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State of South Dakota

Harlan J. Bushfield, Governor

STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

NO. 42

MAGNETOMETER SURVEYS

DURING 1941

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by

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Vermillion, S. Dak.
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MAGNETOMETER SURVEYS
DURING 1941

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Professor of Geology
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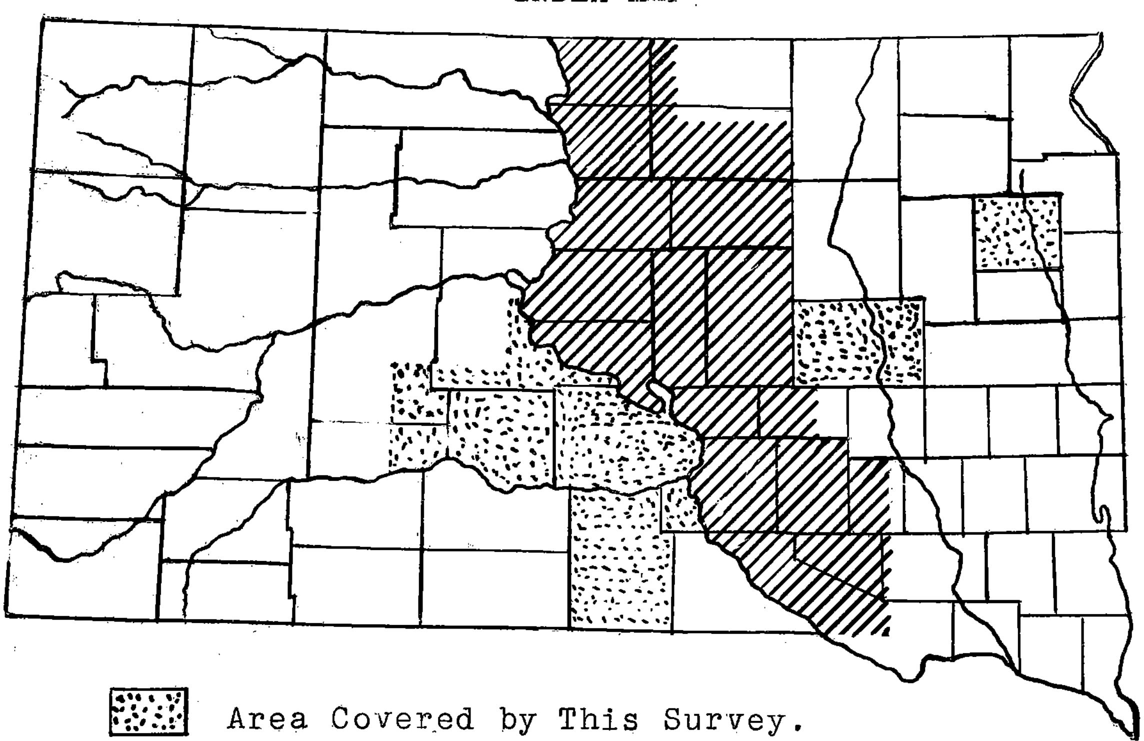
INDEX MAP



Area Covered by This Survey.

Area Covered by Previous Surveys.

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INTRODUCTION

Purpose and Area

In order that our national reserves of oil may not be exhausted within one or two decades, it is necessary that the search for new fields be ceaseless. Much of the state of South Dakota falls within an area that is now being intensively prospected by a number of oil companies, although no oil is produced from the area on a commercial scale. The geologic search for oil east of the Missouri River is handicapped by a covering of glacial drift which hides bedrock outcrops that might serve as clues to structures that may contain oil. In a large area lying between the Missouri River and the Black Hills the rock outcrops are poor except along the Missouri and its tributaries, although no glacial mantle is present. For these reasons geophysical work has been undertaken as an aid to geological interpretation.

In the geophysical methods the variations in readings of instruments operated at the surface of the ground result from variations in the deeply buried rock formations. It is possible to interpret the readings in terms of geologic structures that might control the accumulation of oil. The geophysical methods in general do not locate oil directly but rather aid in finding the rock structures in which oil is likely to be localized, if it is present at all. Some geophysical measurements locate rock structures and determine the depths to certain formations rather accurately, as in the case of the seismic methods. Such work is slow and costly. Other methods are less expensive and may be used to cover large areas rapidly, but give only a very general idea of the larger features of the geologic structure. Such is the case with the magnetic methods that have been adopted by the State Geological Survey for the purpose outlining the large regional geologic trends. The results of surveys with the magnetometer should not be used to locate drilling sites, but rather may guide the intelligent prospector to areas that deserve further investigation with more accurate, but more expensive methods.

The survey during 1941 is a continuation of those made by Jordan (Jordan and Rothrock, 1940a, 1940b)*

* References in parentheses are to papers listed in the bibliography at the end of the report.

projected survey of the entire state. In the eastern part of the state, Codington County and the eastern three-quarters of Beadle County, not already covered by Jordan, were surveyed. West of the Missouri River a considerable area south and southwest of Pierre, as far south as the Nebraska line, was covered, including all of Jones, the largest part of Lyman not surveyed by Jordan, nearly all of Tripp, more than half of Stanley in the east and south, the southeastern part of Haakon, and the eastern third of Jackson counties. This region is believed to be of particular interest because much of it has been less intensively surveyed by the oil companies than have areas to the north. The purposes of covering this region were to investigate the possible westward extension of the pre-Cambrian ridge, traced by Jordan (Jordan and Rothrock, 1940a, p. 11) to the vicinity of Chamberlain, and to outline conditions about the southeast margin of the Lemmon geosyncline, which is the important basin of west-central South Dakota (Tulsa Geological Society, 1941).

The months of July and August, 1941, were spent in the field. Of this time, 7 working days were needed in Codington County, 6 in Beadle County, and the remainder in the area west of the Missouri River. A total of 190 townships, or about 6,850 square miles were covered. Eight new base stations and 237 new magnetometer stations were occupied, in addition to checks at a number of stations established by Jordan.

Acknowledgments

The magnetometer that was used as the base instrument was borrowed from the Carter Oil Company. The privilege of using it is gratefully acknowledged, because without it only a much smaller area could have been covered. Thanks are due the land owners who granted permission to set up base stations. In many cases the interest and courtesies extended beyond mere use of the land. Mr. Andrew Betts, a student at the South Dakota School of Mines, operated the base instrument and did the daily computation of results. To his care in operating the instrument and his willingness to make the extra efforts required to keep the work progressing efficiently, much of the success of the survey is due. The writer is grateful to Dr. E. P. Rothrock for his aid in laying out the general plans of the surveys and for discussions concerning the geologic significance of the results.

THEORY AND PRACTICE OF MAGNETOMETER SURVEYS

The Earth's Magnetic Field

The theory of magnetic surveys has been covered in detail in earlier reports (Jordan and Rothrock, 1940a, p. 3-4; 1940b, p. 4), but may be briefly reviewed here. It is well known that the earth itself is a magnet or at least seems to contain a large magnet. The region around any magnet is known as its magnetic field. A magnetic field is characterized by magnetic lines of force, which define the strength and direction of the magnetic field at any particular place within the field. The stronger a magnet is, the greater is the number of lines of force issuing from it. At any place within the field of a magnet the strength of the field, or its intensity, is dependent upon the number of magnetic lines passing through a unit cross-section area; the greater the number of lines of force, the greater is the strength of the field at that place. The direction of the lines of force at a particular place define the direction of the magnetic field. In a magnetic field the direction of the lines of force may be observed by means of a freely suspended magnetized needle. Such a needle will assume a position parallel to the lines of force. In South Dakota the magnetic lines of force have a direction between 10 and 15 degrees east of north (declination) and are inclined downward to the north (inclination) at angles between 71 and 74 degrees from the horizontal.

Magnetic lines of force pass through any substance placed in a magnetic field. Certain substances when placed in a field are said to be more magnetic than some other substances. For example, iron is more magnetic than wood. This is explained by saying that the lines of force pass through the iron more readily than the wood, and so the lines of force are concentrated in the iron in greater number than in the wood. The iron is said to have higher magnetic permeability. If a magnetic substance such as iron, is placed in air in a magnetic field, lines of force are crowded from the air into the iron, as shown in Figure 1. It is to be noted that in moving along the direction of the lines of force and approaching the magnetic body, the magnetic lines of force become more crowded, that is the magnetic intensity, as measured in the air, becomes greater as the iron is approached.

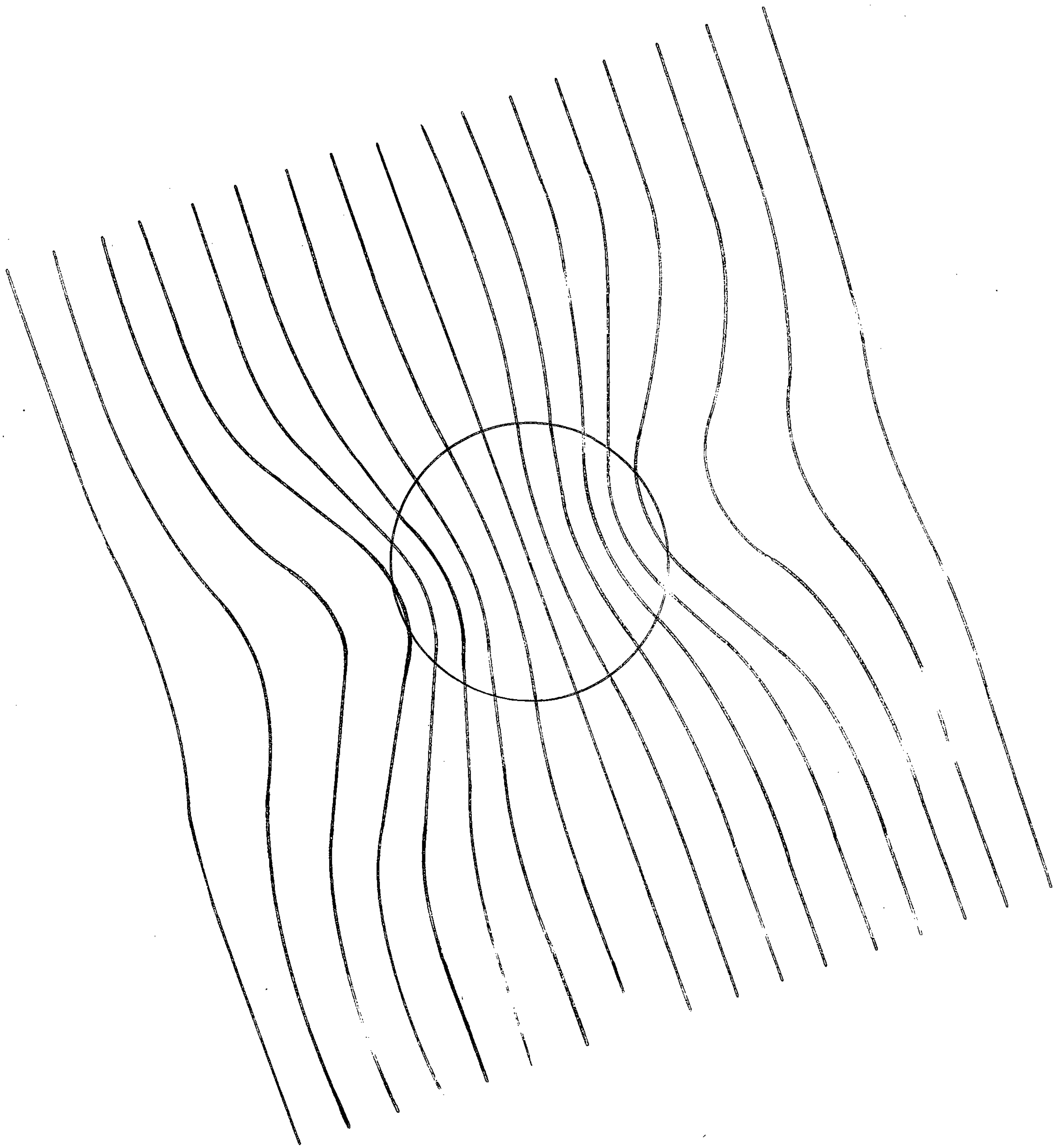


FIGURE 1. Distortion of Magnetic Field by Sphere of Magnetic Material.

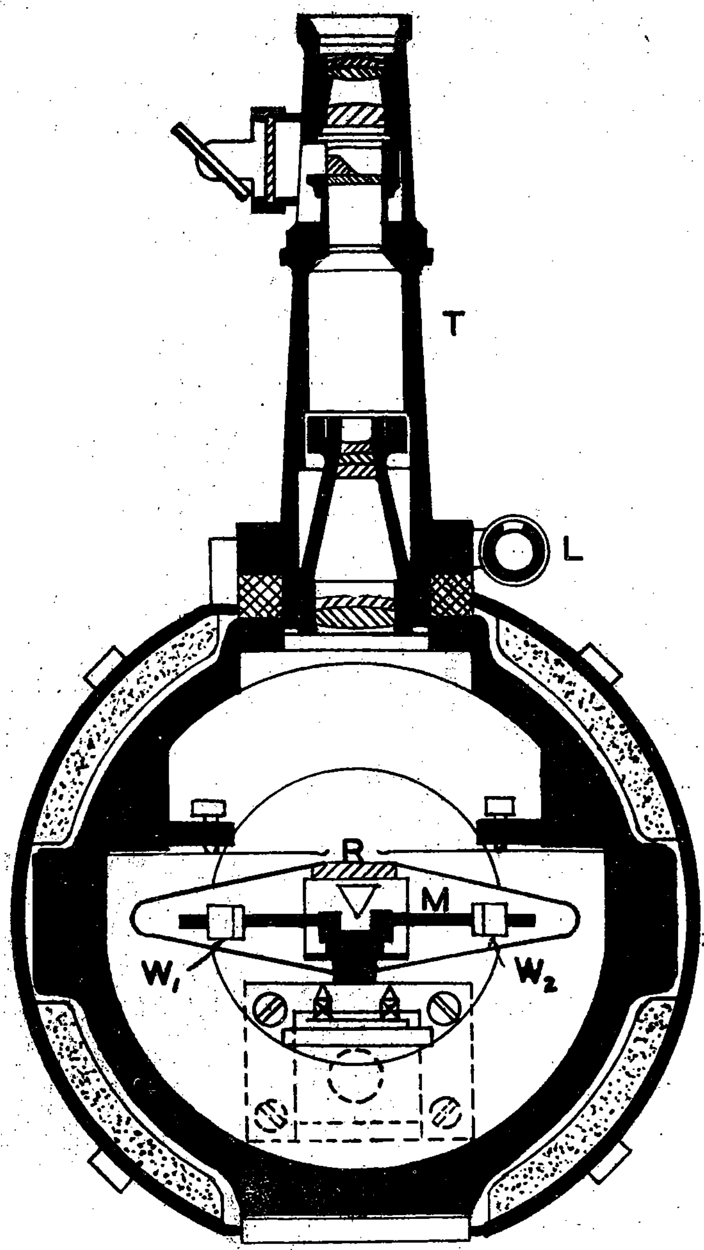
In a like manner different rock formations have different magnetic permeabilities because of the variation in content of magnetic iron compounds in the formations. Immediately beneath the surface of much of the state (or immediately beneath the glacial drift in the eastern part of the state) are sedimentary rocks with relatively low magnetic permeability. The thickness of these rocks varies from zero to several thousand feet. Below the sedimentary rocks are igneous and metamorphic rocks which are of pre-Cambrian age and which have somewhat higher magnetic permeability. Where these rocks of high permeability are less deeply buried; that is, where they are closer to the surface, the magnetic intensity measured at the surface of the ground should be higher, because the lines of force crowd more closely together at points nearer such rocks. These are the fundamentals by which magnetic surveys for geologic purposes are justified. More detailed geologic interpretation requires modification of these fundamentals, as will be seen in the last chapter of this report.

Construction of the Magnetometer

The intensity of the earth's magnetic field is measured at the earth's surface by means of an instrument known as the magnetometer. Since the lines of force are inclined the measurement of the total intensity at any point should be by means of an instrument which can measure intensities in the direction of that inclination. Practically, field instruments are constructed to measure either the horizontal or vertical component of the intensity. Since the vertical component has the more direct relationship to the form of the surface of the pre-Cambrian rocks, only that component has been measured by the State Geological Survey. The instrument used is known as a vertical magnetometer and has been described in detail in an earlier report (Jordan and Rothrock, 1940a, p. 5.)

The essential part of the instrument (Figure 2 and Plate I) is a pair of parallel magnets rigidly attached to a block and carrying knife edges. This magnetic system may be clamped during transportation, but at a station is lowered onto a pair of quartz bearings, oscillates briefly, and comes to rest. If not counterbalanced, the magnetic system would align itself with the lines of force of the earth's field. However, by means of counterweights, shown in Figure 2, the system has previously been adjusted so that it always comes to rest in a nearly horizontal position. The gravitational pull on the counterweights is

SECTIONAL DRAWING
OF
VERTICAL FIELD BALANCE



LEGEND

M- MAGNETS
R - PLANE MIRROR
W_1-COUNTERWEIGHT
L - LEVEL
T - TELESCOPE
W_2- COUNTER-WEIGHT

FIGURE 2

opposed to the magnetic attraction of the earth's field. This gravitational pull is practically constant, while the magnetic attraction varies depending upon the kind of rocks beneath a station, or upon the depth to a magnetic formation that is everywhere present, but at variable depth at different places. At points where the magnetic intensity is highest, the dip of the magnetic system becomes steepest. Its inclination is observed by a telescope attached to the top of the instrument (Figure 2).

Both magnetometers used in the survey were balances of the Schmidt type. The field instrument (Plate I) was of the type in which either a vertical or horizontal magnetic system may be used, but in this case was fitted with the vertical system (Fig. 2). The scale constant, determined in Vermillion with a large coil constructed by Dr. Jordan, was found to be 10.5 gamma. The gamma is the unit of magnetic intensity and is 1/100,000 of an oersted, or about 1/57,000 of the total vertical field in South Dakota. To determine the relative magnetic intensity at a point, the reading of the magnetometer in scale divisions is multiplied by the scale constant. The base instrument (Plate I) had the old type case, but was fitted with a temperature-compensated magnetic system. The latitude screw was set in Vermillion, and the scale constant adjusted to 23.4 gamma.

Magnetic Maps

The results of magnetic surveys may be shown in various ways (Joyce, 1937, p. 107-111) but one of the easiest ways is by means of isodynamic contour maps. The magnetic intensity at each field station is first plotted on a map. Then, with reference to these station values, lines of equal magnetic intensity, known as isogams (Nettleton, 1940, p. 163), are drawn on the map, much as contour lines would be drawn on a topographic map. Magnetic maps giving the results of the present survey are shown as Figures 7 and 8 and a large map at the end of the report. Discussion of the geologic significance of the maps is given in a later chapter. A map showing the combined results of all work done by the State Geological Survey to date is shown as Figure 3.

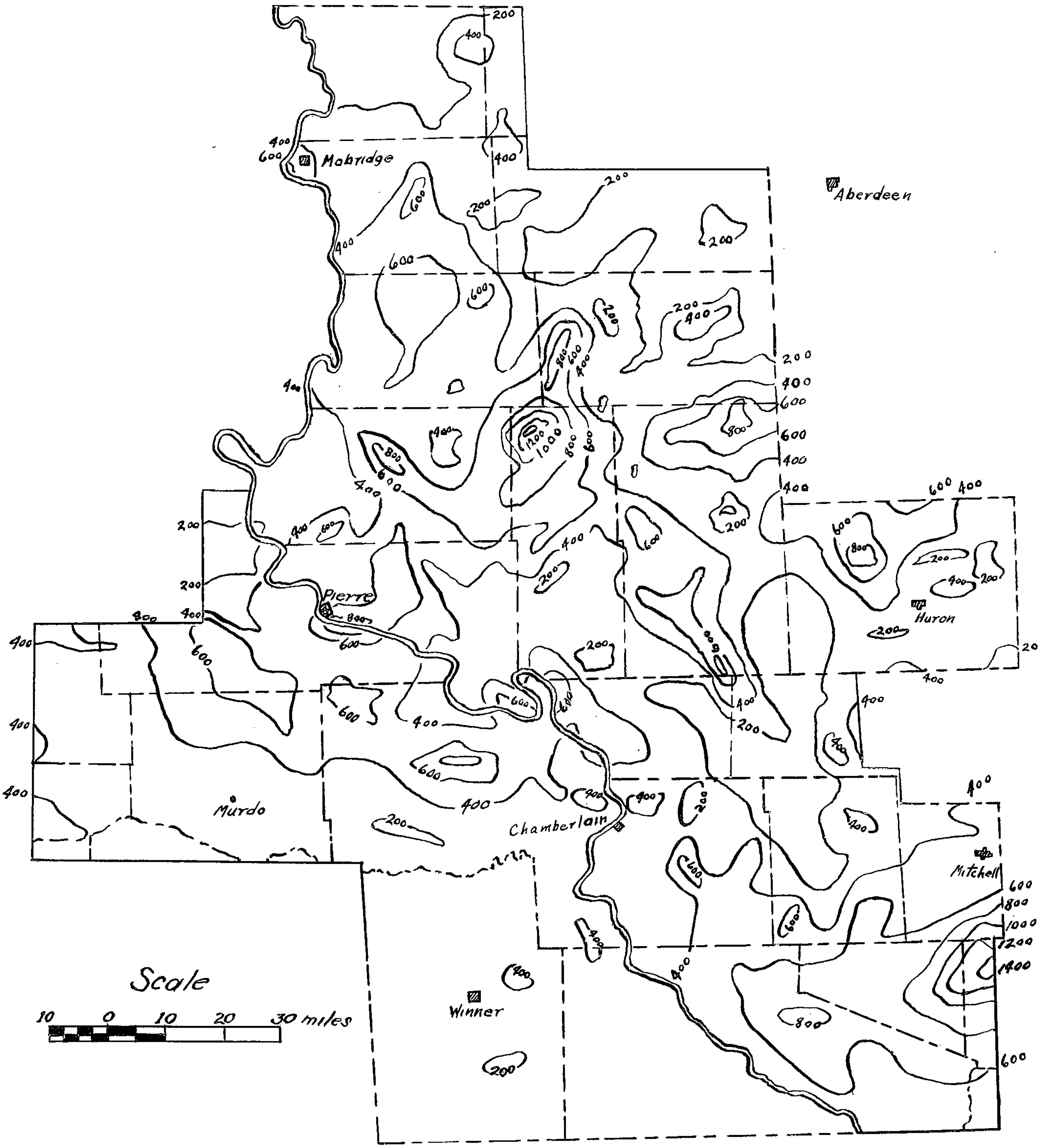


Figure 3. Magnetic Map of Magnetometer Surveys of 1939, 1940, and 1941 Combined.

Procedure

General:

Two field methods of magnetic surveys have been described in detail in the reports of earlier work, and need not be covered at length here. One method (Jordan and Rothrock, 1940a, p. 6-9) is used when only one instrument is available. The instrument is read at a station the magnetic intensity of which is known, or to which an arbitrary value has been assigned. Next the instrument is read at a second station, and then is returned for a reading at the first station. During the time that has elapsed the magnetic intensity as read at the first station has changed, because the value of the magnetic field slowly and continuously changes. However, the change is practically constant over considerable areas. By plotting the readings against time in a manner described in the earlier report, the value read at the second station is corrected for the change that has occurred. In a similar manner the value of a third station may be found relative to either the first or the second station, or both, and so on. The stations are laid out in a network that has a rude corrdinate pattern, and each station is tied by magnetic readings as described, to the four stations that are closest to it in the coordinate system. Because of the necessity of revisiting a given station so many times, the method is slow, but is used when only one instrument is available.

The method used during the summer of 1940 (Jordan and Rothrock, 1940b, p. 9) and during the present survey, is possible only with two or more instruments. A base station is established and one of the instruments is set up near the base and read at intervals of 10 or 15 minutes. From these readings a curve of the variation of the earth's magnetic field is plotted (Fig. 4). The other instrument is first read at the base station and then read at the various field stations located in a grid or network about the base station and within convenient driving distances The values at the field stations are corrected by reference to the curve of readings of the instrument left near the base. When this method is used it is not necessary to tie each field station directly to its neighboring field stations, but only to tie it to the base station. Thus much time is saved. After all of the area about a base station has been surveyed, another base is established and tied magnetically to the first base. The survey progresses by establishing a number of such bases, and covering the area about each.

As in the earlier work, the field stations were spaced about 6 miles apart. Such spacing is sufficiently close to discover all of the regional magnetic anomalies. Base stations are about 30 miles apart. After a base has been established all of the field stations are marked on a road map before any are occupied. The county maps of the State Highway Commission are useful for this purpose. Stations are chosen first along main highways, next along secondary roads, and finally at other points accessible by poorer roads so as to fill in the grid with stations from 4 to 7 miles apart, generally 6, if possible. The number of new stations established per working day averaged 7, including days in which few or no stations were set because of location and tying of bases and checking of old stations. The largest number established in one day was 14.

Tables showing the manner of recording and calculating results have been given and explained in earlier reports (Jordan and Rothrock, 1940a, p. 7-9; 1940b, p. 7-15). The corrections applied also were described, but will be reviewed briefly in the following paragraphs with particular reference to the present survey.

Corrections

Daily Variation: The manner of correcting for daily variation of the earth's magnetic field, using a base instrument, has been described in the preceding section on general procedure. The field magnetometer is returned to the base station and read at noon and in the evening, as well as in the morning before starting work. This return to the base is necessary in order to compare the readings of field and base instruments, so that the readings of the field instrument may be corrected for daily variation.

Checking-in: It would be expected if the base instrument read 45 gamma less at noon than it did in the morning, for example, that the readings of the field instrument as taken at the base in the morning and at noon would vary by the same amount. Actually the changes in readings of the two instruments usually differ by a small amount, called by Jordan (Jordan and Rothrock, 1940b, p. 9, 11-13, Fig. 3) the "checking-in" error. This error is distributed linearly with time in a manner described by him. The average checking-in error during the present survey was 14 gamma, and in one apparently normal case was as high as 37 gamma. The latter figure seems too

Temperature: The temperature coefficients of the magnetic systems used were not large enough to be of importance. However, the temperature was recorded for each observation.

Auxiliary magnet: If at a given station the magnetic intensity has increased or decreased to the point where it appears that the scale of the instrument will disappear from the field of view at the next station, an auxiliary magnet is inserted in the proper place beneath the head of the tripod so as to bring the scale back to or beyond the center of the field of view. Two readings are taken, one without the magnet and one with it inserted. The difference in the readings is a correction to be applied to the future stations at which the scale would be off the field of view of the auxiliary magnet were not used. When another station is reached at which it is apparent that readings again can be obtained without the magnet, another pair of readings, with and without the magnet, are taken. The correction obtained by this set of readings generally is slightly different than the correction obtained when the magnet was inserted. The difference in corrections is an error believed due to the temperature coefficient of the auxiliary magnet and is distributed linearly with time.

When the instruments were adjusted at Vermillion, the latitude screws were not correctly adjusted for the in tensity increase in going northward to Codington County. For this reason the scales of both field and base instruments were just off the field of view for most points in the county. Rather than take the time to return to Vermillion to readjust the instruments the survey was undertaken with all possible precautions. The base was established at a place where it was not necessary to use auxiliary magnets to secure readings, but at most of the field stations the auxiliary magnet was needed. This is an undesirable procedure because the auxiliary magnet has a temperature coefficient that cannot be eliminated. Since it was early in the summer and temperature changes were not great it is believed that the errors are not serious, particularly in relation to the large anomalies in that area. No such difficulty was encountered in the other areas surveyed.

high, but reoccupation of stations taken at times of large corrections gives values that satisfactorily check within a few gamma. In three cases checking-in errors, considerably larger than the high figure given, required that the work be repeated. The causes were found in all three cases. Moderate to large checking-in errors have been attributed to temperature changes (Jordan and Rothrock, 1940b, p. 9) in the base instrument. In the present survey both base and field instruments had temperature-compensated systems, but the size of the checking-in error has been analyzed with respect to temperature changes in both instruments, with the thought that undetected temperature coefficients might exist. However, no correlation has been found. Whatever the cause of the checking-in error, it seems to operate systematically, because in most cases it has a direction such as to decrease the amount of the daily variation correction. In only 12 per cent of the graphs constructed did the checking-in error operate to increase the size of the daily variation correction.

It was hoped to save time by eliminating the noon check-in, but because of the checking-in error this was found infeasible. Recalculation of a typical set of daily observations, as though the noon check-in had been omitted, showed that too large errors would result in the stations occupied just before noon. In the particular case studied the maximum error was 15 gamma for the last morning station.

Latitude and longitude: In South Dakota the intensity of the vertical component of the earth's magnetic field increases toward the north-northeast because the intensity is highest at the north magnetic pole. In order to show the magnetic variations that are caused by geologic features, it is necessary to eliminate this natural northeastward increase. This is done by subtracting a certain magnetic value for every mile that a station lies north of the base station (latitude correction) and by subtracting another smaller magnetic value for every mile that a station lies east of the base station (longitude correction) or by adding in the case of a station west or south of the base. The correction to be applied may be calculated from charts of the U. S. Coast and Geodetic Survey (Howe and Knapp, 1938, map 4). The values used are as follows: Codington County, latitude correction 7.0 gamma, longitude correction 2.8 gamma; Beadle County, latitude correction 9.0 gamma, longitude correction 3.1 gamma; area west of the Missouri River, latitude correction 9.0 gamma, longitude correction, 3.2 gamma.

Magnetic Storms:

The largest partof the earth's magnetic field originates within the earth, but a small portion of the field is of external origin and is of variable intensity. This variation is not simultaneous over the entire earth, but is related to the earth's rotation and so occurs with local time. The use of the base instrument eliminates this daily variation in the external field. Occasionally the external field varies rapidly and by large amounts and approximately simultaneously over the entire earth. Such variations are known as magnetic storms and frequently interfere with magnetic observations because the changes are rapid. Magnetic storms were encountered on several occasions. On July 5 variations of 20 to 30 gamma were observed within several seconds. Accurate observations are impossible under such conditions. During all other disturbances, the variation was so slow that the field observer was not aware of the storm until he returned to base. On some of these occasions, as on August 4, the variation was regular and did not exceed 100 gamma, and a check of certain critical stations on the following day showed the values obtained during the storm were acceptable. On other days, as on August 26 and 27, the changes were so irregular or rapid as to invalidate the work. The chart of base station readings for part of this storm is shown as Figure 4.

On some occasions the approach of a thunder shower caused local magnetic disturbance, as shown in Figure 4. Even though the disturbance is not large, stations taken at that time are invalid because the variations cannot be assumed to be the same over a considerable area.

The average morning or afternoon variation read on the base station instrument, including days when magnetic storms occurred, was 43 gamma. Omitting the magnetic storms the average is 37 gamma. It is probable that any variation larger than 60 gamma, or smaller than that if the variations are extremely irregular, should be treated as a magnetic storm, and the stations taken at the time not be accepted until certain critical stations have been checked.

Location of Base Stations:

In tying the present work to the earlier surveys it was necessary to reoccupy certain base stations located in

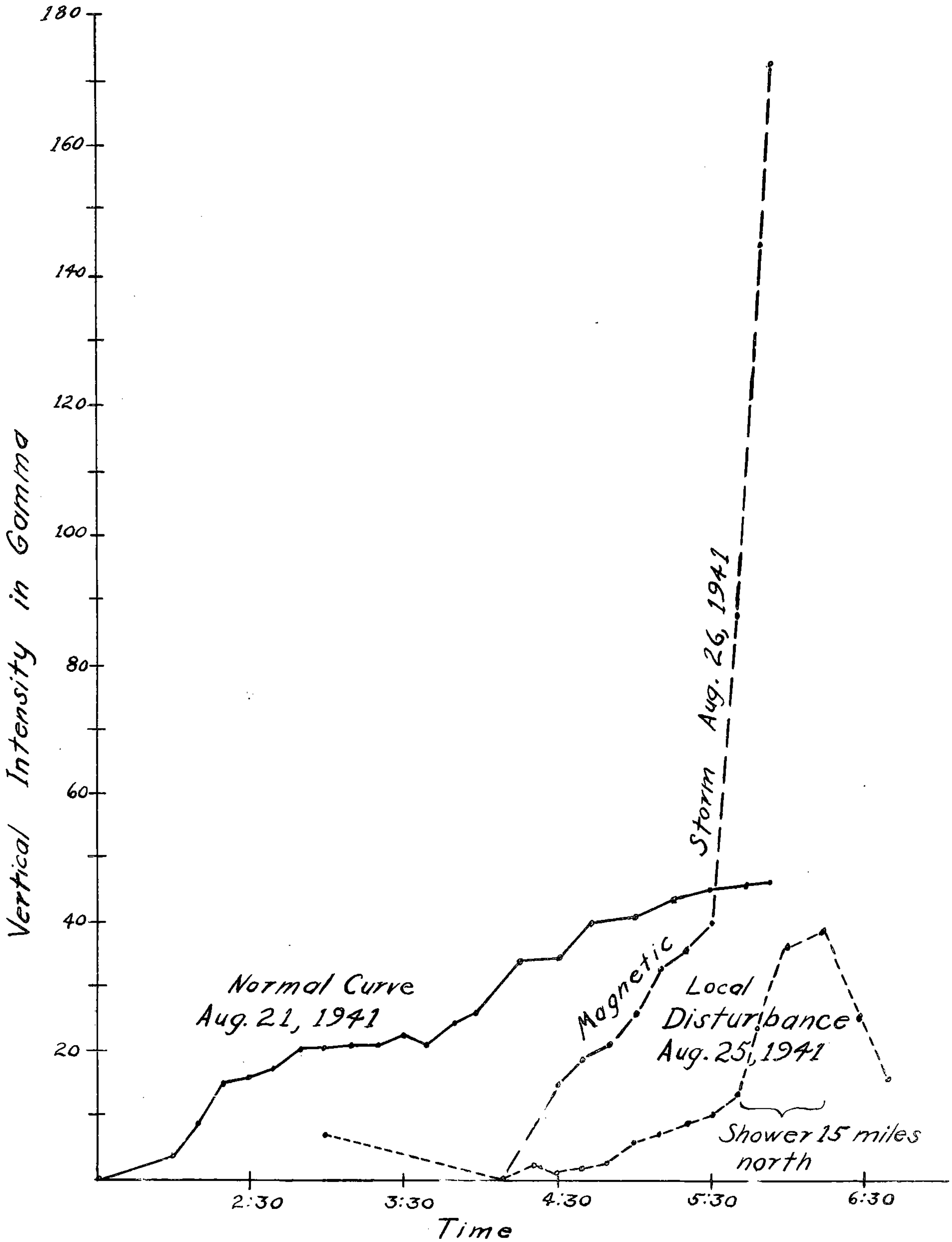


Figure 4. Curves Showing Variations of Earth's Magnetic Field

1940. Because of disappearance of the markers it was not possible to exactly relocate any of the points from the written descriptions. Good checks were obtained in tying the Huron base to two stations established during 1940, using approximate locations; so the possible dangers were not realized. However, in checking on the reestablished base, G, at Pierre, the values failed to check by more than 100 gamma. Readings taken at a number of points within a few tens of feet of the base showed that the variation was so abrupt within a few feet, that nothing but the exact relocation of the base would suffice for checking. A map giving values of vertical intensity at the points of observation in the immediate vicinity of the base is shown as Figure 5. It is plain that a mistake of one foot in relocation would cause error. This was not discovered until the base had been used for a number of stations on the west side of the Missouri River. Therefore, the base as approximately relocated was called G and its value determined with reference to the base D, at Chamberlain.

The cause of the difficulty at Pierre is believed to be the presence of a large number of glacial boulders scattered on the surface and buried in the soil. Similar conditions and difficulties were encountered at the base, B, at Wessington Springs. Failure satisfactorily to tie base D, to station 243 north of Pierre, probably is due to similar conditions at 243, although no glacial boulders are visible. It is believed that where glacial drift is present, which would include all points east of the Missouri River, special care must be taken in locating stations, particularly bases. However, at some places where even boulders were present, no difficulty was found in obtaining check readings within a radius of a few hundred feet. It is suggested that if it is not possible to obtain such check readings at several points close to a proposed base, the base should be established elsewhere. If it is not possible to establish the base elsewhere, its location should be carefully described with exact distances and bearings to fixed reference points and should be illustrated by a sketch or photograph. Elaborate precautions probably are not necessary where glacial materials are absent. At the base D, on the alluvium of American Island, near Chamberlain, readings taken within 50 feet in several directions from the probable location of the original base did not vary more than 5 gamma from the value at the reestablished base.

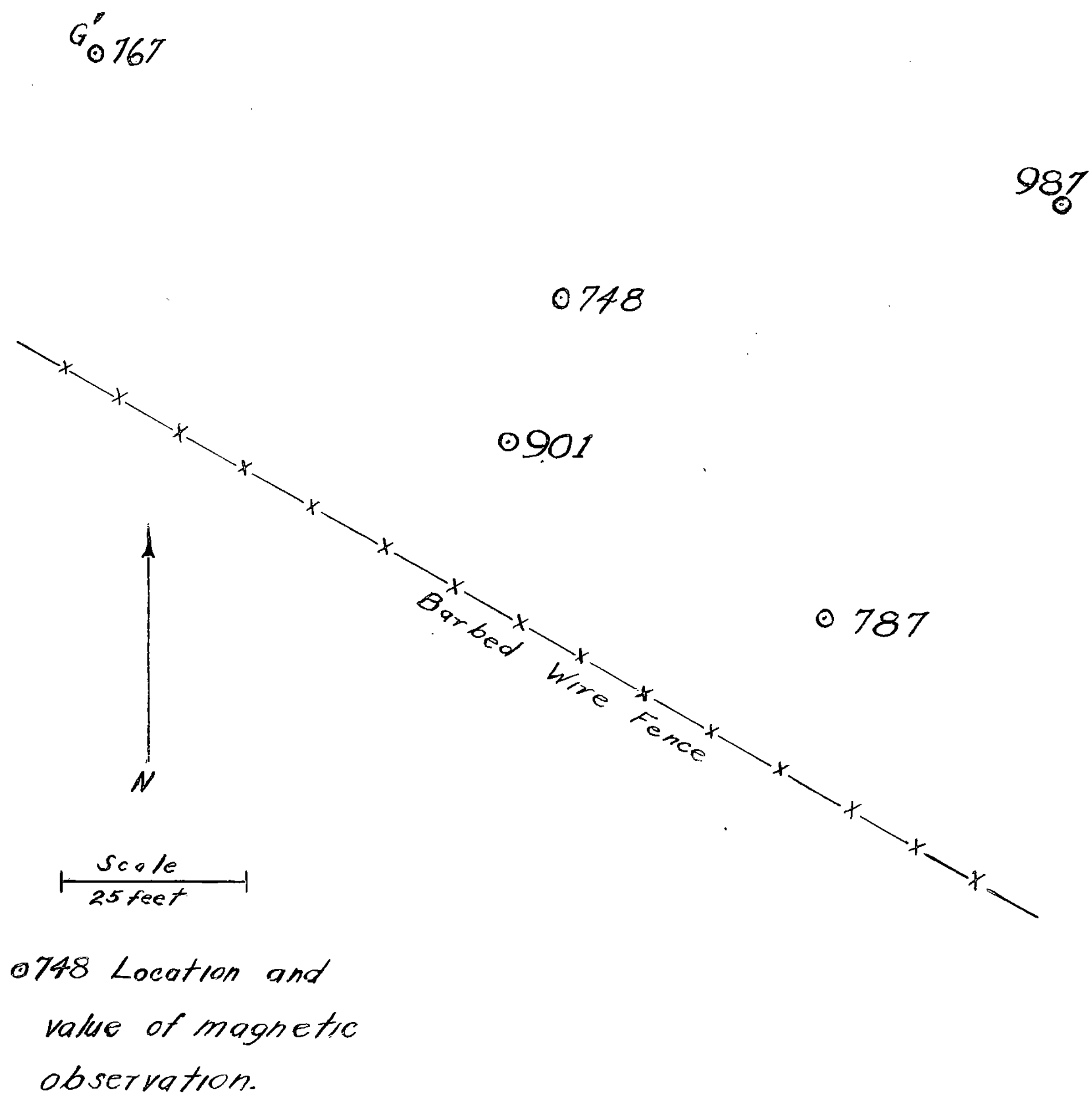


Figure 5. Map Showing Variation of Magnetic Intensity Near Pierre Base.

Adjustment of Base Net:

The 1941 surveys were tied to Jordan's work of 1940 by observations at stations A, D, and 132. Ties were also attempted at his stations B and G but were unsuccessful because the stations could not be exactly relocated. Base station G' was located within a few tens of feet of G, but the intensities differ by 104 gamma because of large local variations within short distances. The ties made by Jordan and by the writer are shown in Figure 6. The differences between the stations are shown beside the legs of the net, the arrows pointing in the direction of higher intensity. If the work had been perfectly accurate all the readings along the legs of a given polygon should add up to zero. However, each time the complete circuit of a polygon is made, the sum of the readings is increased by a certain small amount, indicated by the figure in the center of a circular arrow pointing in the direction of increase of reading. To adjust these errors the method of least squares was used. On the east side of the Missouri River are four circuits or traverses, including three by Jordan and one by the writer. For best accuracy it was necessary to adjust this entire net. The four-traverse net is tied to Jordan's 1939 survey through stations 12, 83, and 97. These three stations are part of a net that he adjusted by the solution of 62 simultaneous equations. Since the present survey is part of a project not yet complete it is believed desirable not to attempt to readjust the 1939 survey again until the entire project is completed. The difference that would result in any case probably would not be greater than 2 or 3 gamma. On the west side of the Missouri River the stations formed a net of two traverses or circuits. The adjustment of the base net is shown in Table I and the original and adjusted values of the base stations are given at the end of Table III.

Only in the case of base station B was the new re-adjusted value different than the adjusted value obtained by Jordan following the 1940 survey. The new value is one gamma higher and all stations in B group in his report (Jordan and Rothrock, 1940b, Table IV, p. 28) should be increased by that amount. The readjusted values of the station of the B group located in Beadle County are shown in Table II.

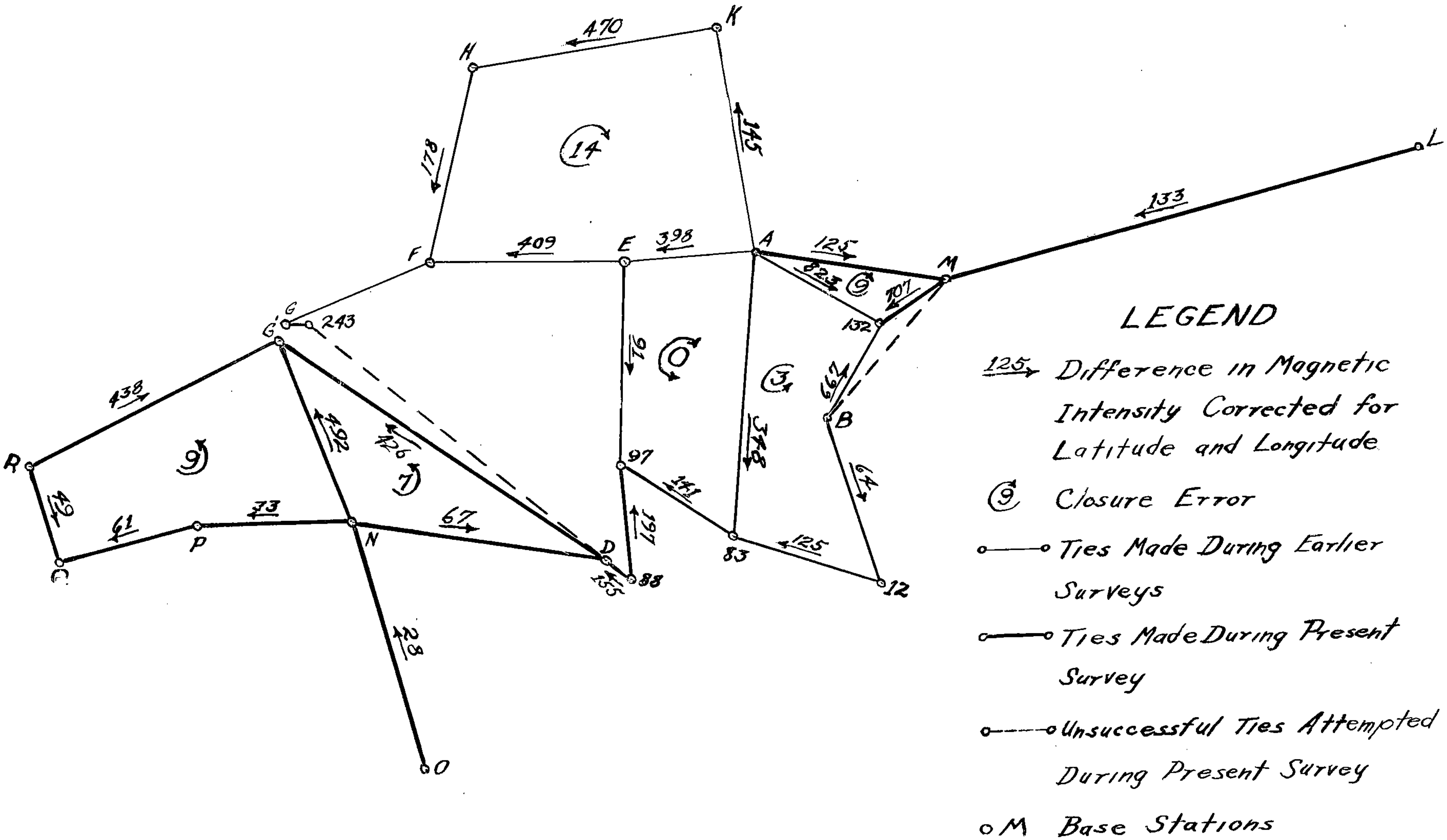


Figure 6 - UNADJUSTED BASE STATION NET

TABLE I

INTENSITY DIFFERENCES BETWEEN BASE STATIONS

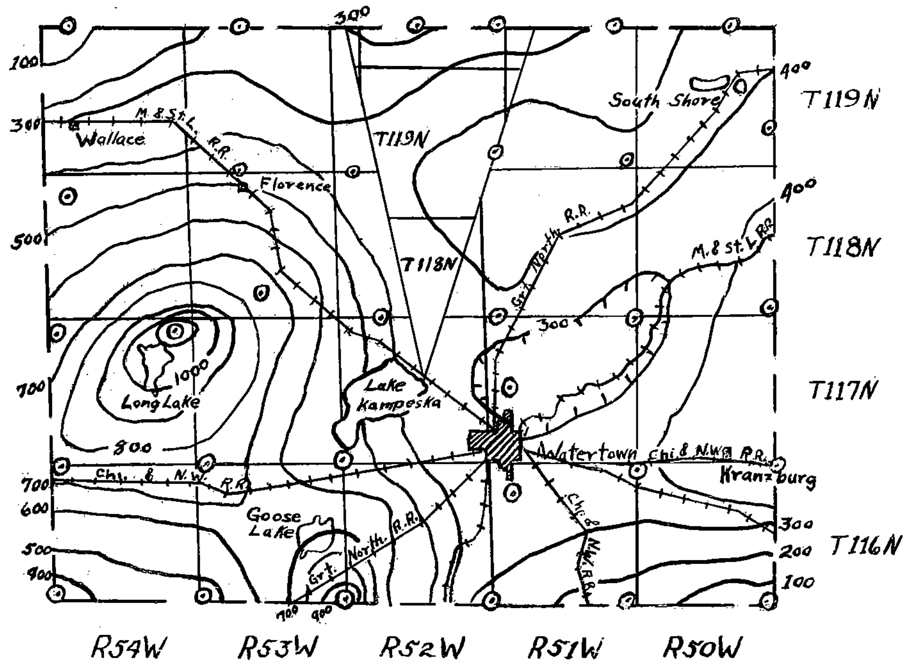
(Arrow points to station of higher intensity)

Stations	Measured Value	Adjustment	Adjusted Value
12←B	64	−0.31	63.69
132←B	667	+0.31	667.31
132←M	707	−3.1	703.9
A→M	125	−3.1	121.9
L→M	133		
132←A	823	+2.79	825.79
83←A	348	−0.8	347.2
E←A	398	−1.91	396.09
97←E	91	+1.11	92.11
F←E	409	−3.02	405.98
F←H	178	+3.02	181.02
K→H	470	+3.02	473.02
K←A	145	+3.02	148.02
G'←D	426	−1	425
N→D	67	−1	66
N←O	28		
N→G'	492	+1	491
N→P	33	+2	35
Q←P	61	+2	63
Q←R	49	−2	47
G'←R	438	+2	440

TABLE II

READJUSTMENT OF STATIONS OF GROUP B
IN BEADLE COUNTY

Station	Township	Range	Section	Corner	Vert. Int.	Adj. Int.	Readjusted Int. – 1941
152	108N	66W	2	NE	129	128	129
153	110	66	36	SE	24	23	24
154	109	65	1	NE	223	222	223
155	109	65	36	SE	213	212	213
163	109	64	36	SE	355	354	355
164	109	64	1	NE	329	328	329



LEGEND

⊙ Magnetic stations

Magnetic contours
Contour interval 100 gamma

Railroads

Towns

6 miles — Scale

Figure 7. Magnetic Map of Codington C unty, South Dakota.

MAGNETIC RESULTS OF THE SURVEY

The locations, original intensities, and adjusted intensities of all stations of the present survey are shown in Table III at the end of the report. An interval of 100 gamma was chosen for the magnetic map. Although the accuracy of the work might justify a smaller interval, the spacing of the stations does not. In only one case was the contouring of an extreme high done on the basis of one station. That is the high on the eastern edge of Beadle County. Additional readings taken at near points support the value found for that station. In the case of all other highs, a group of two or more stations with the regular six-mile spacings show the regional character of the anomalies.

Codington County

The magnetic map of Codington County is shown in Figure 7. The largest high, with peak of 1154 gamma, centers north of Long Lake, about 13 miles west-northwest of Watertown. Another high with maximum of 905 gamma centers near Grover, on the county line, 9 miles southwest of Watertown. The survey did not completely outline this high, and a higher point might be found farther south in Hamlin County. Two smaller highs with maxima of little more than 500 gamma were incompletely outlined. One is at the northeast corner of the county and the other is on the eastern border, directly east of Watertown. It is possible that in both cases higher points might be found by extension of the survey into Grant and Deuel counties.

In summary, an area of high magnetic intensity underlies about 7 townships in the western part of the county, and smaller highs occur in the north-central part, also at the northeast corner, and along the eastern border. The magnetic high in the western part of the county is elongated in a northwesterly direction, which is the trend previously noted by Jordan and Rothrock (1940b, p. 20) in an area a number of miles to the west and southwest. On the other hand, the two peaks on this high might be considered to form parts of trends to the northeast if taken in combination with the highs in the northeastern and eastern parts of the county. This trend is accentuated by the form of the magnetic trough which extends in a northeasterly direction from the southwest corner of the county to a point on the eastern edge of the county, northeast of Watertown.

Beadle County

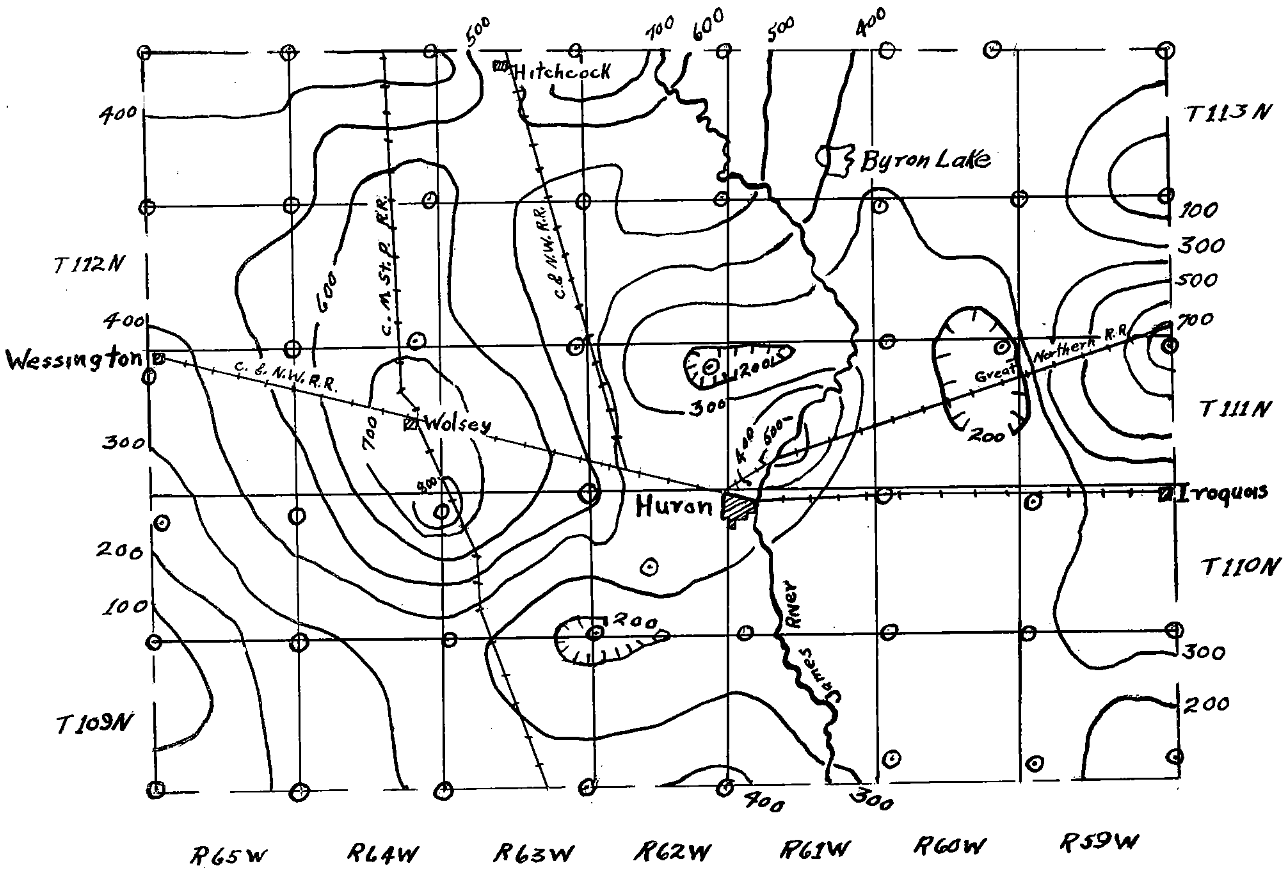
The results for Beadle County are shown on a magnetic map in Figure 8. The most prominent feature is a high with elongated form extending from the southern to the northern part of the county, and having a high point of 823 gamma at a station about 4 miles south of Wolsey. To the northeast a high point of 785 gamma was found 3 miles east of Hitchcock. This high extends into Spink County and was not completely outlined. A small high with 200 gamma closure based on one station occurs 4 miles northeast of Huron. Another high based on one station extends eastward into Kingsbury County and was only partly outlined; an intensity of 854 gamma was read at a point one mile southwest of Osceola.

Three closed lows are grouped in a region within a radius of 12 miles about Huron. Another prominent low in the northeastern part of the county extends into Kingsbury County and was not completely outlined. It is interesting to note that each of these lows might be considered to be paired with an adjacent high. The low in the southwestern part of the county is part of a magnetic trough extending to the northwest beyond St. Lawrence in Hand County.

Area Between Pierre and Nebraska Line

The results of the survey of the area south of Pierre are shown by the map at the end of the report. The two most prominent features in this region are (1) the group of highs north of highway 16 or the Milwaukee Railroad, and (2) the region of almost uniform magnetic readings south of that line and also west of Murdo. In the group of highs mentioned, four are along a northwesterly line approximately parallel to the general course of the Missouri River. At the northern end a high near Ft. Bennett has been incompletely outlined. To the southeast the next high is near Pierre and the other two are between Pierre and Kennebec or Reliance. Farther to the southeast along the same line and in the area surveyed by Jordan during 1939, a high is found near Red Lake. Other highs in the northern half of the area are just to the west of the Big Bend of the Missouri and also to the northeast Van Metre along Bad River. The northwestern end of the latter anomaly was not completely surveyed. Between the high at Van Metre and the line of highs through Pierre is a magnetic trough. Its southeastern end is near Presho and at its

MAGNETIC MAP
OF
BEADLE COUNTY, SOUTH DAKOTA



LEGEND

Magnetic stations

Magnetic contours
Contour Interval - 100 gamma

Railroads

Rivers

Towns

←6 miles→ Scale

northern end northwest of Pierre it divides. One part trends northeastward toward Okobojo and the other extends northwestward to the southwest of Ft. Bennett. In this part of the trough is the lowest reading yet found in the state, -21 gamma.

The southern part of the region and the area west of Murdo are marked by uniformly low intensity. Most readings are between 200 and 400 gamma. A search for bases near Mission in Todd County and near White River in Mellette County shows that at those places the magnetic intensity is little different than in Tripp and southern Jones counties.

In Tripp County small highs are found 10 miles east of Winner and also near Ideal. Lowest readings are near Colome and in the southwestern corner of the county. In Lyman County a small high occurs about 15 miles southwest of Oacoma and another was incompletely outlined near Iona. In the area west of Murdo the intensity is rather uniform but averages about 100 gamma higher than in Tripp County and the southern part of Lyman County. At the extreme western edge of the area surveyed, in the district extending from Belvidere north to Ottumwa, the magnetic values rise well above 400 gamma, which is higher than is found anywhere else in the region of uniform readings. Extension of the survey to the west would be of interest be cause it would show whether this high is a local feature, or persists, or increases to the west.

INTERPRETATION OF RESULTS

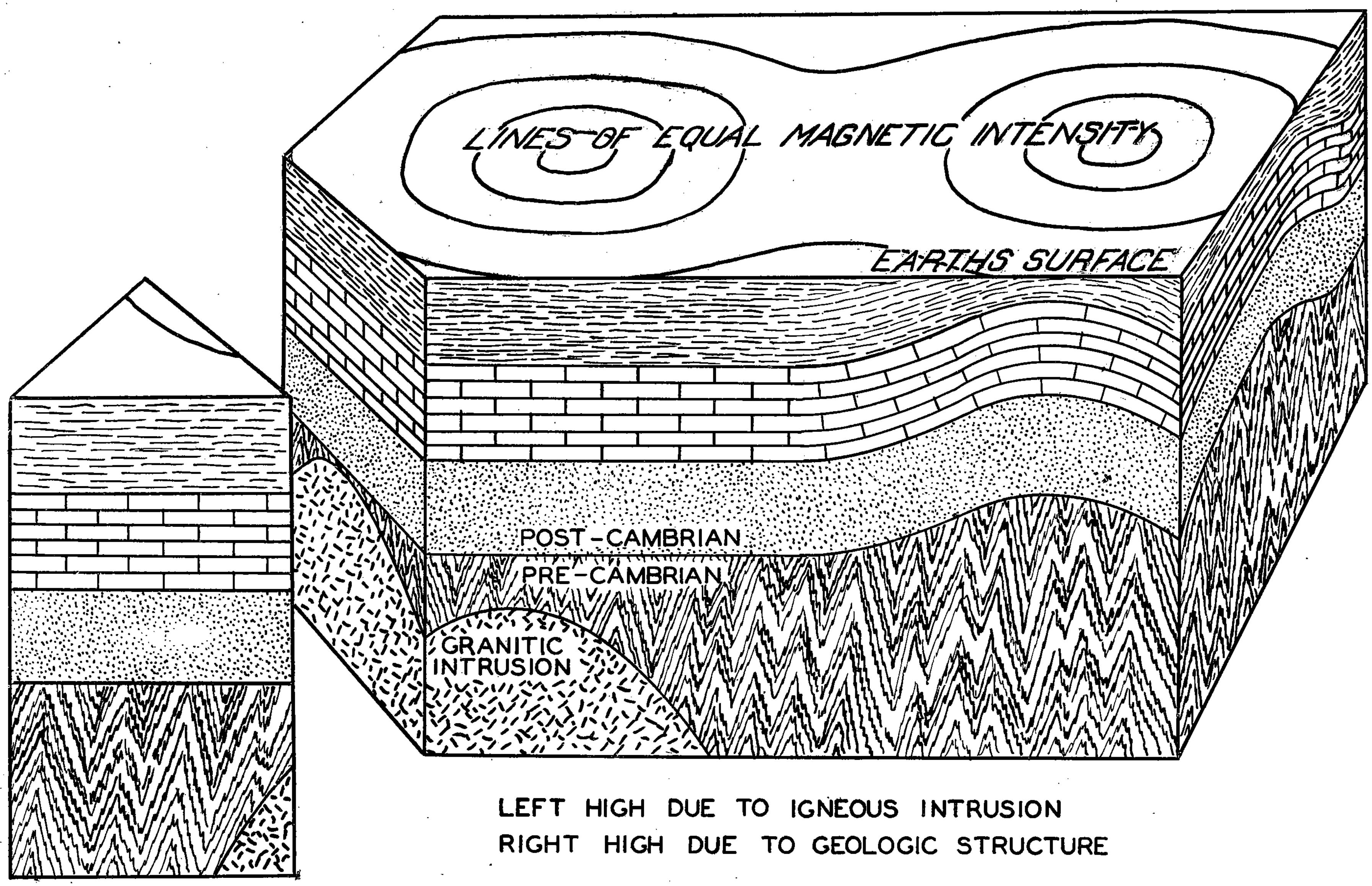
Theory of Interpretation

The fundamentals on which the interpretation of magnetometer surveys is based have been outlined briefly in an earlier section on "The Earth's Magnetic Field." It was stated that where the pre-Cambrian rocks are less deeply buried, magnetic highs are to be expected. Such relatively shallow depths may occur where there were ridges in the pre-Cambrian topography that were buried by younger sedimentary rocks. Above these ridges the sedimentary rocks may assume a structure favorable to the accumulation of oil, if other geologic conditions are correct. If the depth to the top of the pre-Cambrian ridge is considerable, that is, 1000 feet or preferably considerably more, the chances that structures above the ridge will contain oil are better than if the depth to the top of the ridge is slight. In the latter case there is little chance of finding oil above the ridge. However, if the top of the pre-Cambrian ridge occurs at shallow depth, its position is of geologic significance because it may mark the edge of a basin in which a considerable thickness of sedimentary rocks may be found. In such a case smaller magnetic highs within the basin might mark places favorable to further prospecting.

The pre-Cambrian rocks may be raised toward the surface and give magnetic highs at places where folding or faulting subsequent to deposition of the sedimentary rocks has produced structures favorable to the accumulation of oil. The interpretation of magnetic highs in terms of folds or faults is based on the assumption that the surface of the pre-Cambrian rocks is deformed in a manner similar to the overlying sedimentary beds. It should be understood that oil is to be expected only in the sedimentary rocks above the pre-Cambrian surface, not in the pre-Cambrian rocks themselves.

In addition to the causes of magnetic highs just described, Rothrock (Jordan and Rothrock, 1940a, p. 21-24) has described other equally plausible causes. He includes: (1) Large masses of igneous rocks intruded in the pre-Cambrian rocks. Such igneous rocks are likely to be more magnetic than the surrounding pre-Cambrian rocks and so would give a magnetic high similar to that caused by high

TWO CAUSES OF MAGNETIC HIGHS



LEFT HIGH DUE TO IGNEOUS INTRUSION
RIGHT HIGH DUE TO GEOLOGIC STRUCTURE

FIGURE - 9

points in the surface of the pre-Cambrian. The possibilities are shown in Figure 9. Geologic conditions of this kind are known to exist in the pre-Cambrian where exposed in South Dakota. (2) Accumulations of magnetic iron in metamorphosed pre-Cambrian rocks, such as in the ore districts of Minnesota. Such conditions are possible in the buried formations of South Dakota, but have not been proved. In any event, variation of iron content of the metamorphic rocks is likely. (3) Magnetic sands collected along old sea shores. So far as is known, the sedimentary rocks above the pre-Cambrian surface do not contain unusual concentrations of magnetic material.

Another possible cause of magnetic disturbance might be found in regional variations of the magnetic iron content or portions of the glacial drift sheets in the eastern part of the state. Such variations have not been proved in South Dakota, and in any event their effects would not likely give persistent regional highs such as would result from the characteristics of the pre-Cambrian rocks.

Geologic Significance of Results

Codington and Beadle Counties:

The magnetic results in Codington and Beadle counties should be considered in terms of the possibility of variation in depth to the pre-Cambrian surface and also in terms of the possibility of variation of the magnetic properties of the pre-Cambrian rocks, such as might be caused by the presence of igneous intrusions. According to a map shown by Darton (1909, Pl. X) the general elevation above sea level of the pre-Cambrian surface rises from less than 500 feet in western Codington County to more than 900 feet in the eastern part of the county. However, it must be noted that the points on which Darton's map is based are not numerous enough to give more than the regional slope of the pre-Cambrian surface. Since the topographic elevation of much of Codington County is about 1,750 feet, it may be assumed that in a general way the depth to the pre-Cambrian is perhaps less than 850 feet in the eastern part of the county and perhaps more than 1,250 feet in the western part, not allowing for the thickness of glacial drift. Because of this it should be expected that the magnetic intensities would be higher in the east than to the west. Actually the reverse is the case. The large magnetic high occupies the western half of the county. Therefore, it might be more safe to conclude that the irregularities of the magnetic field result from differences in the magnetic properties of the pre-Cambrian rocks. This idea is supported by the fact that pre-Cambrian granite crops out in Grant County, 18 miles east of the northeast corner of Codington County. In contrast, the pre-Cambrian outcrops farther south in the state are quartzite, which generally is less magnetic than granite. Quartzite intruded by granite might cause a magnetic picture such as is found here. However, it cannot be denied that the magnetic anomalies might be caused by high points of the pre-Cambrian surface.

Comparison of maps prepared by the U. S. Geological Survey (Todd, 1904, 1909; Todd and Hall, 1904; Darton, 1909), showing contours on the surface of the pre-Cambrian rocks, with the results of the magnetic survey, indicates that in Beadle County it is possible that the magnetic survey may furnish a rather general key to the form of the pre-Cambrian rocks. It should be noted that the data from which the U. S. Geological Survey maps were drawn were so scanty that the correlation between pre-Cambrian surface and the magnetic results may be more apparent than real. From the viewpoint of the prospector the form of the pre-Cambrian is less important than the structural form of some key bed, such as the Dakota sandstone, because the accumulation of oil is more closely related to the structure shown by such a bed. A map prepared by the South Dakota Geological Survey shows structure contours on the Dakota sandstone, based on well logs. The correlation between this map and the magnetic results is not as good as is the correlation between the magnetic map and the contour map on the pre-Cambrian.

There are two geological factors to be considered. The elevation of the pre-Cambrian in Beadle County varies between 200 and 400 feet above sea level (Darton, 1909, Pl. X) while the elevations at the surface of the ground are about 1300 feet. Allowing for a thickness of glacial till of 50 to 100 feet (Todd, 1904, p.5), it may be concluded that the total thickness of sedimentary rocks in which oil might occur is between 800 and 1050 feet. This relatively small column of sedimentary rocks is not as favorable to the existence of oil accumulations as is the much greater thickness found in the western half of the state. The same consideration limits the possibilities in Codington County. The second unfavorable geological factor is that, where encountered in numerous wells, the porous formations contain large amounts of artesian water, which possible could have flushed out any oil that might have been present.

Finally, it has been noted by Todd (1904, p. 1) that deep wells in Beadle County have encountered both granite and quartzite in the pre-Cambrian rocks. Since hese two rocks are likely to have differing magnetic permeabilities, the chances are good that at least some of the magnetic highs result from differences in composition of the pre-Cambrian rocks, rather than from irregularities in their surface. The paired highs and lows might furnish material for an interesting scientific study, but more data are needed before interpretation is attempted.

Area Between Pierre and Nebraska Line:

The magnetic results throw light on the probable trend of the ridge or pre-Cambrian rock traced as far west as Chamberlain by earlier work (Jordan and Rothrock, 1940a, p. 17-18). The large area of uniformly low readings west of the Missouri River in the region between highway 16 and the Nebraska line, indicates that the ridge does not extend westward or southwestward from Chamberlain into that area. If the ridge can be traced west of the Missouri River, it must be represented by the line of highs between Reliance and Ft. Bennett. These highs are along the extension of the trend of the magnetic high southeast of Chamberlain mapped by Jordan. If the highs do not result from a pre-Cambrian topographic ridge, then they probably represent structural deformation in which the pre-Cambrian rocks and the younger sedimentary series have been involved. The same statements may be applied to the high west of the Big Bend of the Missouri and to the one partly outlined northeast of Van Metre.

The depth to the pre-Cambrian rocks in this region is not known, but near the north end of the highs the Standing Butte well penetrated 2408 feet of sedimentary rock without reaching the pre-Cambrian (Gries, 1940, p. ii). The sedimentary rocks are believed to thin in the direction of Chamberlain, but it is not known by what amount. If Darton's (1909, Pl. X) map is correct the depth to the pre-Cambrian at Chamberlain may be less than half that near Ft. Bennett. In spite of this, the magnetic anomalies are no stronger to the south than to the north. From these facts it might be concluded that the highs do not result from relief in the pre-Cambrian surface, but from igneous intrusions or other magnetic rocks in the pre-Cambrian. Certainly this possibility cannot be excluded and should be kept in mind in prospecting the area.

The geologic significance of the small highs in Tripp and southern Lyman counties is doubtful. The depth to the pre-Cambrian is not known, but is considerable, because a map by Darton (1918, Pl. I) indicates that the elevation of the top of the Dakota sandstone is 400 to 600 feet above sea level, which would be 1200 to 1400 feet below the surface of the ground at the edge of the cover of Tertiary rocks.

The area of uniformly low readings west of Van Metre and Midland is interesting, particularly in view of the increase in intensity that is indicated at the west edge of the area of survey along a line from Belvidere to Ottumwa. If the intensity should continue to increase to the west, the trough of magnetic intensities would follow a northwest-southeast line through Murdo. This is somewhat east of the trough of the Lemmon geosyncline, which is believed to pass through the region near Philip and Kadoka (Gries, 1940, Pl. V).

RECOMMENDATIONS

It should be well understood that reconnaissance surveys of the kind represented by the present magnetic work are not intended to be used in locating drilling sites. The purpose is to indicate areas most favorable to additional prospecting by more detailed methods. Because of the possibility that any given magnetic high may result from magnetic differences in the pre-Cambrian rocks, or from causes other than irregularities in the pre-Cambrian surface, the magnetometer cannot be trusted as an unfailing indicator of structures favorable to accumulation of oil. Recognizing these dangers, it nevertheless is possible to indicate certain areas that are more favorable to prospecting than other areas.

Most important of the highs outlined during the 1941 season are those north of Highway 16, along the Missouri River and west of it. Because of geological factors, it is probable that more favorable conditions are likely to be found at the north end of this group of highs than at the south.

Next in importance to the highs just mentioned are those in Beadle County, because of the possibility that they may have a structural cause. The highs in Codington County probably are relatively unfavorable because of the possibility that they result from variations in magnetic properties of the pre-Cambrian rocks. Regardless of structural conditions, neither Beadle nor Codington County appears to be highly favorable as a prospecting ground because of other geologic factors.

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TABLE III

Locations of Stations
and
Magnetic Intensities

GROUP L -- Codington County

Station	Town-ship	Range	Section	Corner	Vert. Intensity	Adj. Vert. Intensity
415	116N	51W	36	SE	38	36
416	116	52	36	SE	112	110
417	116	52	31	SW	287	285
418	116	53	31	SW	907	905
419	116	54	31	SW	485	483
420	116	55	31	SW	365	363
421	116	55	6	0.2 mi. S of NW	719	717
422	116	55	1	0.2 mi. S of NE	754	752
423	116	51	1	NE	507	505
424	118	51	36	NE	486	484
425	117	51	6	NW	239	237
426	116	52	1	0.05 mi. S of NE	365	363
427	117	52	18	SE	224	222
428	116	52	18	NE	384	382
429	117	53	31	SW	505	503
430	118	53	33	SW	404	402
431	118	54	28	SE	776	774
432	119	51	24	SE	361	359
433	119	51	2	NW	512	510
434	119	52	1	NE	306	304
435	118	52	1	0.05 mi. W of NE	465	463
436	118	52	19	SE	397	395
437	119	52	30	SE	502	500
438	119 of Sisseton Res.	52 of	25	NE	266	264
439	119 of Sisseton Res.	52 of	29	NE	198	196

TABLE III
(Cont.)

Station	Town-ship	Range	Section	Corner	Vert. Intensity	Adj. Vert. Intensity
440	118N	53W	6	NE	371	369
441	119	54	23	SW	493	491
442	119	54	5	NE	210	208
443	119	55	5	NW	20	18
444	118	55	7	NE	458	456
445	117	55	7	NW	685	683
446	117	55	1	SW	1156	1154
447	113	55	18	SW	292	290
GROUP M - Beadle County						
448	113	62	36	SE	559	557
449	113	62	1	NE	549	547
450	113	60	6	NE	339	337
451	112	60	31	SW	269	267
452	112	60	6	NW	299	297
453	112	59	6	NW	356	354
454	111	62	6	NW	465	463
455	112	62	6	NW	470	468
456	113	63	1	NE	787	785
457	113	64	1	NE	352	350
458	113	64	6	NW	353	351
459	113	64	36	SE	682	680
460	111	63	36	SE	510	508
132	110	64	1	SE	828	823
461	110	62	16	SW	353	351
462	109	62	31	SW	344	342
463	110	63	36	SE	154	152
464	110	62	36	SE	210	208
465	111	61	16	SE	540	538
466	111	60	31	SW	240	238
467	111N	60W	2	NE	166	164
468	113	60	1	NW	388	386
469	113	59	1	NE	347	345
470	113	59	36	SE	83	81
471	112	59	36	SE	856	854

TABLE III
(Cont.)

Station	Town-	Range	Section	Corner	Vert. Inten.	Adj. Vert. Intensity
472	111	59	36	NE	308	306
473	110	59	6	0.2 Mi.S of NW	279	277
474	109	52	36	0.1 Mi.W of SE	418	416
475	109	61	25	SE	234	232
476	109	60	36	NE	245	243
477	109	59	36	NE	138	136
478	109	59	1	NE	383	381
479	110	59	31	SW	280	278
480	110	61	36	SE	247	245
GROUP G' - Pierre Base						
481	5N	30E	13	N$\frac{1}{4}$ Cor.	726	725
482	5	30	7	0.2 Mi. E of SW	235	234
483	5	29	18	SW	354	353
484	6	28	12	Rd. Junc. 0.15 Mi. ESE of center.	161	160
485	7	28	9	Rd. Junc. near center	-20	-21
486	8	29	8	Rd. Junc. S. of N. $\frac{1}{4}$ Cor.	576	575
487	6	29	3	0.3 Mi.W of SE	149	148
488	7	29	22	0.3 Mi.S & 0.1 Mi. E of NW	118	117
489	4	31	24	SE	491	490
490	4	33	19	0.2 Mi.E. of W $\frac{1}{4}$ Cor.	597	596
491	4N	33E	22	0.25 Mi.N of SE	546	545
492	109N	76W	6	0.25 Mi.N & 0.25 Mi. W of SE	498	497
493	109	76	26	0.4 Mi. S. of NE	528	527

TABLE III
(Cont.)

Station	Town-ship	Range	Section	Corner	Vert. Intensity	Adj. Vert. Intensity
494	4N	30E	11	0.25 Mi.N & 0.25 Mi. W. of SE	364	363
495	4	30	31	0.4 Mi. S & 0.1 Mi. E. of NW.	507	506
496	4	29	31	0.3 Mi. W of SE.	648	647
497	3	28	33	0.2 Mi. & 0.1 Mi. N of SE	612	611
498	109N	79W	34	NW	446	445
499	109	78	34	0.25 Mi.E. of SW	738	737
500	108	77	4	NW	633	632
501	108	77	33	NW	773	772
502	108	78	19	SE	593	592
503	3N	31E	18	NW	451	450
504	2	30	7	NW	671	670
505	1	29	6	SE	479	478
506	2	31	7	0.2 Mi. W. of NE	437	436
GROUP D -- Chamberlain Base						
507	103N	72W	3	0.1 Mi.E. of NW	239	239
508	102	72	5	0.4 Mi.N. & 0.5 Mi. W. of SE.	323	323
509	107	74	12	0.6 Mi.W. of SE	419	419
510	108	75	36	0.3 Mi.W. of SE	339	339
511	107	75	7	SW	276	276
512	108	76	22	center	218	218
513	108	76	30	0.25 Mi. E. of W. ¼ Cor.	409	409
514	107	76	7	center	346	346
515	106	76	6	SE	602	602
516	106	75	18	NE	832	832

TABLE III
(Cont.)

Station	Town-ship	Range	Section	Corner	Vert. Intensity	Adj. Vert. Intensity
517	106N	75W	13	SE	695	695
518	105	75	24	0.1 Mi.S. of NE	218	218
519	101	72	2	SW	437	437
520	101	71	5	0.4 Mi.S. & 0.4 Mi. W. of NE	304	304
521	101	72	34	SE	280	280
522	101	71	32	0.25 Mi.E. & 0.15 Mi. N of SW	327	327
523	101	73	1	0.2 Mi. W. of SE	353	353
524	101	73	36	SW	337	337
525	105	74	14	NE	225	225
526	104	75	3	SE	216	216
527	104	74	19	0.2 Mi. E. of SW	221	221
528	104	74	3	SE	255	255
529	103	73	6	0.1 Mi. S. & 0.1 Mi. E. of NW.	244	244
530	103	73	3	0.1 Mi. S. of NE	248	248
531	103	73	32	SW	410	410
532	101	73	6	0.4 Mi. S. of NW	287	287
533	102	74	31	SW	255	255
534	102	75	1	SW	272	272
GROUP O – Winner Base						
535	99	75	7	NW	265	266
536	99	74	7	NW	420	421
537	99	74	12	NE	363	364
538	100	75	12	SE	353	354
539	101	75	34	NE	248	249
540	101	76	33	NE	313	314
541	101	77	33	SE	228	229
542	100	77	36	SE	235	236
543	99	78	1	NW	251	252
544	100	78	7	NW	213	214

TABLE III
(Cont.)

Station	Town-ship	Range	Section	Corner	Vert. Intensity	Adj. Vert. Intensity
545	99N	79W	1	SE	240	241
546	98	74	12	NE	300	301
547	98	76	11	0.15 Mi.W of NE	271	272
548	98	75	10	NE	325	326
549	97	75	12	0.4 Mi. S of NE	251	252
550	97	74	12	E $\frac{1}{4}$ Cor.	336	337
551	96	73	7	SW	292	293
552	102	75	29	SE	234	235
553	102	76	29	SE	219	220
554	101	77	3	NW	232	233
555	98	75	31	SE	156	157
556	96	74	7	NE	258	259
557	96	75	5	SW	258	259
558	96	76	8	NW	277	278
559	97	76	5	NW	263	264
560	95	77	12	0.2 Mi.N. of NE	251	252
561	95	76	32	0.75 Mi.S. of NW	214	215
562	95	75	31	0.1 Mi.E. of SW	228	229
563	95	75	7	0.25 Mi.W. of NE	271	272
564	95	74	32	SW	234	235
565	95	75	2	NE	270	271
566	102	78	32	SE	261	262
567	101	78	31	NW	222	223
568	98	78	2	NW	244	245
569	99	78	31	SW	234	235
570	98	79	5	E.$\frac{1}{4}$ Cor.	201	202
571	100	79	33	SW	215	216
572	98	77	29	SW	271	272
573	96	77	5	NE	243	244
574	95	77	5	NE	231	232
575	95N	78W	6	SW	163	164
576	96	78	6	SW	218	219
577	98	79	25	SE	239	240

TABLE III
(Cont.)

GROUP N -- Presho Base

Station	Town-ship	Range	Section	Corner	Vert. Intensity	Adj. Vert. Intensity
578	105	76	8	0.35 Mi.N. of SW	200	201
579	106	77	34	SW	185	186
580	102	77	4	NE	267	268
581	103	78	31	0.1 Mi.N. & 0.1 Mi.E. of SW	291	292
582	102	78	2	N $\frac{1}{4}$ Cor.	275	276
583	103	76	26	0.15 Mi.N. of SW	259	260
584	105	75	8	NW	220	221
585	105	76	36	SW	227	228
586	103	76	3	NE	230	231
587	103	77	3	SW	263	264
588	104	77	9	NE	271	272
589	104	78	4	NW	309	310
590	103	78	3	SW	297	298
591	103	79	8	0.15 Mi.N. of SE	311	312
592	104	79	8	0.05 Mi.S. of NE	323	324
593	105	79	12	NW	321	322
594	106	78	1	NE	389	390
595	107	78	30	NE	378	379
596	108	79	33	NW	433	434
597	107	79	28	SW	358	359
598	106	79	30	0.2 Mi.N. of SW	390	391
599	106	78	18	SW	304	305
GROUP P -- Murdo Base						
600	2S	29E	31	0.25 Mi.E. of SW	286	289
601	3	29	33	0.1 Mi.E. of W.$\frac{1}{4}$ Cor.	265	268
602	1	29	9	NW	303	306
603	2	28	10	SE	295	298
604	1	30	7	NE	398	401

TABLE III
(Cont.)

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Vert Intensity
605	1N	30	5	SW	559	562
606	1	30	1	NE	488	491
607	1	30	25	SE	471	474
608	1S	31	19	NW	398	401
609	2	30	12	SW	334	337
610	2	31	14	NE	366	369
611	3	31	3	SW	325	328
612	3	31	33	0.1 Mi.N. & 0.1 Mi. W.of SE.	311	314
613	3	30	33	W ¼ Cor.	281	284
614	3	30	4	NW	297	300
615	2	30	5	NE	329	332
GROUP Q -- Stamford Base						
616	1	28	21	NE	331	336
617	1N	28	21	SW	386	391
618	2	28	28	SW	447	452
619	1	27	21	0.3 Mi.N. & 0.2 Mi. W.of SE.	330	335
620	2S	26	26	0.4 Mi.S. & 0.2 Mi. W. of NE.	386	391
621	2	27	14	NW	318	323
622	2	27	36	SW	325	330
623	3	27	24	0.4 Mi.N. & 0.1 Mi. W. of SE.	325	330
624	1	27	23	NW	318	323
625	1N	26	35	SW	307	312
626	2S	26E	3	NW	361	366
627	3	23	15	0.4 Mi.S. & 0.1 Mi. E. of NW.	410	415
628	2	23	16	SW	440	445
629	1	23	16	SW	377	382
630	1	24	19	SE	339	344
631	2	24	16	SW	388	393
632	3	24	8	0.1 Mi.N. & 0.2 Mi. W. of SE.	435	440

TABLE III
(Cont.)

Station	Town-ship	Range	Section	Corner	Vert. Intensity	Adj.Vert. Intensity
633	3	24	1	0.1 Mi.N. of SE.	359	364
634	2	25	9	NW	353	358
635	1	25	11	SE	385	390
GROUP R - Midland Base						
636	2N	25	36	Center	310	317
637	2	26	35	SW	320	327
638	2	27	33	NE	390	397
639	2	26	4	NE	336	343
640	3	27	17	0.3 Mi.W. of NE.	399	406
641	3	26	4	SW	286	293
642	2	25	9	SW	343	350
643	3	25	9	SW	394	401
644	4	25	17	NE	343	350
645	4	24	16	SE	386	393
646	1	25	31	S $\frac{1}{4}$ Cor.	355	362
647	1	24	19	W $\frac{1}{4}$ Cor.	370	377
648	1	23	7	0.15 Mi.N. of SW.	430	43[illegible]
649	2	23	18	0.1 Mi. W. of SE.	354	361
650	3	22	12	SE	386	393
651	4	23	20	0.3 Mi. W. of NE.	408	415
652	3	23	13	SE	396	403
653	2	23	13	SE	337	344

TABLE III
(Cont.)

BASE STATIONS

Station	Town-ship	Range	Section	Corner	Vert. Intensity	Adj.Vert. Intensity
L	115N	50W	1	0.1 Mi. S. of NW	-12	-14
M	111	62	1	SW	121	119
N	105	78	11	0.3 Mi. S. of NE	276	277
O	99	76	31	0.6 Mi. W. & 0.3 Mi. S. of NE.	248	249
P	2S	29E	3	0.4 Mi.W. & 0.3 Mi. S. of NE.	309	312
Q	2	25	24	0.2 Mi.W. of SE.	370	375
R	1N	25	7	0.25 Mi.S. & 0.4 Mi. E. of NW.	321	328
D	104N	71W	17	S ¼ Cor.	343	343
G'	5N	31E	21	SE of center	769	768*

* The value of G' used in drawing isogams is 845 which is the average of 6 readings close to the base.