ash or bentonite. About 1400'
	NIOBRARA	Speckled, white and dark gray chalky shale. Ferrugenous rock at top. 250'
	CARLILE	Pyritiferous, finely sandy gray shales and friable fine grained sandstones. About 340'
	GREENHORN	Black shales, thin chalky shales, in part speckled and thin shelly limestones.200'
	GRANEROS	Black shale at top. Intercalated dark gray sands toward the base. 370'
	DAKOTA	Coarse, angular, clear quartz sand. 25'
LOWER CRETACEOUS	FUSON	Black, bituminous, pyritiferous shale.205'
	LAKOTA	Pyritiferous fine to coarse sand. 70'
JURASSIC	MORRISON	Light gray-green shale, and fine grained sandstone. About 180'
	SUNDANCE	Somewhat fossiliferous green shale and gray, fine grained sandstones. Pink limestone near the base. About 285'
TRIASSIC	SPEARFISH	Red shale and gypsum-100' plus or minus.
PENNSYLVANIAN	MINNELUSA	Reddish shale and sandy limestone. 140'
MISSISSIPPIAN	CHARLES	Limestone, thin sandstone, variegated shale and anhydrite. 400' plus or minus.
	PAHASAPA	Limestone, in part oolitic and fossiliferous. Conglomerate near base. About 550'
ORDOVICIAN	WHITEWOOD	Dolomite and dolomitic limestone. About 500'
CAMBRIAN	DEADWOOD	Basal sandstone, 20'; green shale, 90'
PRE-CAMBRIAN	GRANITE	Pink and gray biotite granite.

R.E.M.

FIGURE 6

base of the Agency shale member of the Pierre formation at an elevation of 1537 feet sea level datum. Because only a driller's record is obtainable, it is impossible to get detailed geological information about this well. The first water flow is from a sand called the Dakota and was struck at a depth of 1317 feet. The well produced ample supplies of water for the Agency and a flow of gas for many years but was finally abandoned and filled in.

8. Lincoln Park well. This well was drilled for the city of Mobridge in 1928 to supply water for a city park situated on the Missouri bottoms. It is located about 30 miles from Timber Lake at an approximate elevation of 1600 feet, sea level.

This well showed Greenhorn limestone from 1265 to 1330 and encountered the Dakota sand from 1725 to 1750 feet, the bottom of the hole. An abundant flow of water was encountered and a flow of gas which was used in the park for a time.

A study of the well records reveals that the subsurface section is thinning from west to east, eliminating or lensing out both Triassic and Jurassic beds. For example, the log of the Cosden Company's Ole Tanberg test in Sec. 9, T 11 N, R 19 E, indicates that Spearfish, Sundance and Morrison formations are present. The log of the Carter No. 2 toward the east and south in Sec. 12, T 9 N, R 27 E, indicates that the Spearfish and Morrison formations have wedged out and show a thinner Sundance section. The Carter No. 1 farther east in Sec. 34, T 118 N, R 78 W, shows none of the Triassic or Jurassic formations. Furthermore, comparison of the Cosden and Carter well records indicates that the upper Cretaceous section, including the Graneros, Greenhorn, Carlile, Niobrara, and Pierre formations, thins rapidly toward the east.

The evidence suggests that a more or less continuously sinking basin of deposition lay toward the west of this area while the eastern portion fringed a stationary or possibly rising area, which was either wholly emergent or covered by relatively shallow seas during much of Mesozoic time. The alternate and less likely possibility is that the various formations were deposited more or less evenly over the whole area, but that they were wholly or partially eroded from the eastern part during periods of uplift and emergence.

It is likely that during Morrison (upper Jurassic) time the western part of the area was a slightly emergent region of low relief, as it was apparently the recipient of non-marine sediments deposited in shallow lakes, swamps and on the flood plains of meandering, low gradient streams. It is likely that much of the alluvium was stripped from the east part of the area, which was probably completely emergent at the time.

The generalized columnar section, Fig. 6, is based largely on data from the Ole Tanberg and Carter wells described above. The subsurface section from the base of the Triassic to the base of the Fox Hills is constructed largely from information from the log of the Ole Tanberg well, which is located west and south of the area mapped. Because of the evidence listed above, it is likely that the upper Cretaceous section in the central part of the Timber Lake area is thinner than it is at the location of the Tanberg well. It is also likely that the Triassic and Jurassic portions of the section have thinned or have disappeared either wholly or in part. In other words, the upper portion of the columnar section, Fig. 6, is more likely to approximate the subsurface section in extreme western Dewey County and in eastern Ziebach County than it is in central Dewey and Corson Counties. However, it is thought best to include the Triassic and Jurassic formations in the generalized section because of the value of the red Spearfish shale as a key bed when it is present in the section, and because of the possible value of Sundance sands as oil bearing horizons.

Probably the upper Cretaceous interval logged in the Carter No. 1 in Sec. 34, T 118 N, R 78 W, will apply more directly in the Timber Lake area than will those of the Cosden well. This assumption is strengthened by the evidence that the interval between the Greenhorn and Dakota formations in the White Horse well (nearest to Timber Lake) approximates the Dakota-Greenhorn interval in the Carter No. 1, but is about 225 feet shorter than the Dakota-Greenhorn interval in the Tanberg well.

Inspection of the logs of the Carter wells will indicate that the Charles formation of Mississippian age also thins toward the east. It is assumed here that the Charles formation is present under the Timber Lake area.

DEPTHS AND OIL POSSIBILITIES OF THE SECTION

1. The Hell Creek Formation-(Fig. 4) This formation is not of marine origin and it is not likely that it contained oil at any time in its geologic history. Aside from this consideration, its present character as a surface formation with lack of protecting cover to confine oil or gas renders it hopeless as a possible source of oil.

2. Fox Hills Formation-The sands of the Fox Hills may have contained oil in past geologic time, but their presence at the surface places them in the Hell Creek class in so far as oil possibilities are concerned.

3. Pierre Shale-Assuming that a test is located on the upland and not in the larger valleys, the top of the Pierre formation will probably be reached at a depth of about 125 feet and the base at about 1525. In this area the Pierre shale apparently does not contain permeable members which hold promise as reservoirs for oil. One or more thick bentonite layers may be useful as subsurface horizon markers or key beds.

4. Niobrara Formation-The Niobrara should be found at a depth of about 1525 to 1625 feet. It does not hold much promise as an oil reservoir but is one of the best subsurface key beds because of its wide distribution and consistent lithological features. In general it consists of speckled (white on dark gray) chalky shales, interspersed with non-speckled shales which are usually calcareous. The foraminifera Globerina cretacea d'Orbigny is abundant.

5. Carlile Formation-Should lie from 1625 to 1975 but below the upland. This is a shale formation containing fine sands which are probably the youngest potential oil bearing rocks in the area.

6. Greenhorn Formation-Should be encountered from 1975 to 2035 but, like the Niobrara, the Greenhorn does not hold much promise as an oil reservoir, although it does form an excellent marker for subsurface structural control. It con-

tains abundant microfossils including Globigerina and shell fragments and aragonite rods from the pelecypod Inoceramus labiatus. It includes shelly limestone and speckled chalky shales like those of the Niobrara. Some black shale occurs which may be finely intercalated with brown fragments of aragonite from the shells just mentioned showing the typical columnar cleavage of the mineral.

7. Graneros Formation-Probably lies from 2035 to 2295 feet below the surface. Intercalated sands toward the base of this essentially shaly formation may possibly produce shows or even commercial quantities of oil. In the Tanberg well black tarry residues were reported from sandy phases of this formation.

8. Dakota Sandstone-Tops at about 2295 feet and bottoms at about 2395 feet below the surface. The Dakota sandstone is in many respects one of the most promising oil reservoir rocks in the section. In the Cheyenne Agency well and in other wells not far from the Timber Lake area, the Dakota sand has produced salt or brackish water and enough gas to supply limited lighting and power needs. This indicates proper porosity and permeability characteristics. However, a discouraging factor is that no oil has been produced and the gas has been of the "dry" type, not necessarily associated with oil.

9. Fuson Formation-Lies between 2395 and 2455 feet. Logs of the Tanberg and Carter wells indicate that the Fuson formation thins rapidly eastward bringing the so-called Dakota and Lakota sands nearly together. However, a study of drilling samples from the Carter No. 1 test indicates a shale break of about 50 feet between the first two sandstones to appear below the Niobrara. This break is probably equivalent stratigraphically to the 200 foot black shale "fuson" section reported in the Tanberg well. It is not unlikely that a shale break of about 60 feet divides the sands of the "Dakota-Lakota" group in the Timber Lake area. The possibility of commercial oil production from the Fuson appears remote, although an asphaltic residue was reported in a sandy phase near the base of the Fuson formation in the Tanberg test.

10. Lakota Sandstone-Should be found from a depth of 2455 feet to 2525 feet. What has been said regarding the Dakota applies to the Lakota with the added encouragement that much asphaltic material appears in the upper portion of the Lakota in the Tanberg test. E.R. Applin, geologist, who examined the cuttings, reported "an ether test gives a good oil show."

11. Morrison Formation-Probably not present. The Morrison formation does not appear to be represented in the Carter wells because of the thinning or lensing out to eastward previously noted. It is not considered likely that Morrison beds are present in the subsurface near Timber Lake. The section logged as Morrison in the Tanberg well showed cross bedded sandstones and light gray-green shale, but as Morrison beds are considered to be non-marine in origin, they would probably not contain oil even if present in the Timber Lake area under favorable structural conditions. However, there is a remote possibility that oil might have migrated from marine source beds into the Morrison sands. If, in addition, the Morrison sands pinch out up-dip in the area there is a chance that oil might be trapped at the point of pinch-out. This type of stratigraphic trap is, of course, a possibility where permeable members lense out and are sealed by impermeable. (See Fig. 8B.)

12. Sundance Formation-Lies approximately in the depth interval of 2525 to 2725 feet. Marine beds, probably of Sundance age, were encountered in the Carter No. 2 test. It is likely that Sundance shales and sandstone are present in the subsurface of the Timber Lake area. If so, the sands may possibly contain oil where they occur in local anticlines. It is also possible that some or all of the Sundance sands may lense out in the area and become the loci of oil accumulation. (Fig. 8B)

13. Spearfish Formation-Probably not present. Bright red shale and gypsum, probably of Spearfish age, was encountered in the Tanberg well but not in either of the Carter tests. It is not thought probable that the Spearfish appears in the subsurface of the Timber Lake area. If it does, it will make a conspicuous horizon marker. In any event, the Spearfish formation does not hold much promise as a producer of oil.

14. Minnelusa Formation-Should be encountered from 2725 to 2865 feet. Reddish shale and sandy limestone, probably equivalent to the Minnelusa, appear in the Carter No. 2 test. This formation is probably present in the subsurface at Timber Lake. There is a chance that a porous phase of the sandy limestone might produce oil in the Timber Lake area. Sandy limestones have produced oil in Illinois, Oklahoma and elsewhere.

15. Charles Formation-Lies between 2865 and 3265 feet below the surface. Clastics and associated evaporites of the Charles formation have appeared in wells over a large part of the western great plains.* The Charles is present in the Carter tests where it thins to eastward and it is likely that it is present or perhaps lenses out in the Timber Lake area. Sands and porous limestones, associated with evaporites such as anhydrite and gypsum, have produced oil in west Texas and at other localities, and it is not beyond the bounds of reasonable speculation that they might produce in the Timber Lake area. If porous formations of the Charles (See generalized section, Fig. 6.) lense out in the Timber Lake area, stratigraphic oil traps may be formed. (Fig. 8B)

16. Pahasapa Formation-Will be encountered from 3265 to 3815 feet. A thick limestone probably equivalent to the Pahasapa of the Black Hills, appears in both Carter tests. The Pahasapa is reasonably certain to be present in considerable thickness in the Timber Lake area. Limestones of many geologic ages are prolific producers of oil in Texas, Oklahoma, Kansas, Illinois and other petroliferous areas. The Madison limestone of the Rocky Mountain area, which is stratigraphically equivalent to the Pahasapa, produces oil in Montana and elsewhere.

A show of oil was reported as coming from the Pahasapa in the Standing Butte oil test drilled by the South Dakota Development and Refining Company in Sec. 8, T 7 N, R 27 E, Stanley County. The best evidence available would indicate

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*Perry, E.S., and Sloss, L.L., Big Snowy Group: Lithology and Correlation in Northern Great Plains, Bulletin of the A.A.P.G., Vol. XXVII, No. 10, Oct., 1943.

that the Pahasapa has possibilities as an oil producer in the Timber Lake area. To be effective host rocks, limestones must have reasonable permeability and porosity. These conditions are most apt to obtain at unconformities where weathering and solution have rendered the limestone porous. (See Fig. 8C.) Oolitic zones also are sometimes sufficiently porous to hold commercial amounts of oil. The oolitic zones in the Pahasapa and the conglomerate at its base would appear to offer possibilities as oil reservoirs.

17. Whitewood Formation-Should be encountered in the interval between 3815 to 4315 feet below the surface. Approximately 1050 feet of almost solid limestone and dolomite appear near the bottoms of the two Carter wells (Fig. 6). Conglomeratic material is present near the middle of this dolomite-limestone section. It is probable that the conglomerate represents an unconformity, due to the fact that after deposition of a minimum of 500 feet of dolomite and dolomitic limestone the sea retreated, thus exposing the lower half of the series to erosion. The conglomerate probably represents the poorly sorted erosion products which were reworked somewhat by the sea which again invaded the area at the start of Pahasapa time. The conglomerate is thus thought to represent the base of the Pahasapa limestone heretofore discussed.

The lower half of the dolomite-limestone series occupies a stratigraphic position similar to that of the Whitewood formation of the Black Hills and in the absence of evidence to the contrary, it is here correlated with that formation. Much of what was written about the Pahasapa as a potential oil producer applies equally well to the Whitewood.

The Whitewood (Fig. 6) is Ordovician in age. The Arbuckle dolomite of Oklahoma and Kansas is also Ordovician in age and has been a prolific oil producer in both states and especially where it makes unconformable contact with overlying formations (Fig. 8B). It seems reasonable to assume that the Whitewood formation is present in the subsurface of the Timber Lake area and that it is a possible producer of oil, especially in its upper part.

18. Deadwood Formation-Probably lies from 4315 to 4425 feet underground. Twenty feet of sand and granite wash, overlaid by 90 feet of green waxy shale, occur immediately above the granite in the Carter No. 1 well. Similar shale and sand appear at the bottom of the Carter No. 2 test. Because of its stratigraphic position and lithologic character, this section is correlated with the Cambrian Deadwood formation of the Black Hills.

The prospects of the Deadwood's producing oil are not very bright for several reasons. First, so far as is known only one oil pool has produced commercial quantities of oil from sediments of Cambrian age. In the case of this single exception (a Texas pool discovered in 1942) it is thought that the oil originated in younger rocks and migrated into the Cambrian host rock. Second, while the basal Cambrian sand probably has physical properties (porosity and permeability) which might make it a potential host rock for oil, it is apparently shielded from contact with a possible source rock by the probably non-petroliferous Cambrian green shale above it and by the certainly barren pre-Cambrian granite underlying it.

All factors considered, it is likely that the Deadwood is represented in the subsurface of the Timber Lake area, but the formation holds little promise as a producer of commercial amounts of oil.

19. Pre-Cambrian Granite-Will be encountered at about 4425 feet below the surface. Igneous rock is certainly present beneath the Timber Lake area, as it is at some depth in all parts of the earth. For obvious reasons including its great age and the high temperature which it has experienced in past geologic time, the granite is absolutely hopeless as a source of oil. It would be as profitable to drill in a tombstone for oil as to continue drilling after it is certain that fresh granite or other pre-Cambrian rocks such as schists, gneisses or Sioux quartzite have been encountered by the bit.

SUMMARY

In summing up the petroleum possibilities of the section underlying the Timber Lake area, the following statement seems reasonable.

1. From the surface down to approximately 1600 feet the section offers little promise of producing significant amounts of oil or gas because of lack of members of sufficient porosity and permeability.

2. From a depth of about 1600 feet down to the granite (at an expected depth of about 4425 feet) various formations may contain oil because 1) they have sufficient porosity and permeability and 2) they are in contact with marine rocks, such as black or bituminous shales and organic limestones, which are ordinarily considered to be good source rocks for petroleum.

3. No commercial oil has been discovered in the Timber Lake area and the nearest commercial production is more than 100 miles away. The area is untested, however, as no deep wells have been drilled in it and only a few tests in the vicinity have penetrated all formations down to the pre-Cambrian.

4. The area has enough promise to warrant several "top of the granite" tests. To have the best chance of success these should be located on the basis of the best combinations of surface and subsurface information obtainable. If possible, surface geology and subsurface studies of cores and cuttings from nearby drilling wells should be aided by core drilling or geophysical studies, or both.

STRUCTURE

INTRODUCTION

Since the purpose of the survey was to obtain more accurate information on the regional structure of this part of South Dakota, a review of the general structure of the state is in order. It has been shown in many previous reports of the State Geological Survey that the folding of the Black Hills and Rocky Mountain arches influenced the structure of sediments over the entire state. The pressures which formed these bulges also formed troughs between and in front of these mountains. The Rocky Mountain fold is, of course, the master fold in this part of the continent. The Black Hills, however, are part of a minor fold which parallels the Rockies. The mountainous fold known as the Black Hills continues northward as a plains fold into Montana where it is known as the Glendive anticline. It also is continued south of the Black Hills by the Chilson anticline and the Chadron arch of Nebraska and the Darton arch of Nebraska and Kansas. Thus, this reflection of the Rocky Mountain fold can be followed from western Montana through western Nebraska and into Kansas.

East of this anticline, a structural trough or downfold was formed along its entire length. Like the fold, however, the trough consisted of several basins caused by the down warping of certain portions more than others. South Dakota is affected by a basin known in geologic literature as the Moose Jaw Synclinorium, which has its center in Saskatchawan, Canada. From this center the axis rises southward through western North Dakota, where it is known as the Williston Basin and thence through western South Dakota, where it is known as the Lemmon Syncline. It finally reaches a saddle in the extreme southern part of South Dakota or northwestern Nebraska. The axis of this structure passes somewhere near the cities of Philip and Lemmon, but its flanks cover the entire state between the Black Hills-Glendive anticline and the outcrops of pre-Cambrian rocks in eastern South Dakota.

Between the Black Hills fold and the Missouri River the down warping is more pronounced, the dips averaging from 10 feet to 40 feet per mile over most of the region and reaching as high as 10 degrees on the flank of the Black Hills outcrops.

East of the Missouri River the sediments slope westward at a much lower rate, averaging about $1\frac{1}{2}$ feet per mile. Thus a terrace like structure is formed whose front trends southwest from Campbell County to Todd County. This has been called the Eureka-Mission Terrace, since Eureka in McPherson County and Mission in Todd County are located on it.

As will be noted from the structure map accompanying this report, the area covered by this survey lies on the east flank of the Lemmon syncline between the western edge of the Eureka-Mission Terrace and the axis of the syncline.

REGIONAL STRUCTURE

Maps which have been published on this area show its regional structure to be a monocline in which the sediments slope northwest toward the axis of the Lemmon syncline. Contour lines trended northeast-southwest across the area, and their even spacing indicated a uniform dip. The rate of dip averaged about 10 or 15 feet to the mile.

These maps were based on information obtained largely from the logs of old water wells of which only one, the White Horse well, lay near the area mapped. The structural contours were drawn on what was supposed to be the top of the Dakota sand. This was located entirely from drillers' logs and estimates made from reports of the well owners and drillers. Moreover, these wells were widely scattered, there being but one or two wells to each county north of the Cheyenne River. This meant that the structural contour lines had to be largely interpolated.

The present mapping gave much better control, especially in the area of outcrop. Interpolation had to be done, therefore, only across the large valleys of the Moreau, Grand, and Missouri Rivers and on the uplands between them. This control shows that the flank of the Lemmon syncline in this area trends much more nearly east and west than had been supposed. Contour lines are far from straight lines but indicate that the strike trends in a general direction of about 65 degrees east of north. Thus, the direction of the slope of the sediments is approximately 25 degrees west of north and their rate of slope about 30 feet to the mile.

This is considerably greater dip than was indicated by the older maps. This strike is nearly at right angles to the strike of the axis of the Lemmon syncline and the reason for this change in direction is not apparent from the data now at hand. It is expected that further mapping will shed light on this problem.

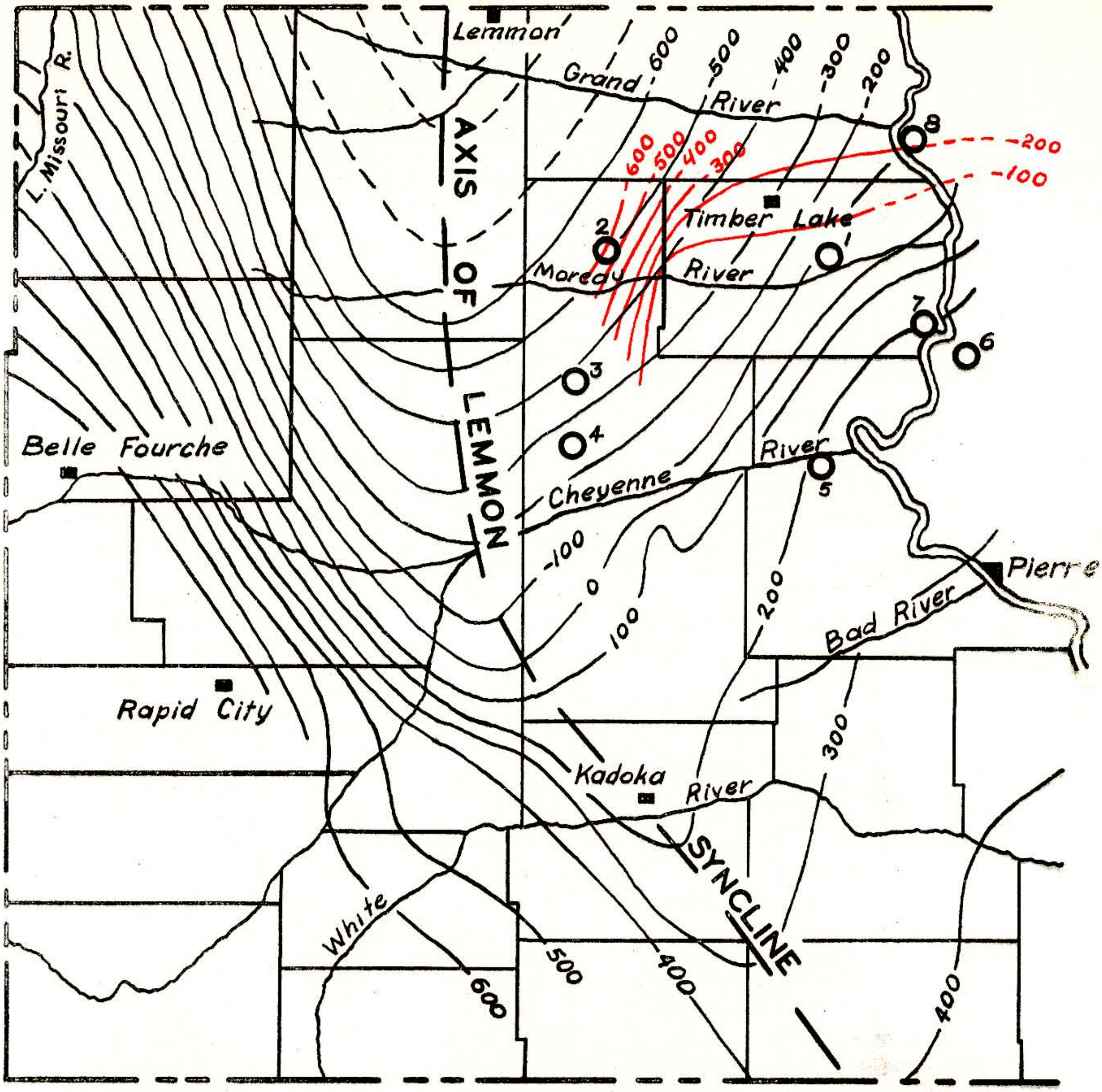
Recent magnetic work which has not been published to date, indicates a very large "high" area in northwestern Stanley County. This apparently means a pre-Cambrian ridge or mountain in this area and it is possible that the northward dip in the Timber Lake region is the slope of sediments off this buried ridge. Whatever the cause, it is evident that this flank of the Lemmon syncline is not a smooth slope but is disturbed by lesser flexures. The elevations taken on the Isabel-Firesteel coal seam indicate that the dip is not so steep beneath the divide between the Moreau and Grand Rivers as it is near the Grand and that minor structures occur on this slope also. This is assumed from the increasing distance between contours as one proceeds northward.

The stratigraphy in the Irish Creek well in northern Ziebach County near the center of T 15 N, R 20 E, indicates a westward dip of over 40 feet to the mile. Apparently then, somewhere between this well and the Ziebach County line the regional dip changes from north to westerly. This would indicate that there is a terrace-like structure just south of the area which has been mapped.

LOCAL STRUCTURES

The regional dip indicated by the elevations on the base of the Fox Hills is not a smooth slope. Low flexures in these sediments are the rule and break the diagrammatic surface that is so often indicated for the flanks of large synclines like the Lemmon syncline. The same can be noted in the coal seams in the Isabel-Firesteel area. Minor structures, therefore, are common. Some of these flexures are sharp and well-defined. They are low folds typical of plains structures.

One of the most pronounced of these seems to be in the vicinity of Red Earth Creek where sharp dips to the east, north and west have been mapped. The south end is in the



REGIONAL STRUCTURE MAP
Western South Dakota
Contours represent the top of the Dakota Sandstone.

Black contour lines after Huntley, Darton, et al.

Red contour lines show the change in the structural picture revealed by the surface mapping described in this report.

Deep tests near the Timber Lake area

1. White Horse
2. Irish Creek
3. Cosden-Tanberg
4. Red Scaffold
5. Carter Oil #2
6. Carter Oil #1
7. Cheyenne Agency
8. Lincoln Park Mobridge

Figure 7

valley of the Moreau. This structurally high area is about 9 miles across and appears to be worth further prospecting for drilling sites.

The second "high" area lies south of Glencross. The curving of the contours indicates that a low fold may be found in the Moreau valley south of the breaks. This region would also be worth investigation if drilling sites were being sought.

The course of the 1950 contour line, which trends northwestward in the vicinity of Trail City and turns back southwestward above Firesteel, suggests a low fold somewhere under the highland north of Timber Lake. The lack of outcrops in this region makes it impossible to get further details on this structure from a survey such as this one. However, this region would be worth inspecting if detailed structures were being sought.

A pronounced reversal of the regional dip occurs in the southwestern corner of the map, in the southeast quarter of T 15 N, R 21 W, and the southwest quarter of T 15 N, R 22 W. This dip was followed for four miles in a southeasterly direction. It appears to be the southeastern flank of a structure mapped in 1925 by Mr. Roy A. Wilson.* There was no evidence of a top or closure at the place indicated by Mr. Wilson. However, this may be due to a difference in the interpretation of the key bed. Due to the closing of the field season, it was impossible to check the structure further, but it is worth investigating as a site for test drilling.

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*Wilson, Roy A., The Ragged Butte Structure, Circular 24, S. Dak. Geo and Nat. Hist. Sur., 1925.

APPENDIX

APPENDIX

FACTORS EFFECTING OIL FINDING

This part of this report is designed for the general reader who may be interested in the principles of petroleum geology. It is hoped that the following description will help to clarify portions of the foregoing text in which reference was made to various types of oil traps.

ORIGIN OF OIL

Time and space do not permit a detailed discussion of the various theories and experiments dealing with this subject, but the great mass of experimental and observational evidence points to the organic origin of petroleum. It is probable that plants and animals of many types have contributed to petroleum. Some are relatively large in size and include such organisms as fishes and the trunks of trees. However, many, such as algae and diatoms (unicelled plants) and foraminifera (unicelled animals), may be so small as to be individually almost invisible to the unaided eye. Some marine forms, such as plankton (floaters) and nekton (swimmers), have no hard parts and may contribute great quantities of organic material without leaving any other trace.

Modern sediments, accumulating in both marine and fresh water, yield oil to solvents and much more to distillation at temperatures from 350° to 500° C. The amount yielded has varied from zero to 28 gallons per ton of sediment. It is noteworthy that most commercial oil deposits are associated with salt water thought to be residual (connate) sea water and are found in rocks which were undoubtedly deposited in salt water as indicated by the marine fossils which they contain.

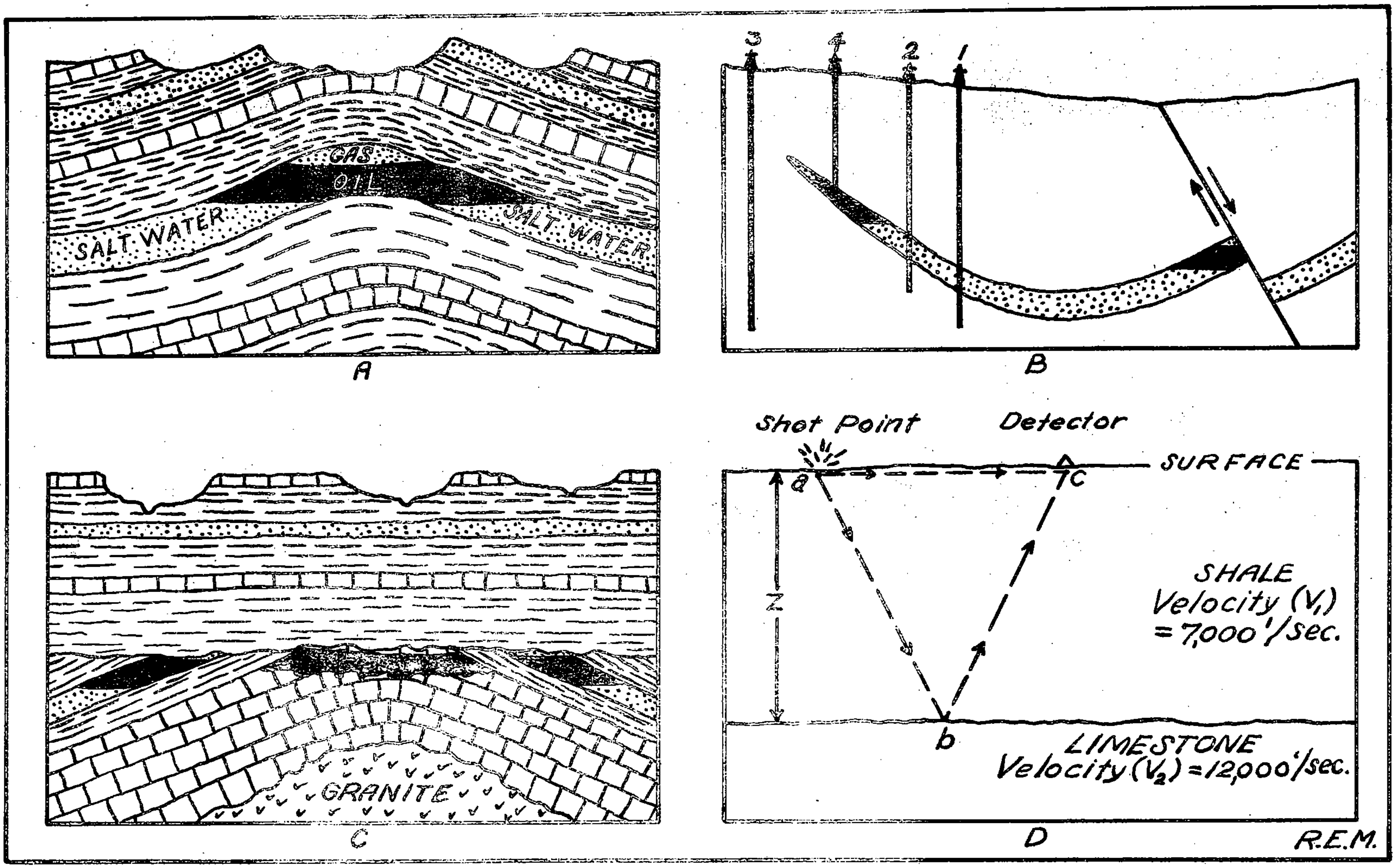
ACCUMULATION OF OIL

Muds or fine grained sediments generally contain more organic material than do the sands which are coarser in texture. Given sufficient time and the pressure of overlying sediments the muds consolidate into shales and the sands into sandstones. In commercial oil deposits it is generally found that the oil occurs in sandstones or in porous limestones whereas the shales, the original source beds, act as confining beds and are relatively barren of oil. This apparent anomaly is probably due to the fact that salt water has about 3 times the surface tension of crude oil. Also, the pore space in fine grained shales tends to be capillary or subcapillary in size, whereas the larger voids in sandstones are mostly supercalippary openings. The amount of capillary pull varies inversely as the size of the pore. Therefore, salt water tends to be drawn into the capillary openings of shale, displacing oil and gas which tend then to fill the larger voids in sandstone or in porous limestone.

OIL TRAPS

<u>Accumulation in Anticlines</u> Most of the rocks with which oil is associated were laid down in shallow continental seas, the individual beds or strata being deposited one over the other in essentially parallel and horizontal position. From time to time in the geological history of the earth these horizontal beds are folded into arches and troughs by forces acting from within the earth's body. It is something like the wrinkling of the skin on a drying apple. At places these crustal movements have been of such magnitude and intensity that the beds have been folded, overturned, crushed and distorted almost beyond recognition. Petroleum would usually be dissipated and destroyed in these areas. However, in other areas the rocks are folded to a moderate or slight degree and concentration of oil in commercial amounts is favored by the resulting structures. Where the beds are upfolded or distorted so that they bow upward, the structure is called an anticline. When the strata is bowed down, the structure is called a syncline.

Fig. 8A shows a cross-section of an anticline in which a sandstone containing salt water, oil and gas is underlaid and overlaid by shales which are relatively impermeable because of their fineness of grain and small pore size. As indicated, the gas, oil, and salt water will tend to segregate according to their relative specific gravities, the gas overlying the oil at the top of the anticline and the salt water occupying the flanks of the fold.



A–Anticlinal oil trap showing as a surface structure.
B–Stratigraphic pinch-out oil trap and faulted oil trap.
C–Oil traps at an unconformity.
D–Diagram to illustrate the principles of **reflection seismic mapping.**

Figure 8

Stratigraphic Pinch-Outs At many places sand formations lense out and are underlaid and overlaid by tight impermeable rocks like mudstones or shales. If these lensing sandstones are tilted and are saturated with water their oil content, if any, may rise as far as the confining formations will permit and be trapped in a stratigraphic pinch-out as shown on the left hand side of Fig. 8B. The region in which such a "pinch-out" occurred would seem to have little promise as no evidence of it is apparent at the surface. The east Texas field, one of the world's greatest oil pools, is of this type. It was discovered by random drilling.

In areas where lensing sands are common the geologist may cut down on the number of dry holes incident to random drilling by the indicated program (Fig. 8B). Wells 1 and 2 made only salt water but did prove the existence and direction of dip of the sandstone. Well 3 was drilled too far up dip and missed the pinch-out. Well 4 was located down dip of 3 in search of the pinch-out and hit the "jack pot."

Faulted Oil Traps The right hand side of Fig. 8B shows how a sand may be faulted and oil sealed off at the fault face by impermeable rock. The Balcones fault region of north Texas has oil pools of this general type. In Fig. 8B the arrows show direction of movement on either side of the fault plane.

Oil Traps Below Unconformities Sedimentary strata may be folded or tilted and beveled by erosion. Later they may again be flooded by the sea and covered by younger sediments. This is called an unconformity. If the later sediments are folded only a little or not at all, there may be little evidence on the surface to indicate potential oil traps at or below the buried erosion surface. Fig. 8C shows this relationship which holds in a general way for some of the Oklahoma and Kansas pools. It is noteworthy that wells producing from the weathered and porous top of the thick limestone (shown by brick work pattern) might be edged by dry holes. However, the geologist familiar with the possibilities of "erosional wedgeout" traps in the flanking sandstones would advise drilling in search of this "wedgeout." The Eldorado pool in Kansas and the Oklahoma City pool have many of the structural and stratigraphic characteristics shown diagrammatically in Fig. 8C.

GEOPHYSICAL METHODS

At several places in this report reference has been made to geophysical methods of exploring for oil. The following short description may be helpful to the layman unfamiliar with these methods of prospecting, especially in distinguishing between legitimate techniques and psuedo-scientific methods, which often mislead the prospective investor.

SEISMIC PROSPECTING

To date seismic prospecting has been the most successful geophysical method applied to discovering oil traps which give little, if any, surface evidence of their presence. The method depends upon the fact that elastic earth waves traveling through rock of relatively low transmission speed and striking an underlying bed of higher transmission speed will, in part, be reflected back to the surface and in part refracted along the upper surface of the high speed bed and then refracted back to the surface of the ground.

The earth waves are caused by exploding a charge of dynamite buried in the earth. The earth waves set up by the explosion agitate detectors or geophones which are placed in the earth at some distance from the shot point. If the instant of the explosion is known, as well as the instant of arrival of the earth wave at the detector, the travel time of the earth wave from shot point to detector can be measured. The time of explosion is recorded by having an electric timing circuit broken by the explosion. Seismograph detectors are made in different ways but in modern ones the ground movement is in some way transformed into an electrical impulse which is amplified and then operates some form of an oscillograph by which the motion is recorded by a beam of light on moving photographic film or paper. The timing is accomplished by marking lines across the film at regular intervals. These are controlled by a tuning fork and time can be read easily to one one-thousandth of a second.

Reflection Seismic Mapping In reflection seismic work the detector is placed fairly close to the shot point. The object is to measure the depth from the surface to some high speed formation such as a massive limestone which can be used as a key bed. By knowing the surface elevation and the depth to the key bed at a number of places the subsurface dips can be worked out so that drilling sites may be located on favorable anticlinal structure.

Figure 8D diagrammatically illustrates the path of the reflected wave from shot point to detector. The first wave to arrive at the detector will be the direct wave taking path ac. This first arrival is ignored in figuring the travel time of the reflected wave. It may be used, however, in calculating V_1, the velocity of the formations above the high speed key bed.

The depth Z to the key bed (Fig. 8D) may be calculated as follows: as the wave path is entirely above the high speed reflecting bed, the velocity V_2 of the reflecting bed does not enter into the calculation for depth Z (See Fig. 8D, path abc). Let the direct path ac=X.

Then where t = travel time

$$t = \frac{2\,ab}{V_1}$$

$$= \frac{2}{V_1}\sqrt{\frac{X}{2}^2 + Z^2}$$

$$V_1^2 t^2 = X^2 + 4Z^2$$

$$Z = \frac{1}{2}\sqrt{V^2 t^2 - X^2}$$

V_1 may be determined by timing the first arrival which takes the direct path ac, but as the value of V normally increases downward, a more accurate average value may be realized by shooting a dry hole before plugging and abandoning the well. If the high speed bed or reflecting horizon can be recognized by coring, sample examining or electric well logging, a dynamite charge may be exploded at the correct depth and the wave timed to the surface.

In actual practice corrections may have to be made for the ultra slow speed "weathered" zone and differences in elevation between shot point and detector.

Refraction Seismic Mapping Refraction seismic mapping may also be used for determining structure on relatively high speed key beds which are not too deeply buried. Refraction seismograph was formerly of great value in discovering salt domes in the Gulf Coast area of Texas and Louisiana. It is not in common use today and would probably not be used in South Dakota, in preference to the reflection method.

GRAVITY MAPPING

There are various devices for measuring small variations in gravity either directly or indirectly. They include the gravimeter, the pendulum and the torsion balance. Fig. 8C depicts a buried structural feature which might show as a gravitational anomaly because granite is somewhat heavier than the average sedimentary rock. A massive buried limestone folded up into shale would have a similar effect. On the other hand, a buried salt dome might have a lower specific gravity than surrounding sediments and would tend to give minima readings.

MAGNETIC SURVEYS

In general igneous rocks such as granite contain more magnetite than do sedimentary rocks. Some hint of the buried structure shown in Fig. 8C might be indicated by a magnetic survey. The structure of Hobbs Field in New Mexico is reported to have first been indicated by a magnetic survey. Recent drilling in Stanley County, South Dakota, proves that a magnetic "high" there is related to the upfolding of pre-Cambrian rocks.

GEOCHEMICAL SURVEYS

Claims have been advanced for certain methods of testing soils for minute traces of gases, parafins and other hydro-carbons. Proponents of these methods claim that they are thus able to find direct evidence of oil pools which may be buried under thousands of feet of sediments. Some of these methods include fluorographic and spectroscopic analysis.

A geodynamic method measures the rate of efflux of the hydrocarbons from the subsurface reservoir. A maximum rate of gas leakage is reported to coincide with the petroleum "high" as opposed to rings or halos reported in soil-gas analysis.

ELECTRIC WELL LOGGING

Electric well logging is designed to determine the character of the rock formations penetrated in a well. Electric well logs are usually used in conjunction with sample logs prepared by a geologist from examination of drilling cuttings. In this method two classes of electrical potential are measured. One of these is the natural or self-potential currents generated as a result of chemical and physical reactions set up between natural conditions in the rock and certain conditions in the drilling mud in the bore hole. In the other class an electrical field is artificially imposed and the change in potential is recorded as the system of electrodes is lowered down the uncased well.

Observed effects are plotted as curves, called a natural potential or self-potential curve, in the first case, and a resistivity curve in the second.

In general the self-potential curve will vary directly as the permeability of the rock. Inspection of the two curves indicates the general nature of the rock; for example, an oil saturated sandstone has a high natural potential and a high resistivity whereas salt water filled sandstone has a high natural potential but a low resistivity.