A VERTICAL MAGNETIC INTENSITY SURVEY OF A PORTION OF SOUTH CENTRAL MICHIGAN

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY

James Walter Brett

1960

A VERTICAL MAGNETIC INTENSITY SURVEY OF A PORTION OF SOUTH CENTRAL MICHIGAN

by

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Submitted to the College of Science and Arts of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Geology

1960

-ACKNOWLEDGEMENTS-

The author wishes to express his sincere appreciation to Dr. William Hinze for his direction and suggestions which aided greatly in the completion of this project.

He also wishes to thank Dr. James Trow and Dr. James Fisher of the Geology Department of Michigan State University for their helpful suggestions pertaining to the project.

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ABSTRACT

The vertical magnetic intensity of Eaton, Clinton, Shiawassee and Ingham counties was measured with a Schmidt-type magnetometer. A three mile station spacing was used.

Wherever possible, three or four readings were taken in the vicinity of the desired station location. The arithmetic mean of the readings was used as the value of vertical intensity for the station site. The standard deviation for each group of observations was computed. The presence of a few high standard deviations in areas of low magnetic gradient indicates that the magnetic readings are affected by magnetic material in the glacial drift.

A vertical magnetic intensity map was prepared utilizing a twenty-five gamma contour interval. Several anomalies were found in the mapped

area. The western extension of the Howell anticline is indicated by high magnetic readings in southeastern Ingham County. Two magnetic highs and one low were found in southern Eaton County. The vertical intensity values display a considerable increase northward in northern Clinton County and northwestern Shiawassee County.

Depth estimations by Peters' "Slope" Method gave a range of 5,016 feet to 7,920 feet in southern Eaton County. The actual depth is not known, but is thought to be in the vicinity of 7,500 feet.

Vacquier's method of aeromagnetic interpretation was used on one anomaly in southern Eaton County. Depth estimations gave an average depth of 7,177 feet. The magnetic susceptibility contrast was found to be .001 which assuming a generally granitic basement would indicate a source material such as gabbro.

The vertical magnetic intensity map was compared with a Bouguer gravity map of the same area. The variation in vertical intensity was reflected in the Bouguer Gravity map.

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INTRODUCTION

Location and Extent

The area of study in this investigation is shown in Figure 1. It is included within 42°25' and 43°08' north latitude and 83°56' and 85°07' west longitude and covers Eaton, Ingham, Clinton, and Shiawassee counties of Michigan.

The area of study is located west of the Howell anticline and covers slightly more than 2200 square miles.

Purpose of Investigation

The purpose of the investigation was threefold:

1. To outline the vertical magnetic intensity of the area.

2. To determine the magnetic effect of glacial drift on a reconnaissance vertical magnetic intensity survey.

3. To correlate the magnetic data with known geological and geophysical data.

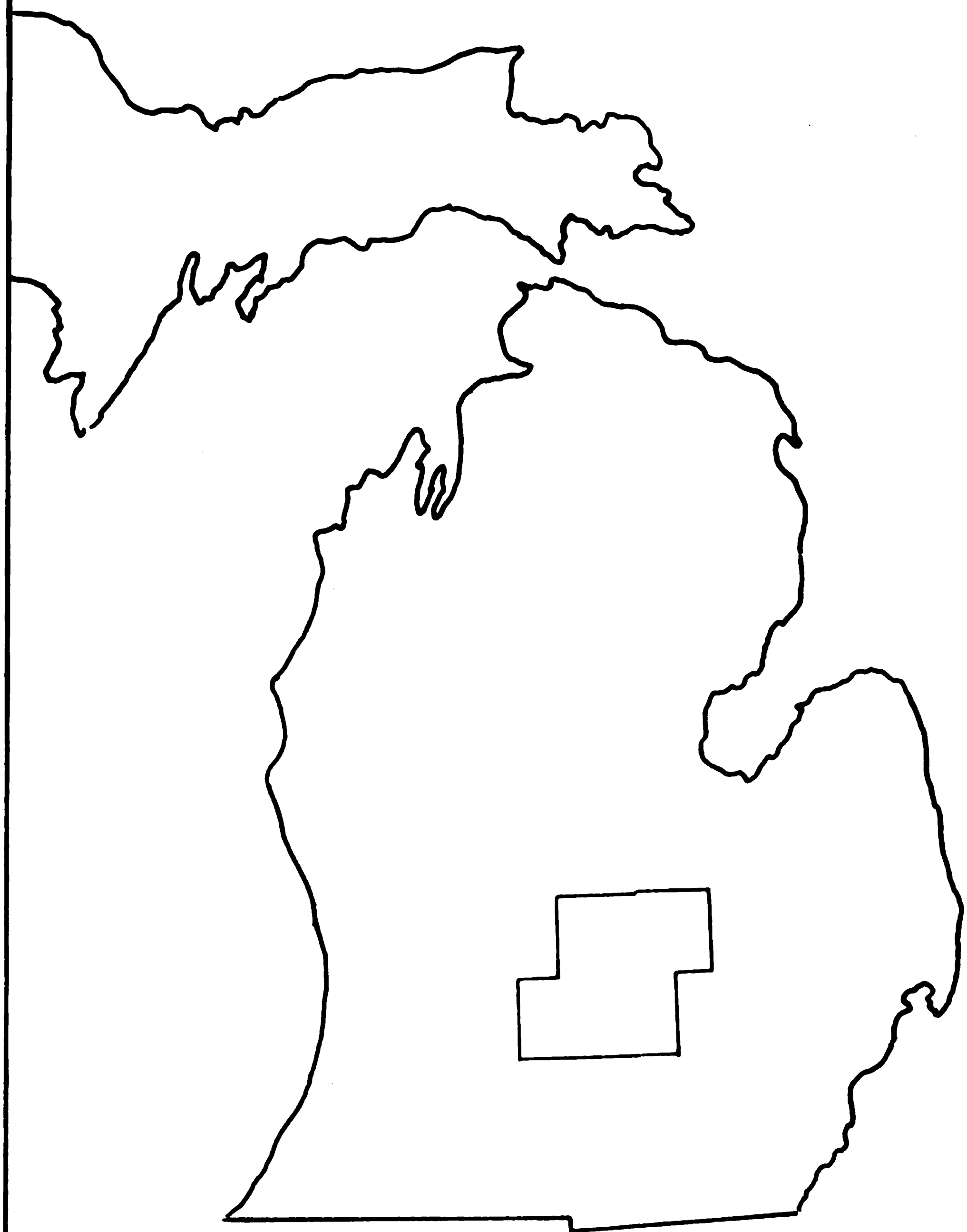


FIGURE 1. LOCATION MAP

Previous Investigations

There is very little information available pertaining to the variations in vertical magnetic intensity over the southern peninsula of Michigan. However, there have been several geophysical surveys, both gravity and magnetic, completed over the Howell anticline. Much attention has been directed toward the Howell anticline because it is the largest and most prominently known structure within the Michigan basin. It is located in Livingston County which is directly to the east of Ingham County.

The first magnetic survey of significance was carried out by Hunt (1952). He interpreted the pronounced magnetic anomaly associated with the Howell anticline as being due to variations in basement relief. The proposed basement high was determined to have a maximum relief of 3,000 feet.

Later, Kinder (1954) re-evaluated Hunt's original survey and on the basis of Trenton deep tests suggested that the anomalies were due, primarily, to lithologic changes of the basement complex.

An extension and reinterpretation of work completed by Kinder was carried out by Behrens (1958). He extended the surveyed area to cover the extreme eastern portion of Ingham County and the northern half of Washtenaw County. Several possible geologic interpretations were suggested, all having to do with changes in the lithology of

the basement complex. Diorite or greenstone were suggested as being the most likely source of the anomaly. Behrens' work is based on Nettleton's solid angle method of calculating the magnetic effects from theoretical bodies. He assumed that the Precambrian surface is horizontal and that the depth to the anomalous body was 6,600 feet.

Many petroleum companies have compiled a considerable amount of geophysical data on the lower peninsula of Michigan. However, it is doubtful if this information will be released.

FIELD PROCEDURES

Station Location

The magnetometer will yield erroneous readings in the presence of metallic objects. Consequently, extreme care was exercised in the selection of station sites. In particular, telephone and power lines, steel culverts, pipe lines, wire fences, automotive vehicles, and farm machinery were avoided. Heiland (1941) lists the safe distance criteria for observations made near many of these objects.

Control points were established by averaging readings from several stations in the immediate vicinity of the desired point. A total of 828 magnetic observations were made, with 293 control points established from these observations. A map indicating the location of all control points is shown in Figure 2.

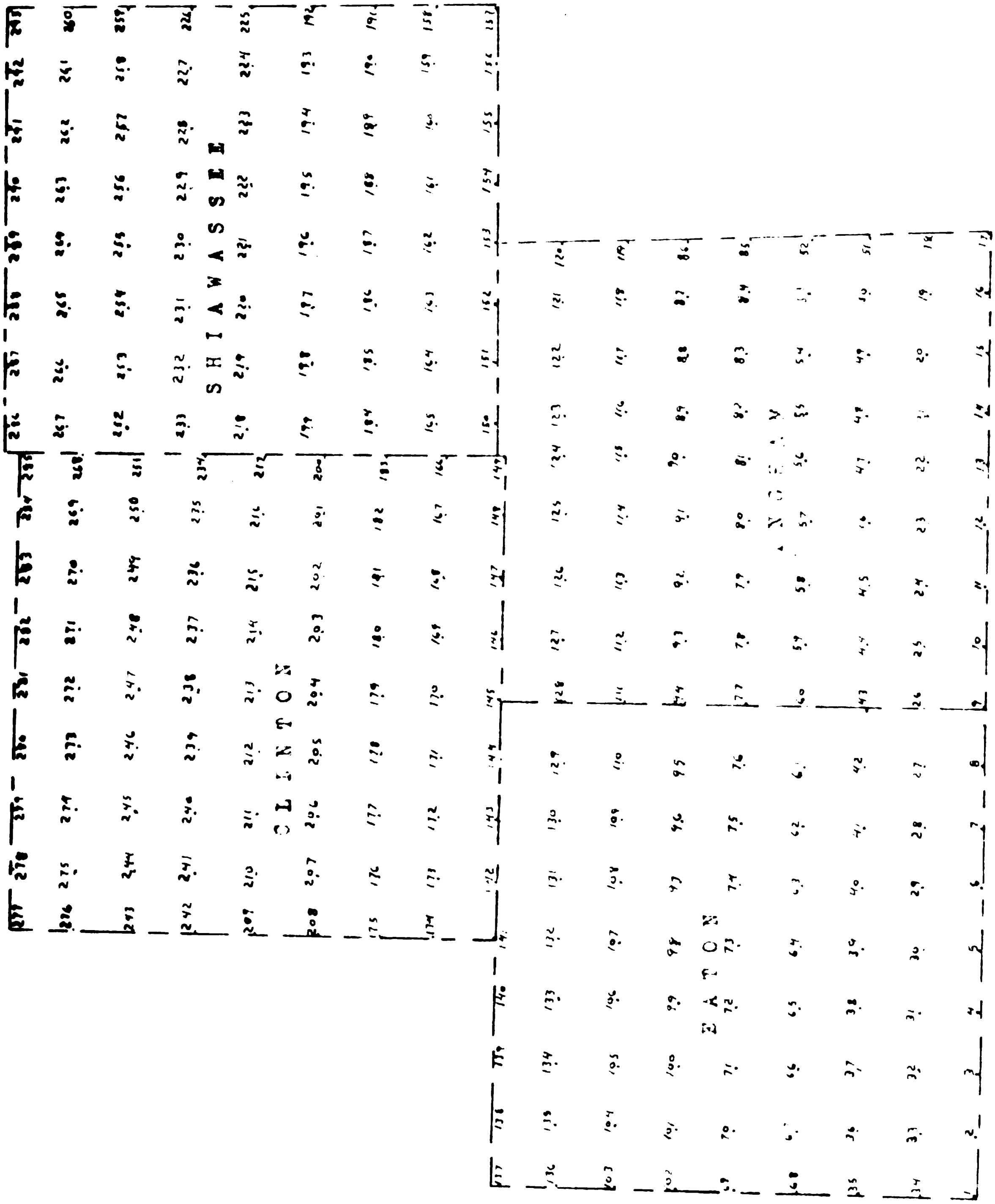


FIGURE 2. CONTROL POINT LOCATION MAP

The control points are at approximately three mile intervals in a grid system throughout the area. Town and Range lines were used as a basis for the station network. Readings were taken on township corners, half-way between the corners, and directly in the center of the individual townships.

In a few cases the stations were inaccessible by road. Consequently, it was necessary to pick an accessible point which was close to the desired location.

In most cases, three or four readings were taken in the vicinity of the control point. The readings consisted of one reading on the control point and two or three more readings at 0.1 mile intervals in several directions from the point. However, in residential and inaccessible areas it was impossible to secure more than one or two readings.

Instrument

The instrument used for the field work is a Schmidt-type magnetic field balance which measures relative changes of the vertical component of the earth's magnetic intensity.

The magnetometer contains a magnetic needle system balanced on a knife-edge about its horizontal axis and oriented with reference to the magnetic meridian. To measure the vertical component, the needle is oriented at right angles to the magnetic meridian and is balanced to come to rest in an approximately horizontal position (Ruska, 1957).

The instrument is equipped with a tripod and an orienting compass.

The calibration constant of the magnetometer as determined with Helmholtz coils by W. J. Hinze in July, 1959, is 12.69 gammas per scale division.

GEOGRAPHY OF THE AREA

Eaton, Ingham, Clinton, and Shiawassee counties display a variety of glacial land forms. Glacial features such as moraines, outwash plains, and till plains are common throughout the area (Martin, 1957).

In general, the relief varies from approximately 700 feet in the northern portion of Clinton County to approximately 950 feet in the southern portion of Eaton County.

The area is extensively farmed. Soil types ranging from muck to a light sandy loam are found throughout the area.

The area of study is primarily an agricultural community. However, due to the presence of large industry, particularly in Lansing, many factory workers have settled in rural areas. Consequently, many dwellings are found along country roads. Quite often these buildings are clustered around crossroads and interfere with the procedure used in establishing magnetic observations for the determination of control points.

GENERAL GEOLOGY OF THE AREA

The stratified rocks of the southern peninsula of Michigan are downwarped into a large synclinal trough which is termed the Michigan basin. The center of the basin is near the geographic center of the southern peninsula. Clinton, Shiawassee, Eaton, and Ingham counties are located south of the center of the basin. Early work by the Michigan Geological Survey and by Martin (1957) indicates that the glacial drift in these counties is underlain by the Grand River and Saginaw formations of Pennsylvanian Age and the Bayport and Michigan formations of Mississippian Age.

Figure 3 gives a generalized stratigraphic column for Michigan.

The four counties are extensively covered by glacial drift of the Pleistocene Age. In general, the glacial drift varies in thickness from 0 to 300 feet and consists of sand, gravel and boulder clay.

Preglacial drainage troughs are known to exist in this area. Moore (1959) has outlined the path of the Durand trough in his study of the Pre-Pleistocene surface of Shiawassee County. Other drainageways are known to exist in Eaton and Clinton counties.

SYSTEM	FORMATION	CROSS SECTION	THICKNESS	DESCRIPTION
PLEISTOCENE			330	GLACIAL DRIFT
PENN.	SAGINAW		?	SANDSTONE
MISS	MICHIGAN		73	SANDSTONE AND SHALES
	MARSHALL		235	SANDSTONE
	COLDWATER		990	SHALE, GREY WITH SANDY SHALE NEAR BASE.
	SUNBURY			SHALE, BLACK
	BEREA-BEDFORD		207	SANDSTONE - SHALE, GREY
DEVONIAN	ANTRIM		207	SHALE, BLACK, BITUMINOUS
	TRAVERSE		354	LIMESTONE AND SHALE, INTERBEDDED
	DUNDEE		278	LIMESTONE, BUFF
	DETROIT RIVER		713	DOLOMITE
	SYLVANIA		358	SANDSTONE, WHITE, FEW THIN DOLOMITE BEDS
SILURIAN	BASS ISLAND		514	DOLOMITE, CHERTY
	SALINA		1652	SALT INTERBEDDED WITH DOLOMITE, ANHYDRITE, SHALE, AND SOME GYPSUM
	NIAGARAN		329	DOLOMITE AND SHALE
	CATARACT		276	DOLOMITE AND SHALE
ORD	CINCINNATIAN			DOLOMITE AND SHALE
	TRENTON		1310+	LIMESTONE
	ST. PETER			SANDSTONE
CAMB	UNDIFFERENTIATED		974?	SANDSTONE OVERLAIN BY DOLOMITE

FIGURE 3. GENERALIZED STRATIGRAPHIC COLUMN FOR SOUTH CENTRAL MICHIGAN

VERTICAL SCALE 0 —— 1000 FEET

Cohee (1945) estimated that the center of the Michigan basin is in the vicinity of southeastern Clare and southwestern Gladwin counties. This relationship is shown by means of a contour map of the top of the Precambrian in Figure 4.

The structure of the Michigan basin, which Newcombe (1933) and Pirtle (1932) have discussed, is complicated with trends of folding developed during various periods of deformation. Both authors consider the Michigan basin to have originated in Precambrian time and to have been subjected to folding at various times with important deformation occurring in late Mississippian time. Cohee (1945) suggests the addition of post-Shakopee and pre-St. Peter folding which affected the major structural features bordering the Michigan basin and probably structures within the basin.

REDUCTION OF DATA

Magnetic Observations

Errors made when orienting a Schmidt-type magnetometer can be partially eliminated by taking two readings at each station. These readings are referred to as the East reading and the West reading; the East reading being made with the instrument oriented so that the north pole of the magnet is toward the magnetic east; and the West reading with the north pole of the magnet toward the magnetic west.

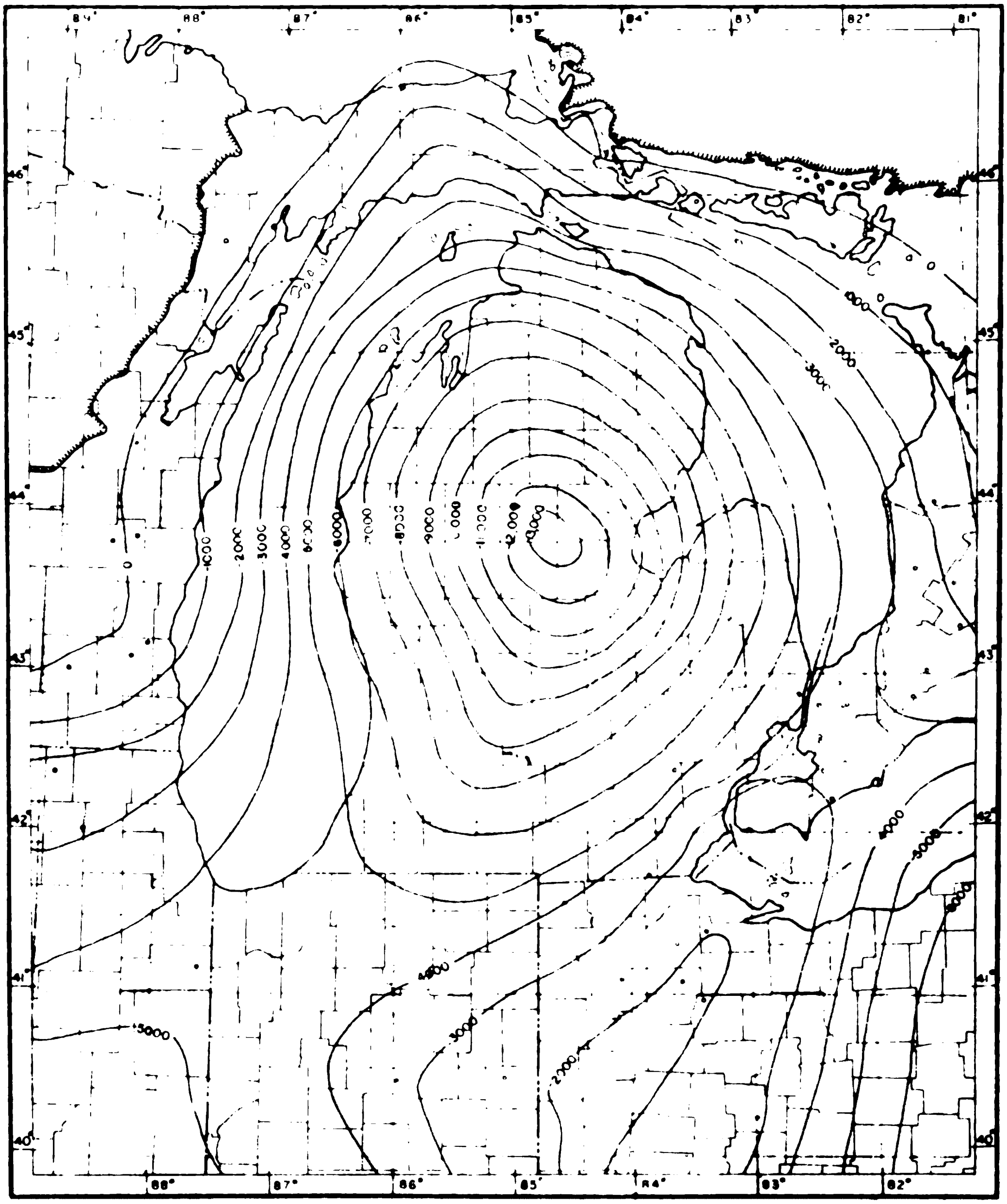


FIGURE 4 CONTOURS ON TOP OF PRE-CAMBRIAN

CONTOUR INTERVAL 1000 FT.

BOUNDARY OF PRE-CAMBRIAN AT SURFACE

• CONTROL POINT (COHEE 1945)

SCALE

0 25 50 75 MILES

These readings are averaged to give the observed magnetic value in scale divisions at the particular station.

The observed value is multiplied by the instrument scale constant (12.69) to give the value in gammas corresponding to the observed value.

Temperature Correction

The magnetometer used in obtaining the magnetic reading for this study is a temperature compensated instrument. However, to secure accurate information it is necessary to make temperature corrections.

The temperature was recorded at each station from a thermometer included within the instrument.

A temperature correction factor of 4.75 gammas per degree was established using the temperature calibration technique suggested by Ruska (1957). The correction was established for temperatures ranging from $+34^{\circ}$C to a - 7.5°C. The data are presented graphically in Figure 5.

The curves represent results of separate calibrations on two different days. The curves were combined for convenience. Values for the East reading and for the West reading are plotted individually on the graph.

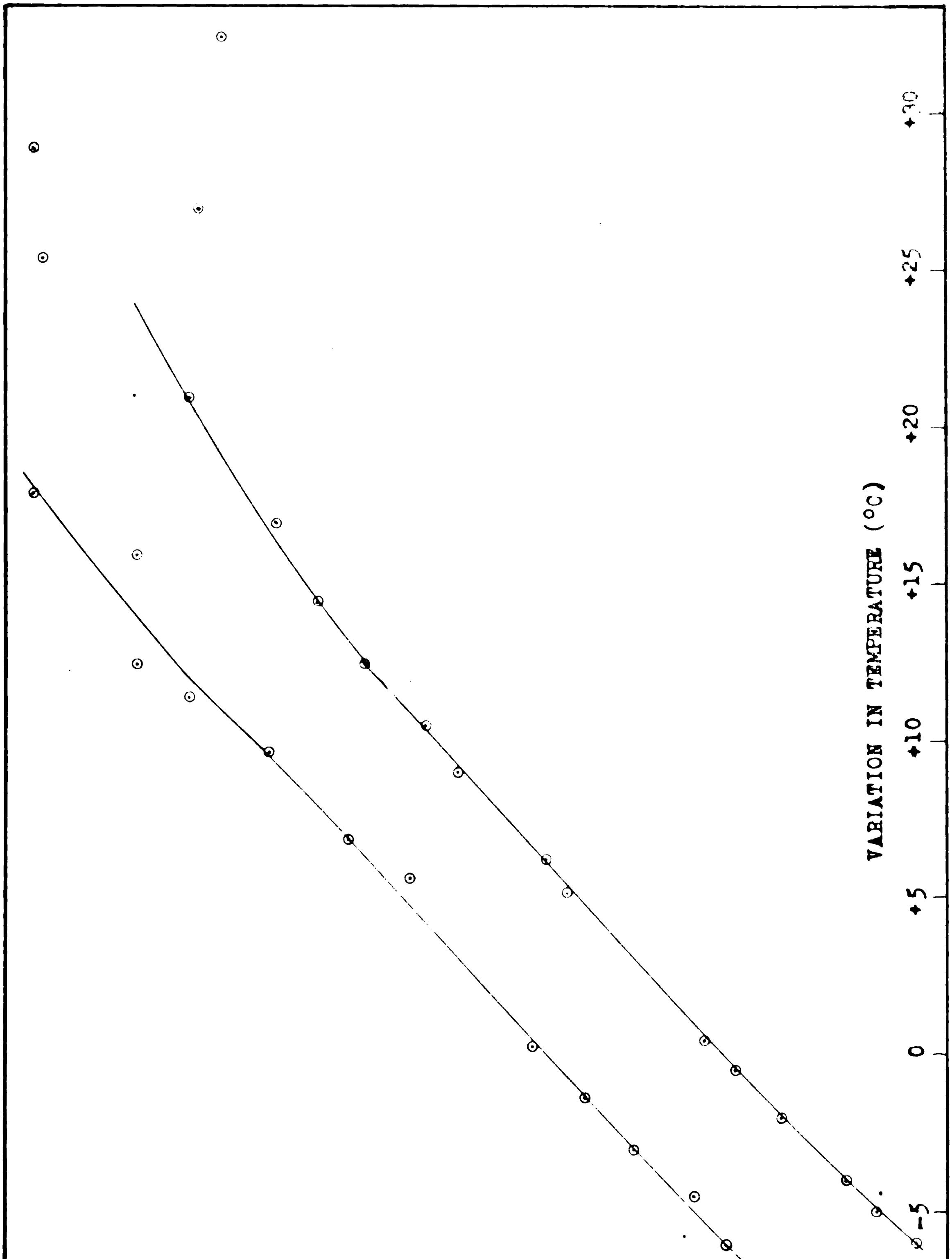


FIGURE 5. TEMPERATURE CORRECTION CURVE

The assumption was made that the temperature correction is constant. This is not necessarily true. The correction curves show a slight curvature and may indicate that the temperature correction will change for a higher range of temperature.

Diurnal Corrections

The diurnal correction is made by establishing a daily base station and returning at intervals of about two hours to repeat the observations. Any differences occurring in this manner are then distributed among the stations established during the interim. This method of making the diurnal correction is often referred to as the "Base Check Method."

The magnitude of the diurnal correction displayed a considerable variation from day to day. In most cases the variation for one day's field work was within 40 gammas.. However, in one instance the variation slightly exceeded one hundred gammas in eight hours. A typical diurnal curve is shown in Figure 6.

Normal Corrections

When computing the results from a magnetic survey of considerable extent it is necessary to remove the normal variation of magnetic intensity over the earth's surface. The normal correction

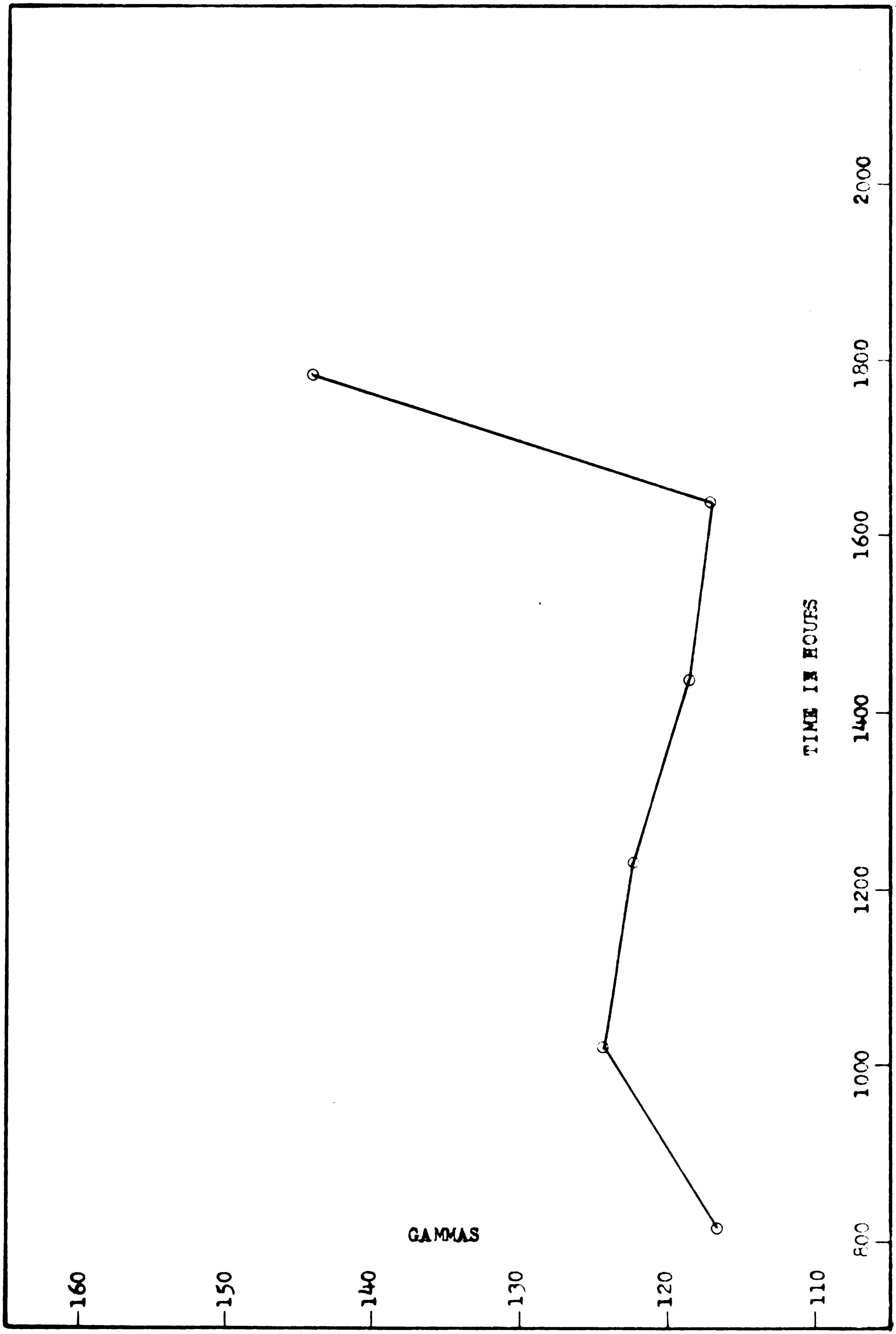


FIGURE 6. TYPICAL DIURNAL CORRECTION CURVE

is determined by interpolation from magnetic charts published by the United States Coast and Geodetic Survey (1955). The normal correction was found to be 6.25 gammas per mile for the southern one-half of the lower peninsula of Michigan.

Correction to Base

As previously mentioned, the earth's magnetic field is subject to a variable change for any given period of time. Consequently, it is necessary to correct the readings taken on any particular day to values previously established. Since all values are corrected to the first day's base station, the need to correct for the annual decrease in magnetism is eliminated.

Conversion to Absolute Magnetic Values

The U. S. Coast and Geodetic Survey has many permanent magnetic stations throughout the country. The permanent station used in establishing the absolute magnetic value for this survey is located on the Boy's Vocational School baseball diamond in Lansing, Michigan. The absolute value defined by the U. S. Coast and Geodetic Survey in September, 1959, is 56,288 gammas. This point is used as station number 127 on the map.

ACCURACY OF DATA

Reduction Error

It is very difficult to make an exact statement as to the accuracy of this type of magnetic survey. Many factors which cause small inconsistent errors cannot be eliminated. For instance, the diurnal correction is determined graphically by the use of straight line curves. Since the diurnal variation probably is not a straight line function, errors of small magnitude cannot be avoided.

Small errors are probably also introduced in the interpolation of the normal correction from the U. S. Coast and Geodetic Survey maps.

Instrument Error

The magnetometer is accurate and sensitive. As a result, it is necessary that the instrument be exactly level. Any departure from the level position will cause a deviation from the true reading.

It is possible to determine the error in reading accuracy by setting up the instrument and taking readings every few minutes over a period of time. In this case, readings were taken for a two and one-half hour period.

A procedure that duplicates field conditions was used for determining the reading error. The instrument was removed from the tripod after each reading. The tripod level was loosened and then re-oriented by use of the compass. The instrument was then again placed on the tripod head. The results of the accuracy determination can be seen in Figure 7.

The diurnal correction is assumed to be a curve which best represents the majority of the readings. Any deviation from the curve is assumed to represent the reading error. The actual deviation from the diurnal correction curve was determined for every point. The average error was computed to be .138 scale divisions per reading. This value represents a reading error of slightly less than two gammas.

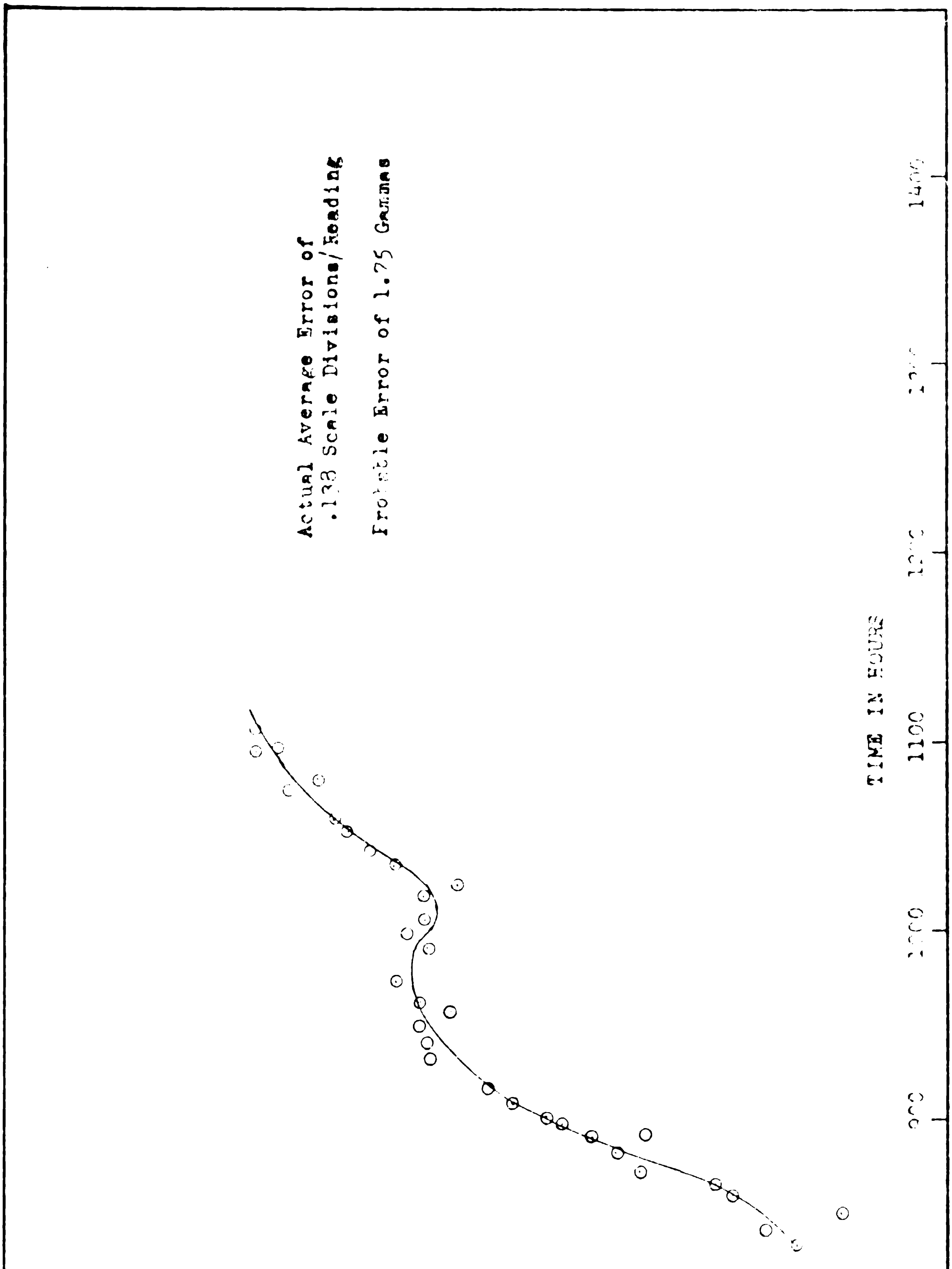


FIGURE 7. ACCURACY DETERMINATION CURVE

EFFECTS FROM THE GLACIAL DRIFT

Nettleton (1940) makes the statement that, "Small, local concentrations of magnetic material, which would cause no measurable anomaly if buried a few hundred feet, may cause local magnetic disturbances which interfere with accurate magnetic work." He then suggests using an excess number of magnetic readings and an averaging system as a solution to this problem.

In this survey, wherever possible, three to four readings were taken in the vicinity of the control point. The arithmetic mean of the readings was used as the value of vertical intensity at the control point.

The standard deviation was computed from control points which were established on the basis of several readings. The following formula was used for the computation:

$$S = \sqrt{\frac{\Sigma fiXi^2 - \frac{(\Sigma fiXi)^2}{N}}{N - 1}}$$

when

S = Standard Deviation

fi = Frequency of Occurrence

Xi = Number of Stations

N = Σfi

The results are shown by means of a bar graph and a percentage curve (Figure 8). The standard deviation exceeded nine gammas in 17.4 per cent of the total number of control points and exceeded twenty gammas in 1.8 per cent of the total number of control points.

In areas of anomalous magnetic readings high standard deviations would be expected. For example, Station No. 42, which is located in the anomalous zone in the southeast corner of Eaton County has a standard deviation of 18.3 gammas. The magnetic gradient is approximately 25 gammas per mile in this vicinity using a 0.1 mile station interval. The highest standard deviation that would be expected from this gradient would be five gammas. With the exception of the western extension of the Howell anticline, the maximum gradient in the mapped area is 130 gammas per mile. This would yield a maximum deviation of approximately 7.5 gammas. From this information it is evident that the high standard deviation would most likely be caused by magnetic material in the glacial drift.

The high standard deviations do not display a definite areal pattern. They are randomly scattered throughout the area of study.

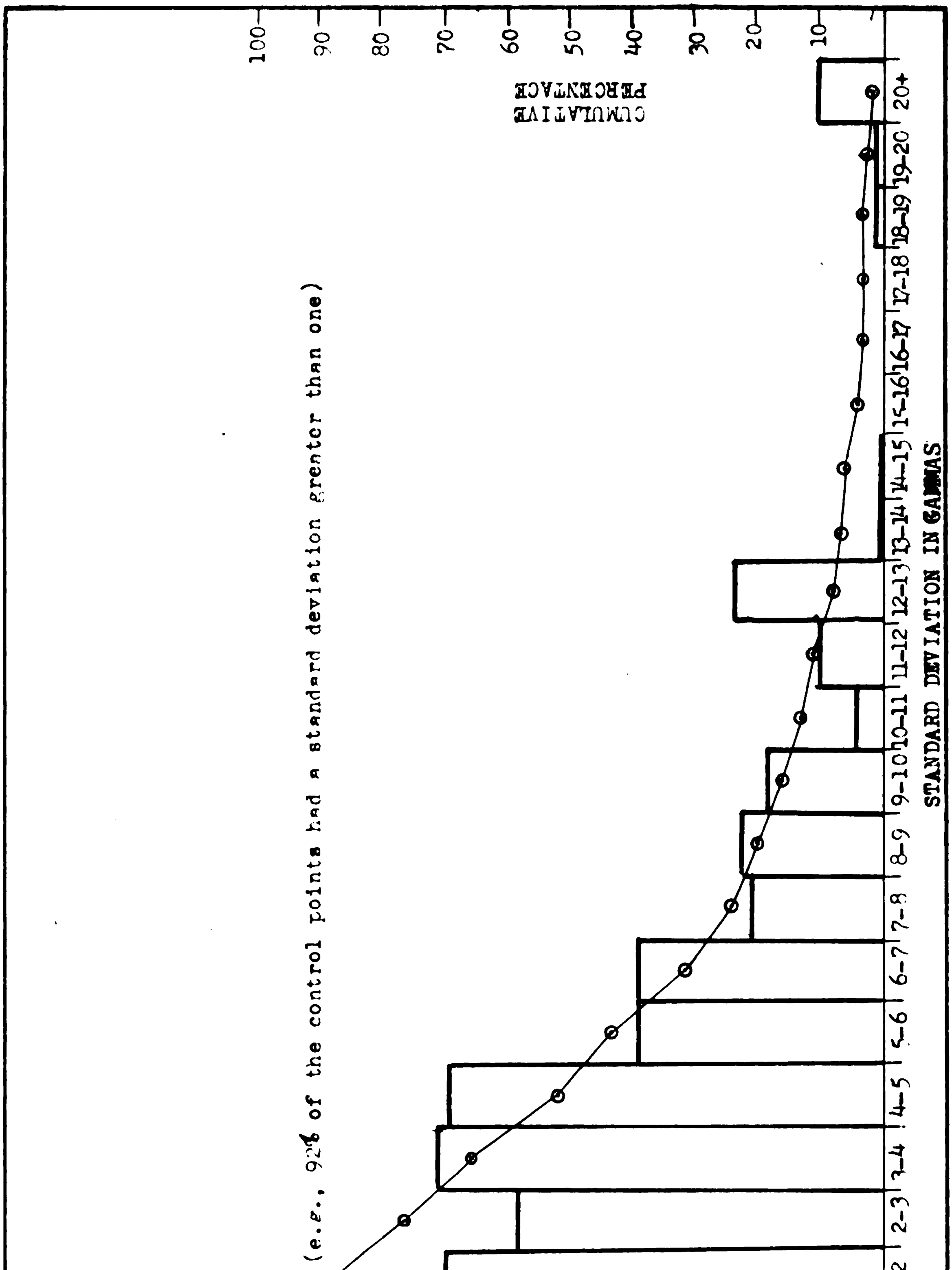


FIGURE 8. BAR GRAPH AND CUMULATIVE PERCENTAGE CURVE SHOWING THE RELATIONSHIP OF STANDARD DEVIATION TO CONTROL POINTS

RESULTS OF SURVEY

The results of the magnetic survey have been prepared in the form of a contour map on the scale of one inch equal to two miles (Plate I), and one inch equal to eight miles (Figure 9). The contour interval is twenty-five gammas on Plate I and fifty gammas on Figure 9.

The maximum observed value of vertical magnetic intensity is 56,808 gammas which is located in T1N R4E in the southeast corner of Ingham County. The lowest observed value, 56,102 gammas, is located in the extreme northeastern corner of Shiawassee County.

There are several anomalies present in the area (Plate I). These anomalies will be described in order of decreasing magnitude.

The large magnetic anomaly associated with the Howell anticline in Livingston County extends into the eastern one-third of Ingham County and the southeastern corner of Shiawassee County (Behrens). The highest magnetic value is found in south central Livingston County. The value is approximately 1,000 gammas higher than the highest observed value in this survey.

The next anomaly to be discussed is located in Eaton County within T2N R6W and T3N R6W. This anomaly extends westward into

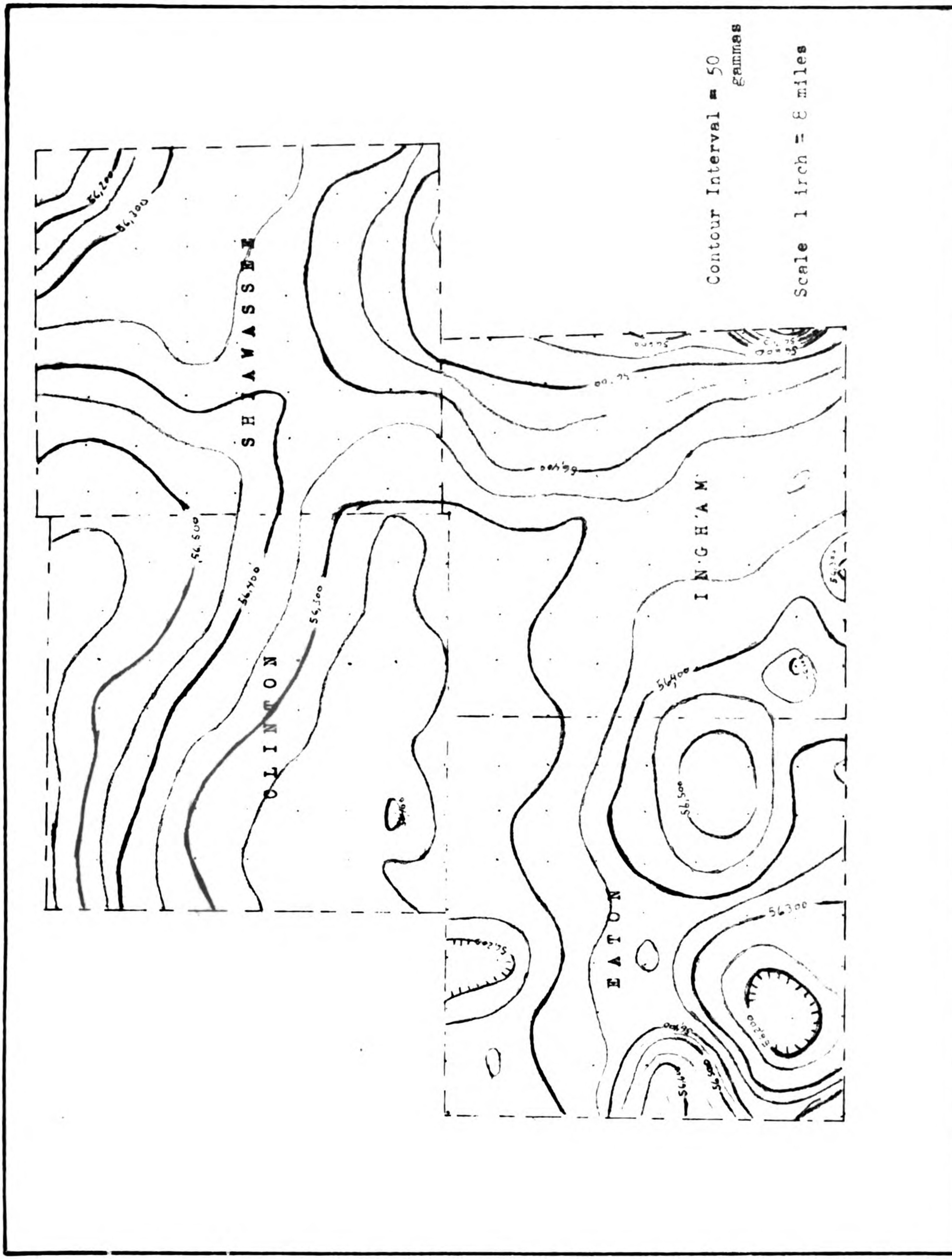


FIGURE 9. A VERTICAL MAGNETIC INTENSITY MAP OF A PORTION OF SOUTH CENTRAL MICHIGAN

Barry County. Complete information regarding the extent and magnitude of the anomaly is not available. The highest observed value within the anomaly is 56,626 gammas.

The northern half of Clinton County and the northwestern corner of Shiawassee County display a considerable increase in vertical intensity as one proceeds northward. The highest observed value in this vicinity is 56,575 gammas.

The next anomaly is located in the southeastern corner of Eaton County. The highest observed value within the anomaly is 56,535. This point is located in the center of T2N R3W.

The first magnetic low to be discussed is located in the southwestern corner of Eaton County. The lowest observed value within the anomaly is 56,184 gammas. The anomaly displays an approximately circular outline.

The next magnetic low is located in the northwestern quarter of Eaton County. The anomaly extends northward into Ionia County. The portion of the anomaly included within the mapped area is located in T4N R5W. The lowest observed value within this anomaly is 56,151 gammas.

The third magnetic low is located in the extreme northeastern corner of Shiawassee County. The lowest recorded value is 56,102 gammas. This anomaly extends northeastward into Saginaw County and Genesee County.

The magnetic anomalies in the southern half of Eaton and Ingham counties are for the most part between 42°25' and 42°35' north latitude. This corresponds with the location of the magnetic anomaly associated with the Howell anticline which is suggestive of an east-west trend.

METHOD OF INTERPRETATION

Introduction

Nettleton (1940) makes the statement, "The magnetic method is similar to the gravity method in that its interpretation is not unique. A given magnetic anomaly may be explained by a variety of causes."

Many methods of interpreting magnetic data have been developed over the past 30 years. Some of these methods are applicable only under certain conditions. Others are "Rule of Thumb" methods that apply only when certain assumptions are known to hold true. In this survey three methods of interpretation were used: the second derivative method; Peters' "slope" method; and Vacquier's total intensity method.

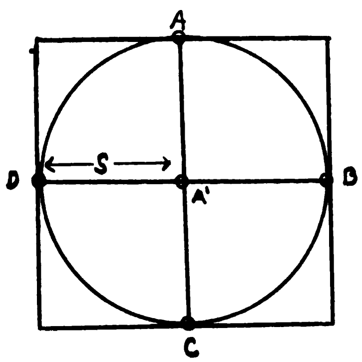
Second Derivative Method

There are many methods of computing second derivatives from magnetic and gravity data. All methods represent the reduction of complicated mathematical formulations to practical schemes of calculations, using values from a regular grid of points to determine averages around circles of different radii from a central point (Nettleton, 1954).

The method of computing the second derivatives for this survey is commonly referred to as the Center-Point-and-One-Ring method. It was selected because it allows maximum possible coverage of the mapped area. The only values not represented are those found on the edge of the map. It can be represented by the following formula:

$$\frac{\partial^2 G}{\partial Z^2} = \frac{4}{S^2}\left[G_0 - \bar{G}(S)\right]$$

where $\frac{\partial^2 G}{\partial Z^2}$ is the derivative value, S is the distance between stations, G_0 is the observed magnetic value for the center point, and $\bar{G}(S)$ is the mean of the four values found in a circle with radius S and center point at G_0. The following diagram illustrates this relationship:



$$G_0 = A'$$

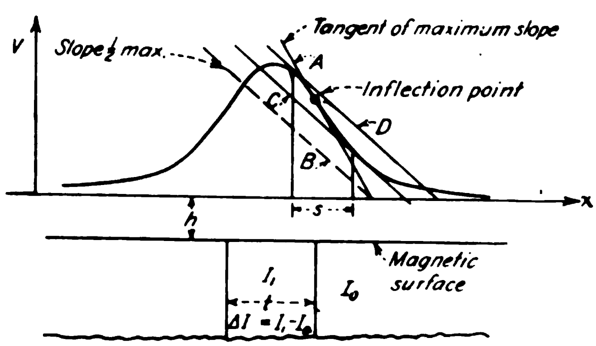
$$\bar{G}(S) = \frac{A+B+C+D}{4}$$

$$S = 3 \text{ Miles}$$

It is necessary to use a constant grid interval to obtain usable data. If the grid interval is not constant the computed values are meaningless.

Depth Estimation by Peters' "Slope" Method

L. J. Peters has developed several methods of making depth determinations. The most commonly used of his methods is the "slope" method. The following diagram illustrates this technique.



This method, described in Dobrin (1952), is based on two assumptions:

1) "The anomalous mass is in the shape of an infinitely long slab with vertical sides which extend to infinity in the downward directions."

2) "It is uniformly magnetized in the vertical direction, having a magnetization of I_x different from the uniformly and vertically magnetized surrounding material."

The inflection points are located corresponding to the maximum slope on the anomaly profile. A tangent is drawn to the inflection point (Line A) and measures its slope. Then one constructs a Line B with half of this slope and draws the two tangents C and D to the anomaly curve which are parallel to B. The horizontal separation S is approximately related to the depth h by the formula

$$S = 1.8h$$

if h and t are about the same magnitude (Dobrin, 1952).

Vacquier's Method

V. Vacquier has developed a method of interpreting aeromagnetic data by comparing observed anomalies with computed magnetic effects of idealized bodies (Vacquier, 1951).

The data obtained from airborne magnetometer measurements is recorded in terms of total magnetic intensity. Consequently, Vacquier's method is based on total intensity.

Measurements of vertical intensity closely approximate total intensity measurements in areas of high geomagnetic latitudes such as Michigan. In this survey, the difference between total intensity measurements and vertical intensity measurements is considered negligible and Vacquier's method of interpretation is applied.

The idealized bodies, used by Vacquier, represent rectangular prisms, with vertical sides, extending infinitely downward. They are considered similar to large lithologic units in crystalline rock with polarization in the direction of the earth's magnetic field. The magnetic susceptibility is constant throughout the prism and is in contrast to the susceptibility of the surrounding rock.

The models are measured in terms of depth of burial to the top of the cell. Dimensions are expressed in terms "n" x "m" where "n" is the side more nearly parallel to magnetic north and "m" the side perpendicular to "n."

"Depth indices" are determined by measuring the horizontal extent of the steepest gradients on the vertical intensity map and the second derivative map (Plate I and II). The same procedure is used to measure the depth indices of the model. The depth is estimated by dividing the depth indices of the observed anomaly by the depth indices from the model. Care must be taken to avoid gradient near the corners of the models, since square corners are not apt to be duplicated in nature.

The procedure used in interpreting a magnetic anomaly is as follows: First compare the model chart with the intensity map and select a usable model. Then determine the depth indices and estimate the depth.

The model charts are set up so that one-half of the model is represented by the total intensity of the anomaly and the other half is represented by the second derivative values of the total intensity. The second derivative values outline the top surface of the source of the magnetic anomaly.

Once the depth estimation has been made and the probable shape of the anomaly secured it is possible to determine the probable susceptibility contrast. This is computed by means of the following formula:

$$k = \triangle Tm / \triangle Tc T$$

Where

k = the minimum susceptibility contrast

$\triangle Tm$ = the total amplitude of the observed anomaly in gammas

$\triangle Tc$ = total amplitude of the intensity anomaly

T = intensity of the earth's magnetic field in gammas

GEOLOGICAL INTERPRETATION

There is no information available on the lithology of the basement in the area of study. However, three well cores which have penetrated the Precambrian surface in Washtenaw County are on file in the University of Michigan core library. Two of these cores indicate a basement complex composed of granite. The other shows indications of granite and a "greenish schistose material." (Behrens, 1958).

Some idea of the depth to the basement complex can be secured from Cohee's map of the top of the Precambrian surface. Interpolation from this map gives a depth range of 6,600 feet in southeast Ingham County to 10,400 feet in northern Clinton County. The anomalous area in southern Eaton County is estimated to be 7,500 feet in depth. Cohee's work is based on only a few wells along the outer rim of the basin and on projection of dips. Consequently, depths obtained from his maps have to be considered rough approximations.

Structural contour maps of the Traverse formation indicate possible faulting in south central Shiawassee County (Gustafson, 1960). Also, a structural high is indicated in southern Eaton County.

The presence of faulting is often reflected in the pattern of streams or rivers. Moore has shown the path of the "Durand" preglacial drainage trough on his Bedrock Topography Map of Shiawassee County. The path of this channel corresponds with the area of faulting suggested by Gustafson.

Moore also suggests the presence of the "Owosso" high in north central Shiawassee County. He considers this high to be a counterpart of the Howell anticline. It is separated from the Howell anticline by the Durand Channel.

GEOPHYSICAL INTERPRETATION

General

Assuming the basement material is granite, a decrease of 78 gammas would be expected as one proceeds northward across the area of study. However, this is not the case. Actually, with the exception of the northeast corner of Shiawassee County, there is a considerable increase northward in vertical intensity values. This would indicate an increase in magnetic susceptibility within the basement rock as one proceeds northward.

According to Nettleton (1940) the magnetic susceptibility of sedimentary rocks is so small in contrast to that of the basement rock that it can be essentially ignored. Therefore, the general appearance of the vertical intensity and the second derivative map can be accredited to either a variation in basement relief or variations of magnetic susceptibility within the basement rock. It is thought that the basement relief is similar in nature to that of exposed Precambrian surfaces in Michigan. An anomaly from this type of relief at a depth of 7,000 feet would not exceed a maximum vertical magnetic intensity of two gammas. Therefore, it is thought that the anomalies are due largely to a lithologic change in the basement rock.

The vertical intensity map shows a decrease in magnetic intensity which corresponds with the path of the Durand Channel in south central Shiawassee County. This magnetic "trough" could be an indication of faulting in this vicinity. The faulting of the Traverse formation suggested by Gustafson substantiates this hypothesis. Also, the anomalies in the southern corner of Eaton County are in the vicinity of a structural high in the Traverse formation. Although no direct correspondence between the high and the anomalies is evident, it is possible that the high is a reflection of movement or intrusion in the basement complex.

Second Derivative Map

The second derivative values have been plotted on a map using a scale of one inch equal to two miles (Plate II). A contour value of five gammas per mile per mile was used.

The western extension of the magnetic anomaly associated with the Howell anticline is not apparent on the second derivative map. This is due to the fact that the control points on the outer edge of the map are not represented by second derivative values.

The major anomalies, with the exception of the western extension of the Howell anticline anomaly, retain the same general appearance and comparative magnitude as on the vertical intensity map.

However, several small, isolated anomalies, which were not recognizable on the vertical intensity map, appear on the second derivative map. Two of these anomalies are considered worthy of mention by the author. The first is located in the northeast corner of Clinton County. It reaches a value of 17.4 gammas per mile per mile. The second anomaly is located on the edge of Ingham County. It is represented by a value of 20.0 gammas per mile per mile.

The anomaly located in the southwestern one-fourth of Eaton County displays a more rectangular outline on the second derivative map than on the vertical intensity map. This indicates a source that would have a rectangular shape.

The increase in vertical intensity in the northern portion of the area of study is converted to a plateau of vertical intensity values on the second derivative map. A high of comparable magnitude which is closely associated with this "plateau" is located in the central portion of Clinton County.

There is no obvious correlation between the location of the Durand trough and the magnetic values in the second derivative map.

It is thought that the largest anomalies are due to a change in the lithology of the basement rock. However, the Precambrian surface was an erosional plane and there is no reason to think of it as being a smooth surface. Relief up to several hundred feet would be expected and could account for some of the small, isolated anomalies on the second derivative map.

Depth Estimations By Peters' "Slope" Method

Three profiles were used to make depth determinations. Peters' "slope" method of approximating depth was used. As previously mentioned, this method will give exact results only if certain assumptions hold true. In this survey it is evident that the sources of the anomalies do not represent bodies of infinite length. It is also doubtful that the bodies will have vertical sides. Consequently, the results can be considered as rough approximations.

The first profile A - A' (Figure 10) gives an approximate depth of 5,016 feet. This value is considerably less than the depth Cohee (1945) suggests in his original work on the Michigan basin.

The depth estimation computed from profile B - B' (Figure 11) gave a value of 7,920 feet. This value is higher than the depth suggested by Cohee.

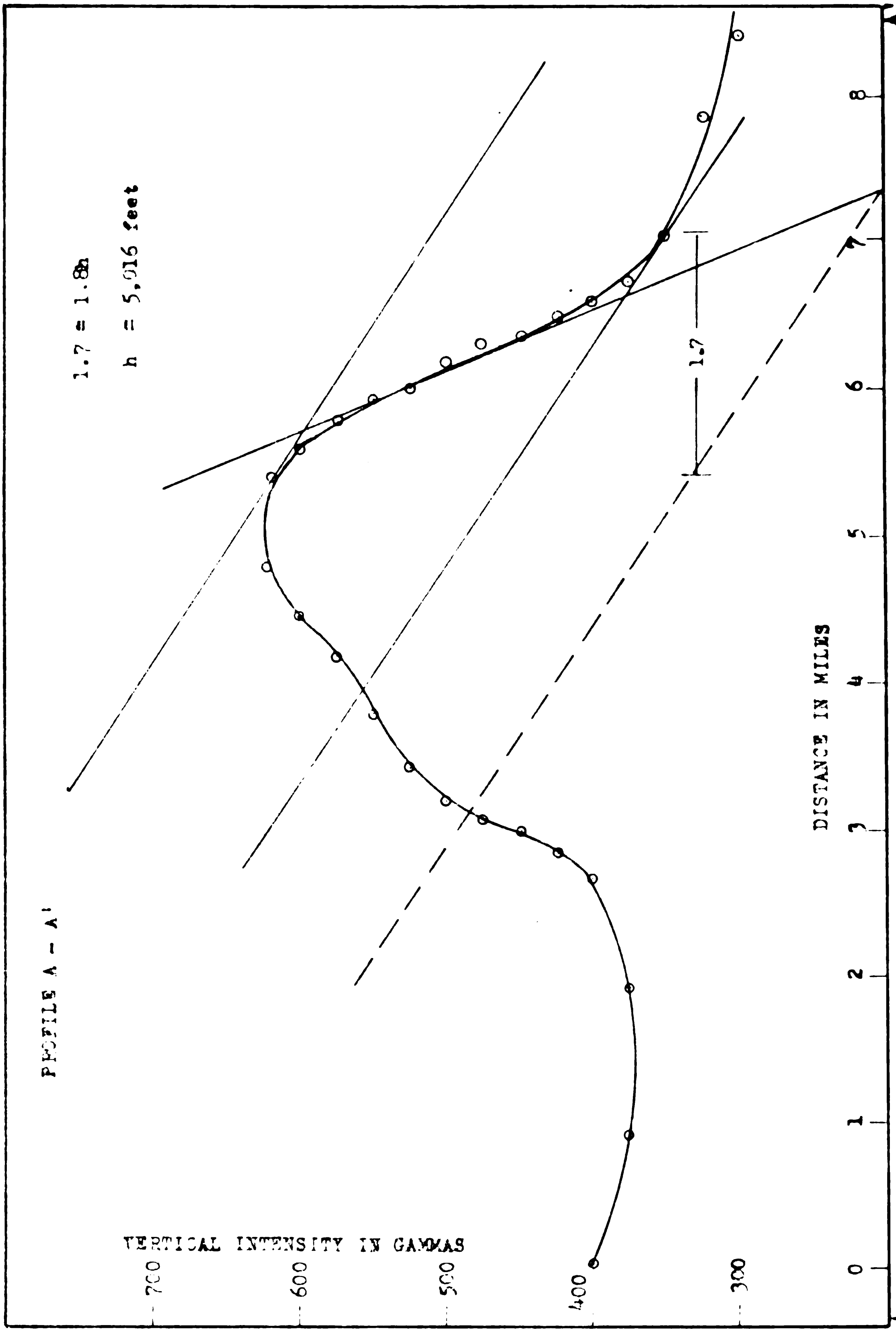


FIGURE 10. DEPTH ESTIMATION IN SOUTHWEST CORNER OF EATON COUNTY BY PETERS' "SLOPE" METHOD

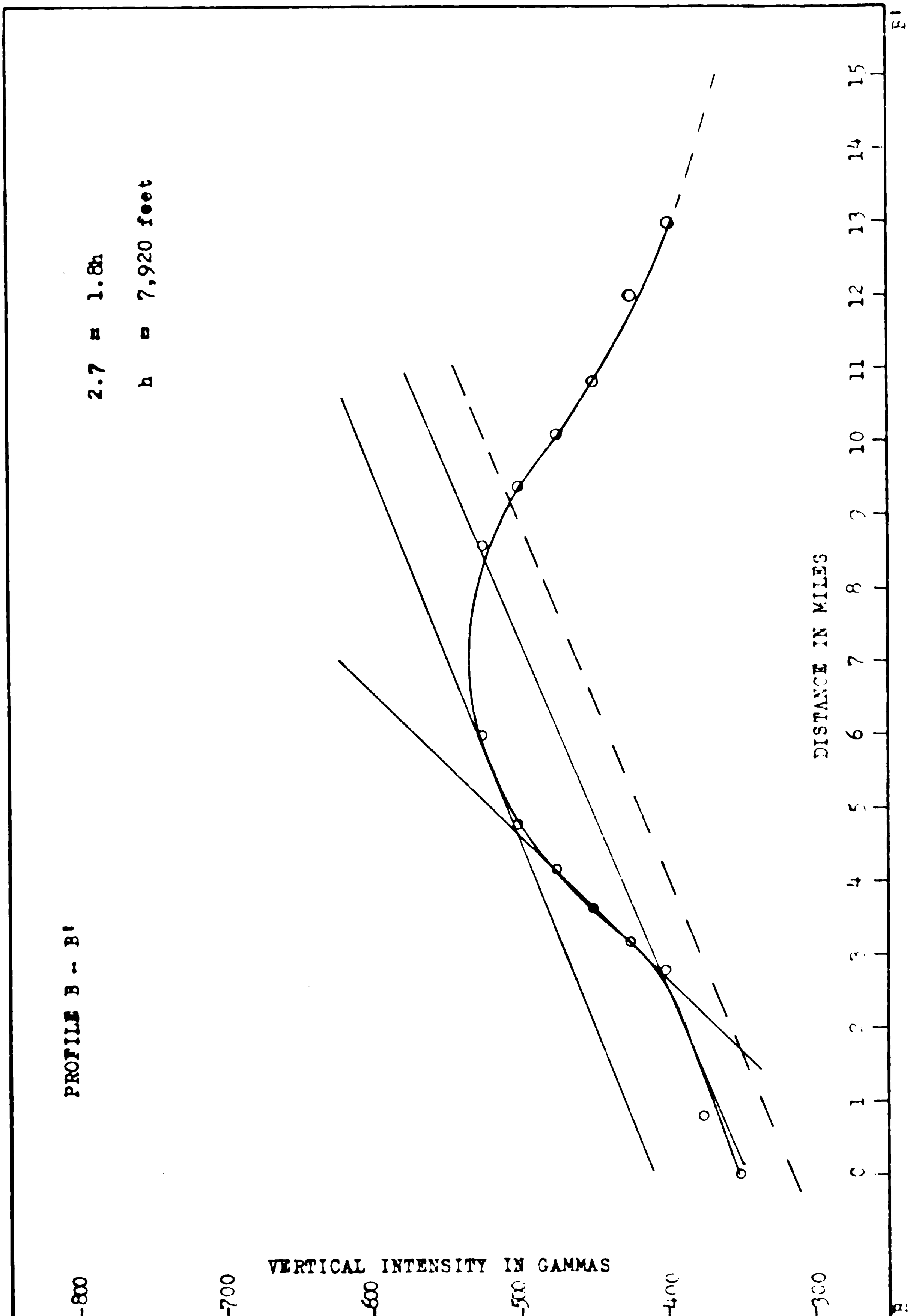


FIGURE 11. DEPTH ESTIMATION IN SOUTHEAST EATON COUNTY BY PETERS' "SLOPE" METHOD

The depth estimation determined from profile C - C' (Figure 12) is 4.19 miles or 22,123 feet. This value is much too high to represent the depth of the basement surface.

Profile B - B' is taken from an anomaly that has not been mapped in its entirety. It is possible that the profile does not intersect the peak of the anomaly. This would be apt to cause a depth estimation of a lesser value than the actual depth.

Profile A - A' intersects the peak of the anomaly. However, the source does not represent a body of infinite length. This could cause the estimation to be greater than the actual depth.

Profile C - C' gave a depth estimation that is much too large to be considered the depth to the basement surface. This is probably due to the width of the anomalous body. It could also be due to a source at great depth within the basement complex.

Interpretation - Vacquier's Method

The anomaly located in the southwest corner of Eaton County was chosen for analysis by Vacquier's method for two reasons. The first is that it displays a rectangular outline and secondly, it is mapped in its entirety. Its maximum amplitude, considering 56,300 as a base, is about 225 gammas.

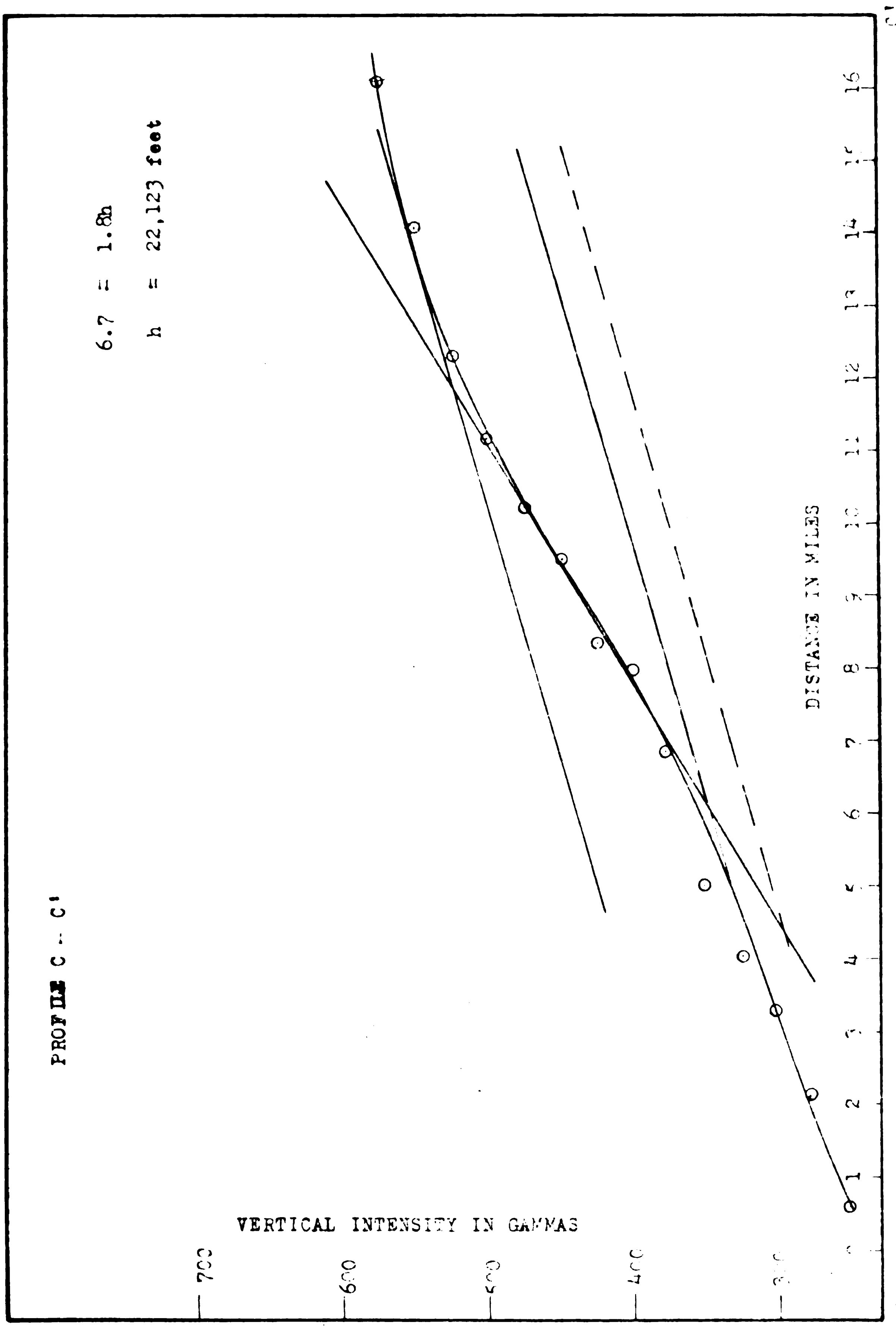


FIGURE 12. DEPTH ESTIMATION IN NORTHERN CLINTON COUNTY BY PETERS' "SLOPE" METHOD

The model selected for comparison is found on page 133 of Memoir 47 of the Geological Society of America (Vacquier, 1951). It is a 4 x 6 model for a magnetic inclination of 75°. The depth indices were determined from the vertical intensity map (Plate I) and the second derivative map (Plate II). The depth indices were then compared with the depth indices determined from the model. The following results were determined:

Vertical Intensity Map	E	=	1.65
Model Chart	E	=	1.30

$$\text{Result } \frac{1.65 \text{ mi}}{1.3} = 6{,}706 \text{ feet}$$

Second Derivative Map	A	=	1.44
Model Chart	A	=	.9

$$\text{Result } \frac{1.44}{.9} = 7{,}648 \text{ feet}$$

Average - 7,177 feet

The probable outline of the top surface of the source is outlined on the second derivative map by the 0 contour in the vicinity of the anomaly.

The magnetic susceptibility contrast (k) was computed by use of the following formula:

$$k = \Delta Tm / \Delta TcT$$

$$k = \frac{235}{4.0 \times 56{,}300}$$

$$k = .001$$

Assuming a generally granitic basement complex, this susceptibility contrast would indicate that a rock type such as gabbro is causing the anomaly.

COMPARISON OF GRAVITY AND MAGNETIC DATA

A Bouguer Gravity Map of Eaton, Clinton, Ingham, Shiawassee and Livingston counties is shown in Figure 13. The map is contoured on a five milligal interval.

There is a very definite relationship between the gravity and magnetic maps. The general appearance of the maps is similar. For every significant increase in vertical intensity there is a corresponding change in gravity measurement.

The western extension of the Howell anticline outlined on the vertical magnetic intensity map corresponds with the western edge of the gravity anomaly located in Livingston County. The increase in vertical magnetic intensity in northern Clinton County and northwestern Shiawassee County corresponds with a similar increase in gravity measurement.

The anomalous area in southern Eaton County, represented by pronounced magnetic anomalies, is indicated by an irregular contour line on the gravity map. This is probably due to the sparse gravity control point distribution in this area.

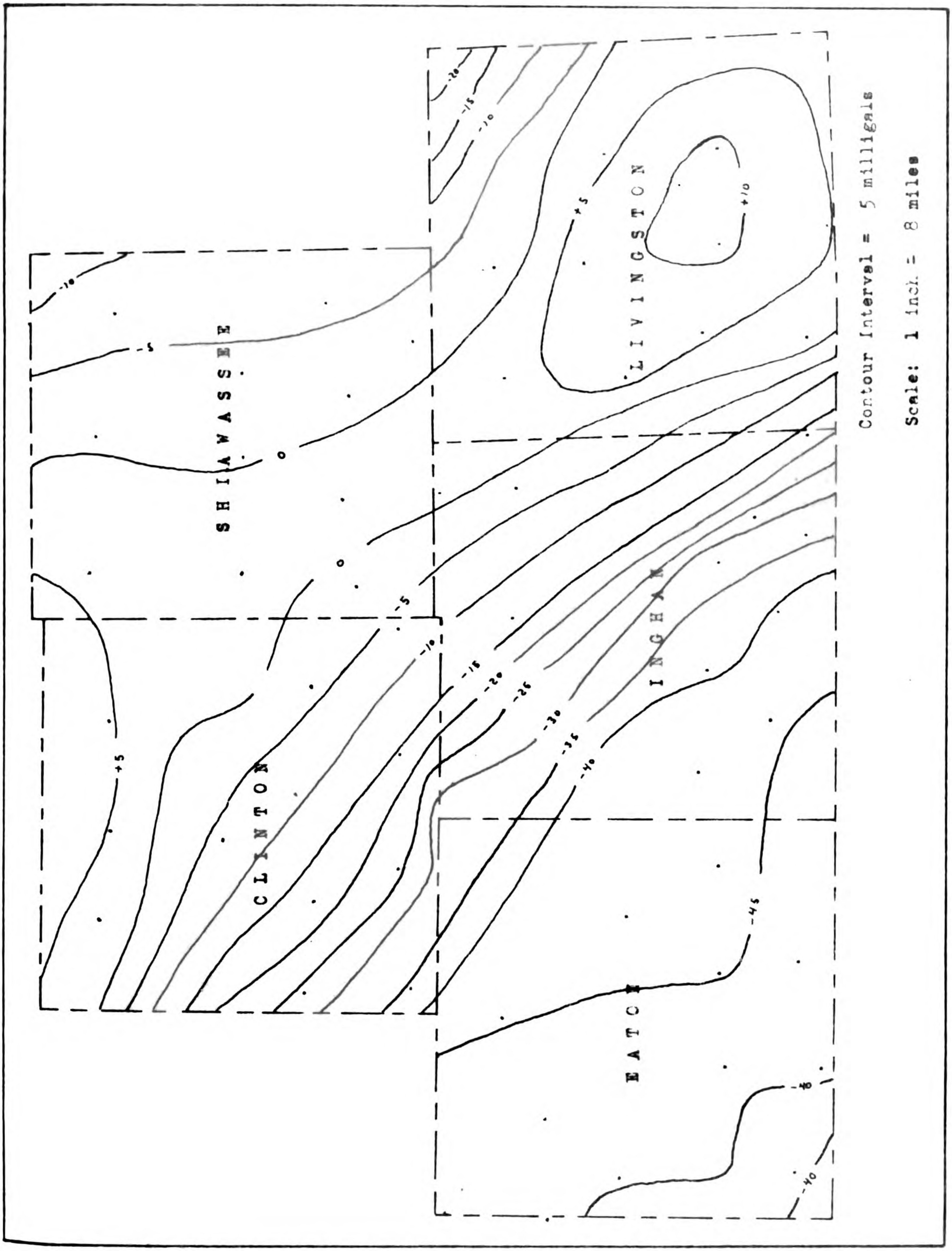


FIGURE 13. BOUGUER GRAVITY MAP OF SOUTH CENTRAL MICHIGAN
INCLUDING LIVINGSTON COUNTY

The correspondence between the maps indicates that the variation in gravity and magnetic measurement is due to the same source.

CONCLUSION

The vertical magnetic intensity of the area of study is shown on Plate I, utilizing a contour interval of 25 gammas. Several magnetic anomalies are present. The western edge of the anomaly associated with the Howell anticline is present in the southeast corner of Ingham County. Several magnetic anomalies are located in, or partly in, southern Eaton County. The northern portion of Clinton County and the northwestern corner of Shiawassee County display a considerable increase in vertical intensity.

The glacial drift has a definite effect on the results of a vertical magnetic intensity survey of this nature. This is indicated by a high standard deviation from the mean of several observations taken in one vicinity to represent a control point. There is definite value in using many stations and a system of averaging to establish control points. However, it would be possible to outline the regional structure by use of fewer stations.

Depth estimations by Peters' method indicate that the depth to the basement surface in southern Eaton County is between 5,500 feet and 8,000 feet. These depth estimations can only be considered a very rough approximation because Peters' method is based on several assumptions which are not completely true.

In this study the difference between vertical intensity values and total intensity values is assumed to be negligible and Vacquier's method for interpreting anomalies from aeromagnetic data is employed. With the use of Vacquier's method, depth estimations of 6,700 feet and 7,650 feet were determined from the anomaly in southeast Eaton County. These depth estimations were taken from the vertical intensity map and the second derivative map, respectively. These estimations are thought to be closer than those determined by Peters' method, but are still only rough approximations of the depth. These depths correspond quite closely with Cohee's determinations.

The minimum contrast in magnetic susceptibility was computed to be .001, which would indicate a contrast between rock types of granite and gabbro.

SUGGESTIONS FOR FURTHER STUDY

This survey can be considered a contribution to the compilation of a vertical magnetic intensity map of Michigan. It is suggested that thesis problems of a similar nature be established and combined with this information in the hope that a complete magnetic picture of Michigan will be developed.

A comparison of the information presented in this thesis with seismic work over the same area would be extremely valuable. This type of comparison should indicate the presence of faulting or fracture zones.

To make depth determinations as accurate as possible, a profile using a small station spacing could be established over the anomalous areas. A station spacing of one-quarter mile should be suitable.

A detailed study of the composition of the glacial drift in this area would be extremely valuable.

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