SOUTH DAKOTA

STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 37

A MAGNETIC SURVEY OF CENTRAL SOUTH DAKOTA

GEOPHYSICS
W. H. Jordan

GEOLOGY
E.P.Rothrock

University of South Dakota
Vermillion, S. Dak.
November, 1940

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

FIGURES: page

TABLES:

PHOTOGRAPHS:

MAPS:

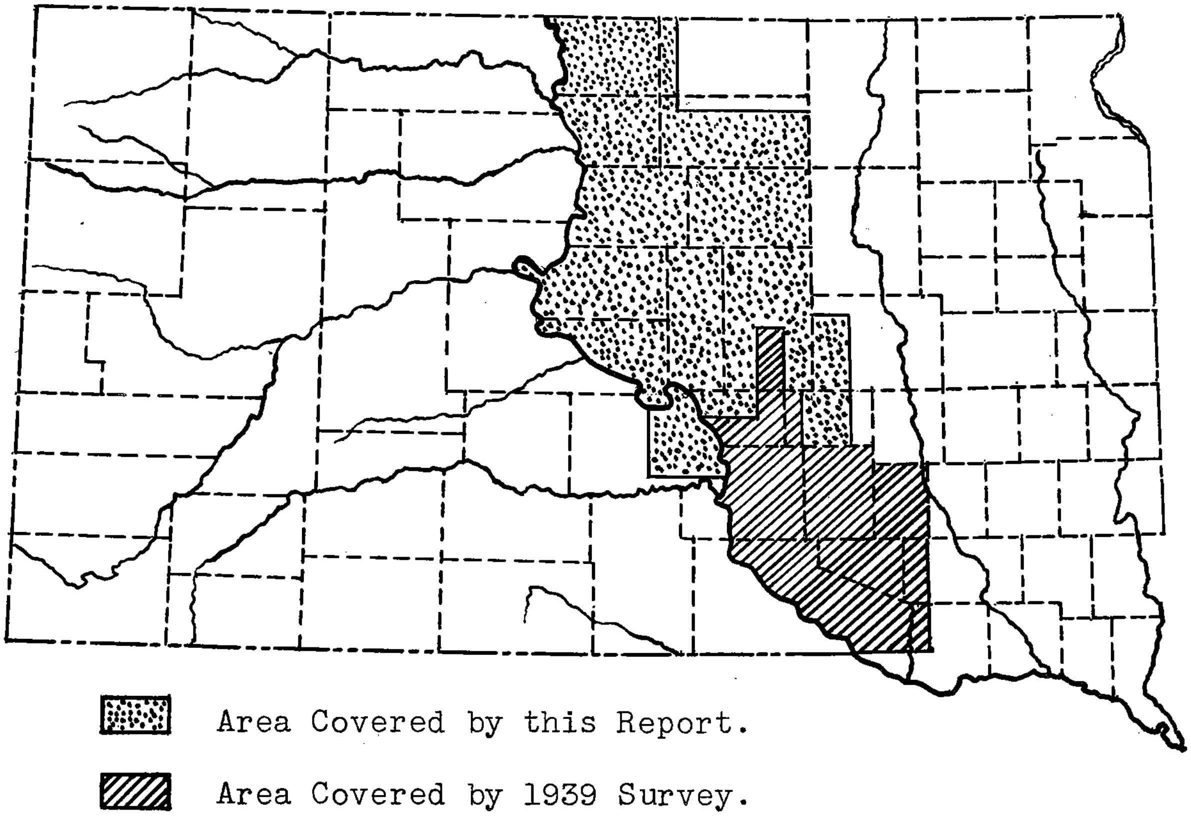
A MAGNETIC SURVEY
OF
CENTRAL SOUTH DAKOTA

--

W. H. Jordan, Physicist
E. P. Rothrock, Geologist

--

INDEX MAP



▨ Area Covered by this Report.

▨ Area Covered by 1939 Survey.

A MAGNETIC SURVEY
of
CENTRAL SOUTH DAKOTA

by

W. H JORDAN and E. P. ROTHROCK

INTRODUCTION

Purpose of Report

The search for oil is a search for geologic structure. Oil is never found except in a place where the rocks have been tilted, folded, faulted, or pinched out--in short, it is found only where a structure exists to trap it. To look for oil without first looking for a geologic structure would be to drill wells at random on the rare chance that one of them might strike a pool. So before any serious attempt at drilling can be undertaken, a knowledge of the geology of the region must be obtained.

Information about the structural geology of eastern South Dakota is difficult to obtain due to the fact that the sedimentary rocks have been covered over with a thick layer of glacial drift in this part of the state. Some data has been obtained from drilling deep water wells through this layer. In other places the layer has been cut through by large streams. While the information gained from these sources is very valuable and reliable, it is greatly limited in scope.

The development of geophysical methods has made it possible to obtain some data about the geology of a region under just such adverse conditions. Geophysical surveys have been made in South Dakota by many oil companies but the results of these surveys are kept secret. Hence this survey was undertaken with a twofold purpose in view; first to obtain information for the people of the state, and second to encourage further activity on the part of the oil companies.

The work described in this report is part of a large program to make a magnetic survey of the entire state. The work was begun in the summer of 1939 and was described in a previous report.[1] The area surveyed at that time is shown on the index map in the front of this report. It included most or all of Davison, Aurora, Brule, and Douglas counties and a good part of Buffalo, Charles Mix and Hand counties. One hundred and eighteen magnetometer stations were set.

The area surveyed this year was chosen so as to be contiguous to the area surveyed last year. It was extended in the direction in which most of the immediate interest of the major oil companies seemed to be centered. The field work was done during the months of July and August, 1940. The senior author operated the field magnetometer. The base magnetometer was operated by Mr. H. W. Buus.

Acknowledgments

Much of the success of this survey is due to the use of an additional magnetometer which was loaned to the State Geological Survey by the Gulf Research and Development Company of Pittsburgh, Pennsylvania. This instrument made it possible to cover nearly three times as much area as would have been possible with a single instrument.

We are very grateful for the many courtesies extended by the citizens of the area surveyed. The generosity of the land owners in permitting us to set up our tent and locate base stations on their property is particularly appreciated.

---

[1] W. H. Jordan, and E. P. Rothrock, A Magnetic Survey of Southeastern South Dakota, S. D. State Geol. Survey, Report of Investigations, No. 33, 1940.

Finally, the authors wish to acknowledge their indebtedness to Mr. H. W. Buus, Assistant Geologist of the State Geological Survey. His care in operating the base magnetometer and his accuracy in computing the data were of inestimable value.

Area of Survey

The region covered in the present survey is shown on the index map. 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. Most of Jerauld and Edmunds counties and a part of Beadle, McPherson, and Lyman counties were also included.

The plan of the survey was to extend the area surveyed during the summer of 1939 as far north as the state line. This is roughly the region between the Missouri and James rivers, north of Highway 16.

PHYSICAL DATA

Theory and Operation of Magnetic Surveys

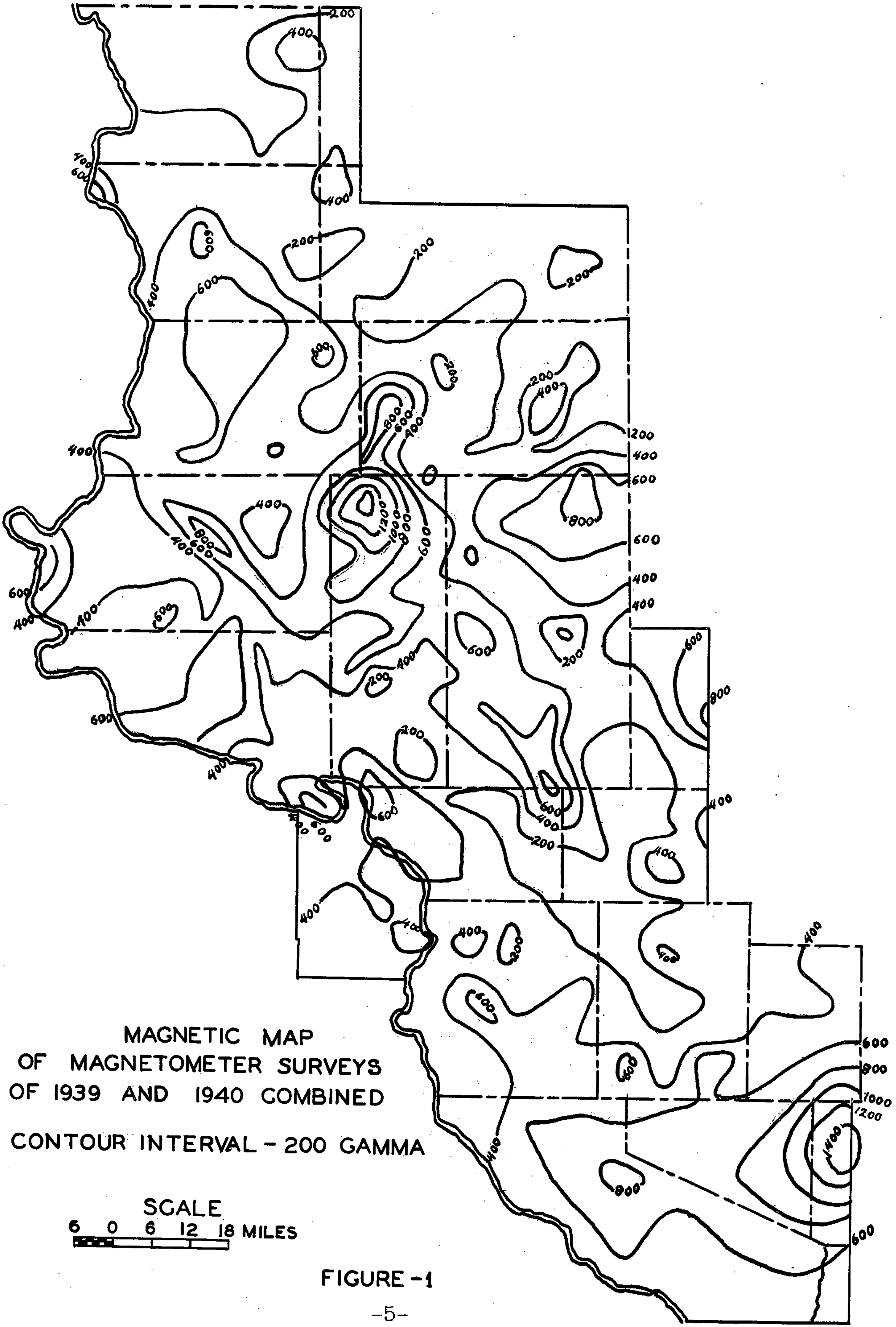
No attempt will be made to give a detailed report of the theory or instruments involved as this material has been covered in a previous report.[2] Briefly, however, the survey was accomplished by means of a vertical magnetometer. The magnetometer consists essentially of a magnet affixed to a quartz knife edge and delicately balanced on a pair of quartz bearings. Variations in the strength of the earth's magnetic field are measured by observing the variations in the position of balance as the instrument is moved from one place to another. Thus by observing the position of balance, or reading, of the magnetometer at a number of stations scattered over a certain area, the vertical intensity of the earth's magnetic field is obtained at these stations. If these stations are then located on a map and lines are drawn connecting all points of the same magnetic intensity, there results a magnetic contour map such as the one shown at the end of this report.

Over a geologic structure such as an anticline or a dome one frequently observes that the earth's magnetic field is considerably stronger than in other regions. This will be true when the rocks forming the structure contain material of high magnetic permeability, such as certain iron compounds. Thus, when a magnetic map is drawn, the regions where the magnetic field is strong are the regions of geological interest.

Not always does the simple theory outlined above apply. There are other things besides an anticline that may cause a region of strong magnetic field. Consequently the magnetic highs shown on the accompanying map should be checked by other means, such as the seismograph or gravimeter, before definitely concluding that a structure exists at those places. Also it must be especially emphasized that the magnetometer, in common with all other geophysical instruments, is of value in searching for oil structure but not for oil itself.

---

[2] W. H. Jordan and E. P. Rothrock, _A Magnetic Survey of Southeastern South Dakota_.

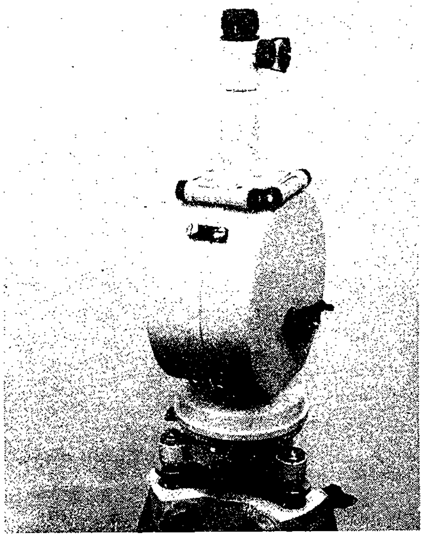


MAGNETIC MAP
OF MAGNETOMETER SURVEYS
OF 1939 AND 1940 COMBINED

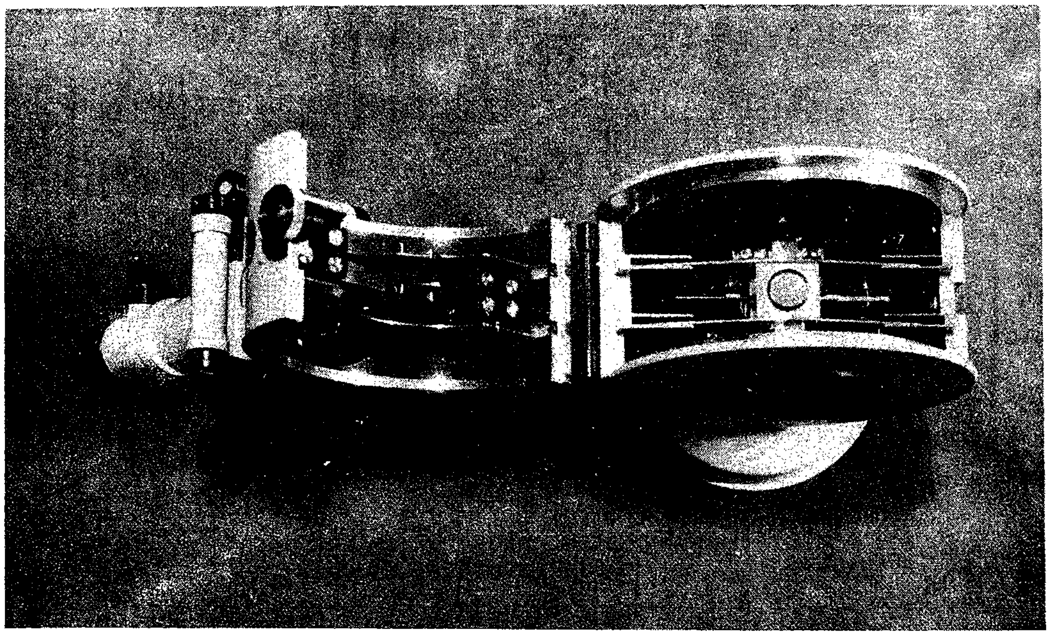
CONTOUR INTERVAL - 200 GAMMA

FIGURE - 1

THE SCHMIDT TYPE MAGNETOMETER



Magnetometer Mounted on Tripod for Field Use



Magnetometer Case Opened
With Magnetic System in Place

PLATE I

Procedure

The magnetometer stations were located at approximately six mile intervals throughout the area covered. This means that there will be one magnetometer station in each township. This was in line with the previous summer's policy which was adopted after careful consideration of the detail desired and the area to be covered. Inasmuch as this was designed to be a regional survey with emphasis only on the broad, regional features, it was felt that the six mile spacing was best adapted to give the desired results.

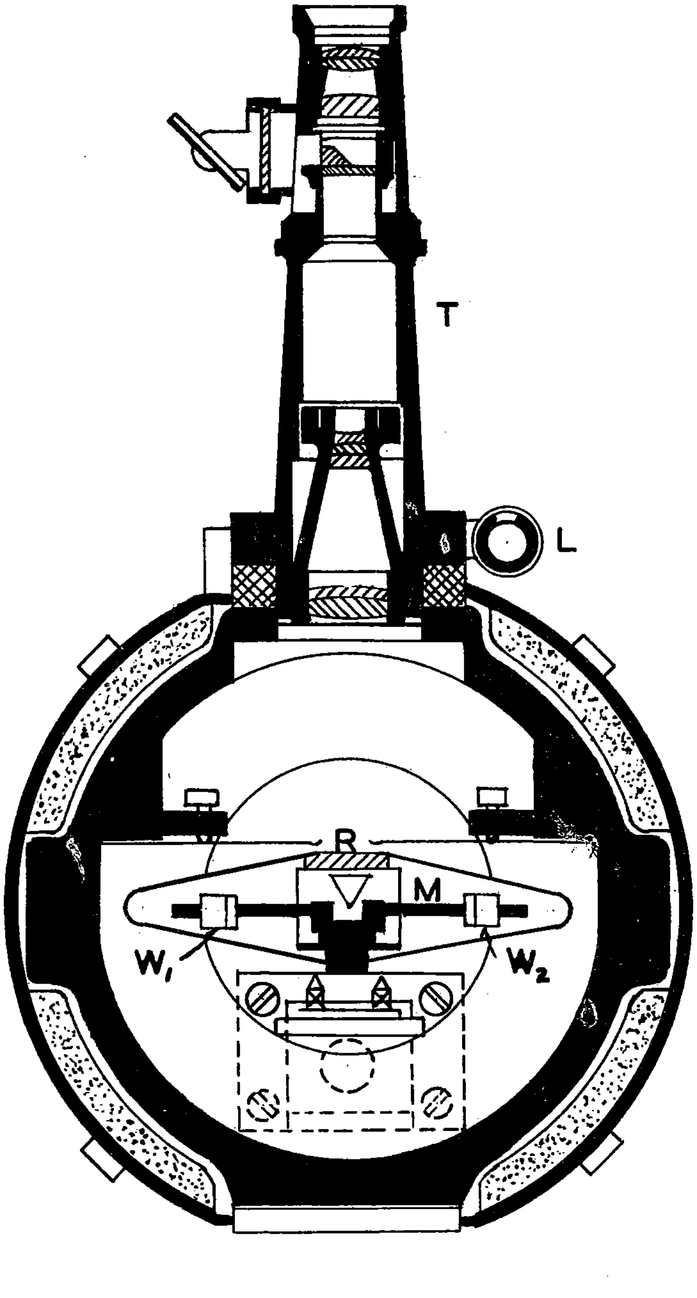
Actually the six mile interval was not rigidly adhered to but served as a guide to the location of stations on good roads. This was done wherever possible, so as to minimize the amount of time spent in driving between stations. That this was an important factor can be seen from the fact that in rough country with poor roads not over seven or eight stations could be set per day. In level country with good roads as many as 16 stations have been set in a day.

What is desired in this, as in most magnetic surveys, is the relative vertical intensity at each station in the area, the measurement being made simultaneously at all stations. Since this is obviously impossible, the next best thing to do is to make the measurement first at one station and then at the next and to correct for the diurnal changes in magnetic intensity that take place while moving between the two stations. This correction is made in either of two ways.

The first method is particularly suited when just one magnetometer is available. A measurement is first made at some initial station. Then the instrument is moved to the next station and a reading taken. This is continued for one or more stations and then the magnetometer is brought back to the initial station for a reading to determine the change that has taken place during the interval that the instrument was away.

The second method uses two magnetometers. One magnetometer, the field instrument, is carried from one station

SECTIONAL DRAWING OF VERTICAL FIELD BALANCE



LEGEND

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

FIGURE 2

to the next, readings being taken at each. Another magnetometer, the base instrument, is located in one place and read at short intervals to determine the diurnal variation in the vertical intensity of the earth's magnetic field. The readings taken by the field instrument are then corrected for the observed changes with time.

A modification of the first method was used during the summer of 1939. This year another magnetometer was obtained and the second method was used. This enabled us to speed up the work a great deal with no significant loss of accuracy. The procedure will be described in some detail in the following paragraphs.

Base stations were located about thirty miles apart, a few miles from the town chosen as headquarters. The base magnetometer was set up in a tent pitched under the shade of some trees. This was to protect the magnetometer from being exposed directly to wind and sun as these factors tend to make the readings less reliable. The base station was then located about 30 yards away and the field magnetometer set up at this spot.

As soon as both magnetometers had been oriented and leveled they were read simultaneously. The base magnetometer was then left undisturbed and was read about every 15 minutes. After reading the field magnetometer at the base station it was dismantled and carried to one of the magnetic stations. Here it was set up and read and then taken to the next station, and so on. This was continued for about four hours when the field magnetometer would again be brought back to the base station and both instruments read simultaneously. Both instruments should record the same change in magnetic intensity during the interval that the field magnetometer was away.

Any error in "checking in" was distributed linearly among the stations by a graphical method to be described shortly. Occasionally "checking in" errors as high as 20 gamma were encountered. These were attributed to temperature changes in the base instrument. Usually the "checking in" error was not more than 5 gamma. The effectiveness of this method has been demonstrated by measurements of the same station on different days. The results, even when a large error of "checking in" was encountered, were always

LOG OF READINGS

MAGNETOMETER SURVEY BASE INSTRUMENT

OBSERVER Hal W. Buus DATE 8/29/40 AREA Faulkton SCALE VALUE 30.0

STA.	TIME	TEMP.	READINGS			AV. - X	GAMMA	TEMP	TEMP.	DIURNAL
			N TO E	N TO W	MEAN	X= 34		- 30	COR.	COR.
Base K	7:40	20.2	37.7	36.8	37.2½	3.2½	97.5	-9.8	-54.0	43.5
K	8:05	18.1	38.2	37.1	37.6½	3.6½	109.5	-12.0	-66.0	43.5
K	8:18	17.6	38.2	37.3	37.7½	3.7½	112.5	-12.5	-69.0	43.5
K	8:31	17.2	38.2	37.6	37.9	3.9	117.0	-12.9	-71.0	46.0
K	8:43	17.0	38.3	37.6	37.9½	3.9½	118.5	-13.0	-71.5	47.0
K	8:55	17.1	38.2	37.3	37.7½	3.7½	112.5	-12.9	-71.0	41.5
K	9:08	17.5	38.1	37.2	37.6½	3.6½	109.5	-12.5	-69.0	40.5
K	9:23	17.8	38.1	37.1	37.6	3.6	108.0	-12.2	-67.0	41.0
K	9:37	18.0	38.0	37.1	37.5½	3.5½	106.5	-12.0	-66.0	40.5
K	9:51	18.4	37.9	37.0	37.4½	3.4½	103.5	-11.6	-64.0	39.5
K	10:06	18.8	37.8	36.9	37.3½	3.3½	100.5	-11.2	-61.5	39.0
K	10:21	19.1	37.7	36.8	37.2½	3.2½	97.5	-10.9	-60.0	37.5
K	10:35	19.7	37.4	36.6	37.0	3.0	90.0	-10.3	-56.5	33.5
K	10:50	19.9	37.2	36.3	36.7½	2.7½	82.5	-10.1	-55.5	27.0
K	11:04	20.3	37.2	36.2	36.7	2.7	81.0	-9.7	-53.5	27.5
K	11:18	20.6	37.1	36.2	36.6½	2.6½	79.5	-9.4	-51.5	28.0
K	11:34	20.9	37.1	36.2	36.6½	2.6½	79.5	-9.1	-50.0	29.5
K	11:42	21.1	37.0	36.1	36.5½	2.5½	76.5	-8.9	-49.0	27.0
K	12:47	22.3	36.8	35.9	36.3½	2.3½	70.5	-7.7	-42.5	28.0
K	1:15	22.8	36.8	35.9	36.3½	2.3½	70.5	-7.2	-39.5	31.0
K	1:28	23.1	36.8	35.9	36.3½	2.3½	70.5	-6.9	-38.0	32.5
K	1:42	23.3	36.9	35.9	36.4	2.4	72.0	-6.7	-37.0	35.0
K	1:58	23.5	36.9	36.0	36.4½	2.4½	73.5	-6.5	-36.0	37.5
K	2:12	23.7	36.9	36.0	36.4½	2.4½	73.5	-6.3	-34.5	39.0
K	2:26	23.9	36.9	36.0	36.4½	2.4½	73.5	-6.1	-33.5	40.0
K	2:41	24.0	36.9	36.0	36.4½	2.4½	73.5	-6.0	-33.0	40.5
K	2:55	23.9	36.9	36.1	36.5	2.5	75.0	-6.1	-33.5	41.5
K	3:10	23.9	37.0	36.0	36.5	2.5	75.0	-6.1	-33.5	41.5
K	3:24	23.9	37.0	36.1	36.5½	2.5½	76.5	-6.1	-33.5	43.0
K	3:39	23.9	37.1	36.1	36.6	2.6	78.0	-6.1	-33.5	44.5
K	3:53	24.0	37.1	36.1	36.6	2.6	78.0	-6.0	-33.0	45.0
K	4:07	24.1	37.0	36.1	36.5½	2.5½	76.5	-5.9	-32.5	44.0
K	4:23	24.5	36.9	36.0	36.4½	2.4½	73.5	-5.5	-30.5	43.0
K	4:38	24.8	36.8	36.0	36.4	2.4	72.0	-5.2	-28.5	43.5
K	4:57	24.9	36.8	35.9	36.3½	2.3½	70.5	-5.1	-28.0	42.5
K	5:23	25.0	36.8	35.9	36.3½	2.3½	70.5	-5.0	-27.5	43.0

TABLE - I

the same to within 3 or 4 gamma at most.

Table I shows the data taken by the base observer during a typical day's run. In column I is recorded the time at which the reading was taken and in column 2 the temperature inside the instrument in degrees centigrade. Column 3 is the reading of the magnetometer when the north pole of the magnet was pointing eastward and column 4 the reading when turned through 180°. Column 5, the average of these two readings, was taken as the true reading. An arbitrary number was subtracted from all the figures in column 5 to obtain column 6. This was done merely to reduce the size of the numbers and thus simplify the arithmetic. The figures in column 6 are then converted into magnetic units by multiplying them by the scale of the instrument, in this case 30.0. The scale value was determined by means of a Helmholtz coil. Thus column 7 is the reading of the instrument in gammas.[3] The figures in column 8 are obtained by subtracting 30 from the temperature, again for the purpose of reducing the size of the numbers. Since the base magnetometer had a negative temperature coefficient of 5.5 gamma per degree, the correction for temperature change was obtained by multiplying column 8 by 5.5. The results are recorded in column 9. The corrected reading, column 10, is then obtained by adding the figure in column 7 to that in column 9. The steady drop in intensity of the earth's field during the morning hours and a subsequent rise in the afternoon is nearly always found.

The data given in column 10 was next plotted on coordinate paper as shown in Figure 3, the vertical intensity being plotted along the vertical axis and the time plotted along the horizontal axis. Thus the change in the earth's magnetic field at any time can be obtained by drawing a horizontal line from the beginning of the curve and taking the difference between the ordinate of the horizontal line and of the curve at the time in question. If, however, it is assumed that the "checking in" error is a linear function of the time, then this error can be distributed on the graph by the following method. In the case shown, the base magnetometer showed the vertical intensity to be 15 gamma less at 12:47 a.m. than it was at 7:40 a.m.

---

[3] The gamma is defined as 10^{-5} oersteds. One oersted is the strength of a magnetic field which exerts one dyne of force on a unit magnetic pole.

CURVE OF DIURNAL MAGNETIC VARIATION AUGUST 29, 1940

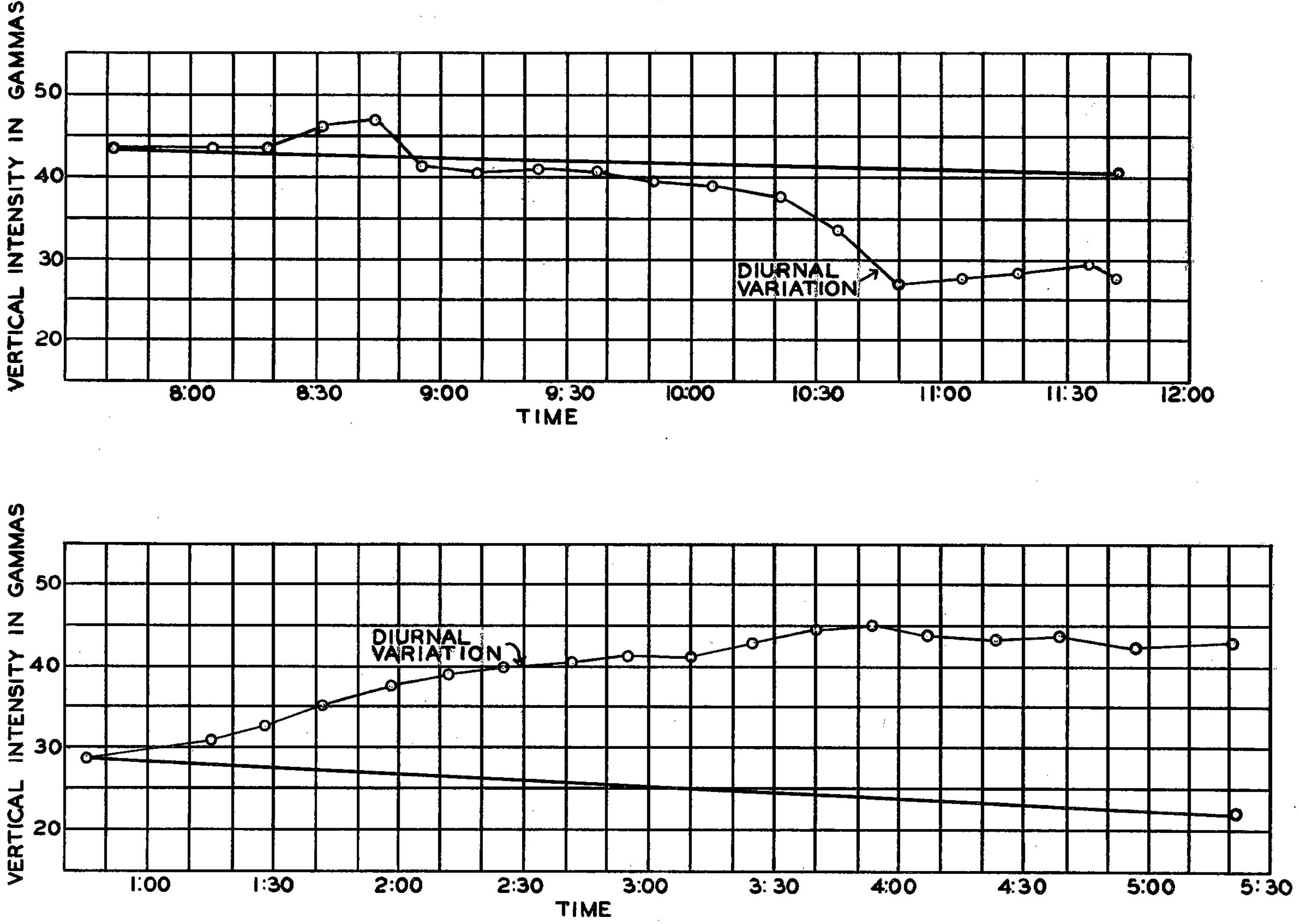


FIGURE - 3

The field magnetometer, on the other hand, (Table II) shows the vertical intensity to be 13 gamma less at 12:47 a.m. than it was at 7:40 a.m. Thus the "checking in" error is 2 gamma. Consequently instead of drawing a horizontal line, a straight line that slopes downward by 2 gamma is drawn. Then the correction to be applied to the field magnetometer at any time can be read off directly from the graph by reading the difference between the straight line and the curve at the time in question. Thus at 10:24 a.m. the correction is 5 gamma.

Table II shows the form on which the data from the field magnetometer was recorded and the actual data taken on August 29. This is for the same period of time that the data shown in Table I was taken.

The number of the station was recorded in the first column. Letters of the alphabet were used to designate base stations while numbers were used for all other stations. The next five columns are the same as in Table I. The temperature of the field magnetometer was recorded but not used since it had a zero temperature coefficient. Column 7 was obtained by subtracting the top figure in column 6 from all the numbers in column 6. Thus the figures in column 7 indicate how high or low each station is with respect to the base station. In order to convert these readings into magnetic units, they were multiplied by 10.3, the scale value of the magnetometer, and recorded in column 8. The scale value was carefully measured at the beginning of the summer's work by means of a Helmholtz coil. The auxiliary magnet correction, if any, was recorded in column 9. The figures in column 10, the so-called time correction, contain both the corrections due to the diurnal change in the earth's magnetic field and the distributed "checking in" error. It is obtained by noting the time at which the reading was taken and referring to the graph of Figure 3 for the correction at that particular moment. For example, station 411 was read at 2:56. Referring to the graph we see that the difference in ordinates of the straight line and the broken line is 16 gamma, which is the figure recorded in column 10. The vertical magnetic intensity of the base station is recorded in column 11. The method of obtaining this will be described in a later paragraph.

LOG OF READINGS

FIELD INSTRUMENT MAGNETOMETER SURVEY

OBSERVER W. H. Jordan DATE Aug. 29, 1940 AREA Faulkton SCALE VALUE 10.3

STA.	TIME	TEMP.	READINGS			AV. - X.	GAMMA	AUX. MAG. COR.	TIME COR.	BASE VALUE Z	LAT. COR.	LONG. COR.	COR. INT.	BASE ADJ.	ADJ. INT
			N TO E	N TO W	MEAN	X=24.8									
K	7:40	19.8	25.1	24.5	24.8	0	0	0	0	141	0	0	141	+4	145
401	8:37	18.8	41.4	41.6	41.5	+16.7	+172	0	-3	141	-158	-35	117	+4	121
402	8:58	18.8	39.2	38.6	38.9	+14.1	+145	0	+1	141	-158	-53	76	+4	80
403	9:17	18.8	53.8	53.3	53.5½	+28.75	+296	0	+1	141	-211	-53	174	+4	178
404	9:39	18.8	51.6	51.2	51.4	+26.6	+274	0	+2	141	-245	-42	130	+4	134
405	10:01	20.2	50.6	49.6	50.1	+25.3	+261	0	+3	141	-245	-21	139	+4	143
406	10:24	20.2	59.0	58.2	58.6	+33.8	+348	0	+5	141	-202	-28	264	+4	268
407	10:53	21.5	41.0	41.0	41.0	+16.2	+167	0	+14	141	-202	-3	117	+4	121
K	11:42	23.0	23.8	23.2	23.5	-1.3	-13	0	+13	141	0	0	141	+4	145
						X=23.25									
K	12:47	23.2	23.3	23.2	23.2½	0	0	0	0	141	0	0	141	+4	145
408	1:39	24.0	40.9	40.6	40.7½	+17.5	+180	0	-8	141	-150	+30	193	+4	197
409	2:02	24.6	33.9	33.6	33.7½	+10.5	+108	0	-11	141	-150	+51	139	+4	143
410	2:28	25.0	33.3	32.7	33.0	+9.75	+100	0	-14	141	-150	+73	150	+4	154
411	2:56	25.0	55.7	55.0	55.3½	+32.1	+331	0	-16	141	-193	+80	343	+4	347
412	3:25	25.0	57.0	56.1	56.5½	+33.3	+343	0	-18	141	-245	+69	290	+4	294
413	3:54	25.3	41.2	40.8	41.0	+17.75	+183	0	-21	141	-193	+59	169	+4	173
414	4:25	25.6	44.1	43.7	43.9	+20.65	+213	0	-20	141	-202	+44	176	+4	180
K	5:23	26.0	25.4	25.1	25.2½	+2.0	+21	0	-21	141	0	0	141	+4	145

TABLE - II

In addition to the changes in the earth's magnetic field due to geologic structures, there is a steady change from the equator to the magnetic poles. This amounts to an increase of about 8.7 gamma per mile northward and an increase of about 3.6 gamma per mile eastward. Since this normal change in field is of no interest in searching for geologic structures it was eliminated from the picture by applying a latitude correction and a longitude correction. Then corrections were recorded in column 12 and 13 respectively. For examples, since station 411 is 22.2 miles north of the base station, a correction of 22.2 x 8.7 or -193 gamma was entered in column 12. Since this station was 22.3 miles west of the base station, a correction of 22.3 x 3.6 or +80 gamma was entered in column 13.

The corrected total intensity of each station is then formed by adding column 8, 9, 10, 11, 12, and 13 together. This sum is recorded in column 14.

The method of finding the intensity of the base station was not greatly different from the method of finding the intensity of any other station. The magnetometers were set up and readings taken at the base station. Then the field magnetometer was set up at some other station, the intensity of which was known. The field magnetometer was then brought back to the base station, set up, and read. The calculations were then carried out just the same as previously described except that the base value was called Z and the value of Z then determined so that the second station would have the value already assigned to it. This procedure was called "tieing" the base station.

In order that the magnetic map of the area surveyed this summer should connect onto the previous summer's map, some of the base stations were tied to stations located last year, as well as to each other. This is best illustrated by reference to Figure 4. The circles indicate the stations that were tied together. Stations 12, 83, 88, and 97 were measured last year and the intensities were taken from last year's report of investigations No. 33. A straight line connecting two circles indicates that those stations were tied together. Station 132 was not a base station, but an ordinary magnetometer station measured from both base A and base B. The small straight arrows with

UNADJUSTED BASE STATION GRID

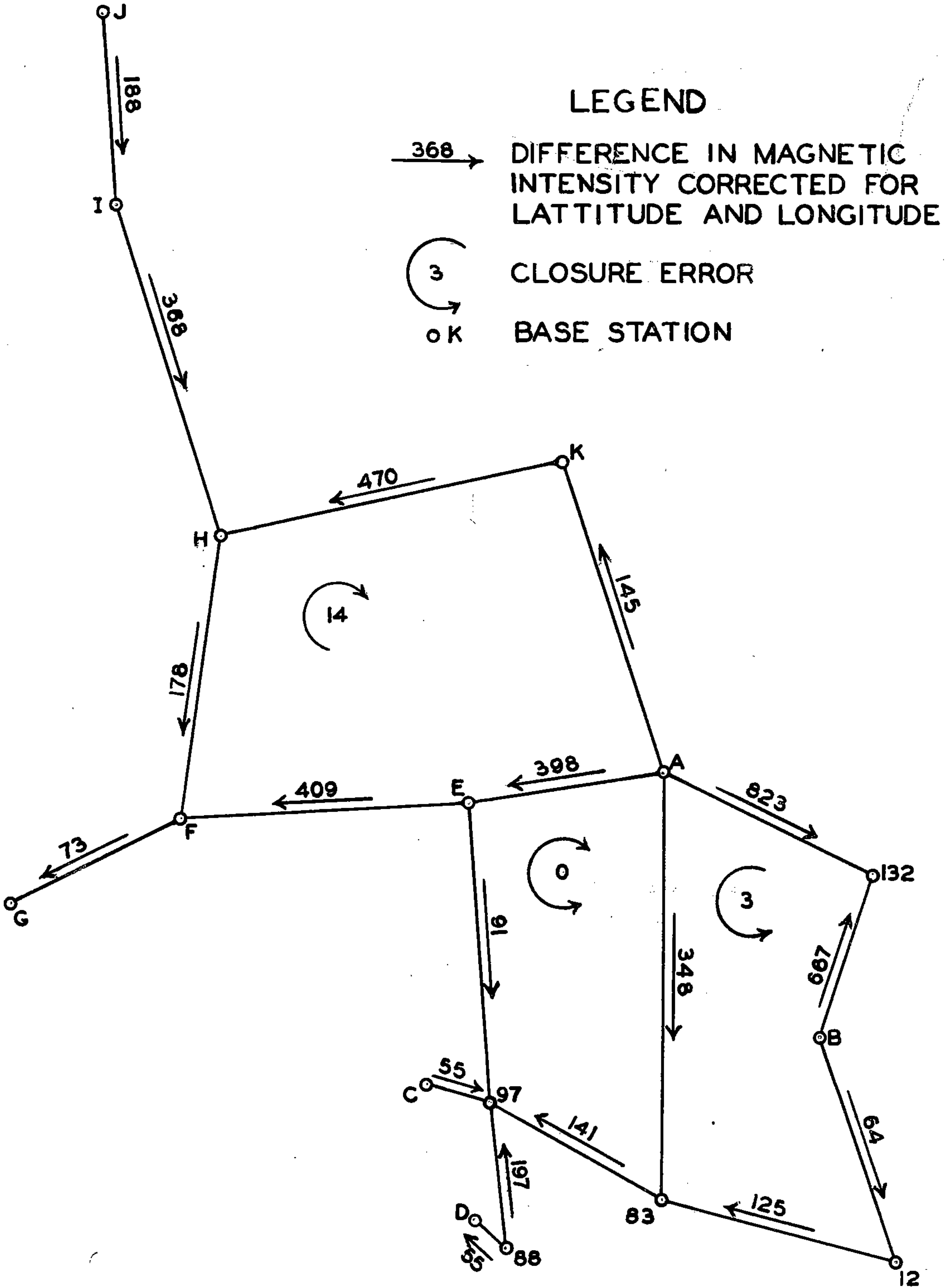


FIGURE - 4

numbers alongside indicate the direction and the difference in measured intensity, the arrow pointing toward the station of higher intensity. It will be noted that there are three closed circuits, the direction and amount of the closure errors being indicated by the circular arrows with the numbers inside. Making the extra ties required to obtain closed circuits gave a check on the accuracy of the work and permitted the errors to be distributed.

The errors were distributed and the circuits closed by the method of least squares. This merely involved the solution of three simultaneous equations, one for each circuit. The adjusted intensity differences are given in Table III. The unadjusted values are also given in this table as an aid to further work, for when more ties are made the entire network should be readjusted. It should be noted that the differences in intensity have been corrected for latitude and longitude changes.

This process of adjusting the networks to distribute closure errors changed the base values slightly. This change was called the base adjustment and was entered in column 15, Table II. Since changing the base value would also change all of the stations measured from that base, it was necessary to add column 15 to column 14 to obtain column 16, which is the adjusted intensity of each station and the value used in plotting the contours. The magnetic intensities and locations of all the stations measured during this summer are given in Table IV. The first station is numbered 119, for numbers 1 to 118 were assigned to stations located the previous year. Base stations were designated by letters A to K and are listed at the end of the table. The stations in this table are listed in groups, Group A being the stations that were measured from base station A, Group B being those measured from base station B, and so on. This is done to aid in carrying out the readjustment mentioned in the previous paragraph.

Considerable care was taken to make the results as accurate as possible. Readings were never taken hurriedly. The magnetometers were always read in two positions and at least two releases were made in each position. Failure of a magnetometer to give consistent readings was immediately

TABLE III

INTENSITY DIFFERENCES BETWEEN BASE STATIONS

(Arrow points to station of higher intensity)

Stations	Measured Value	Correction	Corrected Value
83 ← A	348 gamma	-1.35	346.65 gamma
12 ← B	64 "	+ 55	64.55 "
132 ← A	823 "	+ .55	823.55 "
132 ← B	667 "	- .55	666.45 "
97 ← C	55 "		
E ← A	398 "	-2.2	395.8 "
97 ← E	91 "	+ .8	91.8 "
F ← E	409 "	-3	406 "
G ← F	73 "		
H → F	178 "	+3	181 "
I → H	368 "		
H ← K	470 "	+3	473 "
A → K	145 "	+3	148 "
D ← E	55 "		
I ← J	188 "		

investigated and remedied. The base magnetometer was read carefully and frequently. Work was discontinued on days when the earth's magnetic field was found to be varying rapidly due to magnetic storms. The scale values of the magnetometer was determined by means of a Helmholtz coil and is believed to be correct within two per cent. Inaccuracies in reading and in making time and temperature corrections are believed to have never been more than 5 gamma.

The accuracy obtained is probably considerably greater than necessary for the immediate purpose of constructing a magnetic contour map, considering the size of the anomalies encountered. We were, however, anxious to obtain results in which we could have complete confidence. Also, if ever a more detailed survey of the region is made, the stations here located will be of great value for use as base stations.

The magnetometer stations were located on a map of the region and the adjusted intensity of each station indicated. Contour lines were then drawn through points of equal vertical intensity in the usual manner. A contour interval of 100 gamma was adopted. The result is shown on the large map at the end of this report.

Results

An inspection of the map at the end of this report will show considerable magnetic relief. The intensities are only relative to an arbitrarily selected base value. No attempt was made to obtain absolute values of intensity as it was not felt that this information would have any geologic significance.

It should be emphasized that contouring was rarely ever done on a single station. There was always a general trend which showed on the readings of a number of stations. That this is true in spite of the six-mile interval between stations, is particularly noteworthy. Only in one instance, the high in Faulk County near Seneca, was any exception found, and in this instance several supplementary stations were located, some of which were considerably higher than the one mapped.

The lowest reading was obtained near Miller and was -3 gamma. The highest reading was obtained in the northwest part of Hyde County and was 1402 gamma. Thus the total relief is over 1400 gamma.

A general trend in the northwest-southeast direction should be noted. This is particularly apparent in the trough running through Gann Valley. It can also be noted in the high region running south of Miller up past Highmore and Gettysburg toward Mobridge.

There are several highs that are particularly notable for having several hundred gamma closure and a very steep gradient. Among these should be mentioned the high located about on the line between Hand and Buffalo counties; the high in the northwest of Hyde County; and the high near Seneca in Faulk County. This last high was exceedingly sharp, and showed only on one station on the six mile grid. Supplementary stations located a half mile to a mile away, however, proved that the high does extend over a small area.

The high north of Onida shows a 400 gamma closure; the high east of Faulkton, a 300 gamma closure. The high in the northwest of Campbell County will probably have a 300 gamma closure. The high in the northern portion of Hand County covers a considerable area and might well have a large closure although more stations to the east are necessary to verify this. An anomaly of considerable magnitude seems to be shaping up in Beadle County.

Many other small anomalies are apparent; one south of Wessington Springs; one near Blunt; another northwest of Chamberlain. A very broad high seems to be centered in the north-central section of Potter County.

Anomalies which were partially surveyed and should be completed were found along the Missouri River. One near Big Bend; another south of Pierre. Still another is shown in the western part of Sully County and one near Mobridge.

THE INTERPRETATION OF MAGNETIC DATA

Method

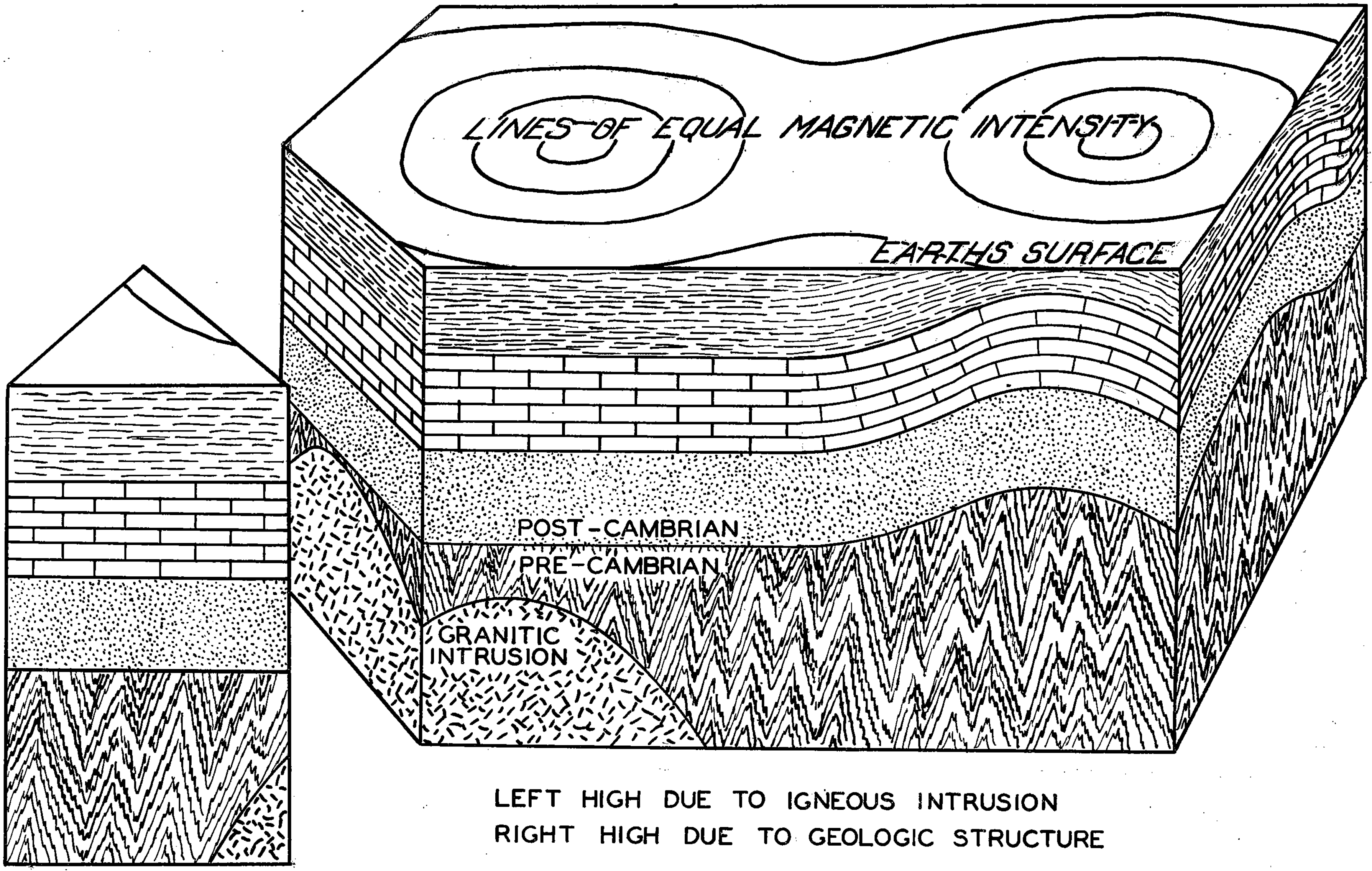
The interpretation of any geophysical data depends to a large extent upon the geological information available. Seismic reflections, variations in the pull of gravity, and resistivity anomalies can be caused by so many things that the operator must know what is causing them before he can use geophysical data with accuracy. The chief function of geophysical prospecting is to follow known horizons and locate rock masses. Anticlinal and other structures can be determined by measuring geophysically the distance below the surface to a known heavy limestone or other formation which will give good reflection of seismic waves, or usable reactions to gravitational or electrical and magnetic properties of the earth. Masses of rock like the buried salt domes on the coast of the Gulf of Mexico can be outlined with the same tests because of the difference between the physical properties of the salt and the surrounding rocks.

Possible Causes of Magnetic Variations

If the earth were a homogeneous mass, the magnetic variations at points over its surface would vary regularly with the distance from the magnetic poles and the center of the earth. Since it is not a homogeneous mass, however, we find such variations in the magnetic field on the surface as are shown on the map accompanying this report. The question to be solved in interpreting these variations, therefore, is what causes them? Once such causes are known, the underground conditions become predictable with reasonable accuracy.

One very potent cause is the presence of a large mass of volcanic rock. Most of these bodies are intrusions which have been injected into the overlying and surrounding rocks by the various processes of vulcanism. In most cases such volcanic rock is more highly magnetic than the rock which it intrudes. Consequently it exerts a greater pull on the magnetic needle and makes notable "highs" in the readings of magnetic stations carried over them.

TWO CAUSES OF MAGNETIC HIGHS



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

FIGURE - 5

A second cause of variation is the accumulation of magnetic iron in metamorphosed rocks. Such accumulations are common in the iron regions of the Lake Superior district and may occur deeply buried in the pre-Cambrian rocks of many other regions. Such bodies of iron disturb not only the dip needle of the magnetometer but the horizontal needles of compasses to such an extent that they are rendered useless in some places.

A third possible cause of variation is magnetic material collected along old sea shores. This usually consists of magnetite sands which are washed from old granitic land masses and deposited as beaches on ancient strand lines. Such shores may be deeply buried but still exert a powerful pull on the magnetometer. The magnetic map will show long, narrow "highs" over such beaches.

A fourth cause of variations is fluctuation in the depth of the pre-Cambrian rocks below the surface. If, as is usually the case, these dense rocks are more highly magnetic than the overlying sediments, they will exert a greater magnetic pull where they lie near the surface than where they lie deep. Thus in regions where the surface of the pre-Cambrian is not level, it is possible to pick out buried ridges or high spots by corresponding highs in the magnetic field. This has been illustrated in the diagram accompanying this report (Fig. 5).

Causes of Magnetic Variation Operating in South Dakota

In the area covered by this survey, bedrock is concealed beneath a thick coat of glacial drift. Little is known of this bedrock except what has been gleaned from well logs and projected from outcrops in the Missouri Valley. The details of the changes as older sediments lap onto the ancient land masses in the eastern part of the state are not known, and though the position and character of these sediments have been the subject of much speculation, only generalities have been brought to light.

From what is known, however, it seems certain that the Paleozoic and Cretaceous sediments are less magnetic than the rocks of the pre-Cambrian group on which they rest.

No accumulations of magnetite or other magnetic substances have been observed in any of the exposed formations, nor have they been reported from well cuttings. In fact, the sands exposed in drilling water wells have been remarkably free from such material. The magnetic highs and lows, therefore, which have been disclosed by this survey may safely be interpreted as the result of variations in the pre-Cambrian foundation.

Little is known of the character of the pre-Cambrian rocks underlying most of the state. It outcrops only in three small areas. In the southeast quarter its outcrops and well records show a very thick, pink quartzite intruded here and there by light colored masses of granite. Well records in the east-central part of the state show that this quartzite thins out and gives way to gneisses. In the northeast corner of the state the pre-Cambrian again outcrops as a huge granite batholith and in the core of the Black Hills it appears as a great series of schists and quartzites, intruded by another large granite batholith.

Thus it is evident that the pre-Cambrian contains within itself rock masses which differ considerably in material and can differ greatly in magnetic properties. Without doubt these variations are reflected in magnetometer readings made at the surface, and it is possible that some of the magnetic "highs" are due to this cause. It would be very unsafe to attempt to interpret the magnetic map in geological terms without keeping this possibility clearly in mind.

The continuity, size and shape of the large highs mapped thus far in South Dakota do not suggest local causes, however. They are rather the sort of anomalies that could occur over high and low pre-Cambrian areas. Continuous low readings can be traced for distances of eighty miles. Between them lie belts of persistent high readings. Two such low zones are especially noticeable. One starts near the southeastern corner of the map and can be traced in a fairly straight northwesterly direction past Gann Valley and Onida to the Missouri River. Readings in this trough lie close to two hundred gamma. A second trough branches from the first just west of Wessington Springs running north and northwest past Miller, Faulkton, Bowdle, Mound City, and Herreid. These readings also give values of about two hundred gamma.

Between these troughs lie belts of high readings whose maxima average about seven or eight hundred gamma. An unusually high one in northern Hyde County reaches a value of fourteen hundred gamma. Three of these belts of high values were included in the area mapped. One lies near the Missouri River roughly following its course. The second and largest runs through Hand, Hyde, Potter, Walworth, and Campbell counties. The third lies at the eastern edge of the area mapped along the line beginning at Wolsey, running through Rockham and ending about six miles northeast of Faulkton. The readings along these highs are not uniform, but form a series of peaks or domes separated by saddles which in some places reach values only one hundred gamma above those of the neighboring trough areas.

It would appear, therefore, that these larger troughs and highs were caused by variations in the elevation of the pre-Cambrian surface. Interpreted thus, this buried surface should have three northwest trending ridges separated by two low troughs, in the area thus far mapped.

The tops of these highlands are not level, but consist of a series of large hills or knob-like projections covering large areas. One in southern Hand County covers six townships. The largest one, which lies in Hyde and Faulk County, covers eight townships. Others less pronounced lie in the vicinity of Wolsey and Rockham, northern Potter County, between Gettysburg and Akaska, in Campbell County northeast of Eureka, near Fort Thompson and Blunt. The northwest-southeast trend of these major troughs and corresponding highs described above corresponds to the general trend of the small structures which have been mapped from surface outcrops and with the trend of the axis of the Lemmon geosyncline--the major structural feature of western South Dakota. One small high west of Chamberlain follows quite closely the location of a long anticline mapped from surface outcrops.[1] It is not possible to check the structure east of the Missouri so easily, however, because of the thick cover of glacial drift.

---

[1] M. E. Wing, Structural Conditions in the Vicinity of Chamberlain, South Dakota, South Dakota State Geological Survey, Report of Investigations No. 39, 1940.

Recommendations

It cannot be stressed too strongly that a magnetic map is not a map of geologic structure, nor an indicator of oil and gas fields. When intelligently used, however, it does serve as a guide to favorable prospecting areas. If used as such the "highs" are the logical places to look for structure, since they may indicate ridges in the pre-Cambrian rocks which can be reflected in overlying sediments.

The areas most favorable for prospecting, therefore, would be the regions within the dome-like contours on the backs of the three long ridges mentioned above. Such places as the large highs in southern Hand and northern Hyde and Faulk counties and large flat highs like those in Potter and Walworth counties, offer excellent prospecting grounds.

The small areas covering less than a township are also worthy of attention as some of them follow known structures. They are as likely to be caused by intrusions and other local conditions as by domes or ridges in the pre-Cambrian rocks and therefore offer a larger element of chance. In a thorough job of prospecting, however, they should not be ignored.

When all is said and done, the magnetic survey leaves a great many questions to be answered, but until further light has been shed on the geology of the region, these magnetic variations offer the only clue to what may lie beneath the surface, and prospecting should be guided accordingly.

TABLE IV

Location of Stations
and
Magnetic Intensities

GROUP A

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
119	111N	67W	19	NE	387	388
120	110	67	17	SE	139	140
121	109	67	16	NE	239	240
122	109	67	36	SW	222	223
123	109	66	18	NE	50	51
124	110	66	19	NE	284	285
125	111	66	18	SE	216	217
126	112	66	18	NE	461	462
127	112	66	1	NE	462	463
128	112	65	1	NE	469	470
129	111	65	6	SW	346	347
130	112	65	36	SE	568	569
131	112	64	36	SW	693	694
132	110	64	12	NE	819	820
133	110	65	12	NE	406	407
134	110	65	7	NW	227	228
135	113	66	17	NW	362	363
136	114	67	32	SW	400	401
137	114	68	10	SE	517	518
138	114	66	36	SE	365	366
139	114	66	2	NE	432	433
140	116	66	36	SW	705	706
141	116	67	36	SE	805	806
142	115	67	36	SE	609	610
143	112	70	11	NE	705	706
144	112	70	34	SE	488	489
145	110	70	1	NW	607	608
146	109	70	12	NW	365	366
147	115	68	10	NE	736	737
148	115	69	13	NW	668	669
149	114	69	12	SW	295	296
150	114	69	34	SE	280	281

GROUP B

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
151	108N	66W	36	SW	79	78
152	108	66	2	NE	112	111
153	110	66	36	SE	24	23
154	109	65	1	NE	223	222
155	109	65	36	SE	196	195
156	108	65	36	SE	232	231
157	107	66	35	SW	152	151
158	106	66	35	SW	57	56
159	104	66	3	SE	67	66
160	104	65	10	NW	417	416
161	105	65	3	NE	165	164
162	108	64	36	SE	461	460
163	109	64	36	SE	355	354
164	109	64	1	NE	329	328
165	106	65	3	NE	490	489
166	106	64	2	NW	250	249
167	105	64	2	NW	237	236
168	104	64	10	NE	259	258
GROUP C						
169	107	71	14	NW	530	530
170	107	70	15	NW	363	363
171	108	70	14	NW	142	142
172	107	72	18	NW	400	400
173	108	73	12	SE	787	787
174	108	72	2	SE of SW ¼	441	441
175	109	71	35	SW	233	233
GROUP D						
176	104	72	5	NW	351	351
177	105	73	27	SW	298	298
178	105	73	9	NE	334	334
179	106	73	15	SW	403	403
180	107	73	28	SE	451	451
181	107	73	14	Center NE¼	477	477
182	108	73	8	NE	339	339
183	105	72	36	SE	460	460
184	105	71	18	NW	332	332
185	106	71	19	SE	350	350

Section	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
186	106N	72W	4	SW	310	310
187	105	72	4	SW	443	443
188	106	74	14	NW	441	441
189	105	72	15	SE of SW ¼	395	395
GROUP E						
190	111	71	16	NE	219	218
191	110	71	4	NE	381	380
192	110	71	34	SW	190	189
193	109	72	11	SE	138	137
194	114	70	35	SW	430	429
195	114	70	2	NW	184	183
196	116	70	34	SE	389	388
197	115	71	3	NW	415	414
198	115	71	34	SW	575	574
199	113	72	26	SE	608	607
200	114	72	36	NW	510	509
201	115	72	26	SE	864	863
202	116	72	26	SE	916	915
203	116	72	7	SE	1401	1400
204	115	72	7	SE	1302	1301
205	114	72	7	SE	801	800
206	113	72	7	SE	662	661
207	113	73	27	SW	487	486
208	114	73	28	SE	941	940
209	115	73	28	SE	732	731
210	116	73	34	NW	1352	1351
211	112	72	26	SE	412	411
212	111	72	23	SE	346	345
213	110	72	23	NE	198	197
214	109	73	1	SW	478	477
215	110	73	28	NE	245	244
216	111	73	27	NW	387	386
217	112	73	34	NW	603	602
218	112	72	17	NW	679	678
219	113	71	16	NE	586	585
220	111	72	17	NW	171	170
221	110	72	8	NW	308	307

GROUP F

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
222	112N	74W	21	NW	550	546
223	111	74	21	NW	287	283
224	110	74	20	SE	371	367
225	110	75	29	NE	412	408
226	111	75	17	SE	359	355
227	112	75	17	SW	359	355
228	111	76	21	NW	783	779
229	111	77	17	SW	590	586
230	112	77	7	SE	491	487
231	113	77	23	NE	378	374
232	114	77	24	NW	373	369
233	113	74	22	NW	690	686
234	113	75	22	NE	652	648
235	114	75	14	SW	537	533
236	114	76	13	SW	610	606
237	113	76	14	SE	533	529
238	114	74	15	SW	612	608
239	115	74	23	NW	717	713
240	115	75	24	NW	416	412
241	115	76	23	NE	304	300
242	115	77	23	SE	923	919
GROUP G						
243	111	79	16	SW	505	501
244	112	79	16	SW	541	537
245	112	80	15	NW	492	488
246	113	80	10	SE	281	277
247	114	80	3	SE	265	261
248	114	81	2	SW	741	737
249	113	81	1	SW Cor SE ¼	404	400
250	110	78	16	NW	775	771
251	110	77	17	SW	621	617
252	110	76	17	SW	554	550
253	111	78	19	NE	387	483
254	112	78	17	SE	578	574
255	113	78	22	NE	614	610
256	113	79	11	SW	535	531
257	109	75	21	SE	353	349

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
258	109N	74W	28	NW	322	318
259	108	74	16	SW	638	634
260	108	75	21	NE	247	243
261	109	76	2	NW	326	322
262	114	78	15	SE	272	268
263	115	78	26	NW	271	267
264	115	79	27	NE	254	250
265	114	79	23	NW	309	305
GROUP H						
266	117	76	13	SE	461	454
267	116	76	23	SE	425	418
268	116	75	24	SW	393	386
269	116	74	27	NE	698	691
270	117	74	25	NE	579	572
271	117	73	25	NW	784	777
272	117	74	19	SW	472	465
273	118	74	27	NW	432	425
274	118	75	29	NE	540	533
275	116	77	24	SW	476	469
276	117	76	19	NW	608	601
277	116	78	23	SW	594	587
278	116	79	22	SE	236	229
279	115	80	1	NE Cor SW ¼	379	372
280	115	80	18	NE	369	362
281	117	78	30	NE	440	443
282	117	78	24	NE	599	592
283	119	75	36	SE	527	520
284	118	74	1	NE	300	293
285	118	73	2	SW	326	319
286	118	72	30	NW	481	474
287	118	76	21	SW	608	601
288	118	77	21	SW	488	481
289	118	79	31	SE	454	447
290	118	78	21	NE of SW ¼	455	448
291	119	78	30	SE of NW ¼	533	526
292	119	76	30	NE	617	610
293	120	76	30	NE	777	770
294	120	77	19	SW	495	488
295	119	77	20	SW	556	549

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
296	119N	73W	10	NE	377	370
297	120	74	36	NE	618	611
298	120	73	10	NE	210	203
299	120	74	9	NE	514	507
300	120	73	10	NW	230	223
301	119	74	7	NW	548	541
302	119	75	30	NW	598	591
303	120	76	25	NE	693	686
304	120	75	4	NW	708	701
GROUP I						
305	122	78	24	NW	404	397
306	123	77	19	NW	252	245
307	123	77	24	SW	680	673
308	122	77	23	SW	522	515
309	121	77	23	SW	633	626
310	121	78	23	SW	393	386
311	121	76	25	NW	613	606
312	122	76	26	NE	592	585
313	123	76	26	NE	209	202
314	123	75	24	SW	251	244
315	123	74	26	NE	222	215
316	122	74	16	NW	112	105
317	121	74	5	SE	257	250
318	122	75	23	SW	327	320
319	124	75	27	NE	282	275
320	124	76	23	NE	233	226
321	124	78	24	SE	300	293
322	124	79	24	SE	304	297
323	123	79	13	SE	351	344
324	124	80	25	NW	609	602
325	125	79	28	NW of NE ¼	257	250
326	125	78	27	NW	306	299
327	125	77	28	SE	276	269
328	124	77	24	SE	303	296
329	125	76	21	SW	279	272
330	126	76	30	SW	228	221
331	126	78	36	NE	234	227
332	124	74	25	NW	423	416
333	123	73	25	NW	184	177
334	122	73	9	SE	187	180
335	121	73	9	NE	232	225

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
336	124N	73W	36	NW	383	376
337	125	73	20	SE	407	400
338	125	74	28	NW	272	265
339	125	75	28	NW of NE¼	185	178
GROUP J						
340	126	75	30	SW	199	192
341	126	75	36	NE	170	163
342	126	74	36	SE	250	243
343	125	73	2	NW	288	281
344	126	73	5	NE	288	281
345	126	74	4	NW	204	197
346	128	75	32	SW	195	188
347	127	74	4	NW	580	573
348	127	73	8	NE	306	299
349	128	73	12	SW	268	261
350	128	74	12	NE	203	196
351	128	75	1	SE	180	173
352	128	75	6	SE	126	119
353	126	76	4	NE	147	140
354	127	75	33	SE	162	155
355	126	77	3	NW	55	48
356	127	78	34	SW	49	42
357	127	78	3	NW	73	66
358	127	77	5	SE	73	66
359	127	76	5	NW	81	74
360	128	77	12	SE	112	105
361	128	77	17	NW	137	130
362	128	78	8	SW	156	149
363	128	79	8	NE	133	126
GROUP K						
364	117	69	35	SW	419	423
365	117	70	34	SE	343	347
366	117	71	35	SW	188	192
367	117	71	7	NE	318	322
368	117	72	27	NW Cor NE ¼	571	575

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
369	118N	72W	2	SW	1032	1036
370	118	71	10	SE	353	357
371	118	70	11	SW	261	265
372	117	70	7	NE	236	240
373	117	69	8	NW	173	177
374	117	68	34	SE	402	406
375	117	67	35	SW	872	876
376	117	66	34	SE	580	584
377	117	66	1	SW	242	246
378	118	66	22	NE	190	194
379	118	67	10	SE	48	52
380	117	66	6	SW	306	310
381	117	67	8	NW	168	172
382	117	68	6	SE	210	214
383	118	68	15	NE	594	598
384	119	70	20	NW	188	192
385	119	71	8	SE	227	231
386	119	72	10	NW	233	237
387	120	72	13	NW	189	193
388	120	71	11	SW	202	206
389	120	70	15	NE	300	304
390	119	67	15	NE	311	315
391	119	66	13	NW	53	57
392	120	66	11	SE	59	63
393	120	67	14	NW	92	96
394	120	68	16	NE	125	129
395	119	68	9	SE	133	137
396	119	69	11	SW	206	210
397	119	70	11	NE	225	229
398	120	69	11	SW	179	183
399	121	69	23	NW	266	270
400	121	68	22	NE	141	145
401	121	67	11	SW	117	121
402	121	66	15	NW	76	80
403	122	66	15	NW	174	178
404	123	66	30	NW	130	134
405	123	68	25	NE	139	143
406	122	67	21	NW	264	268
407	122	68	18	SE	117	121
408	121	70	22	NE	193	197

Station	Township	Range	Section	Corner	Vert. Intensity	Adj. Intensity
409	121N	71W	22	NE	139	143
410	121	72	22	NE	150	154
411	122	72	28	NW	343	347
412	123	72	26	NE	290	294
413	122	71	29	NE	169	173
414	122	71	24	NE	176	180

BASE STATIONS						
A	112N	67W	7	NE	4	-3
B	107	65	12	NW	155	154
C	107	72	22	SW of SE ¼	430	430
D	104	71	17	SW of SE ¼	343	343
E	112	71	16	SE of NE ¼	394	393
F	112	76	17	SW of NE ¼	803	799
G	5N	31E	21	NW ¼ of SE ¼	876	872
H	117N	75W	10	NE of SE ¼	625	618
I	124	76	31	SE	257	250
J	127	77	13	SW of NE ¼	69	62
K	118	69	13	NE	141	145