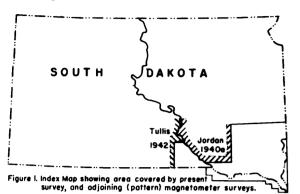
MAGNETOMETER SURVEY OF SOUTHEASTERN SOUTH DAKOTA

Bruno C. Petsch

INTRODUCTION

This report includes ground magnetometer surveys in the southeastern part of South Dakota covering an area of about 155 miles from east to west and 75 miles from north to south. This report includes the following surveys: (1) Hanson and Minnehaha Counties in 1960 by the writer, (2) turner, Clay and the east half of Yankton County in 1943 by the writer (3) the northern part of Charles Mix, all of Douglas, the western part of Hutchinson and the northwestern part of Bon Homme Counties, by Jordan, (Jordan, Rothrock, 1940), and (4) the remainder of the area by the writer

This magnetometer survey of southeastern South Dakota is tied to the magnetometer surveys of Tullis (1942) and Jordan (Jordan, Rothrock, 1940),



LOCATION AND TOPOGRAPHY

The thirteen counties of southeastern South Dakota included in this report are bounded on the south by Nebraska, and on the east by Iowa and Minnesota. The area is drained by the Missouri River and its tributaries. contains Lewis and Clark Lake, and Fort Randall Lake. Below Yankton, the Missouri River is in a long wide alluvial plain. An area of high dissected hills occurs on the western side of the Big Sioux River between Fairview, Beresford, and Richland. South Dakota. The remainder of the area between be Missouri and Big Sioux Rivers ranges from gently rolling plains to level land, bisected by the James River Valley (fig. 2).

FIELD WORK

Observations by the writer were made with an Askania Vertical Ground Magnetometer at intervals of five miles with the assistance of Cleo M. Christensen and Lynn S. Hedges. This network of observations probably utlines the major magnetic features in the area. Supplementary observations

were taken in areas of unusually high readings. The variation was taken from repeated observations at a base station and from daily magnetograms supplied by the Tucson Magnetic Observatory of the U. S. Coast and Geodetic Survey. All magnetic observations were ade in fields and pastures away from power lines, fences and other possibly magnetic objects.

THE GEOLOGIC SETTING

The magnetometer survey of southeastern South Dakota covers an area where the general geology is well known. The area includes six different Geologic Provinces (fig. 2): (1) the Sioux Ridge, which crops out in many places in Minnehaha, McCook, and Hanson Counties; (2) the ortheastern end of the Siouxana Arch which enters South Dakota across Charles Mix and Rutchinson Counties from Nebraska, and possibly joins the Sioux Ridge; (3) the eastern terminus of the Cretaceous overlap, with outcrops along the Big Sloux River; (4) the extreme northern portion of the Forest City basin, which terminates somewhere along the southern flank of the Sioux Ridge; (5) the extreme southeastern part of the Williston Basin or northern part of the Nebraska Basin, which lies west of the Siouxana Arch.

The area is covered for the most part by glacial till of the Wisconsin and Illinoian ice sheets.

The most outstanding geologic feature in eastern South Dakota is the Sioux Ridge (fig. 2). Its' crest extends east-west through Minnehaha, McCook, and Hanson Counties and it continues westward under Cretaceous rocks. The eastern most outcrop of the Ridge is at New Ulm, Minnesota, 100 miles east of Sioux Falls. The Ridge extends westward through the Dell Rapids-Sioux Falls area: the westernmost outcrop of the formation is at Mitchell. It continues in the subsurface westward to Chamberlain, where it turns northwestward into central South Dakota. The total length

Siouxana Arch

The Siouxana Arch of Nebraska (Reed, Svoboda, 1957) is an offshoot of the Cambridge Arch of western Nebraska and trends northeast, although its exact position is not definite in northeastern Nebraska. Its core is probably granite, but there are no outcrops of its Precambrian core throughout its entire length. A buried ridge of Sioux quartzite extends from outhwestward through Lake Andes (Steece, 1961) probably connecting

Cretaceous Overlap

A series of Cretaceous shale, chalk, limestone, and sandstone extends eastward into Iowa and Nebraska from the Rocky Mountains and the Black Hills, as the Cretaceous overlap. Outcrops are found at many places in southeastern South Dakota especially in the hillsides bordering the rivers. The regional dip in the western part of the area is very gentle to the southwest away from the Sioux Ridge. In the eastern part of the area the beds dip more steeply and toward the Sioux Ridge to the northwest. The Cretaceous overlap completely covers the Paleczoic formations of the Forest City Basin and the Williston Basin. Only the upper Cretaceous crop out on the Sioux Ridge, and there are large areas in Minnehaha, McCook, and Hanson Counties where all Cretaceous formations are absent. The Cretaceous is generally less than 1000 feet thick over most of the area, but it reaches 1900 feet thick in the General Crude #1 Shippy Oil Test (Sec. 5, T. 96 N., R. 75 W.), in Tripp County (fig. 3, No. 13) The increased thickness westward is due solely to the thickening of the Pierre Shale. The Cretaceous is only 618 feet thick in the extreme eastern part of the area in the South Dakota Geological Survey #1 Huebner Test Hole (Sec. 25, T. 93 N., R. 50 W.), where all the Cretaceous above the Greenhorn are missing because of the northwesterly dip.

Forest City Basin

Among the major structures of the Mid-Continent is the Forest City Basin which underlies much of western Iowa and appears to extend into Forest City Basin underlie Union, the eastern part of Clay, the southern half of Lincoln, and possibly the southeastern part of Turner Counties.

Williston Basin

A major structure of the Northern Great Plains is the Williston Basin, which underlies most of North Dakota and extends into South Dakota between the Black Hills and the central part of the state. Its There are no data available on the subsurface Williston Basin rocks in Gregory County, but extrapolating data from Tripp County, much of the Williston Basin Lower Paleozoic sequence underlies the Cretaceous overlap in the western part of the surveyed area (fig. 3).

Glacial Deposits

The uppermost and youngest sediments in the geologic column cover the entire area of eastern South Dakota. These deposits are composed of loose unconsolidated boulder clay brought in by the ice sheets and sand and gravel laid down in channels cut by meltwater from the ice fronts. These deposits are covered in part by wind-blown loess, which is as much as 90 feet thick (Todd, 1908). Alluvial material containing silt, sand and gravel makes up the floodplain deposits in all of the present river

PRECAMBRIAN SURFACE AND LITHOLOGY

The surface of the Precambrian basement was plotted (Steece, 1961) from records of water and oil test borings in this area (fig. 5). Therefore the relief of the basement surface is well known. The maximum relief is 1861 feet, from surface outcrops at 1425 feet altitude near Shoux Falls to -436 feet below sea level in the General Crude #1 Shippy Oil Test in eastern Tripp County. The Precambrian surface slopes in a southwesterly direction about 12 feet per mile underneath Williston Basin sediments (fig. 3), and in a southeasterly direction from Sioux Falls to Well No. 12 4 feet per mile under Forest City basin sediments (fig. 4).

The formations comprising the Precambrian basement are pink, gray and red granite, some is biotitic; rhyolite porphyry; diorite; and gabbro dikes of hornblende schist; and quartzite composed of pink to purple tightly cemented sandstone and is designated as orthoquartzite because of its sedimentary origin (Baldwin, 1951). The material forming the quartzite is assumed to have been derived from the Canadian Shield and is called Sioux from outcrops along the Big Sioux River; however, the best type sections are along Split Rock Creek which flows into the Big Sioux River near Corson, South Dakota. The Sioux Formation also contains red and brown shale, slate, conglomerate, pipestone (Catlinite), and clay. The pipestone has been dated as 1.2 billion years old (Goldich and others, 1961). The Sioux Formation has not been divided into other members. It underlies nearly all of the area of this report except parts of Union and Gregory Counties. As much as 3800 feet of quartzite was penetrated in a well i Charles Mix County. The quartzite was deposited on granite as shown by wells (Steece, 1961).

Records from five oil and gas test borings, and a water well at Sioux City show that the Paleozoic formations are about 1200 feet thick at Sioux City but decrease to 638 feet at Jefferson, to 485 feet at Wagner #1 O'Connor Oil Test near Spink (fig. 4). The Precambrian surface beneath the Paleozoic rocks alopes southward from Wells No 8 to No. 12 (fig. 4) at the rate of 27 feet per mile.

Much stratigraphic work remains to be done on the Paleozoic formations in this part of the Forest City Basin. At present the terms Mt. Simon-Lamotte, Eau Claire-Bonneterre, and Franconia-Davis for the Cambrian system, and St. Peter and Decorah-Platteville for the Ordovician system are used (fig. 4). Formations of the rest of the Paleozoic are probably not present in this area. The line of stratigraphic pinchout of the Paleozoic formations rests on the Precambrian Sioux quartzite, but the Paleozoic rocks lie on granite to the southeast of this line. There are no exposures of Paleozoic rocks anywhere in southeastern

MAGNETOMETER SURVEY

General Statement

Theoretically the earth itself is a natural magnet. The force set up between the north and south magnetic poles are made up of four components, declination, inclination, horizontal intensity, and vertical intensity. The vertical component has been determined to be the most satisfactory to measure in geophysical research and magnetometer surveying, because this force is a composite of all conditions that influence the magnetic field emanating from the crust of the earth. These conditions are composed of paramagnetic, diamagnetic, and non-magnetic substances which are in the basement complex, the subsurface sedimentary column, and on the ground surface.

The vertical intensity of the terrestrial magnetic field is illustrated by contour lines (isogams) on maps; the lines connect points of equal value. Variations of the intensity are recognized as positive and negative forces commonly known as magnetic highs and lows, or anomalies. The composite effect of the earth as a great magnet, and the local variations in a given area caused by geologic features, determine the size and shape of anomalies Magnetic highs are generally sought when prospecting for oil and mineral deposits. In addition to changes in the earth's magnetic field caused by rock types and geologic structures, there is a gradual increase in the magnetic intensity toward the north magnetic pole. In this area the vertical intensity increases 8.7 gammas per mile north and 3.6 gammas per mile east (Jordan, Rothrock, 1940). The application of this regional correction to a survey tends to result in a flat magnetic surface. Therefore any anomaly on this surface should be a geologic feature.

Magnetic surveys are used to indicate large trends which are then

investigated with more exact geological and geophysical surveys. Possible causes of magnetometer anomalies are: (1) lithologic composition of rocks in the Precambrian, (2) concentration of magnetic minerals in the overlying sedimentary rocks and the "granite wash" or basal conglomerate developed on the basement, (3) deep-seated iron body, (4) changes in thickness of the red bed section, (5) structure of the sedimentary formations, (6) depth and relief of the Precambrian surface.

It is advantageous to make magnetometer surveys over areas where the geology is known. The solution of a magnetic problem is aided when

The Kursk iron-ore body in Russia is the most spectacular of all magnetic anomalies, as it reaches a magnetic high of almost 150,000 gammas. The Hobbs magnetic high in New Mexico is another and is famous because it was the first magnetometer high to produce oil.

In view of the fact that there are abnormal magnetometer anomalies

in southeastern South Dakota, it is considered necessary to compare them with known anomalies located in other parts of the country (Table 1). Many are famous and are cited in the literature on magnetic investigations

Table 1.-- Comparison of magnetometer highs

of Anomaly	Amplitude (Gemmas)	Precambrian (Depth)	Rock Type
Hobby Dike	1000	outcrop	Peridotite (Warren, 1956)
Pea Ridge	5612	•	?
Bourbon	3699	1400	Rhyolite Porphyry (Searight and others, 1954
Kratz Spring	3 919		?
Vilander	1489		?
Lindsay Hill	4800	outcrop	Magnetite and Hematite Iron ore * (Cook, 1950)
Willowdale	4000	700 (est.) ?
	2916	792	Gabbro
Bula	3000	outcrop	Serpentine (Dreyer, 1947)
	Anomaly Hobby Dike Pea Ridge Bourbon Kratz Spring Vilander Lindsay Hill Willowdale Spink	Anomaly (Gemmas) Hobby Dike 1000 Pea Ridge 5612 Bourbon 3699 Kratz Spring 3919 Vilander 1489 Lindsay Hill 4800 Willowdale 4000 Spink 2916	Anomaly (Gemmas) (Depth) Hobby Dike 1000 outcrop Pea Ridge 5612 Bourbon 3699 1400 Kratz Spring 3919 Vilander 1489 Lindsay Hill 4800 outcrop Willowdale 4000 700 (est. Spink 2916 792

Magnetic Anomalies

The magnetometer map of southeastern South Dakota shows considerable magnetic variation, from broad generally flat uniform and subnormal low areas, to abnormally high magnetic readings. The magnetic high areas can be separated into three geographic (1) a chain of highs extending due south between Menno, South Dakota, and Crofton, Nebraska, about 45 miles long. It is made up of the Gavins Point high, about 15 miles long, whose axis has a summi 1770 gammas. A high of 741 gammas is present south of Utica in T. 94 N., R. 57 W. A magnetic high at Menno has a summit of 695 gammas, and is broad and flat. A long narrow magnetic low parallels the Menno-Crofton (2) The Parkston magnetic high has a broad flat surface which covers more than a township; it does not have a distinct summit, but 14 observations on its top range from 1254 to 1530 gammas. The anomaly is generally circular and the 1000-gamma contour encloses several

(3) The major magnetic anomaly in southeastern South Dakota and probably the most prominent in the Great Plains region is a series (chain) of magnetic highs extending from the Willowdale School three miles east of Yankton due east to Chatsworth, Iowa, a distance of 50

ss. It includes the Willowdale and Spink Highs.
The Willowdale high has three summit's of 3458, 3413, and 3333 gammas and is more than three miles long and about half a mile wide (figs. 6, 7). It is the highest magnetic reading observed to date in South Dakota. The anomaly is straight, its north flank has an even gradient of 2000 gammas in half a mile to the north, and it extends for 5 miles. A deep magnetic low of -807 gammas parallels it on the

The Spink magnetic high is the second largest magnetometer anomally in South Dekota. The anomaly is in Clay and Union Counties in the southeastern part of the State. It has three summits: 1162 gammas 3 miles west of Bub City in Clay County, 2752 gammas 2 miles east of Spink, in Union County, and 919 gammas at Chatsworth, Iowa, on the South Dakota-Iowa border.

The Hub City part of the magnetic high trends eastward to the Union County line then turns southeastward past Spink. The axis of the Spink high lies in a southwest-northeast direction and is 4 miles long and about one mile wide (figs. 8, 9). A magnetic low lies between the Spink and Chatsworth highs. Further observations east of Chatsworth in Iowa may show an anomaly on the order of the Spink or Willowdale highs. From present observations, the Chatsworth anomaly appears to extend northward toward Fairview, South Dakota.

A broad magnetic low in the Jefferson-Elk Point area lies south extend northward toward Fairview, South Dakota.

A broad magnetic low in the Jefferson-Elk Point area lies south of Spink and is bounded on the south by a high in the Sioux City area. In the northern part of the surveyed area, there is a broad moderate high anomaly in western McCook County, and one at Hartford in western Minnehaha County. Two rather abrupt but moderate highs are northeast of Sioux Falls, at Corson, and Renner.

The Corson anomaly has a summit of 480 gammas on the outcrop of an igneous dike, which is only about 200 gammas above normal. The other anomaly northeast of Sioux Falls (fig. 10) has a summit of 388 gammas also taken on the outcrop of an igneous rock intrusion. This is about 300 gammas above normal. Within half a mile north of the latter summit are two low readings of 97 and 74 gammas (fig. 10). The Corson anomaly does not have a comparable low adjacent to it. The anomaly at Renner has a summit of 571 gammas which is about 300 gammas above normal. It is comparable to the two anomalies northeast of Sioux Falls in size and shape except that no outcrops are present.

Geologic Analysis

The Parkston magnetic high is the most extensive anomaly in the area. The high seems to be at the junction of the Siouxana Arch, with the Sioux Ridge, as borne out by contours on the Precambrian

with the Sloux Ridge, as borne out by contours on the Precambrian surface (fig. 5).

The Palensky #1 Wagner Oil Test in Section 17, T. 99 N., R. 61 W., in Hutchinson County, was drilled on the west side of the Parkston anomaly in 1940 with a cable tool rig. According to data in the files of the State Geological Survey, Precambrian pink and purple quartzite was encountered at a depth of 683 feet. The quartzite is non-magnetic, but it might be quite thin, so that other Precambrian rocks beneath or just to the east of the oil test may be causing the anomaly.

Most of the Parkston anomaly is underlain by Precambrian Sloux Most of the Parkston anomaly is underlain by Precambrian Sioux quartzite except for a granite area in northeastern Douglas County which was penetrated in two wells (fig. 5). The Precambrian surface

is topographically high in the anomaly area.

The long magnetic lobe that extends westward from the Parkston high contains an 800-gamma high in Charles Mix County and a 500-gamma high in Gregory County; they are both in a trough of the buried Pre-

In view of the fact that Minnehaha, McCook and Hanson Counties are underlain by the Sioux Formation and the resultant magnetic picture shows moderately uniform magnetic highs and lows, it suggests that all of Turner and Lincoln Counties are underlain with the Sioux where likewise the magnetic intensities are uniform. The Sioux Formation seems to act as a shield, smoothing out magnetic irregularities caused by different rock types beneath it.

The south boundary of the Sioux Formation may be on the eastern flank of the Menno-Crofton magnetic anomaly, and on the northern flank of the Willowdale-Spink anomaly. This is suggested by the Wagner #1

O'Connor Oil Test in Union County which penetrated the Sioux quartzite at 655 feet depth and the SDGS #1 Huebner Test in Union County which penetrated gabbro at 792 feet, and by the Rittershaus #1 Jamesville
Oil Test where diorite was penetrated at 738 feet depth.

A buried ridge of rock types more basic than granite, which could be magnetite-bearing volcanic rocks, may be the cause of the Menno-Crofton and Willowdale-Chatsworth magnetic anomalies. The diorite in the Jamesville test is on the crest of the former anomaly. It is possible

The uniform magnetic field in Minnehaha County is interrupted by four small anomalies; the one at Corson and another just northeast of Sioux Falls are caused by basic intrusions of clivine diabase exposed at the surface. The anomalies at Renner and Colton are comparable to them in intensity and size, suggesting that they too are caused by basic The Menno-Crofton and Willowdale-Chatsworth magnetic anomalies are

hat the Sioux Formation is missing on the anomaly, but surrounds it.

The Menno-Crofton and Willowdale-Chatsworth magnetic anomalies are more pronounced than a similar chain of anomalies (Stanley, Mossman, and Trail City) in north-central South Dakota (Petsch, 1959). The former are in an area where the Precambrian basement rocks are less than 1000 feet deep whereas the latter is where the basement rocks are more than 4000 feet deep. Both anomalous trends have unusually high summits. The Spink magnetic high lies in a southwest-northeast direction. The 1000 gamma contour encloses about 10 sections of land. The summit lies in the NW_{4}^{1} sec. 25, T. 93 N., R. 50 W. near the south end of the axis, although the summit is 2752 gammas, much of the quarter section has observations from 2400 to 2600 gammas. The east side of the anomaly drops off 2200 gammas in a mile. The entire eastern flank of the anomaly has a steep slope bordering on a subnormal low to the southeast. This abrupt change of the magnetic intensity indicates a sharp boundary of

the subsurface mass which causes the Spink High.

Although the Spink magnetic high is locally very prominent, it is part of an anomaly which covers 137 square miles and is more than 24 miles long.

A test boring drilled by the State Geological Survey on the summit

A test boring drilled by the State Geological Survey on the summit

of the Spink magnetometer high in the NN sec. 25, T. 93 N., R. 50 W., on the August Ruebner farm penetrated the follow formations:

Depth to top in feet

Cretaceous	
Greenhorn Formation	120
Dakota Formation	195
Fuson Formation	280
Lakota Formation	315
Paleozoic-Cambrian	
Franconia	618
Galesville	662
Eau Claire	689
Mi. Simon	760
Precambrian	792
т. р.	796

A core 54 inches long and 2 3/4 inches in diameter was taken of the Precambrian with a diamond bit. The following is a log of the core: Lithology

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The Precambrian is a diabasic magnetitic gabbro which was intruded into the granite basement.

A chemical analysis was made of two samples of the core which gave

	"Unaltered rock"	"Altered rock"
Iron	14.47 %	13.61 %
Titanium Dioxide	6.76	3.60
Magnesium Oxide	1.89	5.29
Calcium Oxide	10.39	4.40
Silica	33•43	41.05
Combined Oxides	40.19	33•54
Tose on ignition	11.22	12.23

Rock that contains only 14 per cent iron will not result in a 2700-gamma high at a depth of 800 feet; thus, the source must be in higher-grade iron-bearing material in this vicinity. The gabbro is probably the cause of the Spink magnetic high. The ioux quartzite which acts as a shield reducing the magnetic intensity down to 1100 and 800 gammas. Increased depth of an intrusion would also lower the readings. If the gabbro is in the granite only and dips to the northwest, the high in the Hub City area would be accounted for. The Willowdale magnetic high is 500 gammas higher than the Spink anomaly, and its adjoining low extends 650 gammas deeper. It has a similar steep slope bordering a subnormal low, and opposite the steep slope is a large lobe of 1000 gammas extending southward at least four

It lies in the flood plain of the James River. The ground surface is flat and is about 200 feet lower than that at Spink. The sharpness of the Willowdale anomaly suggests that the source of the magnetic energy is somewhat shallower than at Spink.

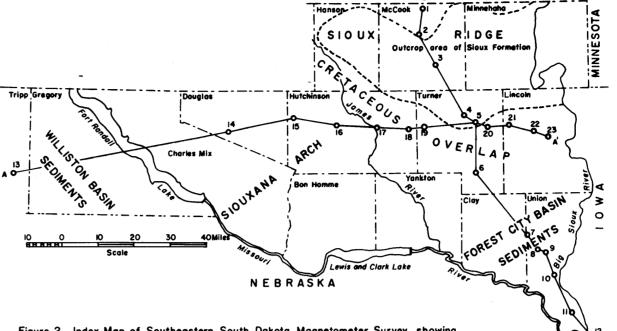
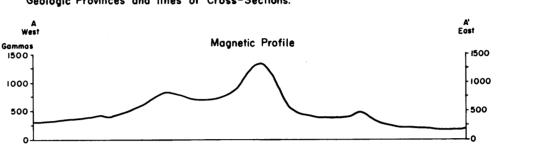


Figure 2. Index Map of Southeastern South Dakota Magnetometer Survey, showing Geologic Provinces and lines of Cross-Sections.



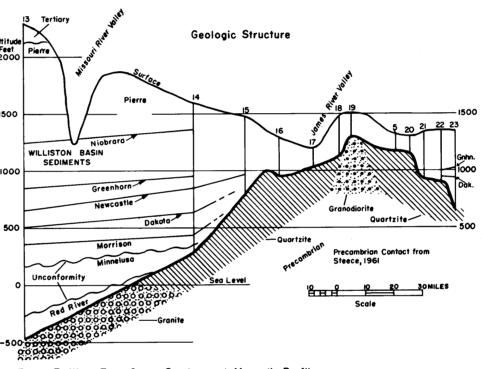
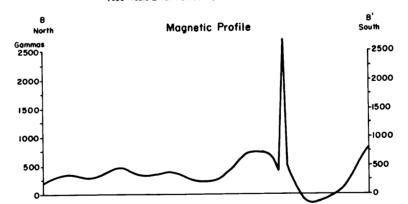
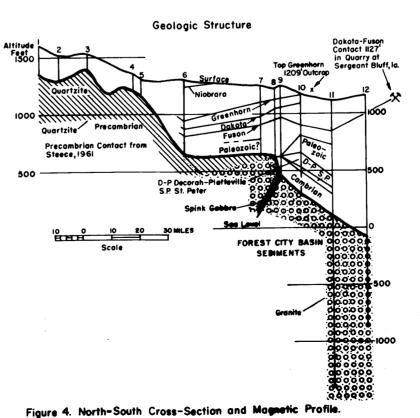


Figure 3. West-East Cross-Section and Magnetic Profile. (see Toble 2 for well data)





(see Table 3 for well date)

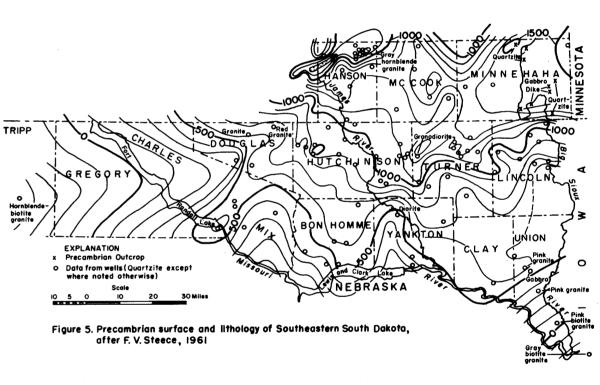
		Tab	le 2				
No.	Well	Sec.	Twp.	Rge.	Altitude	Depth Pc	Altitude Pc
13	General Crude Shippy, Oil Test	N.W. 5,	T. 96 N.,	R.75W.	2282	2725	-460
14	Douglas Dev. Clark "	N. W. 5	98	64	1596	1306	290
15	Palensky i Wagner "	17	99	61	1480e	678	802
16	Pietz farm water well	29	99	59	1310e	361	949
17	Wolf Creek	S.E.31	99	57	1200	182	1018
18	Freeman Town "	N.W. 35	99	56	1490	360	1130
19	Miller farm "	32	99	55	1510e	194	1316
5	Rector farm "	N.W.26	99	53	1300e	85	1215
20	Victor farm *	N.E. 32	99	52	1300	140	1160
21	Lennox Town "	32	99	51	1340	430	910
22	Worthing Town "	S. W. 4	98	50	1355	460	995
23	Omanson Peterson OilTest	N. W. 18	98	49	1350e	686	664
	Estimated Altitude						

e = Estimated Altitude Pc= Precambrian

Table 3								
No.	Well		Sec.	Twp.	Rge.	Altitude	Depth Pc	Altitude Pc
1	Grimme farm water well		N.E. 7	T. 104N.	R.54W.	1600e	227	1373
2	Salem Town "		13	103	5 5	1525e	220	1305
3	Canistota " "		34	102	54	1540	140	1400
4	Parker " "		7	99	53	1360	160	1200
5	Rector farm		N. W. 26	99	53	1300e	85	1215
6	Viborg Town "		S. W. 35	97	53	1308ь	685	623
7	Wagner O'Conner	OilTest	N.E. 31	94	50	1249	655	594
8	Wagner Larson		S. W. 22	93	50	1207	586	621
9	S.D.G.S. Huebner	a	N W 25	93	50	1260e	792	468
10	Wagner Blanchard	OilTest	N.W.29	92	49	1170	839	331
11	Sioux Valley La Fleur	b	S.W. 18	90	48	1115	1027	88
12	Chesterman water well	С	29	89	47	1160	1260	-100

e Estimated Altitude

- a South Dakota Geological Survey, Research Test Hole.
- b Drilled 1487 ft. into granite, total depth 2515 ft.
- c Drilled 751ft. into granite, total depth 2011ft. Sioux City, lowa.
- la. Geol. Sur. vol. 5, p. 258, 1895
- Pc Precambrian



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