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STATE OF SOUTH DAKOTA
George T. Mickelson, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 66

MAGNETIC OBSERVATIONS in SOUTH DAKOTA

by

Bruno C. Petsch
and
Loyd A. Carlson

University of South Dakota
Vermillion, South Dakota
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FOREWARD

E. P. Rothrock

In 1939 the State Geological Survey started a project which was designed to show the part of the earth's magnetic field and its anomalies that exist in South Dakota. As the state was too large to complete in one season, the project was broken down into smaller parcels. Each season's work was published until 1942 when the war interrupted and left some large gaps in the information that was available.

This report is an attempt to review the work that has been published and make available the information that has not yet been published. The report therefore carries maps that were made in 1942 by Mr. Wayne Marshall whose work was not published because he was called into government service immediately after that field season ended. It also contains the work of Mr. Bruno Petsch in 1943 and 1946.

A short paper and accompanying maps by Mr. Loyd Carlson show the magnetic picture for the entire state obtained by plotting data from stations set many years ago by the United States Coast and Geodetic Survey.

Three reports (Reports of Investigations 33, 37, and 42) on magnetic anomalies in South Dakota have been published by the Geological Survey. This one is intended to bring the magnetic data up to date. It is hoped, therefore, that this information may be of help in determining the locus of more detailed prospecting for any product where rock structures or magnetic properties are important and may throw some light on electronic problems which vex radio transmission in South Dakota.

ACKNOWLEDGEMENTS

Acknowledgement is made of the generosity of land owners for allowing the parties to enter fields and pastures for the purpose of taking the magnetic observations.

The writers have freely drawn from Reports of Investigations by other members of the State Geological Survey who have done magnetic work preceding this investigation.

The Department of Physics of the University of South Dakota, under the direction of Mr. T. H. Bedwell and Mr. Richard Zimmerman, constructed the Helmholz coil which was used during the survey to calibrate the magnetometer.

Mr. Guy Frary, State Chemist, furnished an analytical balance which was part of the apparatus used in the susceptibility measurements. In this phase of the work Mr. Don Mitchell of the State Chemical Laboratory made some calibrations. Mr. William Michels, a member of the Chemistry Department of the University, furnished some chemicals which had susceptibility values already determined and these were used to test the equipment.

Mr. Vic Young of the Applied Science Department of the University assembled the magnetic coil.

Messers Kenneth and Harold Morrow, of the Physics Department, calibrated the magnetic coil and assisted in various ways with the procedure.

PART I: MAGNETIC SURVEYS IN SOUTH DAKOTA

B. C. Petsch

INTRODUCTION

The investigation of the earth's magnetism dates back to another century; as time and progress went on, refinements in instruments and techniques rapidly increased. About 1924 and 1925 geophysics, a new science, began. This science set about to measure the physical forces within the earth on a commercial scale. Today several geophysical methods of exploration are recognized, one of which is the magnetometer survey, and have been widely used in geophysical exploration for oil and gas.

Oil companies have made magnetometer surveys over a great portion of the United States, including South Dakota, but the results of these surveys are the property of the sponsors and are seldom, if ever, for public distribution.

In order to make public information concerning magnetic conditions in South Dakota, the State Geological Survey has undertaken a magnetometer survey of South Dakota. To date about one half of the State has been surveyed as the result of five separate investigations.

On these surveys magnetic observations were taken at stations approximately six miles apart. This interval was chosen first in order that a great portion of the State could be surveyed during the time allotted for field work and secondly, because this program was to be a regional survey and the interval selected would not miss any large features in the magnetic picture. Third, as a general rule, even in sparsely populated areas such as west of the Missouri River, there are country roads and trails six miles apart leading from the main highways which form a network over the State. The main factor in carrying on a magnetometer survey rapidly is the availability of good roads.

It is not the purpose of this regional magnetic survey program to locate leasing blocks or drilling sites. Its primary object is to locate the large subsurface anomalies in order to show where to begin exploration with more exact geological or geophysical methods and equipment.

The instrument employed for this program is the Schimdt type Askania vertical magnetometer with the new temperature-compensated magnet system.

The following portions of the text include brief resumes of previous Reports of Investigations published by the State Geological Survey on magnetometer surveys that have been carried on in the past. The combined results of the work to date are plotted on a map of the State. (See map in pocket.)

MAGNETIC OBSERVATIONS
by the
U. S. COAST AND GEODETIC SURVEY

The Coast and Geodetic Survey began magnetic observations in South Dakota in 1900 and to date have established 83 magnetic bench marks. All Counties have at least one bench mark except Charles Mix, Edmonds, Pennington, Hutchinson, Dewey, McPherson, Deuel, Roberts, Corson, Butte, and Gregory which have two each and Jackson, Minnehaha, Harding, and Perkins which have three each. Shannon, Washabaugh, Washington, Armstrong, and Todd have none. Most of these Bench Marks are near county seat towns.

The following table gives a list of the towns where magnetic observations were made and bench marks established. (Table 1)

The stations were well marked. In the early days Bedford limestone posts, 6x6 x 30 inches, and sandstone posts, 24 x 24 inches at the base tapering to 12 x 12 inches at the top, and later bronze disks set in concrete were used as markers. Some markers have been destroyed, others became useless, because construction was put too near, rendering the spot unadaptable for a magnetic station.

During the occupation of these magnetic stations the values for declination, dip, and horizontal intensity were observed. These data are included in Serial No. 453, "U. S. Magnetic Tables and Magnetic Charts for 1925" and serial No. 602 for 1935, which are published by the U. S. Department of Commerce, Coast and Geodetic Survey, Washington, D. C.

Footnotes: Numbers in parentheses on the following pages will refer to references in the back of this report.

MAGNETIC STATIONS OCCUPIED BY USC & GS

1900

Sioux Falls
Redfield
Gettysburg
Watertown
Rapid City
Pierre
Belle Fourche
Huron

1905

Hot Springs
Eureka

1906

Freeman
Interior
Custer
Stearns
Creston
Presho
Howard
Highmore
Vale
Belle Fourche
Bixby
Harding
Chance
Roscoe
Preacher Hill
Selby
Seim
Murdo
Rapid City
Pierre
Watertown
Reva

1907

Salem
Brookings
De Smet
Faulkton
Webster
Aberdeen

1909

Vermillion
Tyndall
Armour
Mitchell
Plankinton
Madison
Flandreau
Woonsocket
Wessington Springs

1911

Parker
Clark
Britton
Canton

1912

Elk Point
Fairburn

1914

Olivet
Humbolt
Alexandria
Colton
Miller
Toronto
Castlewood
Clear Lake
Watertown
Milbank
Ipswich
Sisseton
Leola
McIntosh

1915

Wheeler
Gregory
Winner

1916

Dupree

1916

La Plant
Timber Lake
Mound City
McLaughlin
Yankton
Huron

1922

Lake Andes
White River
Chamberlain
Kadoka
Murdo
Gann Valley
Phillip
Huron
Pierre
Deadwood
Sturgis
Onida
Rapid City
Yankton

1929

Redfield
Aberdeen
Huron
Rapid City
Yankton

1934

Yankton
Martin
Rapid City
Huron
Aberdeen
Buffalo

Stations Repeated

Aberdeen

1907
1922
1929
1934

Huron

1900
1922
1929
1934

Rapid City

1900
1906
1922
1929
1934

Pierre

1900
1906
1922

Yankton

1916
1922
1929
1934

Redfield

1900
1929

Watertown

1900
1906
1914

Murdo

1906
1922

MAGNETOMETER INVESTIGATIONS
by the
STATE GEOLOGICAL SURVEY

Jordan Surveys, 1939

The first magnetic investigations carried on by the State Geological Survey was made by Dr. W. H. Jordan, professor of physics of the University of South Dakota. Jordan's work was done during July and August, 1939. (1) Thirty-three hundred square miles were covered including most or all of Davison, Aurora, Brule, and Douglas counties, over half of Buffalo and Charles Mix counties and a portion of Hand county. A few stations were located in Jerauld, Hutchinson, and Bon Homme counties.

The total magnetic relief was shown to be nearly 1500 gamma. A large magnetic high was discovered extending from Parkston due west to Platte, then northwest to Red Lake. This anomaly may show the trend of the Sioux quartzite buried ridge.

The magnetic survey of South Dakota was continued in July and August, 1940, by Dr. Jordan. (2) The area covered by this survey is about 10,000 square miles. This includes all of Campbell, Walworth, Potter, Faulk, Sully, Hyde, Hand, Hughes, and Buffalo counties. (Figure 1)

This area showed a total relief of over 1400 gamma; the pattern, as shown by the contours, is an irregular field with many highs and lows in the southern portion and more gentle relief in the northern portion. The largest high in the area extends from Seneca southward to Harrold.

Tullis Surveys, 1941

The magnetic survey of South Dakota was continued in July and August, 1941, by Dr. Edward L. Tullis, professor of geology at the South Dakota State School of Mines and Technology at Rapid City, South Dakota. (3) The area covered by this survey is about 6850 square miles. This includes Codington, Beadle, Jones, Lyman and Tripp counties and a portion of Stanley, Haakon and Jackson counties. (Figure 1)

The major feature in Codington County is a 1100 gamma magnetic high west and north of Watertown and small 900 gamma high southeast of Watertown which is an extension of the former. The magnetic field in Beadle county consists of lows in the eastern part and higher intensities in the west including a large 800 gamma high through Wolsey.

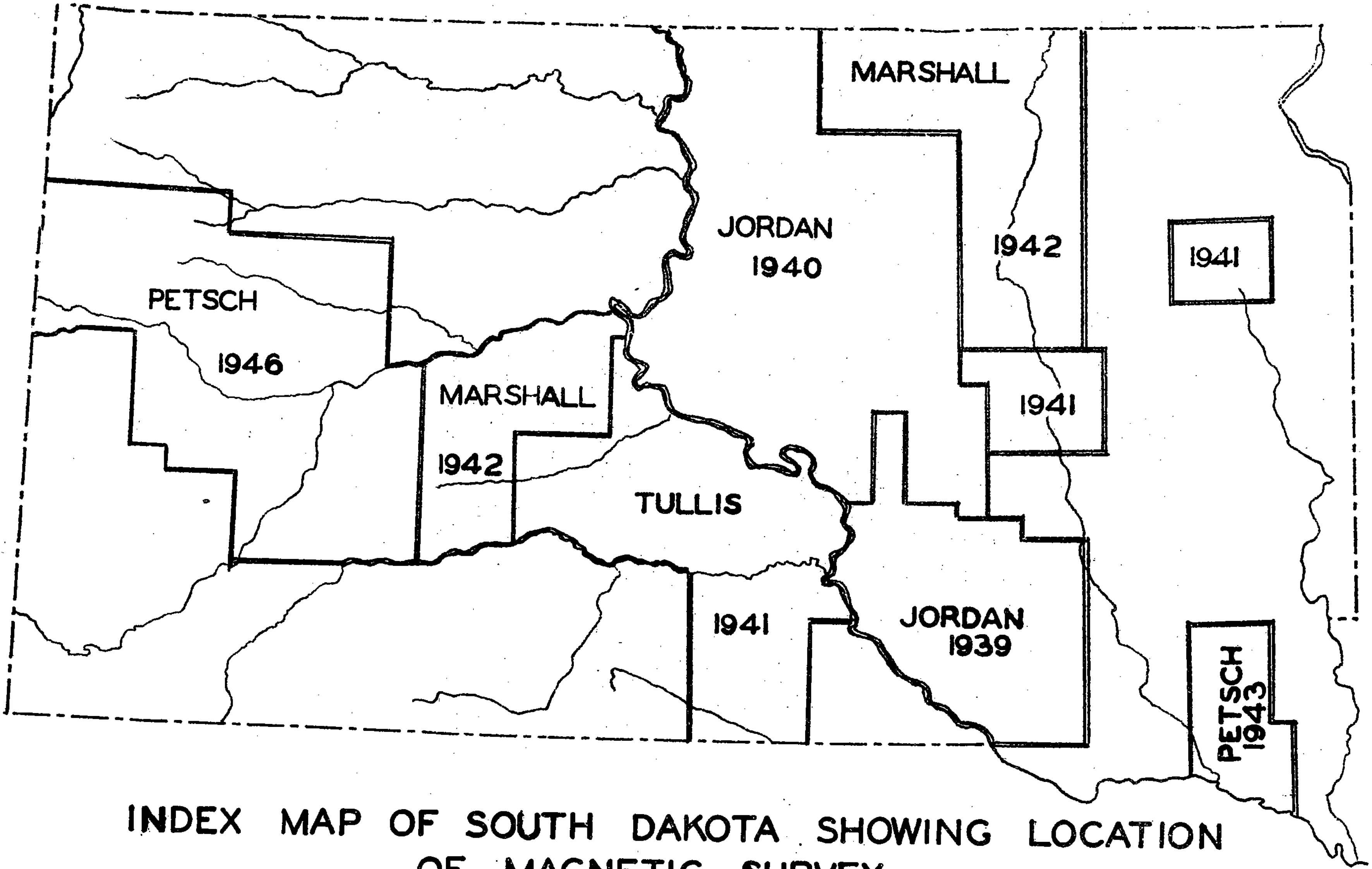
The area surveyed west of the Missouri River by Tullis shows the magnetic field to be generally low and uniform in Tripp county including the southern part of Lyman and Jones counties. Three magnetic highs are present between Kennebec and Pierre.

Marshall Surveys, 1942

The magnetic survey of South Dakota was continued in July and August, 1942, by Dr. W. W. Marshall, assistant professor of physical chemistry at the University of South Dakota. There was no report of this investigation other than a map, because Dr. Marshall went into the war effort and was not able to prepare a manuscript. (Figure 1)

The area covered by this survey is about 5200 square miles and includes Spink, Brown and most of McPherson counties east of the Missouri River and most of Stanley, Haakon and Jackson counties west of the river.

The magnetic features in the area east of the Missouri river in this survey are comparable to those observed in the investigations of adjoining areas. The area west of the Missouri River surveyed by Marshall contains the highest magnetic anomaly so far discovered in South Dakota. This magnetic high is in Stanley county and is 500 gamma higher than others; its observed value is 2060 gamma. The high in western Hutchinson county is 1530 gamma and the high in northern Hyde county is 1400 gamma.



INDEX MAP OF SOUTH DAKOTA SHOWING LOCATION OF MAGNETIC SURVEY

FIGURE 1

Petsch Surveys, 1943

The area covered by this survey is 1300 square miles in the southeastern part of the State. It included the east half of Yankton County, all of Turner and Clay counties. (Figure 1)

The survey shows a 900 gamma high in Clay county and the lowest low, so far observed, in South Dakota, at Mission Hill and Gayville in southeast Yankton County. A more uniform field exists in Turner county probably due to the fact that the Sioux quartzite is shallow in this county and outcrops east of Parker. The gentle magnetic high in northeast Yankton County corresponds to a series of Niobrara chalk outcrops that occur along Clay and Turkey creeks. This agreement suggests that the sedimentary rocks may be structurally high.

Petsch Surveys, 1946

The magnetic survey of South Dakota was continued in July and August, 1946 by Bruno C. Petsch. The area covered by this survey is about 8568 square miles and includes the west portion of Haakon and Jackson counties, all of Butte and Meade county, and the eastern part of Pennington. (Figure 1)

A large magnetic high in the Creighton, Grindstone, Quinn area, and another in the Newell area are the two major anomalies. Aside from these two features the remaining area consists of medium size magnetic highs and lows. (see map in pocket)

The magnetic intensity of the highs in the area of this survey range from 500 to 700 gamma which is one half the intensity of highs east of the Missouri in any area of the same size.

INTERPRETATION OF MAGNETIC ANOMALIES IN SOUTH DAKOTA

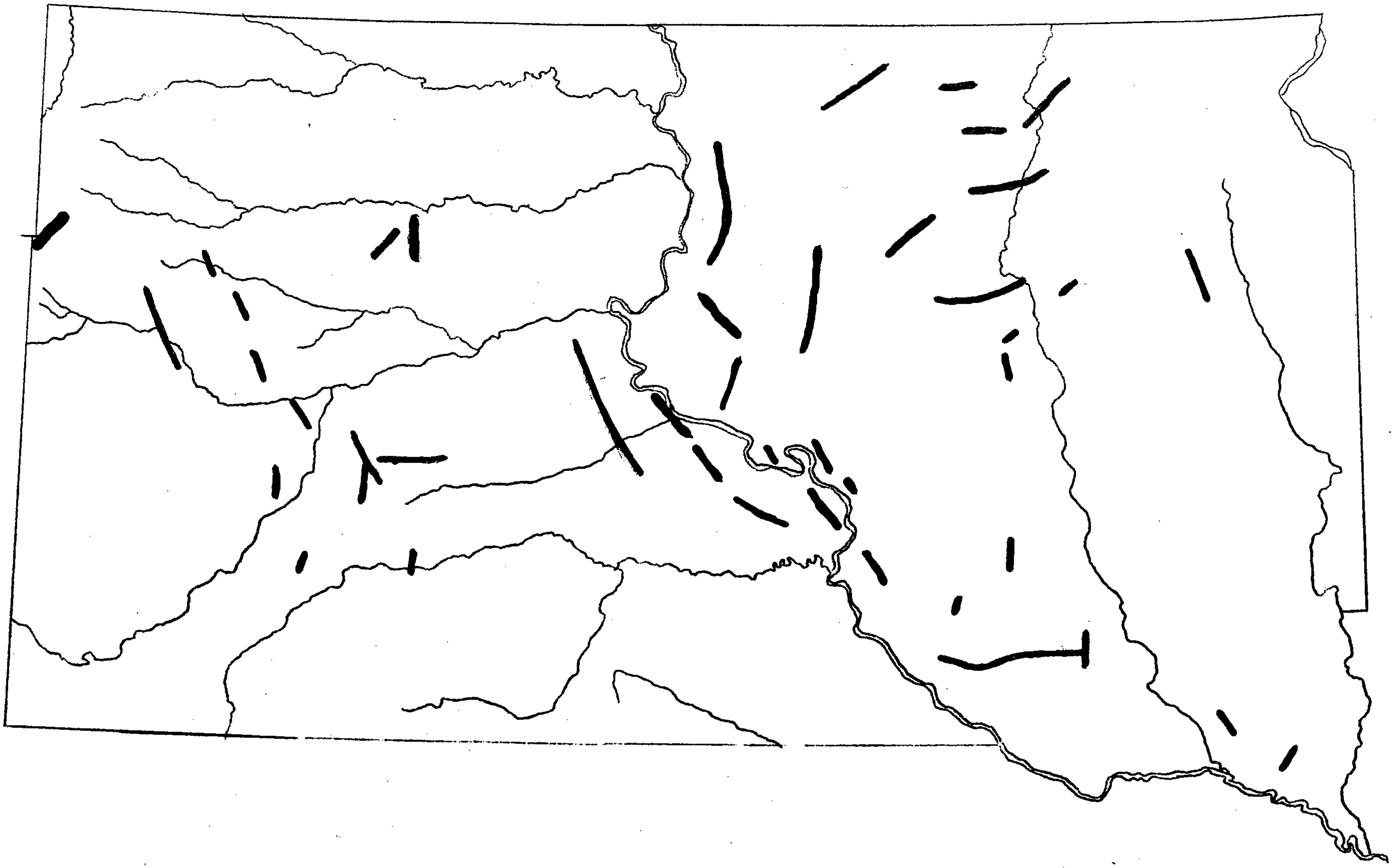
Perhaps one of the first attempts to interpret magnetic anomalies was done by George F. Becker, (4) in 1909. He brought out the fact that curves of equal declination were strongly marked in the principal oil regions in the United States.

An ideal situation would be to have a magnetic high correspond to a geologic "high" or structure; unfortunately many times this is not the case. However a magnetic high shows that a condition is present that is not normal in the rocks beneath.

The magnetic intensities in Western South Dakota resolve themselves into two major categories. First, low intensity values on the pre-Cambrian in the Black Hills; second, higher values on the great plains. This seems to show that the magnetic effect due to the basement complex is not great in the earth's magnetic field. Readings taken at the Needles and Iron Mountain on the pre-Cambrian rocks in the Black Hills are low. The magnetic values in the plains country east of the Black Hills are generally higher than those in the Hills. This condition exists also in Colorado where the granite mountain areas are uniformly low while the plains are magnetically high. (5) Therefore the main magnetic effect appears to be due to the sedimentary sections which make up the plains country. The pre-Cambrian acid igneous rocks minus the sedimentary column reduces the magnetic effect.

The magnetic highs in South Dakota (Figure 2) as far as are known from surveys to date, show two distinct trends. Highs in the western and central part of the State are aligned south-east-northwest in direct parallel to the original trend lines of the Cordilleran Mountain chain fold lines of western North America. (6) In the northeastern part of the State the highs are aligned parallel to the edge of the Archean Shield. The fold lines are the fundamental grain of the continent probably formed in pre-Cambrian times, and are the basement or platform of all subsequent deposition, diastrophism and physiography. The magnetic highs seem to show the original trends of the continental grain as it appears in South Dakota.

The group of magnetic highs in the Pierre-Chamberlain region show a remarkable alignment which suggests buried pre-



TRENDS OF MAGNETIC HIGHS IN SOUTH DAKOTA

FIGURE 2

Cambrian ridges or folding (see map in pocket). The Medicine Butte Anticline northwest of Chamberlain and the anticlines at Pierre are a case in point. The anticlines are parallel with the axis of the magnetic highs.

From the eastern part of the State to the large Stanley County high the contour lines are close together and irregular, from Stanley County to Rapid City the contour lines are farther apart and not as irregular. A flat or uniform area is present from Tripp County northwest through Haakon County which is perhaps the center of the Dakota Basin.

The results of magnetometer work to date in South Dakota (See map in pocket) show four huge highs, the largest is a 2000 gamma high in central Stanley County. In northern Hyde County is a 1400 gamma high; a 1400 gamma high in western Hutchinson County; and a 1100 gamma high in western Codington County. Moderate highs occur generally in the State.

Although the largest high is in Stanley County, two deep lows found are also in Stanley County, one to the northeast and one to the west and northwest. (Figure 3)

A profile from Rapid City to Webster shows the comparitive magnitude of magnetic highs diagonally across the state. (Figure 4)

A magnetometer profile taken across a large basic dike near Corson in Minnehaha County shows it to be magnetically high. An observation taken on the dike is over 200 gamma higher than any of the observations taken within one half mile surrounding it. The dike is a diabase and protrudes through the Sioux Quartzite formation. The diabase has a magnetic susceptibility in the range of 2300×10^{-6}. The reading on top of the dike was 590 gamma; if the reading had been considerably higher, a geologic feature of this type perhaps would account for the above mentioned magnetic highs. Those highs therefore may be due to a thick sedimentary column, a diabase dike, other basic rock, or a geologic structure.

A vertical magnetic survey measures a composite of all conditions that influence the magnetic field which eminates from the crust of the earth. The sedimentary section and the basement complex have certain controls on the magnetic field;

their position, thickness and extent are involved. Some of these factors add and others subtract from the normal field which resolves itself into a problem of elimination in order to have an end product which is a geologic structure, the primary purpose of a magnetometer survey.

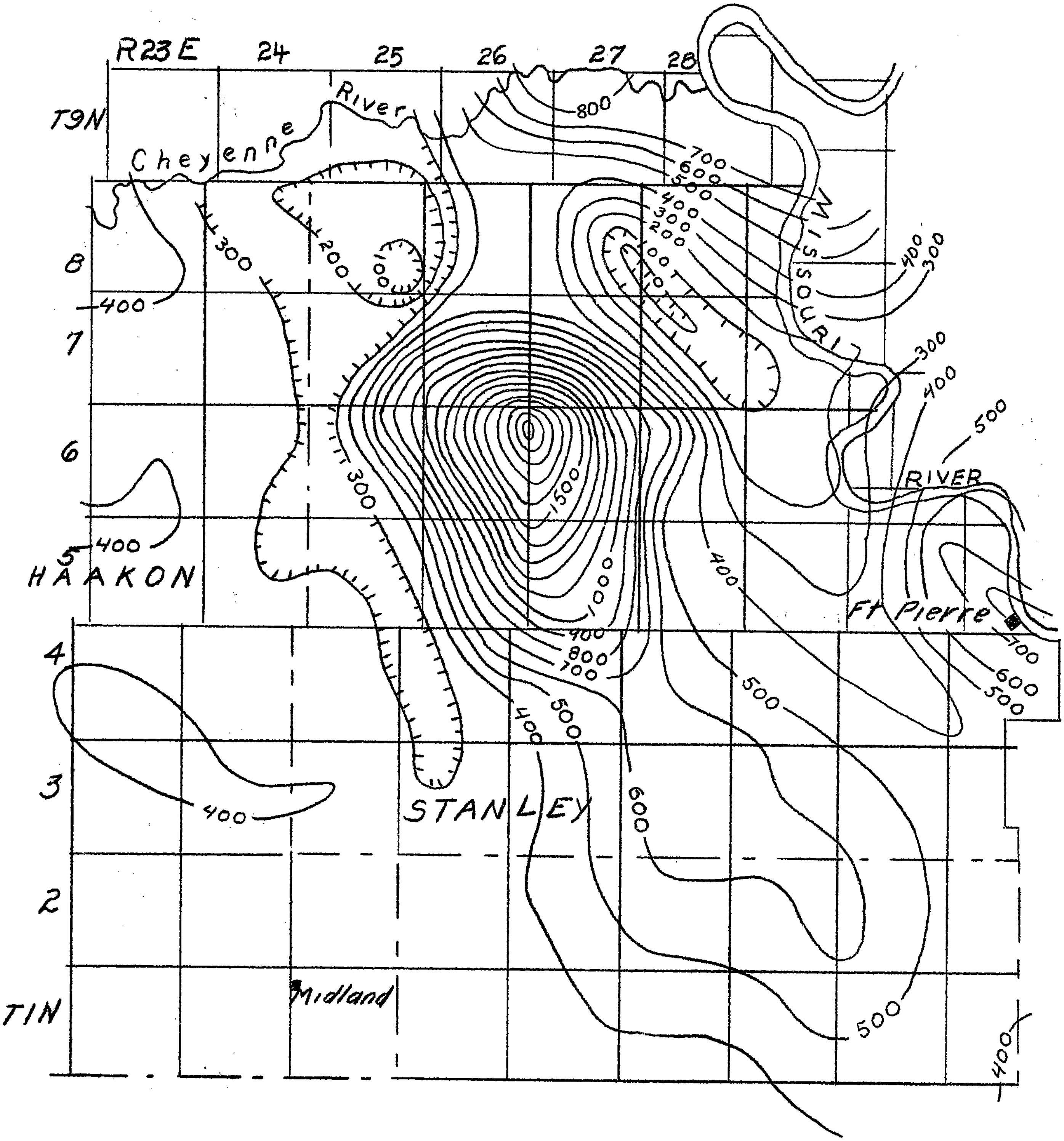
There is no relation between the depth to the pre-Cambrian bedrock and vertical magnetic intensity which is brought out by comparison in statistical analysis. A list of 26 wells was compiled in which pre-Cambrian bedrock had been encountered and the vertical anomaly at each well was interpolated from the contour map in order to obtain a value. (Table 2) To this was applied a statistical test to determine the correlation coefficient (r), assuming linear regression, of one variable on another, or the depth to bedrock on the vertical anomaly. It was found to be 0.048 which is too small. Had r been 0.5 or more, the relation would have been brought out. By examining the list of wells it was obvious that no relation exists.

A variety of causes are responsible for magnetic anomalies. When there is an agreement between an anticline and a magnetic high the cause is due to uniform magnetic susceptibilities of one or more formations in the sedimentary column. A magnetic low over an anticline, in this respect, would result if erosion has removed some of the susceptible formations from its crest.

Changes in thickness of highly susceptible formations could cause magnetic highs or lows. Basic igneous rocks in a pre-Cambrian ridge would be reflected as a magnetic high whereas an acidic igneous ridge would be a low. Distribution of highly magnetic susceptible material in the igneous rocks which make up the basement complex will overshadow influences caused by the sedimentary column and cause anomalies as the case may be regardless of folding or pre-Cambrian ridges.

Magnetite accumulations in granite wash about buried pre-Cambrian hills would also result in magnetic highs.

There is an agreement between magnetic highs and geologic structure in various portions of the State as follows. The magnetic high at Wolsey west of Huron in Beadle county encountered granite at a depth of 1191 feet. There is also a subsiderary high at Huron where granite was struck at the State



Magnetic High in Stanley County

FIGURE 3

PROFILE OF MAGNETIC HIGHS FROM RAPID CITY TO WEBSTER

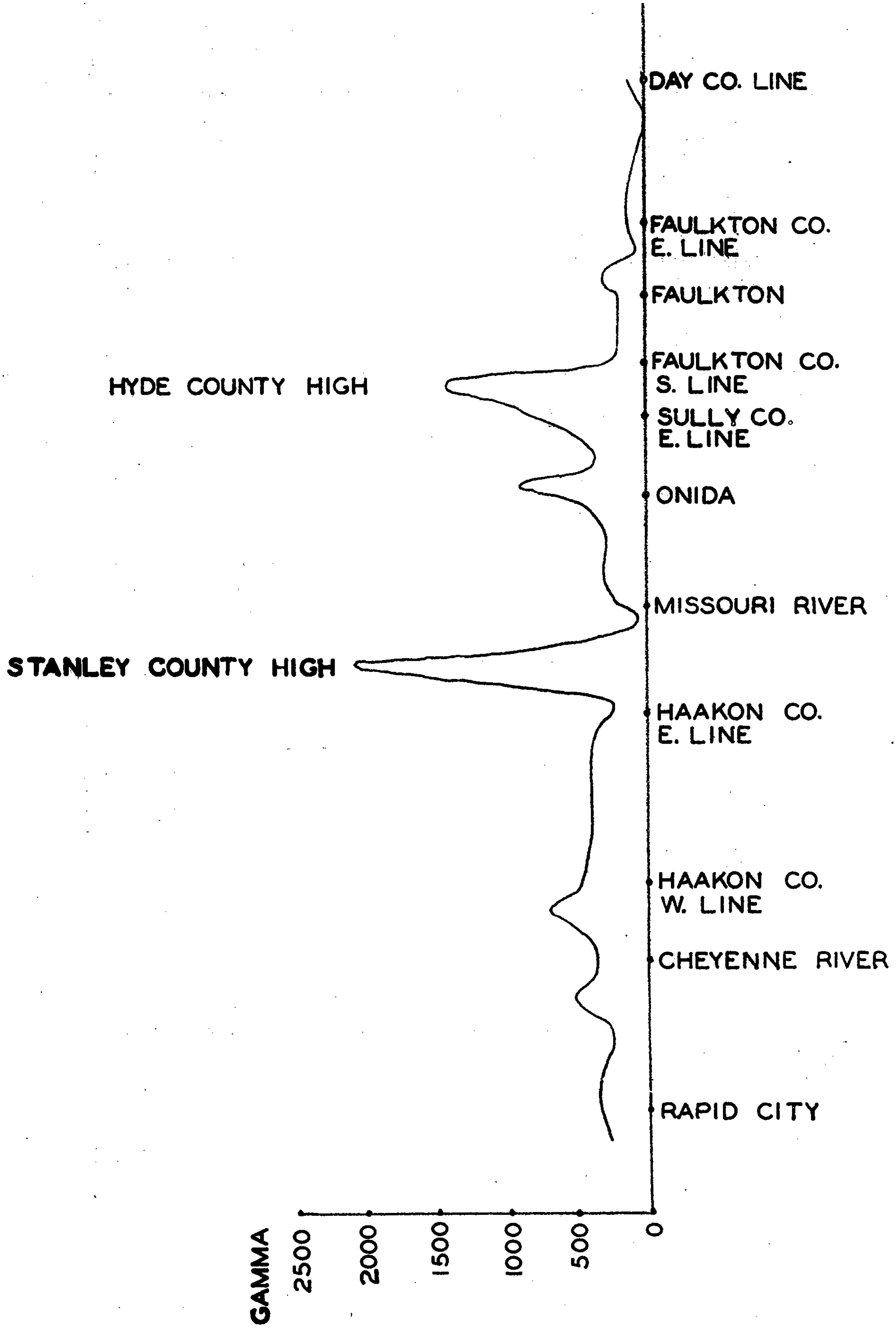


FIGURE 4

Fair grounds at 1176 feet. The magnetic low at Yankton agrees with the low granite in this area. The Medicine Butte Anticline in Lyman County is in a trend of magnetic highs. The structure in T 3 N, R 7 E, Meade County is outlined as a magnetic high area.

It has been reported that several gravimeter highs underlie the magnetic high which is located northeast of Newell.

The contours on the top of the Sioux Quartzite in the southern portion of Brule and Aurora Counties have the same westerly trend as the magnetic contours in that area.

There is a large magnetic high north of Wall in eastern Pennington and western Haakon Counties in the locality of Creighton, Quinn, Grindstone, and Phillip. The 600 gamma contour line forms a closure which agrees with the structure defined by the late Dr. Freeman Ward, formerly State Geologist for South Dakota. (7) A small magnetic high in T 10 N, R 14 E, Meade County, almost agrees with a structure in this township mapped by R. A. Wilson. (8) A few more magnetic observations in the locality may or may not show that the magnetic high agrees with the structure.

It is not known whether the earth gets its magnetic field from within or from outer space or from both. The fact that sun spots with the resultant prominances charge the earth's field producing severe and moderate magnetic storms once or twice a month, suggests that a great deal of the energy is derived from above the earth's surface.

It is possible that the secular change in the earth's magnetism causes magnetic highs and lows to move. It is assumed that the North Magnetic Pole is drifting, (9) hence, the entire field is perhaps drifting. With these ideas in mind the writer suggests that if a magnetic high is mapped in a certain township at this time it is possible that it was not in the township in past geologic history. During severe magnetic storms the field increases or decreases as much as 300 gammas in an hour. This suggests that a magnetic high could be a high for days or several years then could be erased completely for a time. Since the magnetic field of the earth is variable many conditions can present themselves.

TABLE 2

WELLS DRILLED TO PRE-CAMBRIAN

Depth to Pre-Cambrian	Gamma	Wells	County
2385	450	Lang No. 1	Stanley
4206	1500	Dakota No. 1	Stanley
2700	870	State School Land #1	Stanley
3880	750	Carter #2	Stanley
3580	500	Carter #1	Potter
522	1400	Parkston	Hutchinson
995	500	Budlong	Spink
1050	800	Motley	Spink
928	720	Wolsey	Beadle
1080	700	Redfield	Spink
1267	300	Aberdeen	Brown
1256	350	Kimball	Brule
900	250	White Lake	Aurora
745	200	Plankinton	Aurora
576	500	Ft. Randall	Charles Mix
500	400	S 25, T 103, R 61	Davison
1025	790	S 18, T 100, R 62	Douglas
937	680	S 26, T 100, R 64	Douglas
842	300	Henneau	Aurora
2370	650	Pierre Airport	Hughes
280	590	S 18, T 102, R 61	Davison
280	550	S 25, T 102, R 62	Davison
312	360	S 17, T 103, R 61	Davison
228	420	S 29, T 104, R 60	Davison
950	550	Lake Andes	Charles Mix
1778	300	Burkhardt	Lyman

In Stanley County there is a large magnetic high which covers a great portion of the county. This high is the largest so far discovered in South Dakota and its crest has never been drilled. Unless there is an extreme condition in the subsurface which causes the high, perhaps a northwest shift in the magnetic field occurred.

The results observed from wells drilled in Stanley County may illustrate the point. The Phillips-Lang No. 1, an oil test well, was drilled in Sec. 26, T 5 N, R 28 E, where pre-Cambrian rock was struck at 408 feet below sea level which is apparently a quartzite ridge. The Phillips-School Land No. 1, in Sec. 36, T 5 N, R 27 E, struck the quartzite at -846 feet, and the Phillips-Dakota No. 1 in Sec. 16, T 6 N, R 27 E, struck pre-Cambrian granite at -2003 feet.

This subsurface picture does not agree at all with the magnetometer map, indeed it is a far cry from what was expected. If it can be assumed that the earth's field has shifted, moving the entire field 14 miles due southeast, it will put the peak of the magnetic high over the Lang No. 1 where shallow pre-Cambrian was encountered and the low in T 8 N, R 25 E, will cover the Dakota No. 1 or the area of deep pre-Cambrian granite. School Land No. 1 Test well, which encountered the quartzite moderately deep, will be on the flank of the magnetic high. Lastly the magnetic low in T 7 N, R 28 E, will be on an area in the Missouri River Valley that is known to be structurally low from surface mapping. However in view of a possible shift of the magnetic field it is unreasonable to assume that the anomalies would retain their original dimensions and magnitude.

The reading on the Needles, which are a high granite mountainous area in the Black Hills is 161 gammas; the average reading in the plains country is 341 gammas above the Needles reading, which is attributed to the sedimentary column. The average earth's vertical magnetic field for South Dakota is .5731 gaus or 57310 gammas for 1935, showing that 341 gammas are a mere murmur with respect to the magnetic field.

MAGNETIC SUSCEPTIBILITIES OF SOUTH DAKOTA BEDROCK

For additional aid in the interpretation of magnetometer results, it is necessary to know the magnetic properties of the rock formations beneath a station. Most rocks although non-magnetic by themselves become magnetized to a certain extent when placed in a magnetic field. In this respect the study of magnetic susceptibilities of South Dakota's rocks was undertaken.

The method used for this purpose was the "Lord Kelvin Balance Method". The apparatus involved was an electrical magnet and an analytical balance.

The left weighing pan suspension was removed and the magnet was placed inside the case on the glass floor of the balance, in such a position that the magnet gap was directly beneath the agate mount of the left end of the balance beam.

Two "Hot Shot" batteries supplied the current and in the circuit with the magnet was a rheostat, ammeter, and a double throw reversing switch.

Each rock sample was pulverized and the powder was packed to refusal into a glass tube to 5 cm. depth. The same tube was used throughout the experiment. The sample was then suspended from the beam into the magnet and weighed to determine the amount of sample; the current was then turned on to 0.25 amperes and the sample was weighed again. A weight was also taken for currents of 0.50, 0.75, and 1.00 amperes; hysteresis was not involved. The relation between current and the field strength is shown by the graph. (Table 3) From these weighings, the susceptibility was calculated by the following equations for each weight:

$$k = \frac{(m_1 - m_2) \cdot 980}{(\text{Area of Cross Section})} \cdot H^2$$

k volume of susceptibility

m_1 weight in grams, current on

m_2 weight in grams, current off

980	$cm.^{g}/ sec.^{2}$, acceleration due to gravity
H	field strength of coil in gaus

$$K = \frac{D}{d} \cdot k$$

D	Density of solid sample
d	Density of powdered sample

It was shown that the susceptibility decreases with increased field strength. Each sample had a lower susceptibility at 1.0 ampere than at 0.25 ampere. The apparatus would not weigh many samples with a current less than 0.25 amperes. If there would have been more space between the beam and the magnet in the balance case, by taking a longer and larger tube, weights could have been made with less current, thereby obtaining higher susceptibilities as less field strength, but not at field strengths as low as that of the earth which is 0.5700 gaus (average for South Dakota). The susceptibilities of various sediments (Figure 5) range from 2.0 to 36.0 x 10^{-6}, those listed by other investigators run as high as 54; of course, these comparisons depend on the field strength in which they were made.

Glacial drift (gumbotil) has susceptibilities that range from 13.0 to 121.0 x 10^{-6}. (Figure 6) Magnetite particles can be picked out of the higher bumbotil samples with a needle.

FIELD STRENGTH OF COIL

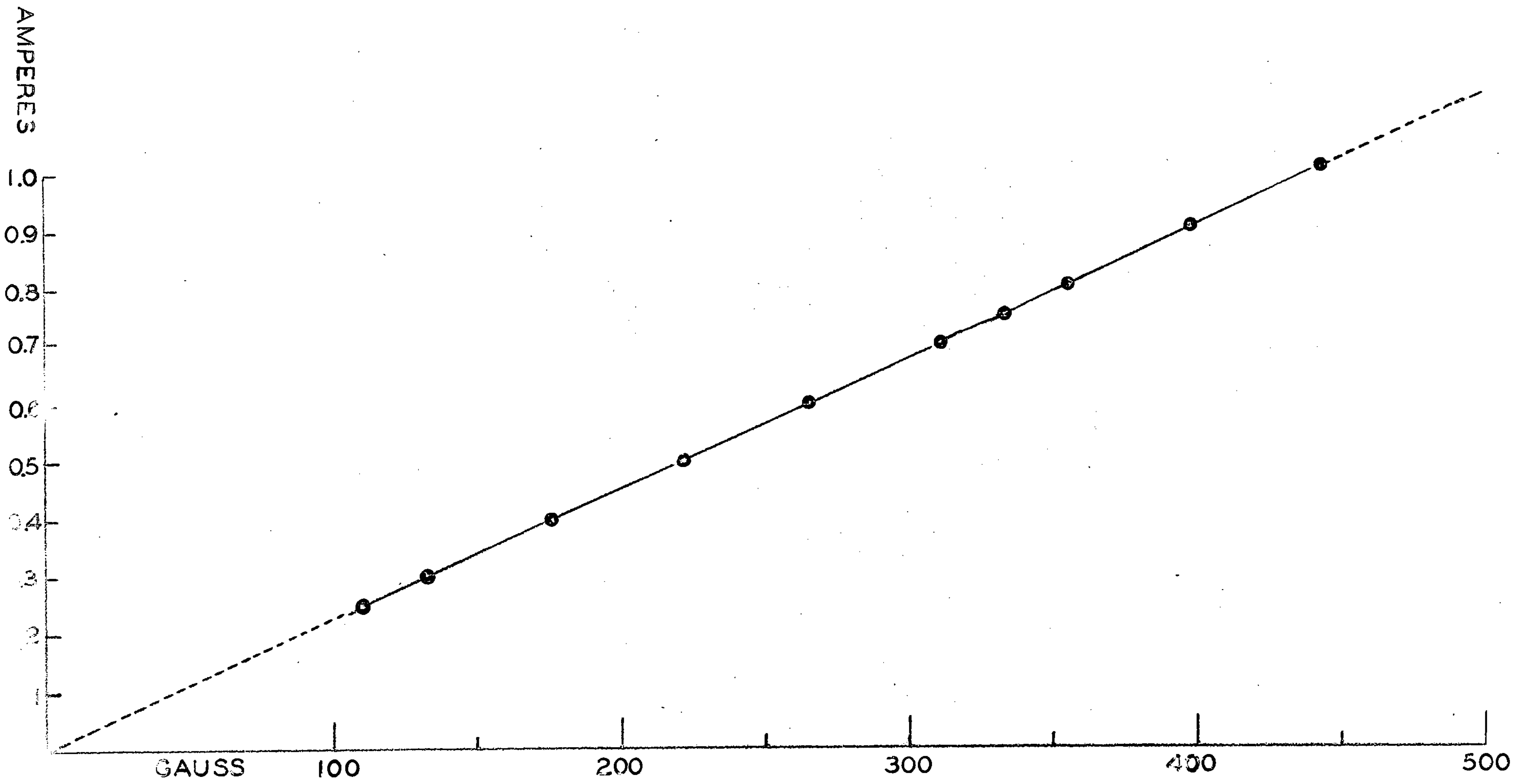


TABLE 3

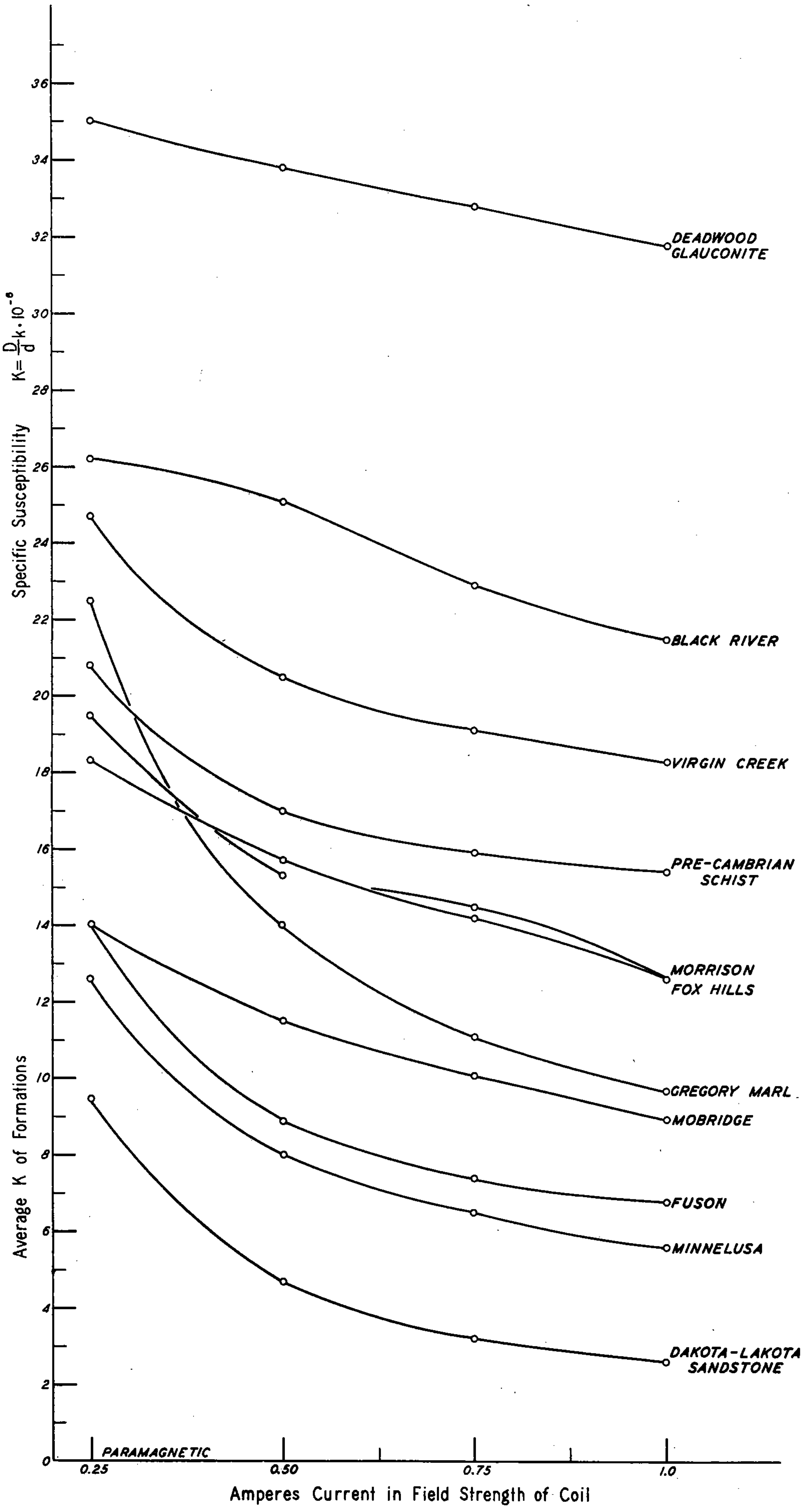


FIGURE 5 GRAPH SHOWING SUSCEPTIBILITIES OF FORMATIONS

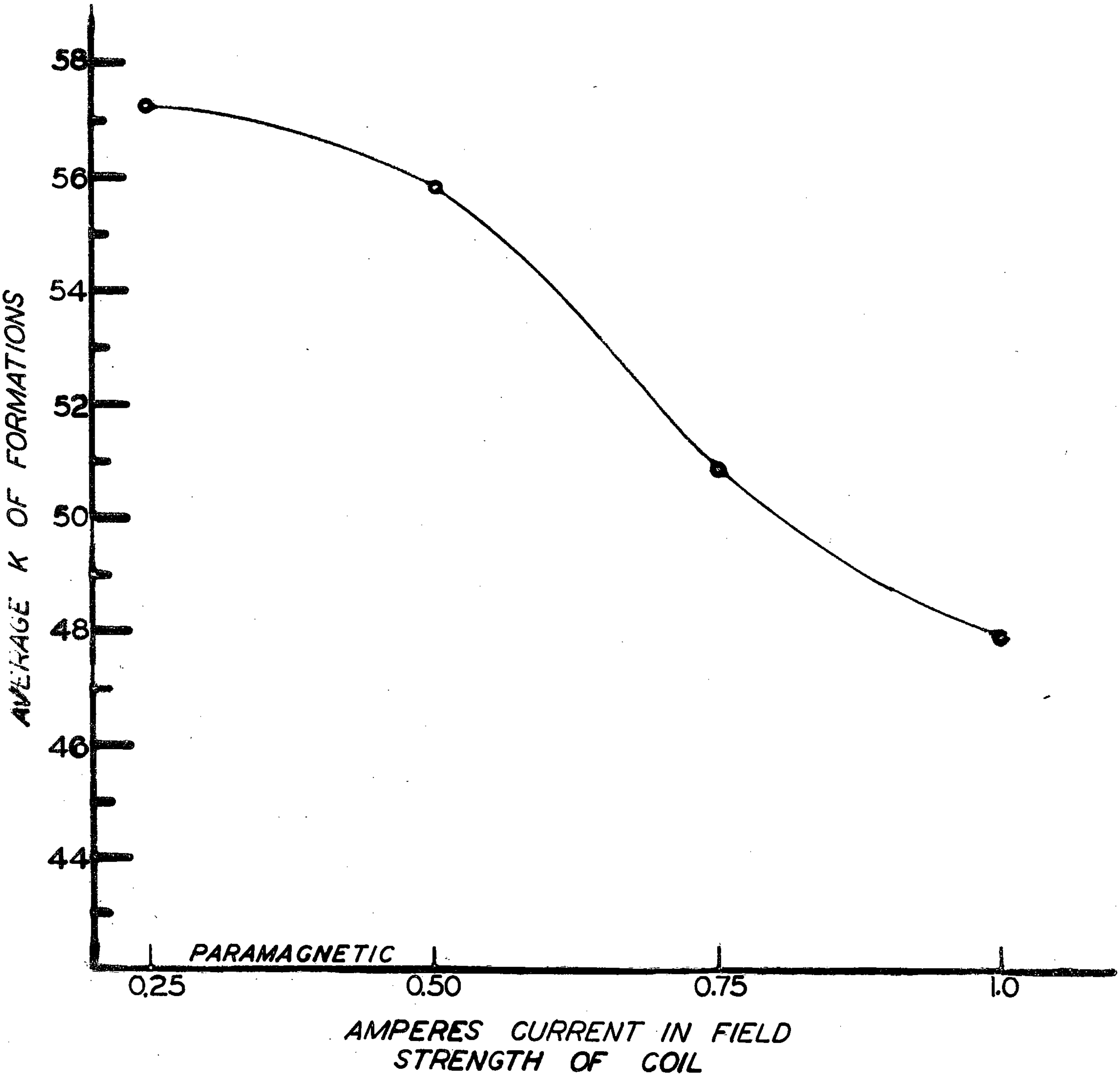


FIGURE 6 GRAPH SHOWING SUSCEPTIBILITY OF GLACIAL DRIFT

PART II: MAGNETIC ANOMALIES IN SOUTH DAKOTA

L. A. Carlson

INTRODUCTION

Location and Size of the Area

The area covered by this report includes the entire state of South Dakota, and small parts of North Dakota, Minnesota, Iowa, and Nebraska, bordering South Dakota.

Purpose of the Report

This investigation was undertaken to outline the larger magnetic anomalies in South Dakota, and to attempt to correlate this information with anomalies mapped by magnetometer surveys of the South Dakota State Geological Survey, and with existing knowledge of the structure and stratigraphy of the state.

Method of Investigation

Data for this investigation was obtained from *United States Magnetic Tables and Magnetic Charts for 1935.* (10)

The values of horizontal intensity were taken directly from the tables. The values of vertical intensity, however, were computed from data given in the tables. Part of the computation was done by the writer and part of it was done a number of years ago by a student at the University of South Dakota, Allison Kalda, whose figures were checked and used by the writer.

Anomalies were determined by the method outlined by Lahee. (11) Lines of normal vertical intensity (10) were drawn on a map of South Dakota. The normal intensity at each station was determined by interpolation between these lines. This value was subtracted from the actual intensity at the station, giving the amount of positive or negative variation from normal. The anomalies thus found were plotted at their proper stations on the map, (Figure 7) and isonomalies (lines of equal anomaly) were drawn, using a contour interval of 100 gamma.

STATE OF SOUTH DAKOTA

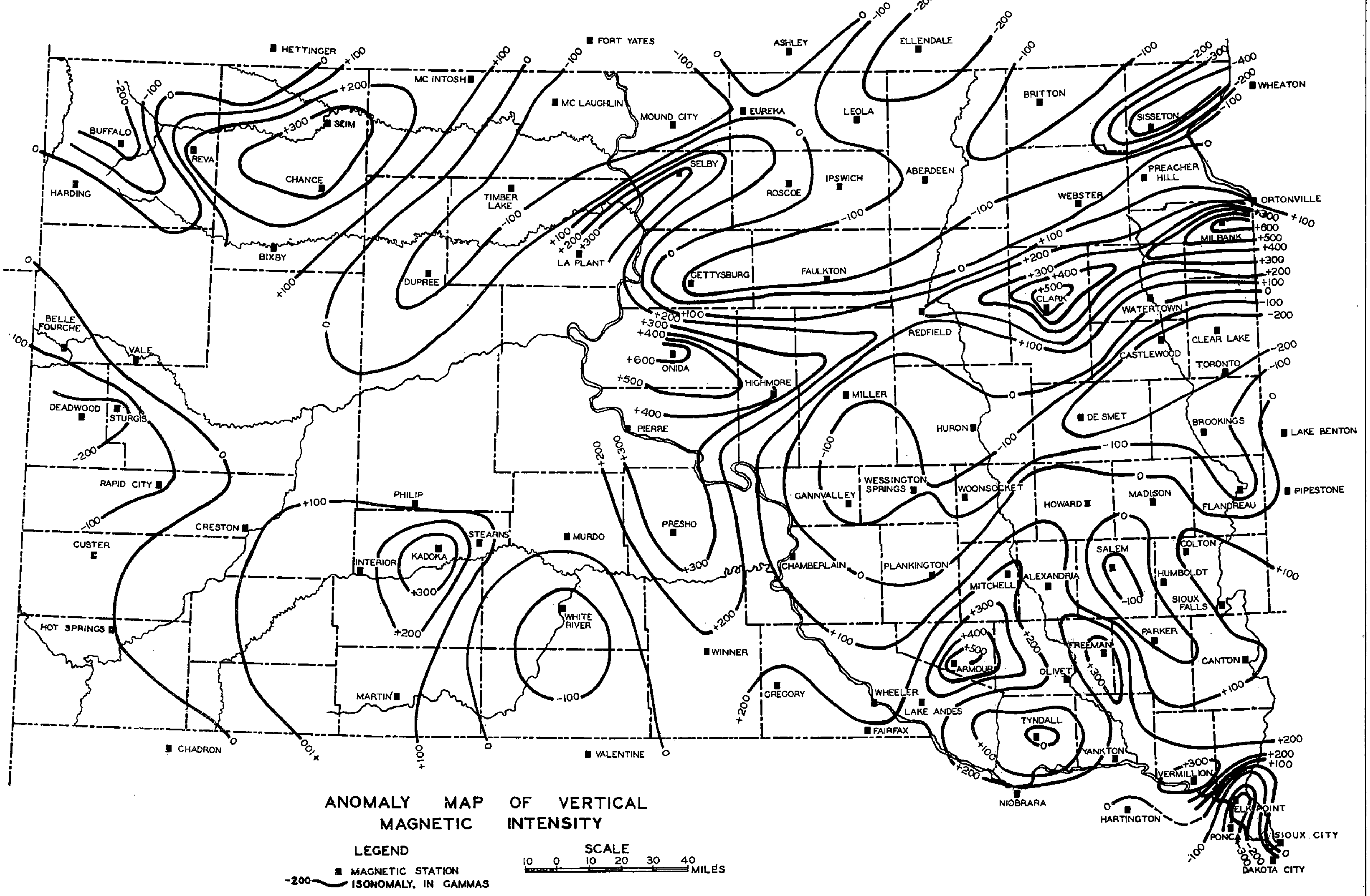
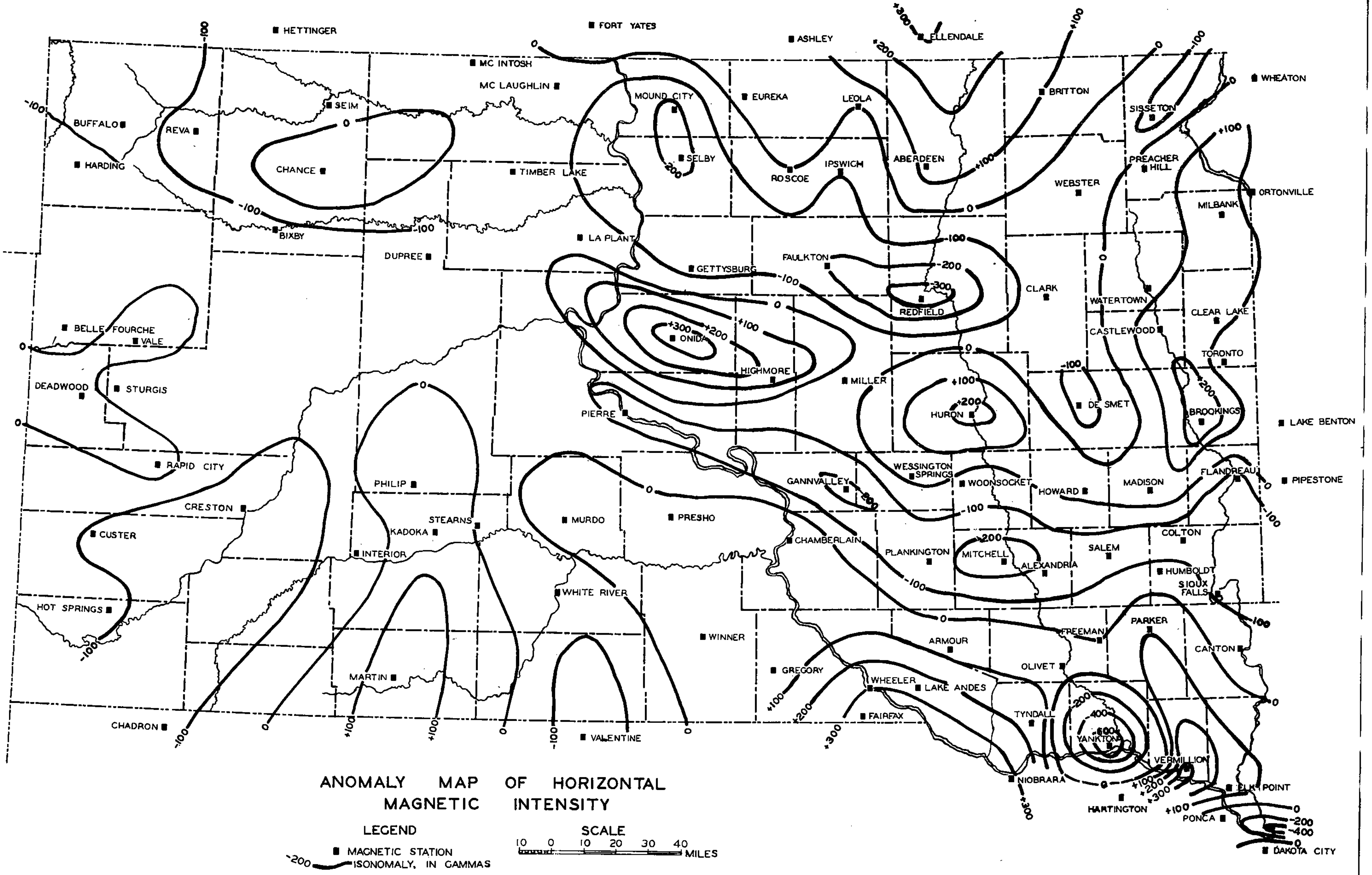


FIGURE 7

STATE OF SOUTH DAKOTA



ANOMALY MAP OF HORIZONTAL MAGNETIC INTENSITY

FIGURE 8

TABLE 4

MAGNETIC INTENSITIES AND ANOMALIES OF UNITED STATES COAST AND GEODETIC SURVEY STATIONS IN SOUTH DAKOTA AND VICINITY

H obs = observed horizontal intensity in gammas
H inter = interpolated horizontal intensity in gammas
△ H = horizontal anomaly in gammas
V obs = observed vertical intensity in gammas
V inter = interpolated vertical intensity in gammas
△ V = vertical anomaly in gammas

Station	H obs	H inter	△H	V obs	V inter	△ V
Elk Point	18130	17970	+ 160	56410	56730	- 320
Vermillion	18290	17980	+ 310	57080	56750	+ 330
Yankton	17150	17920	- 770	57040	56790	+ 250
Tyndall	18150	17970	+ 180	56700	56720	- 20
Fairfax	18490	18140	+ 350	56730	56520	+ 210
Lake Andes	18230	17960	+ 270	56950	56690	+ 260
Martin	18640	18470	+ 170	55980	56860	+ 120
Wheeler	18340	18040	+ 300	56780	56640	+ 140
Olivet	17840	17760	+ 80	57040	56870	+ 170
Gregory	18160	18100	+ 60	56840	56570	+ 270
Canton	17420	17460	- 40	57150	57060	+ 90
Freeman	17610	17610	0	57300	56970	+ 330
Armour	17910	17830	+ 80	57390	56800	+ 590
Winner	18090	18070	+ 20	56740	56560	+ 180
Parker	17610	17510	+ 100	57000	57050	- 50
Hot Springs	18590	18690	- 100	56000	56000	0
Sioux Falls	17190	17290	- 100	56340	56210	+ 130
White River	18080	18120	- 40	56540	56520	+ 20
Humboldt	17330	17310	+ 20	57340	57220	+ 120
Alexandria	17270	17450	- 180	57260	57100	+ 160
Mitchell	17200	17480	- 280	57330	57090	+ 240
Interior	18150	18220	- 70	56590	56400	+ 190
Plankinton	17410	17570	- 160	57000	57000	0
Salem	17190	17340	- 150	57060	57200	- 140
Colton	17040	17180	- 140	57650	57340	+ 310
Custer	18380	18480	- 100	56180	56210	- 30
Chamberlain	17760	17670	+ 90	56960	56920	+ 40
Stearns	17990	18000	- 10	56770	56650	+ 120
Kadoka	18170	18090	+ 80	56990	56570	+ 420
Murdo	17970	17890	+ 80	56760	56750	+ 10
Creston	18070	18240	- 170	56510	56420	+ 90
Presho	17770	17750	+ 20	57160	56840	+ 320
Madison	17140	17060	+ 80	57490	57450	+ 40
Howard	17160	17150	+ 10	57430	57380	+ 50

Station	H obs	H inter	ΔH	V obs	V inter	ΔV
Gann Valley	17310	17530	- 220	56850	57120	- 270
Phillip	18040	17970	+ 70	56750	56660	+ 90
Flandreau	16810	16910	- 100	57420	57560	- 140
Rapid City	18250	18230	+ 20	56330	56440	- 110
Woonsocket	17250	17280	- 30	57130	57260	- 130
Wessington Sgs.	17380	17330	+ 50	57140	57240	- 100
Brookings	17050	16760	+ 290	57550	57710	- 160
Huron	17300	17070	+ 230	57420	57170	- 50
Pierre	17370	17490	- 120	57470	57410	+ 360
De Smet	16750	16890	- 140	57400	57630	- 230
Deadwood	18200	18130	+ 70	56290	56540	- 250
Sturgis	18010	18070	- 60	56370	56580	- 210
Highmore	17400	17210	+ 190	57750	57350	+ 400
Miller	17070	17080	- 10	57320	57420	- 100
Toronto	16530	16510	+ 20	57700	57900	- 200
Vale	17950	17910	+ 40	57100	56730	+ 370
Belle Fourche	17880	17940	- 60	56650	56700	- 50
Onida	17580	17210	+ 370	58040	57340	+ 700
Castlewood	16700	16520	+ 180	57720	57960	- 240
Clear Lake	16560	16420	+ 140	57810	58020	- 210
Redfield	16390	16740	- 350	57850	57720	+ 130
"	16250	16740	- 490	57740	57720	+ 20
Clark	16520	16560	- 40	58570	57970	+ 600
Watertown	16480	16410	+ 70	58110	58030	+ 80
Gettysburg	16830	16960	- 130	57360	57540	- 180
Faulkton	16560	16760	- 200	57560	57700	- 140
Dupree	17050	17200	- 150	57130	57280	- 150
Bixby	17240	17360	- 120	57340	57170	+ 170
LaPlant	16940	16990	- 50	57920	57510	+ 410
Milbank	16210	16060	+ 150	58910	58220	+ 690
Webster	16110	16160	- 50	58090	58150	- 60
Harding	17300	17360	- 60	57110	57080	+ 30
Chance	17180	17110	+ 70	57690	57360	+ 330
Timber Lake	16740	16800	- 60	57430	57600	- 170
Roscoe	16460	16460	0	57910	57900	+ 10
Ipswich	16300	16390	- 90	57920	57940	- 20
Aberdeen	16460	16260	+ 200	57910	58050	- 140
"	16380	16260	+ 120	58140	58050	+ 90
Preacher Hill	16080	16000	+ 80	58310	58240	+ 70
Selby	16360	16560	- 200	58140	57830	+ 310
Reva	17090	17140	- 50	57510	57300	+ 210
Buffalo	16970	17150	- 180	57040	57250	- 210
Sisseton	15700	15800	- 100	57910	58330	- 420
Leola	16140	16140	0	57930	58090	- 160
Mound City	16190	16400	- 210	57530	57930	- 400
Seim	16820	16860	- 40	57950	57540	+ 410
Eureka	16270	17250	+ 20	58010	58040	- 30
Britton	15940	15840	+ 100	58330	58330	0
McLaughlin	16390	16440	- 50	57720	57870	- 150
McIntosh	16430	16480	- 50	57930	57820	+ 110

Minnesota						
Pipestone	17040	16840	+ 200	56740	57600	+ 40
Lake Benton	16350	16650	- 300	56830	56770	+ 60
Ortonville	15960	15960	0	58340	58280	+ 60
Wheaton	15640	15590	+ 50	58370	58470	- 100
North Dakota						
Ellendale	16090	15790	+ 300	58010	58300	- 290
Ashley	16040	15960	+ 80	58290	58160	+ 130
Fort Yates	16300	16200	+ 100	57980	58080	- 100
Hettinger	16710	16700	+ 10	57320	57650	- 330
Nebraska						
Chadron	18820	18940	- 120	55860	55710	+ 150
Valentine	18330	18510	- 180	56080	56150	- 70
Niobrara	18520	18160	+ 360	56770	56550	+ 220
Hartington	18410	18110	+ 300	56540	56610	- 70
Ponca	18040	18090	- 50	56350	56650	- 300
Dakota City	18400	18080	+ 320	56510	56630	- 120
Iowa						
Sioux City	17660	18120	- 460	56750	56660	+ 90

The same procedure was used to obtain a map of horizontal anomalies. (Figure 8)

Actual intensities, interpolated normal intensities, and anomalies for each station are given in Table 4.

SUMMARY AND CONCLUSIONS

The anomaly map of vertical intensity agrees fairly well with results obtained on the magnetometer surveys described earlier in this report, and indicates the types of anomalies to be expected in future magnetometer work.

Vertical and horizontal anomalies, with some exceptions, tend to be both positive or both negative in any given area.

Some of the anomalies appear to be reflections of structural conditions, but most appear to be caused by the stratigraphy and surface or near surface lithology of the area of observation.

THEORETICAL DISCUSSION

Figure 9 is a vector diagram of the earth's magnetic field for the northern hemisphere.

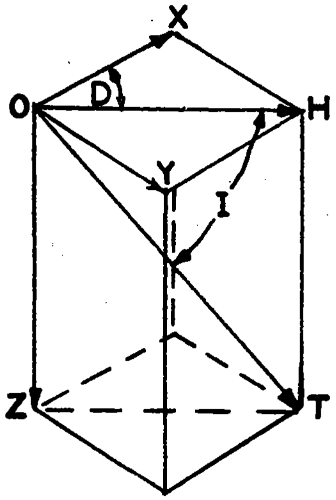


Figure 9. (after Heiland) (12)

The total magnetic intensity T at the point O may be resolved into two components: a vertical vector Z and a horizontal vector H. The angle I is the inclination and the angle D is the declination. The horizontal vector H may be further resolved into two components: a north-south vector X and an east-west vector Y. The trigonometric relationship of Z and H is given by the equation Z = (H) x (tan I).

This report is concerned with the variation from normal of the vertical component Z and the horizontal component H.

The vertical intensity varies from zero at the magnetic equator to a maximum over the poles. The horizontal intensity varies from a maximum over a magnetic equator to zero over the poles. Thus there is a planetary variation of magnetic intensity. Relatively local conditions, such as the structure, stratigraphy, or lithology of the area of observation, may cause further variation.

INTERPRETATION

Correlation of Vertical Anomaly Map with Magnetometer Work

The anomaly map of vertical intensity (Figure 7) agrees quite well with the map compiled from magnetometer surveys through 1946, (See map in pocket) considering that the map of the magnetometer work is based on stations six miles apart and the map of this report is based on stations twenty to fifty miles apart.

Most high and low areas agree. Highs which appear on both maps are the Oneida high, the series of highs along a line including Milbank, Clark, and Redfield, and the Kennebec high. The Vermillion and the Armour highs are present on both, but are differently located.

Lows which appear on both maps are the Ellendale-Leola low, the Wessington Springs-Gann Valley low, and the Black Hills low.

It map be assumed from the agreement of these two maps that the anomaly map of vertical intensity indicates the general type of magnetic anomalies present in areas of the state which have not yet been covered by magnetometer surveys.

Correlation of Vertical Anomalies with Horizontal Anomalies

The vertical and horizontal anomalies tend to be both positive (high), or both negative (low), in any given area. Examples are the Kadoka high, the Oneida high, the Chance high, the Black Hills low, the Jefferson low, the Sisseton low, and the White River low. There are exceptions, however; for example, north of Aberdeen and in the Wessington Springs-Huron areas, the vertical anomalies are low and the horizontal anomalies are high.

The horizontal anomalies appear to be smaller than the vertical anomalies. However, when one considers that in South Dakota the normal horizontal intensity is roughly 15,000 to 17,000 gammas, and the normal vertical intensity is roughly 56,000 to 58,000 gammas, it is apparent that a 100 gamma horizontal anomaly is about equivalent to a 350 vertical anomaly.

Correlation of Anomalies with Structure and Stratigraphy

Magnetic anomalies are caused by the presence or absence of magnetic minerals in the rocks of the area under observation. Hence quantitative structural and stratigraphic interpretation of magnetic data requires knowledge of the magnetic properties of the rocks involved. (12 p. 293-318; 377-456)

The maps suggest that the sedimentary rocks in the state are, on the whole, more strongly magnetic than the igneous. The Black Hills area is low, while the Chance-Seim in the Dakota basin, is high.

At Milbank, where the Milbank granite is over 300 feet deep, the vertical intensity is 690 gammas above normal, while at Ortonville, Minnesota, where the granite is at or near the surface, the vertical intensity is only 60 gammas above normal. This may be due to a concentration of magnetic minerals in the granite near Milbank; a more probable explanation is that the anomaly at Milbank is due to the magnetic properties of the glacial drift, or of the underlying Cretaceous sediments. If one accepts the latter explanation, one may assume that the Milbank granite has little effect on the magnetic intensity in this corner of the state.

Assuming that the anomalies are due to magnetic sedimentary beds, one may interpret the data in several ways. (13) Maximums and minimums will be found where the magnetic bed is near the surface in the crests of anticlines, and minimums will be found in the troughs of synclines. If the magnetic bed has been eroded from the crest of the anticline, the minimum may be found on the crest, and the maximum on the flank, while the anomaly in the trough of the adjacent syncline will be intermediate in value.

Stratigraphic maximums will occur where the magnetic bed is thickest, and minimums where the bed pinches out, or thins over buried relief.

The Sioux Quartzite ridge does not appear on the vertical anomaly map. The long low on the horizontal anomaly map, extending from the eastern border of the state near Sioux Falls to Pierre, may be due to it.

According to C. L. Baker (14) there is a structural high in the Badlands area. The Kadoka magnetic high may be a reflection of this. This might be a case of a magnetic high being caused by the magnetic bed being closer to the surface in the crest of an anticline.

The Perkins county high coincides quite closely with the area of outcrop of the Ludlow formation, while the McLaughlin-Timber Lake-Dupree vertical low coincides closely with the area of outcrop of the Fox Hills formation. Several interpretations are possible here. One is that the Chance high is due to a thickening of the magnetic beds, basinward. The more probable, since the high and low coincide with the outcrop areas of certain formations, is that the anomalies here are controlled by the magnetic properties of the outcropping formation, or formations relatively near the surface.

There are no magnetic stations in a large area in the west central part of the state; hence this area could not be adequately contoured.

It is obvious that, due to the relatively great distances between stations, the anomaly maps give only a very generalized picture of magnetic conditions in the state.

FOOTNOTES

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