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A geophysical investigation of an area in Christian County, Missouri

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A GEOPHYSICAL INVESTIGATION OF AN AREA IN CHRISTIAN COUNTY, MISSOURI

BY

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A

THESIS

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ABSTRACT

A vertical intensity magnetic survey of 144 square miles in Christian County, southwest Missouri revealed an 825 gamma anomaly having a closure of 9 square miles. A three mile gravity traverse across the magnetic anomaly detected a positive gravity anomaly in excess of six milligals.

Calculations showed that a Precambrian hill large enough to cause the observed magnetic anomaly would outcrop at the surface. Because Precambrian rocks are known to be buried under a sedimentary layer, this hypothesis was rejected.

Theoretical anomalies of several geometrical bodies at calculated depths were visually compared with the measured magnetic and gravity profiles. A peridotite plug, depth 4,000 feet, vertical thickness 14,000 feet, cross-sectional radius 4,200 feet; a diabase plug of the same dimensions with heavy non-magnetic sulfide minerals present; and a diabase plug, depth 2,400 feet, vertical thickness 15,600 feet, cross-sectional radius 4,800 feet produced the necessary theoretical anomalies.

On the basis of present geophysical and geological evidence, the structure is not of economic importance.

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TABLE OF CONTENTS

		Page
ABSTRACT		ii
ACKNOWLEDGMENTS		iii
LIST OF FIGURES		vi
LIST OF PLATES		vii
LIST OF TABLES		viii
I.	INTRODUCTION	1
	A. Location of Area	1
	B. Purpose of Investigation	1
	C. Method of Investigation	1
II.	REGIONAL GEOLOGY	2
	A. Stratigraphy	2
	B. Structure	2
	C. Tectonics and Mineralization	2
	D. Physical Constants of the Rocks	4
III.	THE MAGNETIC SURVEY	6
	A. The Magnetometer	6
	B. Instrument Adjustments and Corrections	6
	C. Field Procedure	6
IV.	THE GRAVITY SURVEY	9
	A. The Gravity Meter	9
	B. Instrument Adjustments and Corrections	9
	C. Field Procedure	10
V.	RESULTS OF SURVEYS	12
	A. Magnetic Map and Profile	12
	B. Gravity Profile	12
VI.	INTERPRETATION	17
	A. General	17
	B. General Analysis	17
	C. Buried Hill Calculations	19
	D. Depth Calculations	21
	E. Vertical Cylinder Calculations	25
VII.	CONCLUSIONS	32
VIII.	BIBLIOGRAPHY	33

Page

IX. APPENDICES 35

A. Corrected Magnetic Data. 36
B. Corrected Gravity Data 56
C. Program for Three Dimensional Structure Calculations 59
D. Program for Calculation of Depth by Error in Continuation. 63

X. VITA 66

LIST OF FIGURES

Figure		Page
1.	Idealized Geologic Section	3
2.	Magnetic and Gravity Station Locations	8
3.	A Schematic Diagram of the Magnolia Gravity Meter. . .	9
4.	Vertical Intensity Magnetic Contour Map of the Investigation Area	13
5.	Vertical Intensity Magnetic Profile across Anomaly "A".	14
6.	Bouguer Gravity Profile across Anomaly "A"	16
7.	Grid for Calculation of Structure Using Coefficients of Table I.	20
8.	Theoretical Buried Hill of Basalt.	22
9.	Error Curve Obtained by Means of Coefficients of Table II.	24
10.	Solid Angle Chart for Calculating Gravitational and Magnetic Effects for Discs and Cylinders, Respectively	27
11.	Theoretical Vertical Intensity Magnetic Anomaly over Buried Vertical Cylinder; Z = 4,000 feet, R = 4,200 feet, t = 14,000 feet, $\Delta k = 9,220 \times 10^{-6}$ c.g.s. units, H_z = 0.516 oersteds.	28
12.	Theoretical Gravity Anomaly over Buried Vertical Cylinder; Z = 4,000 feet, R = 4,200 feet, t = 14,000 feet, $\Delta\sigma$ = 0.6 gm./c.c.	29
13.	Theoretical Vertical Intensity Magnetic Anomaly over Buried Vertical Cylinder; Z = 2,400 feet, R = 4,800 feet, t = 15,600 feet, $\Delta k = 5,600 \times 10^{-6}$ c.g.s. units, H_z = 0.516 oersteds.	30
14.	Theoretical Gravity Anomaly over Buried Vertical Cylinder; Z = 2,400 feet, R = 4,800 feet, t = 15,600 feet, $\Delta\sigma$ = 0.3 gm./c.c.	31

LIST OF PLATES

Plate		Page
I.	Magnetic Map Showing Location of Mines and Prospects, Christian County, Missouri	in map pocket
II.	United States Geological Survey Topographic Map of the Ozark Quadrangle	in map pocket
III.	United States Geological Survey Topographic Map of the Fordland Quadrangle.	in map pocket
IV.	United States Geological Survey Topographic Map of the Selmore Quadrangle	in map pocket
V.	United States Geological Survey Topographic Map of the Chadwich Quadrangle.	in map pocket
VI.	United States Geological Survey Topographic Map of the Bradleyville Quadrangle.	in map pocket

LIST OF TABLES

Table		Page
I.	Coefficients for Calculation of Structure	20
II.	Coefficients for Calculation of Error in Continuation for Use in Estimation of Depths.	24

I. INTRODUCTION

A. Location

The area of this regional magnetic survey is in the southeastern part of Christian County, Missouri. This one hundred and forty-four square mile area is twenty miles south of southeast of Springfield. The area boundaries extend from Sec. 30, T27N-R20W to Sec. 28, T27N-R18W; Sec. 30, T27N-R20W to Sec. 31, T26N-R20W; Sec. 28, T27N-R18W to Sec. 33, T26N-R18W; Sec. 31, T26N-R20W to Sec. 33, T26N-R20W (Plate 1). The United States Geological Survey Topographic Maps of the Ozark, Fordland, Selmore, Chadwick, and Bradleyville Quadrangles cover the area (Plates 2-6).

B. Purpose of Investigation

This investigation was undertaken in order to study, in detail, a large known magnetic anomaly. In 1932, in preparation for the Magnetic Map of Missouri, a regional magnetic survey was made, finding this anomaly. From this survey Plate 1 was constructed. Since 1932, no geophysical work had been done until this investigation was initiated. Only at the Mary Arnold Mines in the eastern part of the area (Plate 1), has a detailed geologic study been made. Several zinc mines and lead diggings surround the anomaly. Thus, it was thought that a more detailed regional magnetic survey would be helpful and valuable in making an analysis of the area.

C. Method of Investigation

The vertical component of the earth's magnetic field was measured at intervals throughout the thesis area. This data was used to construct a magnetic map. A gravity profile was made across the anomaly. From the combined data a geological interpretation was made of the major anomaly.

II. REGIONAL GEOLOGY

A. Stratigraphy

The stratigraphic column (Figure 1) shows a sequence of formations whose ages range from the Precambrian to Lower Mississippian. This section was constructed from a study of two well logs. The Mississippian and Ordovician column was taken from M.G.S. log number 19296 at Sparta, Missouri section 36, T27N-R20W in the investigation area. The Cambrian part of the section was provided by M.G.S. log number 1980 at Monnet, Missouri in Barry County section 32, T26N-R27W.

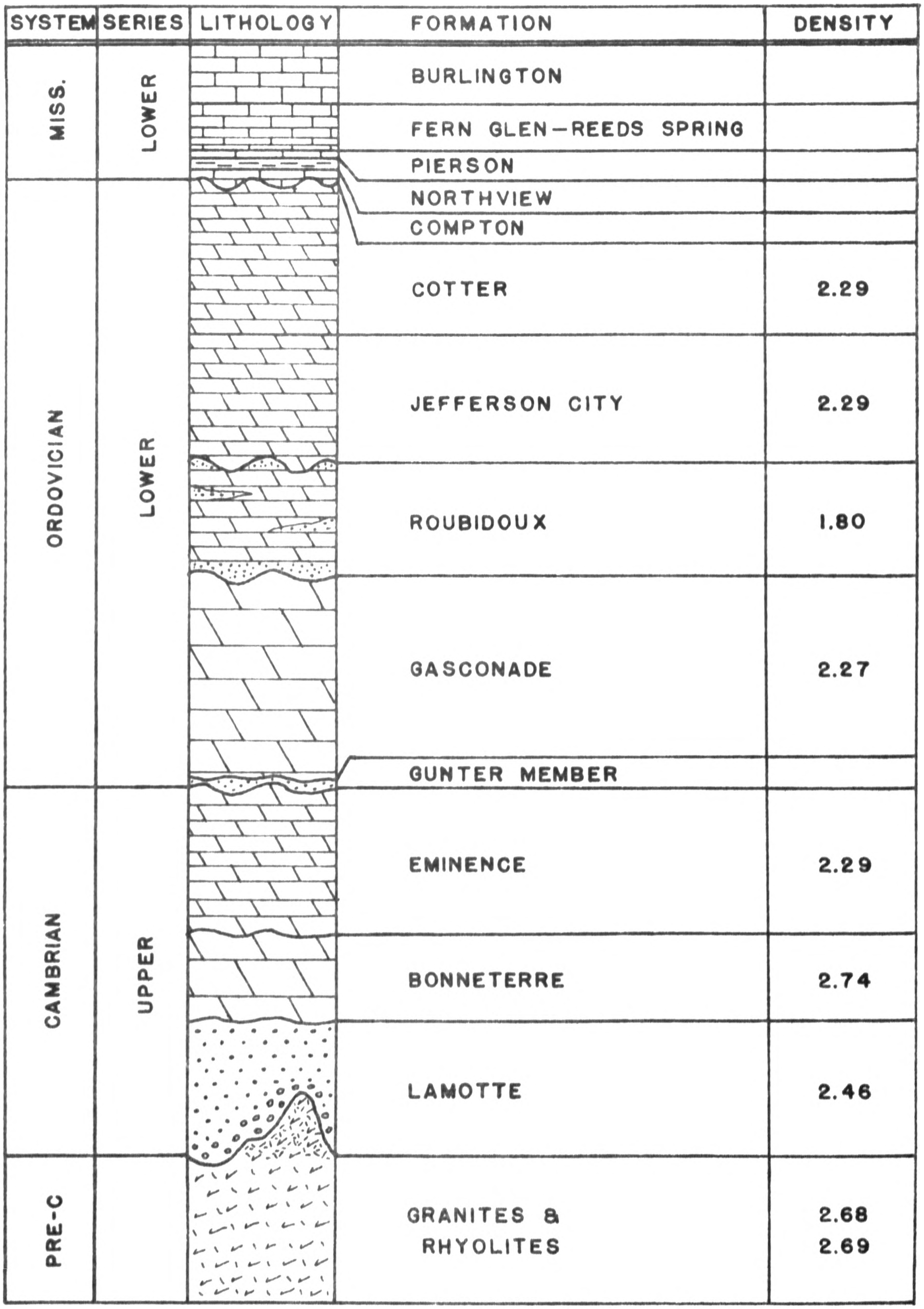
The Lower Mississippian formations occupy the greatest part of the outcrop area. On the flanks of the hills and in the low areas along river bottoms the Cotter and Jefferson City formations outcrop. The contact between the Ordovician and Lower Mississippian lies, in general, along the 1200 foot contour line (Hayes, 1960). The Precambrian basement has been established by the Missouri Geological Survey and Water Resources to be about 1250 feet below sea level (Grenia, 1960). This places it to be approximately 2400 feet below the surface of the ground.

B. Structure

A structure map using the top of the Cotter formation as a marker horizon was prepared by the Eagle-Pitcher Company from water well cuttings (Hare, 1961). This indicated a slight regional dip of the formation as a whole, towards the west-southwest. Very few well logs are present in Christian County, and no drill holes are located either on the flanks or directly over the anomaly.

C. Tectonics and Mineralization

Faulting is known in the eastern part of the investigation area



Vertical Scale
1:3000

Fig. 1. Idealized Geologic Section

at the Mary Arnold Mines (Hayes, 1961). It is also known at the Mon-Ark Zinc-Lead Mines at the edge of the area (Plate 1). The ore bodies extended along these fracture zones striking, in general, north of northwest.

> According to Ballinger (1948, p. 4) "the main ore mineral of the upper horizon is galena, occurring as irregular masses in the clay-filled cavities of both the Burlington and upper Reeds Spring formation. Some zinc silicate ore was mined from the upper zones, but the main zinc sulfide deposits were not developed until the formations below the Reeds Spring formation were explored. These lower zinc sulfide deposits occur in (a) a chert breccia at the base of the Reeds Spring formation; (b) a selvage zone at the top of the Pierson limestone; (c) the Northview shale and Compton limestone where these formations have altered and decomposed into a calcareous mud; and (d) the Cotter dolomite where it is shattered or broken.
>
> The sphalerite occurs both as minute grains and well-developed large crystals disseminated through the "mud" and as veins and fissure fillings in the more solid strata of limestone or chert breccia. Calcite and pyrite occur sparingly."

These shallow ore bodies produced more than five million pounds of lead. The mines were first operated in 1857 and were periodically worked through 1942 and 1943 when they produced around 132 tons of 60-percent zinc concentrate (Ballinger, 1948). Several other zinc mines and lead diggings are also present around the flanks of the anomaly.

D. Physical Constants of the Rocks

In a magnetic survey, it is necessary to consider the composition of the formations to determine the possible source of an anomalous area. A search through the literature and well log data revealed no appreciable amount of magnetic materials present in any of the sedimentary formations. Therefore, the source of the anomaly probably originates from the rocks that form the basement complex.

In gravity interpretation procedures it is necessary to consider the densities of the underlying rocks. The densities of the sedimentary formations (Scharon, 1961) are listed in the stratigraphic column (Figure 1).

Approximately 60-percent of the basement complex in the State of Missouri is composed of granites and rhyolites (Adams, 1959). The susceptibility of the granites vary from 432 to 1,859 x 10^{-6} c.g.s. units. The density varies from 2.6 to 2.69 gm./c.c. (Scharon, 1961).

Basic rocks are known in Missouri. Basalts are present and have a susceptibility of 2037.9 x 10^{-6} c.g.s. units with a density of 3.02 gm./c.c. (Scharon, 1961). Large outcrop areas of diabase, up to two to three square miles, are known in Madison County in southeast Missouri. From normative mineral analyses (C.I.P.W.) of diabases from the Skrainka quarry in Madison County (Hayes, 1961), the analyzed samples were found to contain from 3.25 to 13.46 percent of magnetite. These are theoretical calculations from chemical analyses of the rocks. Calculating susceptibilities from the percentage of magnetite present (Slichter, 1929), the diabases vary from 9,750 to 40,380 x 10^{-6} c.g.s. units. These calculations seem to be high for measured susceptibilities of diabases as given in the literature. Birch (1942, p. 297) lists a diabase as low as 2700 x 10^{-6} c.g.s. units. Density measurements were made of a hand sample from the Skrainka quarry and the average density was found to be 2.97 gm./c.c.

Ultrabasic post-Devonian intrusive rocks are known in southeast Missouri. Most of these are distributed over an area of about 75 square miles in St. Francois and Ste. Genevieve Counties. These are peridotite dikes ranging in size from 8 to 200 feet in diameter (Kidwell, 1947). The susceptibility of peridotite ranges from 4,800 to 22,000 x 10^{-6} c.g.s. units (Dobrin, 1960). The density of peridotite varies from 3.15 to 3.28 gm./c.c. with a mean of 3.23 gm./c.c. (Birch, 1942).

III. THE MAGNETIC SURVEY

A. The Magnetometer

A Ruska Vertical Magnetometer was used in making all measurements. This is a Schmidt type, temperature compensated instrument which measures the vertical component of the earth's magnetic field at a single point in relation to another given point. Thus, observations from point to point will measure the relative change in the earth's magnetic field.

B. Instrument Adjustments and Corrections

The instrument was adjusted and corrections were applied as outlined in the Ruska Field Manual (Ruska, 1957). These follow the standard procedures given in most textbooks. The latitude adjustment was made for the area and the instrument was calibrated before and after the survey with a Helmoltz Coil. The instrument constant was found to be 10.0 γ/S.D. Even though the instrument is temperature compensated, an additional correction of -0.3 $\gamma/^{\circ}C$ was necessary for the required accuracy. An auxiliary magnet was necessary at the stations over the peak of the anomaly and the appropriate corrections were made. Base stations were occupied on an average of every two hours to account for diurnal changes in the earth's magnetic field. Straight line variation was assumed during the time away from the base station and this was applied to the intermediate readings. The normal (latitude and longitude) corrections were calculated from the Magnetic Charts of 1945 (Deel, et al., 1949) and found to be +11.2 γ/mile to the north and +2.4 γ/mile to the east. The final values were corrected to one base station.

C. Field Procedure

During the summer of 1960, one hundred and sixty-six stations were read with the magnetometer within the area of investigation. All readings are relative to the base station at the intersection of Missouri Highway 125 and the north-south farm to market road on the N.E. ¼ of section 31 of T27N-R19W.

When possible, observations were made on a mile grid. The readings, with a few exceptions, were made on the available roads. In regions where there were no available roads, the readings were made by hiking to the station. In the area of the anomaly, readings were made on a ¼ mile grid (Figure 2).

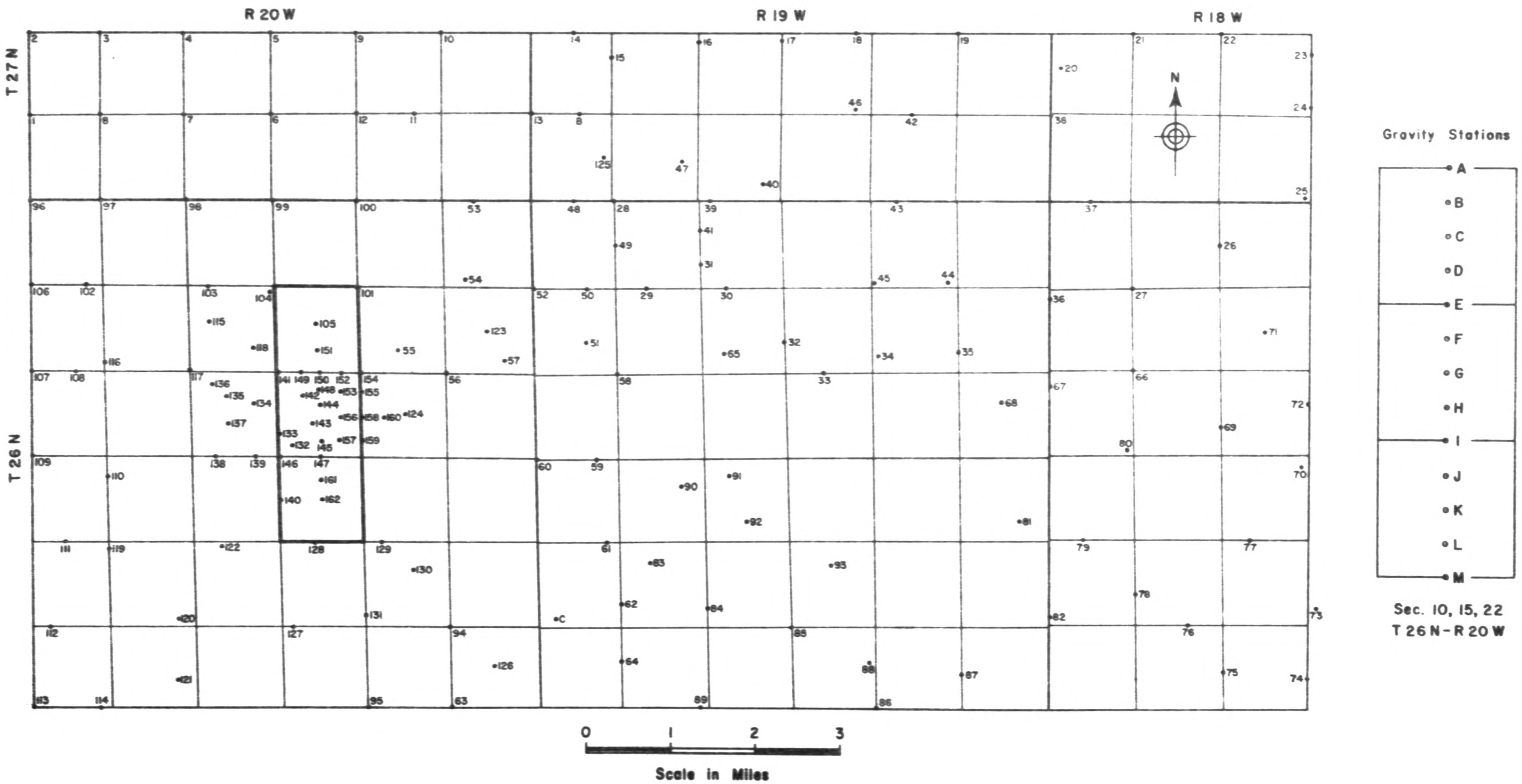


Fig. 2. Magnetic and Gravity Station Locations

IV. THE GRAVITY SURVEY

A. The Gravity Meter

A Magnolia Gravity Meter was used in making all measurements. This is an unstable type instrument which measures the vertical component of the earth's gravitational field at a single point. Thus, observations from point to point will measure the relative changes in the earth's gravitational field.

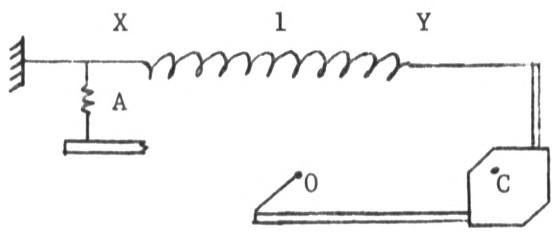


Fig. 3. A Schematic Diagram of the Magnolia Gravity Meter

A schematic diagram of the Magnolia Gravity Meter is given in Figure 3. The instrument utilizes an L-shaped mass pivoted about the lower end point of the L at point 0. The mass has a weight distribution such that the center of gravity of the structure is at C. A pretensioned helical spring of length l joins the mass at Y and is anchored to the instrument housing by means of a stiff wire at X. The force provided by the spring constitutes the labilizing force. A spring (A) is provided as a method of nulling the instrument as a measure of the force required to bring the center of gravity in a line horizontal with the pivotal point 0. The instrument has a built in damper and temperature compensator. In addition, the instrument is enclosed in an insulated, thermostatically controlled electric oven. An external six volt power source is necessary for the operation of the oven. This source also provides the power necessary to operate the lights in the optical system of the instrument.

B. Instrument Adjustments and Corrections

The instrument was adjusted as outlined in the Magnolia Gravity Meter

Manuals and the scale was reset for the area. A scale constant of 0.07361 mg./S.D. was used. This was determined by the Magnolia Petroleum Company for this particular instrument. Nettleton's Profile Method of density determination was used (Nettleton, 1940). A gravity traverse was run across a hill in the area. The gravity values were then reduced for different densities. A density of 2.5 gm./c.c. was found to give the smoothest gravity profile across the hill. This density was then used to give a combined elevation correction of 0.06216 mg./ft. Using this correction all stations were reduced to a datum of + 1000.00 feet. Due to the nature of the topography, terrain corrections were applied to all the readings. Hammer's correction chart and tables were used (Hammer, 1939). The transparent chart was superimposed on the topographic maps of the area and calculations were made for zones C through F. Using the average density of 2.5 mg./ft., a terrain correction factor of 0.0125 mg./correction was applied to the corrections. The latitude corrections were taken from tables (Nettleton, 1940). Base stations were occupied on an average of every two hours to establish the amount of instrument drift. Straight line variation was assumed during the time away from the base station and this was applied to the intermediate readings.

C. Field Procedure

During the spring of 1961, twenty-two stations were surveyed with a dumpy level and rod to obtain accurate elevations. In order to minimize terrain corrections, the base station and the thirteen stations used for the gravity profile were located in as level an area as was possible. The 16 profile stations were spaced at quarter of a mile intervals running north-south across sections 10, 15, and 22 of T26N-R20W (Figure 2). The remaining eight stations traversed a hill. These were used for a density determination. All readings are relative to the base station at the intersection of the farm to market road and the half section fence in the center of section 10 of T26N-R20W.

Power was applied to the instrument for a 24 hour period prior to the commencement of the survey to stabilize it. The gravity meter was then transferred to a jeep and the vehicle's storage battery served as a power source for the instrument. Before occupying each station the instrument was removed from the jeep. To insure stability of the instrument, the power source remained connected.

V. RESULTS OF SURVEYS

A. Magnetic Map and Profile

After the necessary corrections were applied to the measured magnetic data (Appendix A), a vertical magnetic intensity map of the investigation area was prepared (Figure 4). The contour interval is 50 gammas.

There are two areas on the map that are characterized by magnetic anomalies. Anomaly "A" centers in T26N-R20W south of southwest of Sparta. Anomaly "B" centers on the northern edge of T26N-R19W near Oldfield.

Anomaly "A" is approximately circular and has a maximum value of 938 gammas with a relative difference of about 825 gammas with the surrounding area. The anomaly departs from a circular form by an extension to the southeast.

Anomaly "B" is approximately elliptical in shape, striking, in general, east of southeast. It has a much steeper gradient to the south than to the north with a maximum value of 579 gammas with a relative difference of about 425 gammas with the surrounding area.

It was intended to make a rigorous interpretation of anomaly "A" only, with the possibility of outlining any other anomalies in the area. As a result, the station spacing in the vicinity of anomaly "B" is inadequate for extensive interpretation procedures. The extension of anomaly "A" lies in an area accessible only by foot and as a result, few stations were occupied. Consequently, there is insufficient data for a thorough interpretation.

From the data used to construct the magnetic map, a magnetic profile running north-south across anomaly "A" was constructed (Figure 5).

B. Gravity Profile

After the necessary corrections were applied to the measured gravity

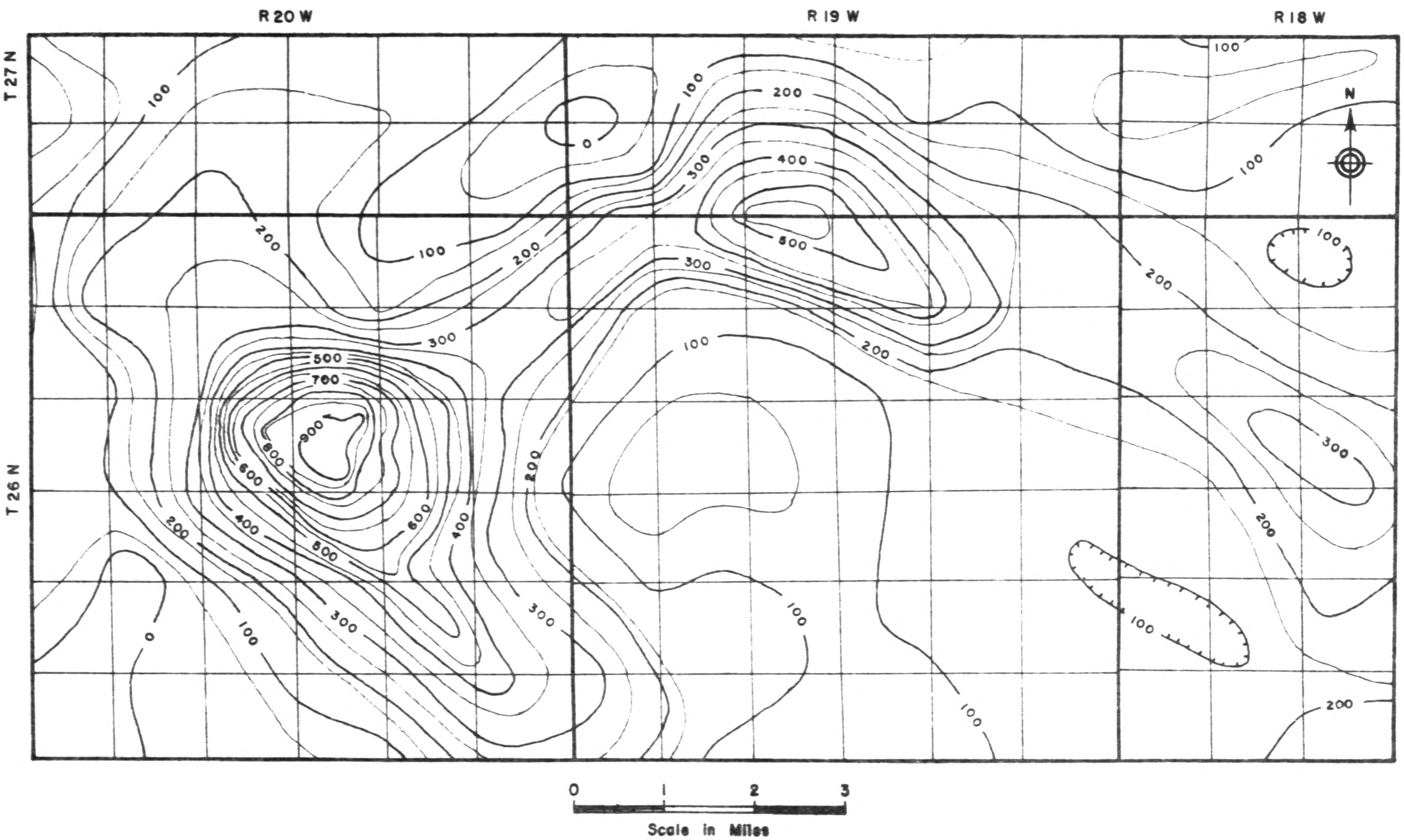


Fig. 4. Verical Intensity Magnetic Contour Map of the Investigation Area

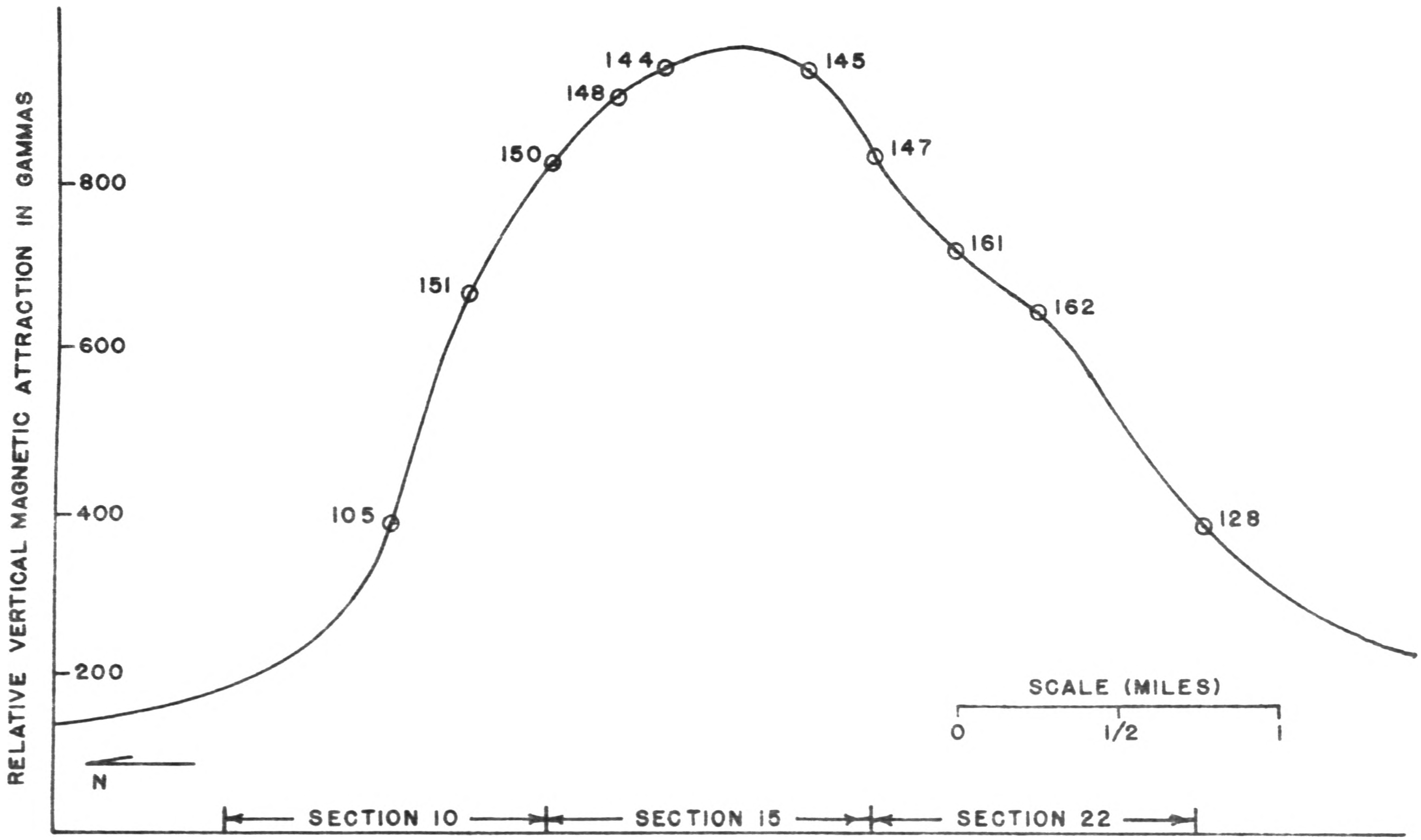


Fig. 5. Vertical Intensity Magnetic Profile Across Anomaly "A"

data (Appendix B), a Bouguer Gravity profile was constructed (Figure 6). The anomaly is in excess of six milligals. This profile is fairly symmetrical, closely corresponding to the magnetic profile. It is, therefore, a logical assumption that the source of the gravity anomaly is the same as the source of the magnetic anomaly.

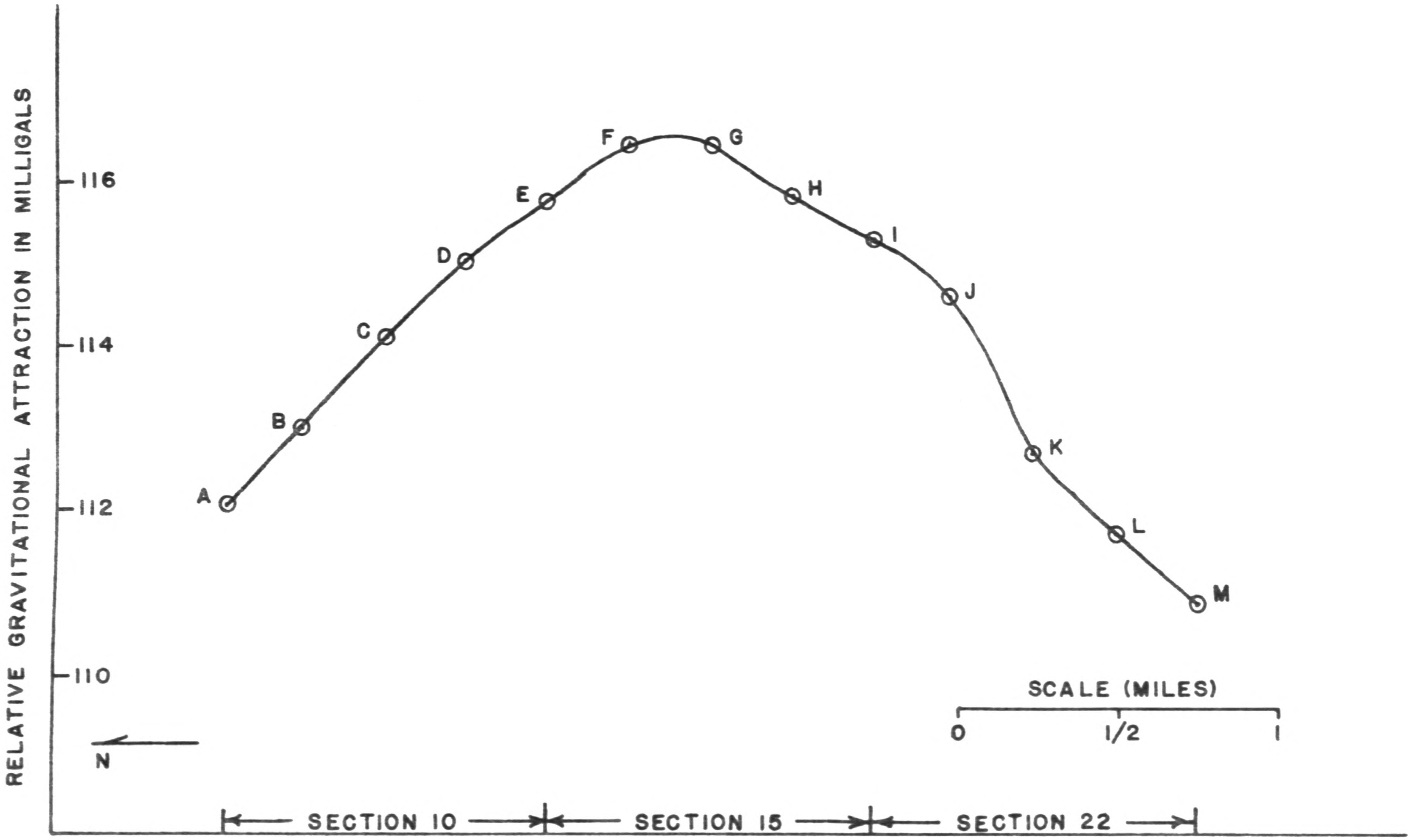


Fig. 6. Bouguer Gravity Profile Across Anomaly "A"

VI. INTERPRETATION

A. General

The interpretation of potential data (magnetic and gravity) has no unique solution for the variables number more than the quantities known. The only known values are the vertical magnitude of the anomaly and the earth's field at the point in question. The unknown values are the depth to the structure, the size and shape of the structure, the direction of magnetization, and the intensity of magnetization.

Several methods for depth determinations have been described in the literature. Some of these will be discussed in detail later in this chapter. A general idea as to the size and shape of the structure can be obtained from a general analysis of the field data. Certain assumptions are usually made in the analysis of vertical magnetic field data, one of these being that the body is assumed to be vertically polarized. This assumption is made where the inclination of the earth's magnetic field is greater than 60 degrees (Nettleton, 1940) and in the area of investigation, the field has an inclination of 68 degrees (Deel, et al., 1949). Another assumption is that the body is uniformly polarized and that this polarization is due to the earth's present magnetic field. The earth's present vertical component in the area is 0.516 oersteds. This was determined by extending the Magnetic Charts of 1945 (Deel, et al., 1949) to the time of the field survey.

There is one additional requirement and, possibly, the most important one in geophysical interpretation. The end result must be geologically possible.

B. General Analysis

Anomaly "A" is thought to be a result of two separate sources, the one causing the fairly symmetrical part that comprises the major part of the anomaly, and the source of the extension of the anomaly to the southeast. The extension, like anomaly "B", is elongate in a general northwest-southeast direction. Anomaly "B" and the extension of anomaly "A" reflect the same general trend present throughout southwest Missouri (Magnetic Map of Missouri, 1943) which could conceivably be an indication of the Precambrian structural control, and could possibly be a reflection of basement topography.

Only the major part of anomaly "A", which is reflected as the northern slope of the magnetic profile, is of primary importance. The extension of the anomaly to the southeast is indicated by a more gentle gradient. Therefore, analysis of the anomaly by primary use of the northern slope should give the most accurate answer.

It is essential to assume that the source of the magnetic anomaly is responsible for the gravity anomaly. Upon examination of the densities of the overlying sediments, it becomes apparent that the anomaly could not be due to a buried hill of granite. The densities of the immediate overlying sediments are approximately equal or even greater than the Precambrian granites and rhyolites. The gravity profile does not reflect the more gentle gradient to the south as does the magnetic profile. This is to be expected if the extension is due to a ridge, for then the ridge would produce either no anomaly or a small negative anomaly and would not be apparent in the gravity profile.

It can be seen from the very broad profiles across anomaly "A" that the source of the anomalies is very large, probably measured in terms of thousands of feet. From a general analysis of the gradient of the sides, the body should lie quite deep. It is also apparent that the body is fairly symmetrical in the horizontal plane.

C. Buried Hill Calculations

A possibility to be considered is that anomaly "A" is due to basement relief. Peters describes a method of calculating basement topography by relating it to the observed intensity (Peters, 1949).

By continuing the observed magnetic field downward to the basement level, Peters derives the equation:

$$f(x,y) = \frac{1}{4\pi^2 I_z} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{H_z(\alpha,\beta,h)\,d\alpha d\beta}{[(x-\alpha)^2 - (y-\beta)^2]^{\frac{1}{2}}} \qquad (1)$$

where

$f(x,y)$ = the basement structure at point $(x,y,0)$

I_z = the vertical polarization of the body

$H_z(\alpha,\beta,h)$ = the observed vertical field at point (α,β,h)

This integral is then approximated by:

$$f(0) = \frac{d}{4\pi^2 I_z x\ 10^5} \Sigma\, C_n H_n \qquad (2)$$

where

$f(0)$ = the basement relief above a mean plane

d = the grid spacing in the same units as f

C_n = an irrational coefficient

Table I gives the values of C_n for values of n and the grid with which they are to be used is shown in Figure 7.

The grid, used to evaluate H_n, is constructed and superimposed upon the magnetic map. The average value of H_n around the circle n is the sum of the values of the vertical intensity at the indicated points divided by the number of points. This process is repeated for all values of n at one station, before moving to another station.

TABLE I

COEFFICIENTS FOR CALCULATION OF STRUCTURE

n	C_n
0	3.670
1	0.985
2	0.910
3	0.427
4	0.382
5	0.267

(after Peters, 1949)

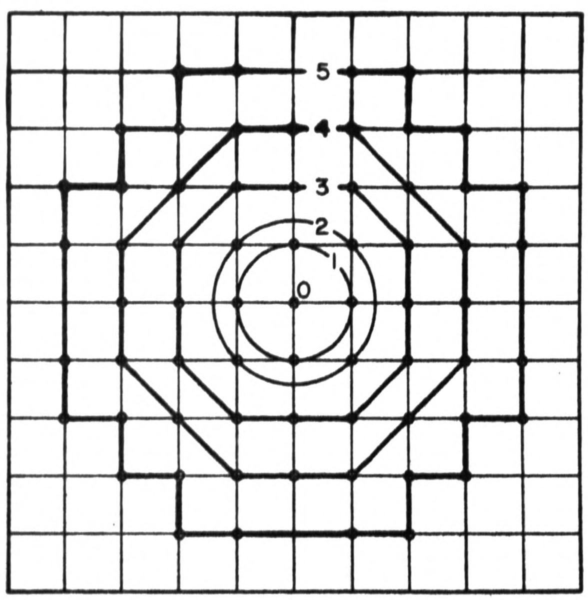


Fig. 7. Grid for Calculation of Structure Using Coefficients of Table I.

This method of interpretation was applied to anomaly "A" and the theoretical structure was calculated for the northern part of the anomaly (Figure 8) by continuing the anomaly downward ½ mile. This places it close to the depth of basement predicted by the Missouri Geological Survey and Water Resources. Equation (2) was evaluated on the Royal-McBee LGP-30 electronic digital computer (Appendix C). Since it is a geophysically improbable situation that the buried structure is one comprised of granite or rhyolite, the susceptibility of basalt was used in calculating this theoretical anomaly. The axis of ordinates of the theoretical anomaly is measured in feet above the ½ mile plane. Upon examination of this axis it is easily seen that the basement would outcrop at the surface. This is an impossible situation, so the feasibility of basement relief is discarded.

D. Depth Calculations

Several definite rules have been given in the literature for estimating the depths to certain shaped magnetized bodies from the widths of their magnetic anomalies. If the anomaly is derived from a single pole, the depth to the pole is 1.305 times the horizontal distance from the center of the anomaly to the point where the anomaly has half of its maximum value. For a sphere, the depth to the center is two times this horizontal distance (Nettleton, 1940). It is pointed out by Peters (1949, p. 310) that these half-width formulas lack precision because it is difficult to obtain isolated anomalies.

A more general technique is described by Peters (1949, p. 311-312) which he calls the "error curve" method. He observed that if continuation of the observed magnetic intensity was carried downward to a depth h and then back again, fairly accurate results were obtained until the

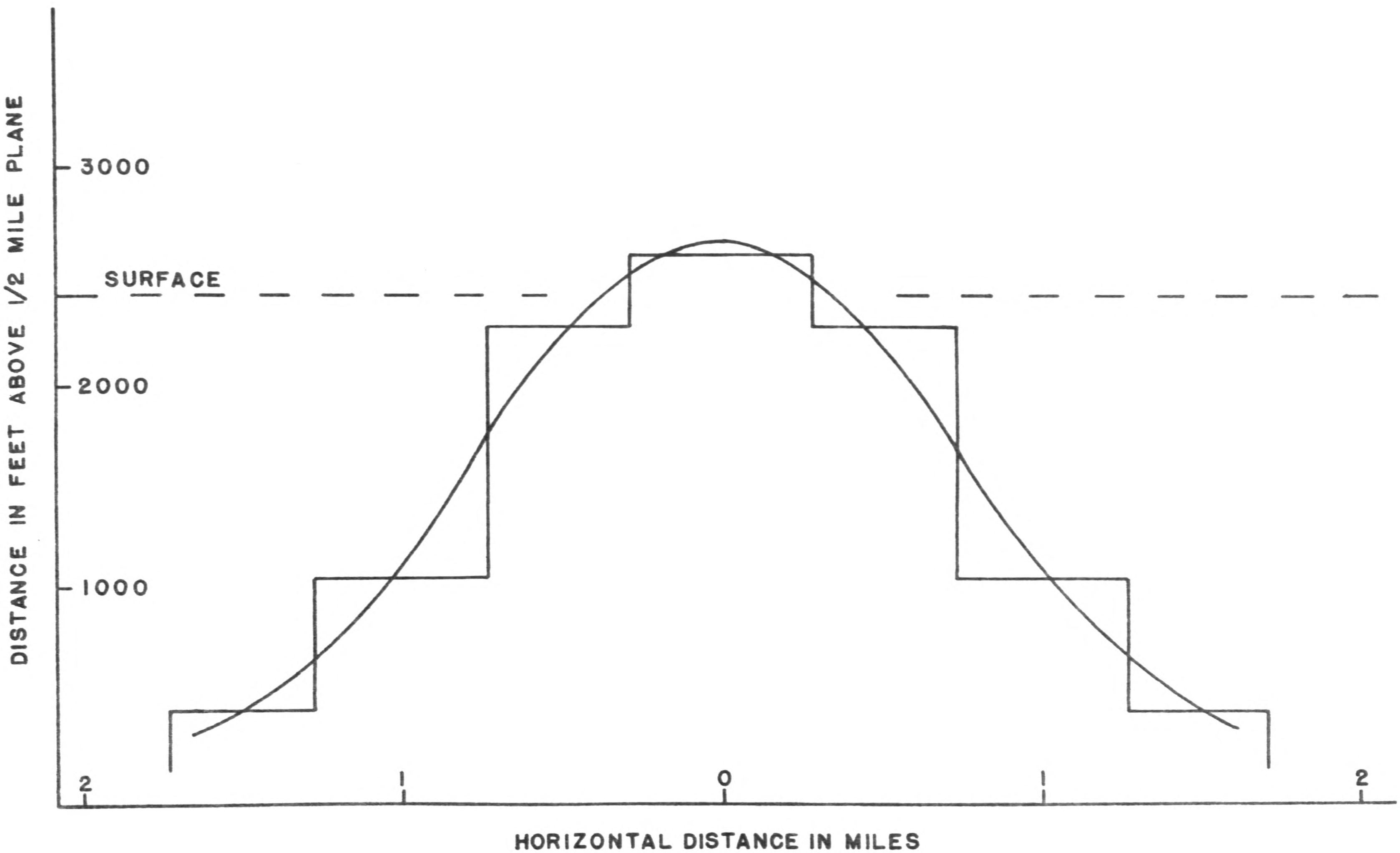


Fig. 8. Theoretical Buried Hill of Basalt.

depth of burial was approached. Beyond this depth the error increased rapidly. Application of this method is given in the following procedure.

H_a is the recalculated surface intensity from continuation downward at depth h. Then

$$H_a = \Sigma \, C_n \, H(b_n h) \qquad (3)$$

where $H(b_n h)$ is the average value of the observed magnetic intensity around a circle of radius $b_n h$, b_n is a specified constant and C_n is an irrational coefficient.

The error in continuation is then

$$E = H_o - H_a = H_o - \Sigma \, C_n \, H(b_n h) \qquad (4)$$

where H_o is the maximum observed magnetic intensity.

The coefficients for the calculation of error in continuation are given in Table II.

The point of maximum curvature on a vertical intensity contour map is first selected. About this point, a series of circles is drawn having radii of $b_n h$ where h is the estimated depth of the anomaly based on one of the short-cut methods. This estimate need not be better than 50% accurate. The average values around these circles are multiplied by the appropriate value of C_n and E is calculated. The process is repeated for h/2, 3h/2, and 2h. E is plotted against h, and for all values of h less than the depth, the error will be small but will diverge rapidly with increasing h as h becomes greater than the true depth of burial. The true depth of burial is at the value of h where E shows a sharp inflection.

This method was applied to anomaly "A". Equation (4) was evaluated on the Royal-McBee LGP-30 electronic digital computer (Appendix D) and the depth to the structure was determined to be approximately 4000 feet

TABLE II

COEFFICIENTS FOR CALCULATION OF ERROR

IN CONTINUATION FOR USE IN ESTIMATION OF DEPTHS

n	b_n	C_n
1	0.1	0.3001
2	0.3	0.5102
3	0.5	0.2622
4	0.7	0.0311
5	0.9	-0.0378
6	1.1	-0.0348
7	1.3	-0.0190
8	1.5	-0.0087
9	1.7	-0.0035
10	1.9	-0.0011
11	2.25	0.0000
12	2.75	0.0007
13	3.25	0.0003
14	3.75	0.0003

(after Peters, 1949)

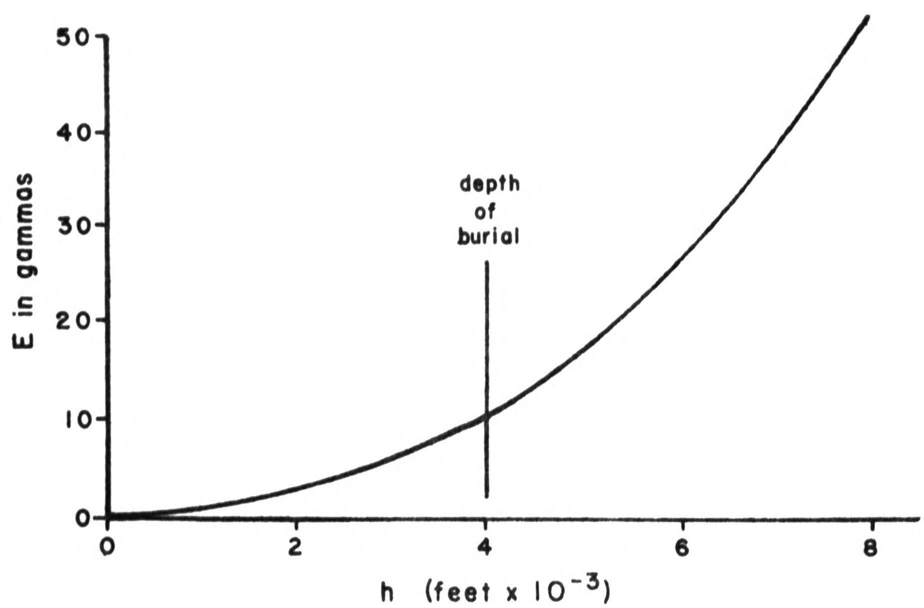


Fig. 9. Error Curve Obtained by Means of Coefficients of Table II.

(Figure 9). This would place the top of the structure approximately 1600 feet below the surface of the Precambrian complex.

E. Vertical Cylinder Calculations

A procedure often used in the interpretation of potential data is to compare an observed magnetic or gravity profile with a theoretical one that would result from a body having a simple geometrical shape. An idea can be gained as to the shape of the body by analyzing the plan view of the anomaly. It was determined by general analysis, that the source of anomaly "A" would be symmetrical in the horizontal plane. A geologically significant case included in this category is that of a buried vertical cylinder. Nettleton (1942, p. 303) has approached the solution of the attraction of this body by means of solid angles.

For a vertically polarized vertical cylinder, the polarization throughout the body can be considered as being concentrated by a surface magnetization of its upper and lower faces. For each face the magnetic effect at the point in question is proportional to the solid angle subtended by the boundary of that face. Therefore, the magnetic effect of a vertically polarized cylinder is proportional to the difference between the solid angles subtended by its upper and lower faces.

The vertical gravitational attraction of a thin horizontal disk at the point in question is directly proportional to the solid angle subtended. For a disk with a thickness less than half its mean depth, its gravity effect can be approximated by considering its mass to be concentrated along its median plane and calculating the effect by means of the solid angle subtended by the boundary of this mean plane. If the effects of several disks, in a stack, are added together, the effect of a vertical cylinder is produced.

A chart giving solid angles for circles over a considerable range is given by Nettleton (1942, Fig. 4). This chart is reproduced in Figure 10.

Nettleton's method of solid angles was applied to determine the source of anomaly "A". In all cases, the host rock was considered to be a granite. The first consideration was a vertical cylinder whose upper face was at a depth of 4,000 feet. This was the depth determined by the error in continuation. It was found that a body with a 4,200 foot cross-sectional radius, a thickness of 14,000 feet, a susceptibility of 9,750 x 10^{-6} c.g.s. units and a density of 3.20 gm./c.c. would closely match the profiles across anomaly "A" (Figures 11 and 12). The physical constants of such a body match those of a large peridotite plug. No bodies of peridotite this large are known in Missouri although it is not an impossible situation. If enough heavy accessory sulfide minerals (galena, sphalerite, pyrite, etc.,) which have a negligible susceptibility were added to the constituents of a diabase plug of the above dimensions to raise the density about 0.3 gm./c.c., then the same magnetic and gravity effect would be produced as that produced by the peridotite. It is of interest to note the possible correlation between a body of this nature and the lead-zinc prospects in the area.

Another possibility that was considered was the effect of a body which outcropped on the Precambrian surface, i.e. at depth of 2,400 feet. Using the same method of interpretation, it was found that a vertical cylinder with a 4,800 foot cross-sectional radius, a thickness of 15,600 feet, a susceptibility of 4,560 x 10^{-6} c.g.s. units, and a density of 2.97 gm./c.c. would closely match the same profiles (Figures 13 and 14). This would correspond to a large diabase plug. Diabase bodies of this areal extent are known and are quite common in Missouri as mentioned in Chapter II.

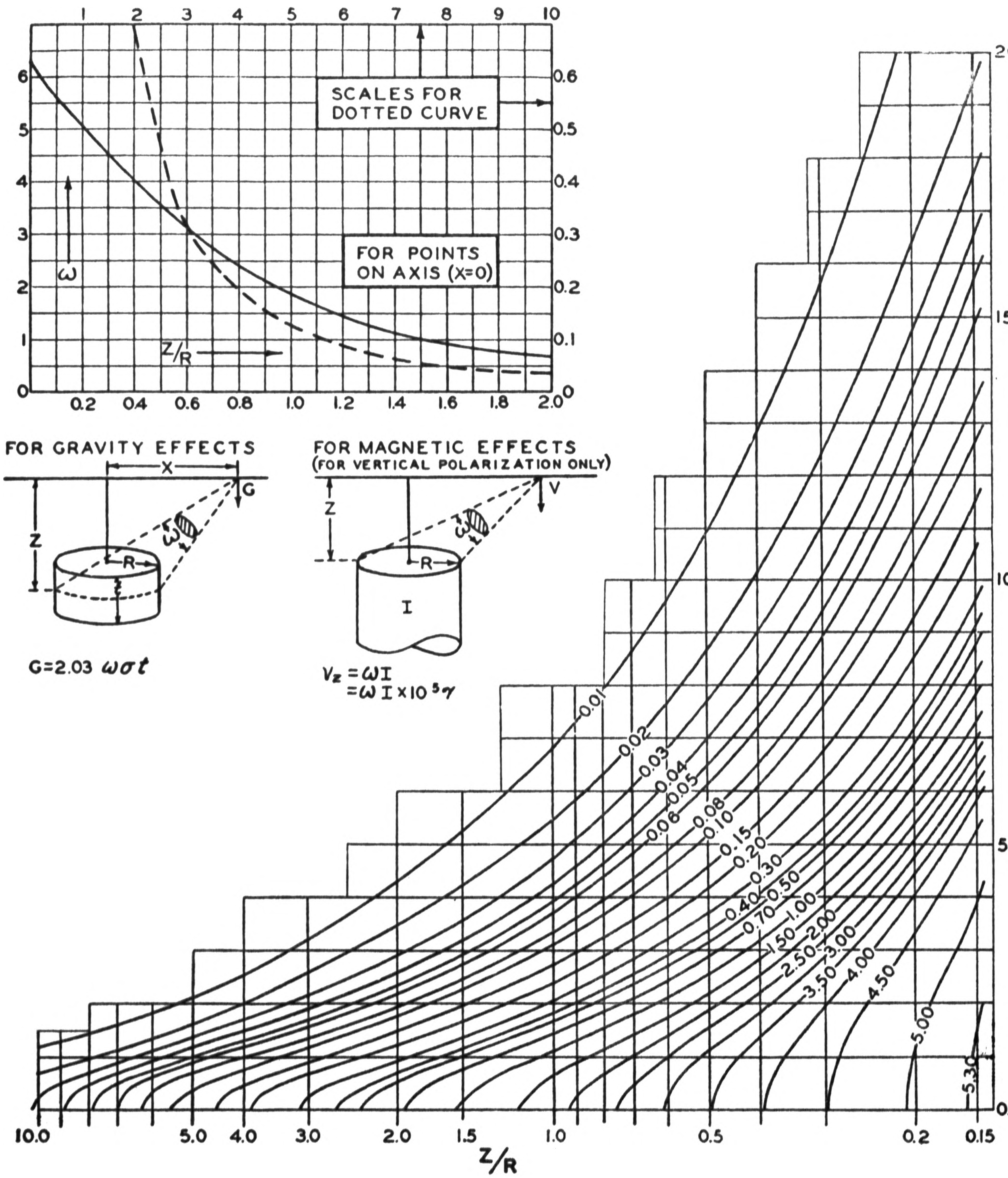


Fig. 10. Solid Angle Chart for Calculating Gravitational and Magnetic Effects for Discs and Cylinders, Respectively, (after Nettleton, 1942).

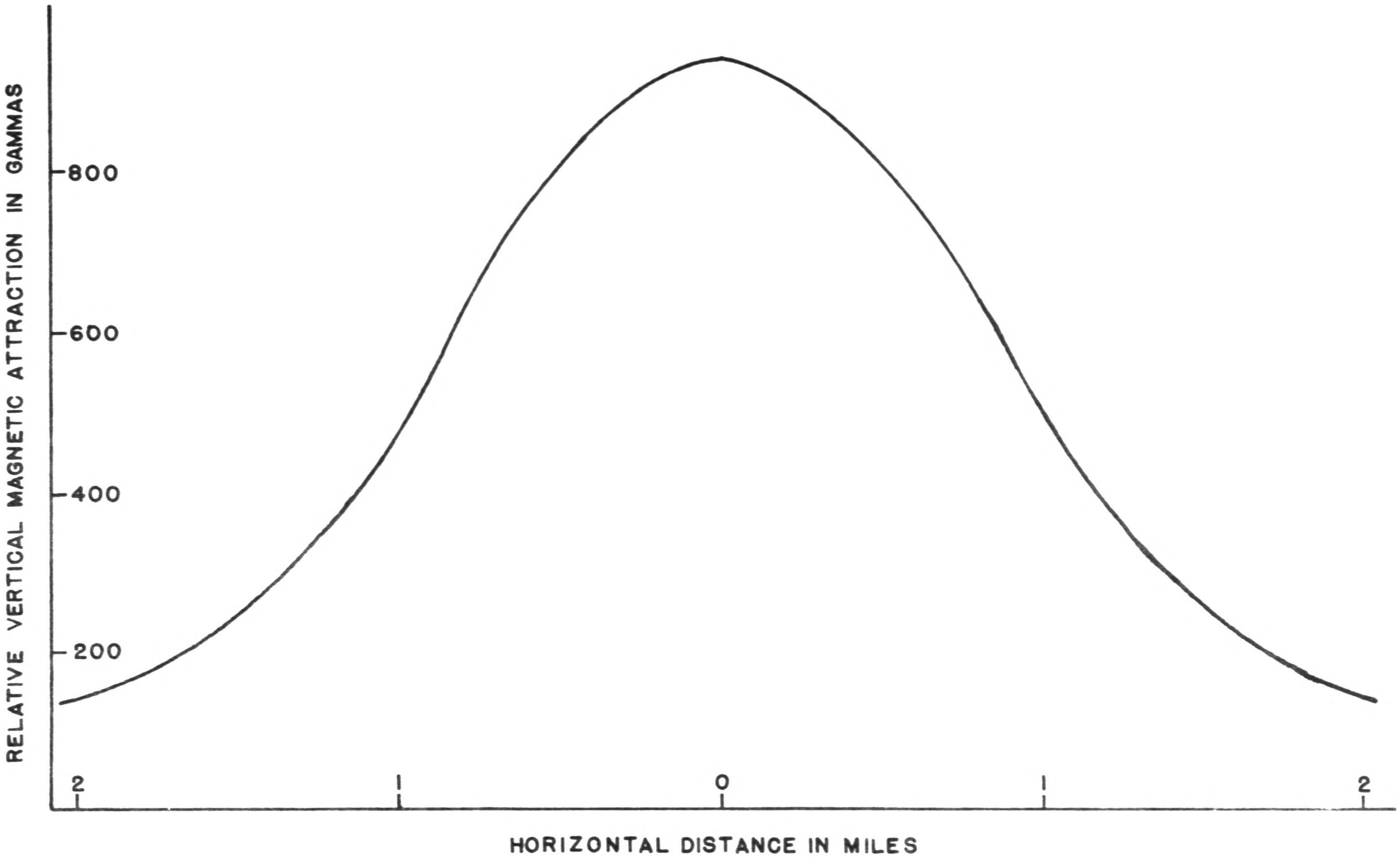


Fig. 11. Theoretical Vertical Intensity Magnetic Anomaly over Buried Vertical Cylinder; Z = 4,000 feet, R = 4,200 feet, t = 14,000 feet, $\Delta k = 9{,}220 \times 10^{-6}$ c.g.s. units, $H_z = 0.516$ oersteds.

Fig. 12. Theoretical Gravity Anomaly over Buried Vertical Cylinder; $Z = 4,000$ feet, $R = 4,200$ feet, $t = 14,000$ feet, $\Delta\sigma = 0.6$ gm/c.c.

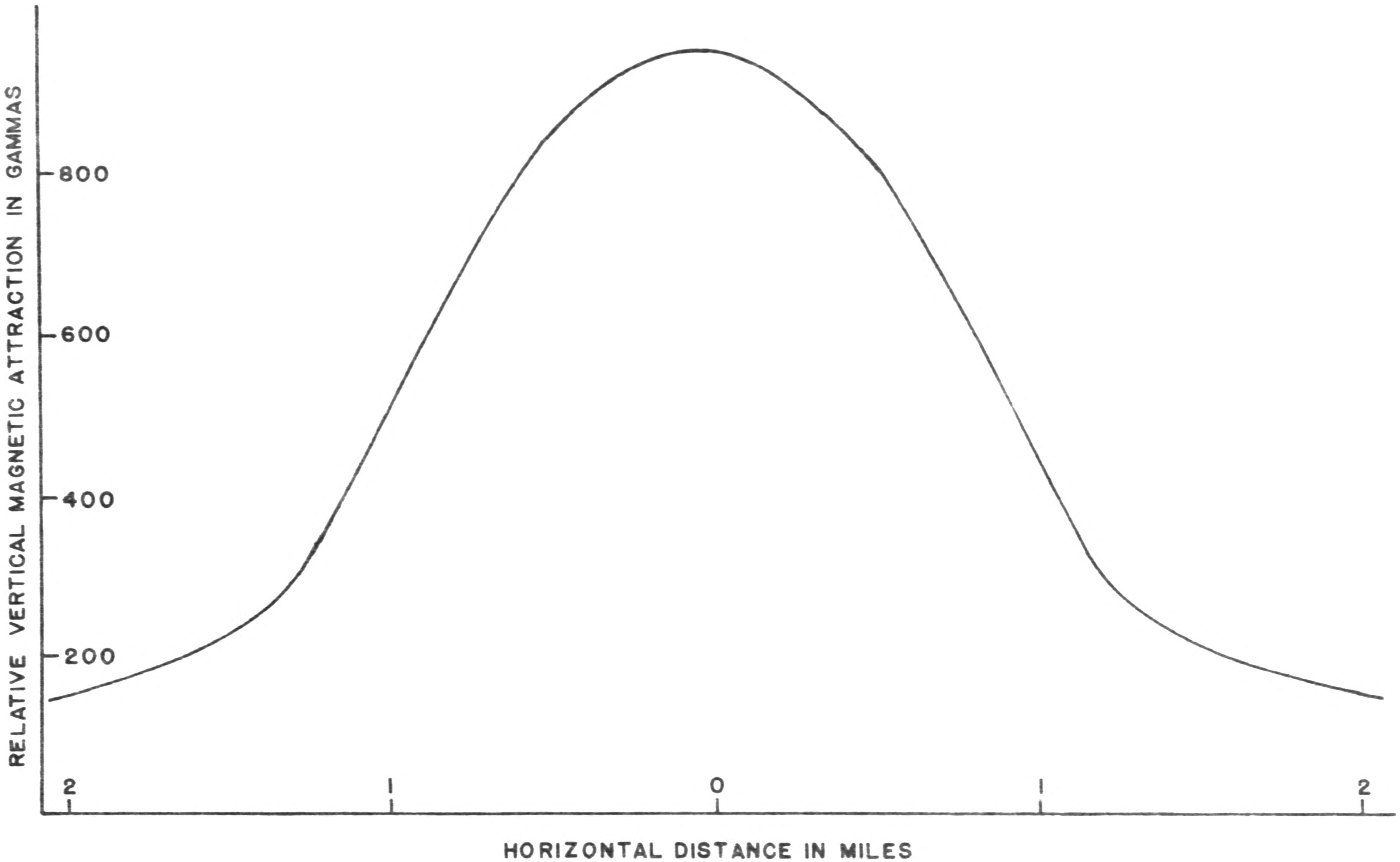


Fig. 13. Theoretical Vertical Intensity Magnetic Anomaly over Buried Vertical Cylinder; Z = 2,400 feet, R = 4,800 feet, t = 15,600 feet, $\Delta k = 5{,}600 \times 10^{-6}$ c.g.s. units, $H_z = 0.516$ oersteds.

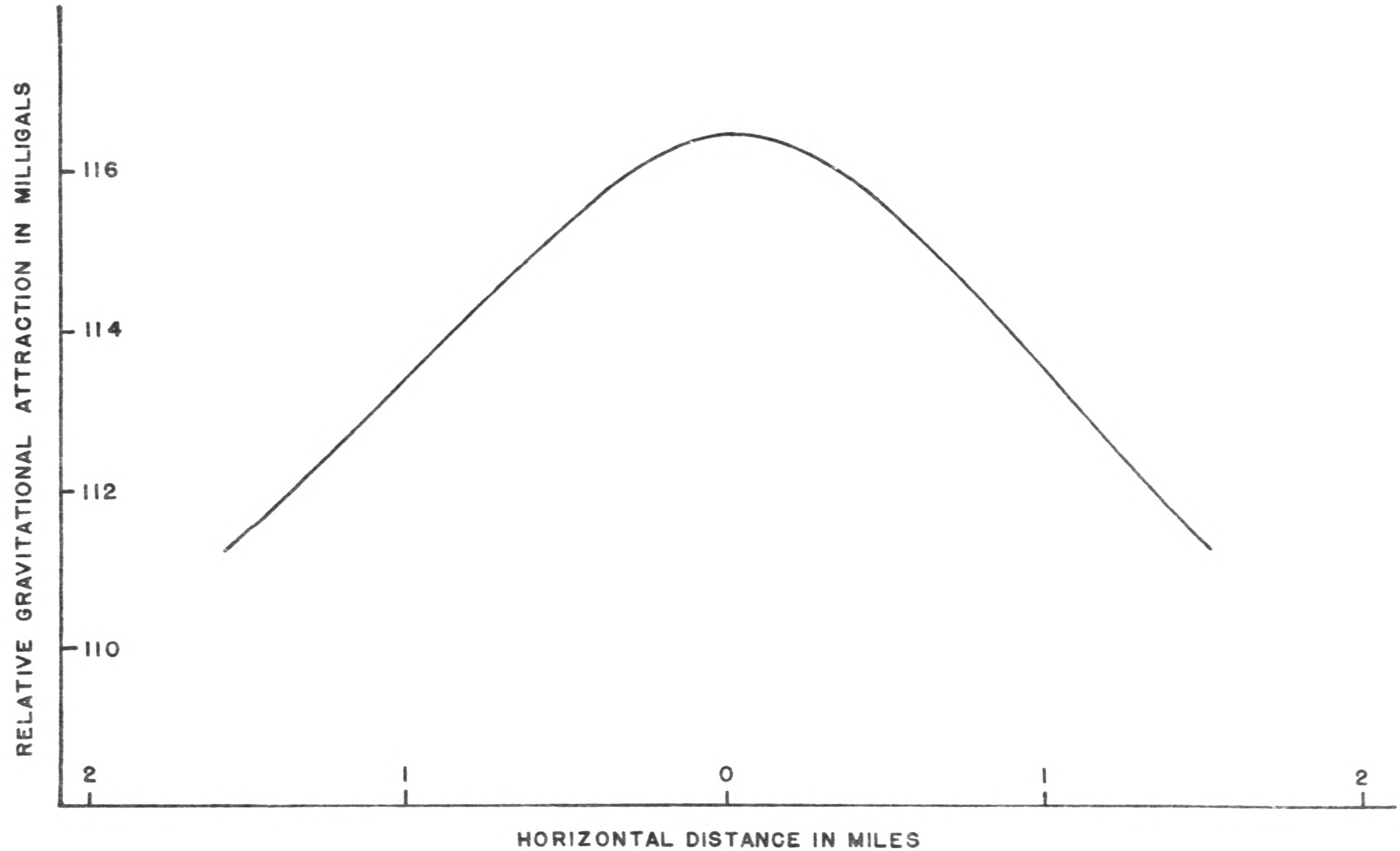


Fig. 14. Theoretical Gravity Anomaly over Buried Vertical Cylinder; Z = 2,400 feet, R = 4,800 feet, t = 15.600 feet, $\Delta\sigma$ = 0.3 gm./c.c.

VII. RESULTS AND CONCLUSIONS

The results and conclusions are as follows:

1. The known major vertical magnetic anomaly in the area of investigation was outlined in detail. The survey revealed a rather large, broad, nearly circular shaped anomaly. This magnetic survey was supplemented with a gravity traverse which resulted in a positive symmetrical anomaly across the major magnetic anomaly.

2. It was shown that it is unlikely that the structure causing the major anomaly found in the investigation area is the result of a buried Precambrian hill of either granite, rhyolite or basalt.

3. Depth calculations indicate the source of the major anomaly to be at a depth of 4,000 feet below the surface of the area, 1,600 below the buried surface of the Precambrian complex.

4. The magnetic and gravity profiles were matched with theoretical curves over buried vertical cylinders, which correspond with the following geological bodies;

   a. a large peridotite plug, at a depth of 4,000 feet, a thickness of 14,000 feet and a cross-sectional radius of 4,200 feet,

   b. a large diabase plug of the same dimensions and depth, with heavy sulfide minerals (galena, sphalerite, pyrite, etc.) present which would increase the density of the body but not the susceptibility, and

   c. a large diabase plug outcropping on the Precambrian surface, at a depth of 2,400 feet, with a cross-sectional radius of 4,800 feet, and a thickness of 15,600 feet.

5. On the basis of present geophysical and geological evidence, the structure is not of economic importance.

VIII. BIBLIOGRAPHY

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IX. APPENDICES

APPENDIX A

CORRECTED MAGNETIC FIELD DATA

Project Christian County, Missouri Sheet 1 of 19

Location Christian County, Missouri Date June 16, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
M. Sta.	81.3	0825	23.5	+3.5	-1	813	812	-	0	0	812	812	0	415
Hub 1	35.8	0905	26.5	+6.5	-2	358	356	-	-3	-121	812	688	-332	83
M. Sta.	81.0	0940	29.0	+9.0	-3	810	807	-	-5	0	812	807	0	415

Project Christian County, Missouri Sheet 2 of 19

Location Christian County, Missouri Date June 17, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 1	31.3	0857	21.5	+1.5	-0	313	313	-	0	0	313	313	0	83
1	32.5	0922	23.0	+3.0	-1	325	324	-	-1	+4	313	316	+8	91
2	29.8	0945	26.0	+6.0	-2	298	296	-	-1	+15	313	327	-31	52
3	34.2	1000	27.0	+7.0	-2	342	340	-	-2	+18	313	329	11	94
4	33.1	1020	28.0	+8.0	-2	331	329	-	-2	+20	313	331	-2	81
5	35.4	1037	28.5	+8.5	-3	354	351	-	-2	+23	313	334	17	100
6	41.1	1055	29.0	+9.0	-3	411	408	-	-3	+11	313	321	87	170
7	41.7	1112	29.5	+9.5	-3	417	414	-	-3	+9	313	319	95	178
8	27.2	1125	30.0	+10.0	-3	272	269	-	-4	+7	313	316	-47	36
Hub 1	31.2	1142	30.0	+10.0	-3	312	309	-	-4	0	313	309	0	83
Hub 1	32.0	1231	32.0	+12.0	-4	320	316	-	+3	0	313	316	0	83
9	39.2	1305	32.0	+12.0	-4	392	388	-	+4	+25	313	342	46	129
10	38.7	1323	33.0	+13.0	-4	387	383	-	+5	+27	313	345	38	121
11	37.9	1345	33.5	+13.5	-4	379	375	-	+6	+15	313	334	41	124
12	41.0	1403	33.5	+13.5	-4	410	406	-	+7	+14	313	334	72	155
Hub 1	32.5	1420	34.0	+14.0	-4	325	321	-	+8	0	313	321	0	83

Project Christian County, Missouri Sheet 3 of 19

Location Christian County, Missouri Date June 21, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
M. Sta	81.7	0815	24.0	4.0	-1	817	816	-	0	0	816	816	0	415
Hub 2	29.8	0905	27.0	7.0	-2	298	296	-	-4	-101	816	711	-415	0
M. Sta	81.2	0950	30.0	10.0	-3	812	809	-	-7	0	816	809	0	415
Hub 2	28.6	1035	32.0	12.0	-4	286	282	-	0	0	282	282	0	0
13	27.0	1050	32.5	12.5	-4	270	266	-	0	-1	282	281	-15	-15
14	39.1	1105	32.5	12.5	-4	391	387	-	-1	+11	282	292	95	95
15	36.2	1120	33.0	13.0	-4	362	358	-	-1	+9	282	290	68	68
16	35.2	1135	33.0	13.0	-4	352	348	-	-2	+14	282	294	54	54
Hub 2	28.4	1155	33.5	13.5	-4	284	280	-	-2	0	282	280	0	0
Hub 2	28.2	1255	34.5	14.5	-4	282	278	-	-4	0	282	278	0	0
17	31.4	1315	35.5	15.5	-5	314	309	-	-1	+16	282	297	12	12
18	33.8	1335	36.0	16.0	-5	338	333	-	+1	+19	282	302	31	31
19	38.6	1350	36.0	16.0	-5	386	381	-	+3	+22	282	307	74	74
20	36.0	1405	37.0	17.0	-5	360	355	-	+5	+19	282	306	49	49
21	43.2	1420	37.0	17.0	-5	432	427	-	+7	+27	282	316	111	111
22	40.8	1435	37.0	17.0	-5	408	403	-	+9	+29	282	320	83	83
23	37.8	1450	37.0	17.0	-5	378	373	-	+10	+28	282	320	53	53
Hub 2	30.1	1520	37.5	17.5	-5	301	296	-	+14	0	282	296	0	0

Project Christian County, Missouri | Sheet 4 of 19

Location Christian County, Missouri | Date June 22, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 2	30.4	0800	25.5	5.5	-2	304	302	-	0	0	302	302	0	0
24	45.8	0830	28.0	8.0	-2	458	456	-	-3	+21	302	320	136	136
25	43.8	0905	30.0	10.0	-3	438	435	-	-6	+9	302	305	130	130
26	38.6	0930	32.0	12.0	-4	386	382	-	-8	+1	302	295	87	87
27	48.6	0955	33.0	13.0	-4	486	482	-	-11	-7	302	284	198	197
Hub 2	29.2	1045	35.0	15.0	-5	292	287	-	-15	0	302	287	0	0
28	64.1	1105	36.0	16.0	-5	641	636	-	-22	-10	302	270	366	366
29	36.0	1135	37.0	17.0	-5	360	355	-	-32	-20	302	250	105	105
Hub 2	26.9	1155	38.0	18.0	-5	269	264	-	-38	0	302	264	0	0
Hub 2	26.1	1300	39.0	19.0	-6	261	255	-	-47	0	302	255	0	0
28A	63.3	1320	39.0	19.0	-6	633	627	-	-43	-10	302	249	378	378
30	39.1	1340	39.0	19.0	-6	391	385	-	-40	-18	302	244	141	141
31	47.1	1355	39.0	19.0	-6	471	465	-	-37	-16	302	249	216	216
32	35.0	1410	39.0	19.0	-6	350	344	-	-35	-24	302	243	101	101
33	35.0	1425	39.0	19.0	-6	350	344	-	-32	-27	302	243	101	101
34	42.0	1455	39.0	19.0	-6	420	414	-	-27	-23	302	252	162	162
35	43.9	1515	39.5	19.5	-6	439	433	-	-23	-21	302	258	175	175
36	49.9	1530	39.0	19.0	-6	499	493	-	-20	-11	302	271	222	222
37	44.6	1600	39.5	19.5	-6	446	440	-	-15	+3	302	290	150	150
38	34.0	1615	39.5	19.5	-6	340	334	-	-14	+13	302	301	33	33
Hub 2	29.9	1635	39.5	19.5	-6	299	293	-	-9	0	302	293	0	0

Project Christian County, Missouri　　Sheet 5 of 19

Location Christian County, Missouri　　Date June 23, 1960

Instrument ______　　Scale Constant ______　　Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 2	29.3	0830	26.0	6.0	-2	293	291	-	0	0	291	291	0	0
39	86.3	0850	28.0	8.0	-2	863	861	-	-1	-8	291	282	579	579
40	79.0	0920	28.0	8.0	-2	790	788	-	-2	-4	291	285	503	503
41	74.5	0950	28.5	8.5	-3	745	742	-	-3	-10	291	278	464	464
Hub 2	29.0	1010	29.0	9.0	-3	290	287	-	-4	0	291	287	0	0
42	40.6	1045	29.0	9.0	-3	406	403	-	-4	+9	291	296	107	107
43	56.2	1100	29.5	9.5	-3	562	559	-	-4	-2	291	285	274	274
44	51.3	1120	30.0	10.0	-3	513	510	-	-3	-12	291	276	234	234
45	72.4	1140	30.5	10.5	-3	724	721	-	-3	-14	291	274	447	447
Hub 2	29.1	1213	31.0	11.0	-3	291	288	-	-3	0	291	288	0	0
Hub 2	29.1	1305	32.5	12.5	-4	291	287	-	-4	0	291	287	0	0
46	39.6	1350	33.0	13.0	-4	396	392	-	-3	+8	291	296	96	96
47	69.9	1440	34.0	14.0	-4	699	695	-	-2	-4	291	285	410	410
48	59.2	1505	33.5	13.5	-4	592	588	-	-1	-11	291	279	309	309
Hub 2	29.4	1525	33.0	13.0	-4	294	290	-	-1	0	291	290	0	0
49	57.0	1545	32.0	12.0	-4	570	566	-	+1	-16	291	276	290	290
50	46.9	1600	32.0	12.0	-4	469	465	-	+2	-22	291	271	194	194
51	38.7	1612	31.5	11.5	-3	387	384	-	+3	-29	291	265	119	119
52	67.0	1630	31.0	11.0	-3	670	667	-	+5	-24	291	272	395	395
Hub 2	30.2	1700	31.0	11.0	-3	302	299	-	+8	0	291	299	0	0

Project Christian County, Missouri | Sheet 6 of 19

Location Christian County, Missouri | Date June 24, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 2	28.8	0835	23.0	3.0	-1	288	287	-	0	0	287	287	0	0
53	33.1	0855	23.0	3.0	-1	331	330	-	-3	-14	287	270	60	60
54	55.0	0907	23.0	3.0	-1	550	549	-	-4	-24	287	259	290	290
55	69.7	0930	22.5	2.5	-1	697	696	-	-7	-35	287	245	409	409
56	60.8	0950	22.0	2.0	-1	608	607	-	-10	-37	287	240	367	367
57	53.4	1015	22.0	2.0	-1	534	533	-	-13	-35	287	239	246	246
Hub 2	27.2	1040	22.0	2.0	-1	272	271	-	-16	0	287	271	0	0
58	30.6	1100	21.0	1.0	0	306	306	-	-15	-33	287	239	67	67
59	24.5	1120	21.0	1.0	0	245	245	-	-15	-45	287	227	18	18
60	31.8	1150	22.0	2.0	-1	318	317	-	-14	-46	287	227	90	90
Hub 2	27.5	1210	22.0	2.0	-1	275	274	-	-13	0	287	274	0	0
Hub 2	27.8	1300	23.0	3.0	-1	278	277	-	-10	0	287	277	0	0
61	31.9	1325	23.5	3.5	-1	319	318	-	-7	-56	287	224	94	94
62	36.0	1340	24.0	4.0	-1	360	359	-	-5	-63	287	219	140	140
63	44.2	1405	26.0	6.0	-2	442	440	-	-3	-82	287	202	238	238
64	42.0	1425	26.0	6.0	-2	420	418	-	-1	-71	287	215	203	203
Hub 3	54.0	1445	28.0	8.0	-2	540	538	-	+2	-67	287	222	316	316
Hub 2	29.4	1507	29.0	9.0	-3	294	291	-	+4	0	287	291	0	0

Project Christian County, Missouri Sheet 7 of 19

Location Christian County, Missouri Date June 27, 1960

Instrument ________ Scale Constant ________ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 2	30.1	1450	24.5	4.5	-1	301	300	-	0	0	300	300	0	0
Hub 4	25.2	1512	27.0	7.0	-2	252	250	-	+4	-36	300	268	-18	-18
Hub 2	31.0	1540	29.0	9.0	-3	310	307	-	+7	0	300	307	0	0

Project Christian County, Missouri — Sheet 8 of 19

Location Christian County, Missouri — Date June 28, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 3	53.7	0845	25.0	5.0	-2	537	535	-	0	0	535	535	0	316
65	33.4	0910	27.0	7.0	-2	334	332	-	-2	+41	535	574	-242	74
66	53.0	0950	28.0	8.0	-2	530	528	-	-5	+49	535	579	-51	265
67	45.6	1010	29.0	9.0	-3	456	453	-	-6	+45	535	574	-121	195
68	40.4	1025	30.0	10.0	-3	404	401	-	-7	+41	535	569	-168	148
69	61.0	1055	31.0	11.0	-3	610	607	-	-9	+44	535	570	37	353
70	54.1	1115	31.5	11.5	-3	541	538	-	-10	+41	535	566	-28	288
Hub 3	52.5	1205	32.0	12.0	-4	525	521	-	-14	0	535	521	0	316
70	55.1	1335	33.0	13.0	-4	551	547	-	0	0	547	547	0	288
71	44.8	1400	34.0	14.0	-4	448	444	-	+7	+17	547	571	-127	161
72	50.8	1425	35.0	15.0	-5	508	503	-	+13	+8	547	568	-65	215
70	56.9	1440	36.0	16.0	-5	569	564	-	+17	0	547	564	0	288
73	39.1	1505	37.0	17.0	-5	391	386	-	+19	-19	547	547	-161	127
74	48.9	1530	38.0	18.0	-5	489	484	-	+21	-28	547	540	-56	232
75	46.5	1552	38.0	18.0	-5	465	460	-	+23	-25	547	545	-85	203
76	39.0	1610	38.0	18.0	-5	390	385	-	+25	-25	547	547	-162	126
77	50.5	1632	37.0	17.0	-5	505	500	-	+27	-12	547	562	-62	226
70	58.0	1645	38.0	18.0	-5	580	575	-	+28	0	547	575	0	288

Project Christian County, Missouri Sheet 9 of 19

Location Christian County, Missouri Date June 29, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
70	56.2	0915	26.0	6.0	-2	562	560	-	0	0	560	560	0	288
78	30.7	0937	28.0	8.0	-2	307	305	-	-2	-21	560	537	-232	56
79	35.5	1000	30.0	10.0	-3	355	352	-	-4	-16	560	540	-188	100
80	39.3	1020	31.0	11.0	-3	393	390	-	-6	-3	560	551	-161	127
81	34.8	1043	32.0	12.0	-4	348	344	-	-8	-16	560	536	-192	96
82	37.0	1135	33.0	13.0	-4	370	366	-	-12	-27	560	521	-155	133
70	55.0	1200	34.0	14.0	-4	550	546	-	-14	0	560	546	0	288
Hub 3	54.2	1315	36.5	16.0	-5	542	537	-	0	0	537	537	0	316
83	35.7	1338	37.0	17.0	-5	357	352	-	+1	+9	537	547	-195	121
84	36.1	1355	38.0	18.0	-5	361	356	-	+2	+4	537	543	-187	129
85	31.5	1410	39.0	19.0	-6	315	309	-	+3	+5	537	545	-236	80
86	30.3	1430	38.0	18.0	-5	303	298	-	+4	-3	537	538	-240	76
87	37.0	1457	38.5	18.5	-6	370	364	-	+6	+4	537	547	-183	133
Hub 3	55.1	1530	39.0	19.0	-6	551	545	-	+8	0	537	545	0	316

Project Christian County, Missouri Sheet 10 of 19

Location Christian County, Missouri Date June 30, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 3	55.3	0855	26.0	6.0	-2	553	551	-	0	0	551	551	0	316
88	31.4	1030	29.5	9.5	-3	314	311	-	-6	+3	551	548	-237	79
Hub 3	54.7	1055	31.0	11.0	-3	547	544	-	-7	0	551	544	0	316
89	24.4	1110	32.0	12.0	-4	244	240	-	-8	-8	551	535	-295	21
Hub 3	54.6	1125	33.0	13.0	-4	546	542	-	-9	0	551	542	0	316

Project Christian County, Missouri Sheet 11 of 19

Location Christian County, Missouri Date July 1, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 3	53.0	0850	26.5	6.5	-2	530	528	-	0	0	528	528	0	316
90	30.0	0910	27.0	7.0	-2	300	298	-	0	+21	528	549	-251	65
91	28.6	0925	28.0	8.0	-2	286	284	-	0	+25	528	553	-269	47
92	31.0	0945	28.0	8.0	-2	310	308	-	-1	+18	528	545	-237	79
93	33.5	1000	29.0	9.0	-3	335	332	-	-1	+17	528	544	-212	104
Hub 3	53.0	1047	30.0	10.0	-3	530	527	-	-1	0	528	527	0	316
94	66.7	1110	31.5	11.5	-3	667	664	-	+1	-4	528	525	139	455
95	28.2	1135	31.0	11.0	-3	282	279	-	+4	-18	528	514	-235	81
Hub 3	53.7	1200	31.0	11.0	-3	537	534	-	+6	0	528	534	0	316

Project Christian County, Missouri Sheet 12 of 19

Location Christian County, Missouri Date July 5, 1960

Instrument ____________ Scale Constant ____________ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 4	23.1	0955	22.0	2.0	-1	231	230	-	0	0	230	230	0	-18
96	31.3	1010	24.0	4.0	-1	313	312	-	0	+9	230	239	73	55
97	41.1	1027	25.0	5.0	-2	411	409	-	0	+11	230	241	168	150
98	48.0	1045	26.0	6.0	-2	480	478	-	-1	+14	230	243	236	218
99	45.1	1100	27.0	7.0	-2	451	449	-	-1	+16	230	245	204	186
100	33.6	1120	28.0	8.0	-2	336	334	-	-1	+18	230	247	87	69
101	39.0	1142	28.5	8.5	-3	390	387	-	-2	+7	230	235	152	134
Hub 4	23.1	1215	29.0	9.0	-3	231	228	-	-2	0	230	228	0	-18
Hub 4	24.8	1330	30.0	10.0	-3	248	245	-	+15	0	230	245	0	-18
102	47.6	1345	31.0	11.0	-3	476	473	-	+15	0	230	245	228	210
103	55.1	1415	32.0	12.0	-4	551	547	-	+16	+3	230	249	298	280
104	50.1	1435	33.0	13.0	-4	501	497	-	+16	+5	230	251	246	228
105	64.7	1456	33.0	13.0	-4	647	643	-	+16	0	230	246	397	379
Hub 4	25.1	1530	34.0	14.0	-4	251	247	-	+17	0	230	247	0	-18
106	29.0	1550	32.0	12.0	-4	290	286	-	+20	-3	230	247	39	21
107	35.0	1603	33.0	13.0	-4	350	346	-	+22	-14	230	238	108	90
108	32.9	1620	33.0	13.0	-4	329	325	-	+24	-12	230	242	83	65
Hub 4	26.4	1700	32.0	12.0	-4	264	260	-	+30	0	230	260	0	-18

Project Christian County, Missouri Sheet 13 of 19

Location Christian County, Missouri Date July 6, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 4	24.2	0845	23.5	3.5	-1	242	241	-	0	0	241	241	0	-18
109	32.8	0903	24.0	4.0	-2	328	326	-	0	-25	241	216	110	92
110	29.5	0922	25.0	5.0	-2	295	293	-	0	-26	241	215	52	34
111	27.7	0937	26.5	6.5	-2	277	275	-	0	-35	241	206	69	51
112	19.2	0957	28.0	8.0	-2	192	190	-	0	-47	241	194	-4	-22
113	18.1	1016	29.0	9.0	-3	181	178	-	0	-59	241	182	-4	-22
114	19.3	1030	29.0	9.0	-3	193	190	-	0	-56	241	185	5	-13
Hub 4	24.4	1050	30.0	10.0	-3	244	241	-	0	0	241	241	0	-18
115	55.8	1120	30.0	10.0	-3	558	555	-	-2	-1	241	238	317	299
116	34.2	1157	30.0	10.0	-3	342	339	-	-5	-11	241	225	114	96
Hub 4	23.8	1212	30.0	10.0	-3	238	235	-	-6	0	241	235	0	-18
115	56.2	1330	31.0	11.0	-3	562	559	-	0	0	559	559	0	299
117	53.8	1346	32.0	12.0	-4	538	534	-	+1	-7	559	553	-19	280
115	56.7	1508	32.0	12.0	-4	567	563	-	+4	0	559	563	0	299
118	80.9	1525	32.0	12.0	-4	809	805	-	+6	+1	559	566	239	538
115	57.0	1542	32.0	12.0	-4	570	566	-	+7	0	559	566	0	299

Project Christian County, Missouri Sheet 14 of 19

Location Christian County, Missouri Date July 7, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr.	Diurn. Variat. γ	Norm. Corr. γ	Base Value	Sum Corr.	Vert. Int. Base=0 γ	Vert. Int. Base=X
Hub 4	24.0	0920	25.5	5.5	-2	240	238	-	0	0	238	238	0	-18
119	19.2	0943	28.0	8.0	-2	192	190	-	-1	-34	238	203	-13	-31
120	23.4	1000	28.0	8.0	-2	234	232	-	-2	-41	238	195	37	19
121	15.0	1017	29.5	9.5	-3	150	147	-	-3	-51	238	184	37	19
122	33.9	1107	31.0	11.0	-3	339	336	-	[illegible]	[illegible]	238	201	135	117
Hub 4	23.0	1222	30.5	10.5	-3	230	227	-	[illegible]	0	[illegible]	[illegible]	0	-18
Hub 2	28.8	1330	32.0	12.0	-4	288	284	-	0	0	284	284	[illegible]	0
123	59.0	1350	33.0	13.0	-4	590	586	-	0	-30	284	254	[illegible]	332
124	79.8	1425	33.5	13.5	-4	798	794	-	+1	-44	284	241	553	553
125	37.3	1505	33.0	13.0	-4	373	369	-	+2	-5	284	281	88	88
Hub 2	29.0	1535	33.0	13.0	-4	290	286	-	+2	0	284	286	0	0

Project Christian County, Missouri Sheet 15 of 19

Location Christian County, Missouri Date July 19, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
Hub 3	55.0	0937	25.0	5.0	-2	550	548	-	0	0	548	548	0	316
126	56.9	0958	27.5	7.5	-2	569	567	-	-3	-9	548	536	31	347
127	34.0	1031	28.5	8.5	-3	340	337	-	-7	-9	548	532	-195	121
Hub 3	53.9	1106	31.0	11.0	-3	539	536	-	-12	0	548	536	0	316
127	33.1	1307	34.0	14.0	-4	331	327	-	0	0	327	327	0	121
128	60.0	1355	34.5	14.5	-4	600	596	-	+5	+12	327	344	252	373
129	77.9	1512	33.5	13.5	-4	779	775	-	+13	+14	327	354	421	542
130	78.0	1620	32.5	12.5	-4	780	776	-	+20	+11	327	358	418	539
131	52.5	1651	32.0	12.0	-4	525	521	-	+24	+4	327	355	166	287
127	35.9	1731	32.0	12.0	-4	359	355	-	+28	0	327	355	0	121

Project Christian County, Missouri Sheet 16 of 19

Location Christian County, Missouri Date July 20, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
115	55.2	0917	26.0	6.0	-2	552	550	-	0	0	550	550	0	299
132	0.5	1024	29.0	9.0	-3	005	002	-1104	-2	-17	550	-573	575	874
133	3.1	1041	29.5	9.5	-3	031	028	-1104	-2	-13	550	-569	597	896
134	0.2	1059	30.0	10.0	-3	002	-001	-1104	-2	-10	550	-566	565	864
135	-16.7	1115	30.0	10.0	-3	-167	-170	-1104	-3	-10	550	-567	397	696
136	-27.7	1151	31.0	11.0	-3	-277	-280	-1104	-4	-9	550	-567	287	586
136	82.7	1154	31.0	11.0	-3	827	824	-	-4	-9	550	537	287	586
115	55.0	1212	33.0	13.0	-4	550	546	-	-4	0	550	546	0	299
136	85.0	1339	35.0	15.0	-5	850	846	-	0	0	846	846	0	586
136	-14.2	1342	35.0	15.0	-5	-142	-146	-992	0	0	846	-146	0	586
137	-6.0	1405	35.0	15.0	-5	-60	-65	-992	+6	-5	846	-145	80	666
138	-28.9	1435	35.0	15.0	-5	-289	-294	-991	+7	-9	846	-147	-147	439
139	-17.2	1523	34.0	14.0	-4	-172	-176	-991	+13	-8	846	-140	-36	550
140	-24.1	1546	32.0	12.0	-4	-241	-245	-990	+16	-12	846	-140	-105	481
136	-12.1	1617	30.0	10.0	-3	-121	-124	-990	+20	0	846	-124	0	586
136	86.9	1619	30.0	10.0	-3	869	866	-	+20	0	846	866	0	586

Project Christian County, Missouri Sheet 17 of 19

Location Christian County, Missouri Date July 21, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat.	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
118	82.5	0840	26.0	6.0	-2	825	823	0	0	0	823	823	0	538
118	-16.8	0843	26.0	6.0	-2	-168	-170	-991	-2	0	823	-170	0	538
141	8.2	0856	27.5	7.5	-2	082	080	-991	-5	-2	823	-175	255	793
142	20.0	0907	28.5	8.5	-3	200	197	-991	-7	-4	823	-179	376	914
143	20.0	0924	29.0	9.0	-3	200	197	-990	-12	-6	823	-185	382	920
144	21.1	0941	31.0	11.0	-3	211	208	-990	-17	-5	823	-189	397	935
118	-18.5	0959	32.0	12.0	-4	-185	-189	-990	-22	0	823	-189	0	538
118	80.4	1002	32.0	12.0	-4	804	800	0	-23	0	823	800	0	538
143	18.5	1028	32.0	12.0	-4	185	181	NA	0	0	181	181	0	920
145	20.1	1050	33.0	13.0	-4	201	197	NA	0	-2	181	179	18	938
146	4.5	1119	32.0	12.0	-4	45	41	NA	0	-6	181	175	-134	786
147	8.8	1131	31.0	11.0	-3	88	85	NA	0	-5	181	176	-91	829
143	18.4	1147	30.0	10.0	-3	184	181	NA	0	0	181	181	0	920

Project Christian County, Missouri — Sheet 18 of 19

Location Christian County, Missouri — Date July 22, 1960

Instrument ______ Scale Constant ______ Computer E. J. Ballantyne, Jr.

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
144	21.2	0833	25.0	5.0	-2	212	210	NA	0	0	210	210	0	935
148	17.1	0903	26.0	6.0	-2	171	169	NA	-4	+3	210	209	-40	895
149	8.7	0920	26.0	6.0	-2	87	85	NA	-7	+5	210	208	-123	812
150	9.2	0936	27.0	7.0	-2	92	90	NA	-9	+5	210	206	-116	819
151	-7.1	0951	28.0	8.0	-2	-71	-73	NA	-11	+8	210	207	-280	655
152	8.1	1008	28.0	8.0	-2	81	79	NA	-14	+6	210	202	-123	812
144	19.6	1030	29.0	9.0	-3	196	193	NA	-17	0	210	193	0	935
153	17.1	1052	30.0	10.0	-3	171	168	NA	-14	+4	210	200	-32	903
154	-1.1	1113	30.0	10.0	-3	-11	-14	NA	-11	+7	210	206	-220	715
155	5.0	1134	31.0	11.0	-3	50	47	NA	-8	+5	210	207	-160	775
144	21.0	1210	31.0	11.0	-3	210	207	NA	-3	0	210	207	0	935

Project Christian County, Missouri Sheet 19 of 19

Location Christian County, Missouri Date July 25, 1960

Instrument ______ Scale Constant ______ Computer ______

Station	Avg. Read. S.D.	Mean Time	Mean Temp. °C	Mean Temp. -20°C	Temp. Corr. γ	Avg. Read. γ	Corr. Read. γ	Aux. Mag. Corr. γ	Diurn. Variat. γ	Normal Corr. γ	Base Value γ	Sum Corr. γ	Vert. Int. Base=0 γ	Vert. Int. Base=X γ
144	18.9	1005	32.0	12.0	-4	189	185	NA	0	0	185	185	0	935
156	8.8	1035	33.0	13.0	-4	88	84	NA	-2	-1	185	182	-98	837
157	3.6	1052	34.0	14.0	-4	36	32	NA	-3	-4	185	178	-146	789
158	-3.1	1106	34.0	14.0	-4	-31	-35	NA	-4	0	185	181	-216	719
159	0.0	1121	34.5	14.5	-4	00	-04	NA	-5	-3	185	177	-181	754
160	-9.3	1135	35.0	15.0	-5	-93	-98	NA	-6	+1	185	180	-278	657
144	18.2	1158	35.0	15.0	-5	182	177	NA	-8	0	185	177	0	935
143	17.1	1214	35.0	15.0	-5	171	166	NA	0	0	166	166	0	920
161	-4.7	1237	35.0	15.0	-5	-47	-52	NA	+1	-7	166	160	-212	708
162	-12.3	1251	35.0	15.0	-5	-123	-128	NA	+2	-10	166	158	-286	634
143	17.4	1311	35.0	15.0	-5	174	169	NA	+3	0	166	169	0	920

APPENDIX B

CORRECTED GRAVITY FIELD DATA

Project Christian County Gravimeter Mobile 3-10 Sheet 1 of 2

Location T26N, R20W, Sec. 10,15 Scale Value 0.07361 MS/SD Date Mar 16

Traverse N-3 Datum Elev. 1000.00 Elev. Factor 0.06216 mg/ft. Computer Ballantyne

Station	Read.	Δs	Δg	Obs g	Elev.	Elev. Corr.	Lat. Corr.	Terr. Corr.	Total Corr.	Corr. g	Ref. Lat.	Miles N or S	Miles x k
C-2	954.5	0	0	100.00	1288.9	-	-	-		-	-	-	-
B	947.3	-7.4	-.54	99.46	1284.7	17.70	4.28	0.06		112.94	36°58'	+0.12	+0.17
A	924.3	-30.5	-2.25	97.75	1300.0	18.65	4.50	0.08		111.98	36°58'	+0.27	+0.39
C-2	955.0	0	-	100.00	1288.9	-	-	-		-	-	-	-
C	954.0	-.8	-0.06	99.94	1289.0	17.96	3.94	0.07		114.03	36°58'	-0.12	-0.17
D	964.4	+9.7	+0.71	100.71	1284.0	17.65	3.60	0.21		114.97	36°58'	-0.35	-0.51
D-1W	970.4	+15.8	+1.16	101.16	1282.6								
2W	974.2	+19.7	+1.45	101.45	1276.8	} Used for Nettleton's Profile Method							
3W	983.7	+29.3	+2.16	102.16	1265.0								
4W	997.1	+42.8	+3.15	103.15	1250.6								
E	964.7	+10.5	+0.77	100.77	1286.6	17.82	3.29	0.39		115.69	36°58'	-0.57	-0.82
D-4E	987.7	+33.7	+2.48	102.48	1256.8								
3E	976.5	+22.7	+1.67	101.67	1271.0	} Used for Nettleton's Profile Method							
2E	969.6	+15.9	+1.17	101.17	1279.1								
1E	966.6	+13.0	+0.96	100.96	1282.2								
C-2	953.5	0	-	-	1288.9	-	-	-		-	-	-	-
F	1151.3	+198.0	+14.57	114.57	1075.3	4.68	3.05	0.21		116.41	36°57'	+0.27	+0.39
G	1113.1	+159.9	+11.77	111.77	1117.5	7.30	2.73	0.06		116.40	36°57'	+0.05	+0.07
H	1150.3	+197.3	+14.52	114.52	1052.0	3.23	2.31	0.34		115.78	36°57'	-0.24	-0.35
I	1145.8	+193.0	+14.21	114.21	1044.0	2.74	1.96	0.25		115.24	36°57'	-0.48	-0.69
C-2	952.4	0	-	-	1288.9	-	-	-		-	-	-	-

Project Christian County Gravimeter Mobile 3-10 Sheet 2 of 2

Location T26N, R20W, Sec. 22 Scale Value 0.07361 mg/SD Date Mar. 17

Traverse N-S Datum Elev. 1000.00 Elev. Factor 0.06216 mg/ft. Computer Ballantyne

Station	Read.	Δs	Δg	Obs g	Elev.	Elev. Corr.	Lat. Corr.	Terr. Corr.	Total Corr.	Corr. g	Ref. Lat.	Miles N or S	Miles x k
I	1143.0	0		114.21	1044.0	-	-	-		-	-	-	-
K	1111.2	-31.2	-2.30	111.91	1026.9	1.67	1.48	0.47		112.57	36°56'	+0.18	+0.26
L	1097.8	-44.3	-3.26	110.95	1020.6	1.28	1.12	0.42		111.53	36°56'	-0.07	-0.10
M	1086.1	-55.8	-4.11	110.10	1016.4	1.02	0.79	0.45		110.78	36°56'	-0.30	-0.43
J	1130.4	-11.1	-0.82	113.39	1043.7	2.72	1.83	0.30		114.58	36°56'	+0.42	+0.61
I	1141.2	0			1044.0	-	-	-		-	-	-	-

APPENDIX C

PROGRAM FOR THREE DIMENSIONAL STRUCTURE CALCULATIONS

$$f(o) = \frac{d}{4\pi^2 I_z x 10^5} \Sigma C_n H_n$$

APPENDIX C

PROGRAM FOR THREE DIMENSIONAL STRUCTURE CALCULATIONS

$$f(o) = \frac{d}{4\pi^2 I_z x10^5} \Sigma C_n H_n$$

The three dimensional structure calculation was programmed for the Royal-McBee LGP-30 electronic digital computer in the floating point interpretive system 24.2. The words "floating point" imply that the numbers in a problem are represented in two parts, occupying two addresses. The first part represents the significant digits of the number, and the second part represents the location of the decimal place.

The program is set on track 48. The constants and coefficients are stored on track 50 and the values of H_n are stored on track 51 as follows:

Address	Data #1	Address	Data #2
5000	$H_z x10^5$	5100	Station
02	k	02	H_0
04	4	04	H_1
06	π	06	H_2
08	d	08	H_3
10	0	10	H_4
12	C_0	12	H_5
14	C_1		
16	C_2		
18	C_3		
20	C_4		
22	C_5		

Note: The first sequential location is specified by the first word on the tape, therefore place 5000' on the tape prior to $H_z x10^5$ and 5100' prior to the station. Follow the first set of data by g' and the second set by f'.

THREE DIMENSIONAL STRUCTURE CALCULATION

Program Input Codes	Stop	Location	Instruction: Operation	Instruction: Address	Stop	Contents of Address	Notes
;0004800							
100000000		X					
		4800	r	6300			enter 24.2
		01	u	0400			enter 24.2
		02	m	0000			carriage return
		03	i	0000			enter data
		04	u	0000			enter alpha num.
,00000005		05	4040	2054			print headings
		06	10t4	24.j			print headings
		07	60f8	20(8	X		print headings
		08	1008	20)8			print headings
		09	1040	4000			print headings
		10	1c	0006			set counter
		11	1e	0000			set counter
		12	1i	0002			set counter
		13	b	5006		π	
		14	m	5006			π^2
		15	m	5004	X	4	$4\pi^2$
		16	m	5002		k	$4\pi^2 k$
		17	m	5000		$H_z x10^5$	$4\pi^2 I_z x10^5$
		18	r	5008		d	$d/4\pi^2 I_z x10^5$
		19	h	5120			hold
		20	1b	5012		C_n	C_n
		21	1m	5102		H_n	$C_n H_n$
		22	a	5010		$\Sigma C_n H_n$	$\Sigma C_n H_n$
		23	h	5010	X		hold
		24	1z	4820			loop
		25	b	5100		point	
		26	z	0001			print point
		27	d	0000			tab
		28	b	5010		$\Sigma C_n H_n$	
		29	m	5120			f(o)
		30	z	0003			print f(o)
		31	m	0000	X		carriage return

THREE DIMENSIONAL STRUCTURE CALCULATION

Program Input Codes	Stop	Location	Instruction: Operation	Instruction: Address	Stop	Contents of Address	Notes
		32	z	0000			stop
		33	6	5010		$\Sigma C_n H_n$	
		34	s	5010			$\Sigma C_n H_n = 0$
		35	h	5010			hold
		36	u	4803			to next point
.00004800		37					
		38					
		39					
		40					
		41					
		42					
		43					
		44					
		45					
		46					
		47					
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		60					
		61					
		62					
		63					

APPENDIX D

PROGRAM FOR CALCULATION OF DEPTH

BY ERROR IN CONTINUATION

$$E = H_o - \Sigma C_n H(b_n h)$$

APPENDIX D

PROGRAM FOR CALCULATION OF DEPTH BY ERROR IN CONTINUATION

$$E = H_o - \Sigma C_n H(b_n h)$$

The calculation of depth by error in continuation was programmed for the Royal-McBee LGP-30 electronic digital computer in floating point interpretive system 24.2.

The program is set on track 48. The coefficients are stored on track 50 and the values $H(b_n h)$ are stored on track 51 as follows:

Address	Data #1	Address	Data #2
5000	0	5100	h
02	C_1	02	H_o
04	C_2	04	$H(b_1h)$
06	C_3	06	$H(b_2h)$
08	C_4	08	$H(b_3h)$
10	C_5	10	$H(b_4h)$
12	C_6	12	$H(b_5h)$
14	C_7	14	$H(b_6h)$
16	C_8	16	$H(b_7h)$
18	C_9	18	$H(b_8h)$
20	C_{10}	20	$H(b_9h)$
22	C_{11}	22	$H(b_{10}h)$
24	C_{12}	24	$H(b_{11}h)$
26	C_{13}	26	$H(b_{12}h)$
28	C_{14}	28	$H(b_{13}h)$
		30	$H(b_{14}h)$

Note: The first sequential location is specified by the first word on the tape, therefore place 5000' on the tape prior to 0 and 5100' prior to h. Follow the first set of data by g' and the second set by f'.

CALCULATION OF DEPTH BY ERROR IN CONTINUATION

Program Input Codes	Stop	Location	Instruction: Operation	Instruction: Address	Stop	Contents of Address	Notes
;0004800	'						
10000000	' X						
		4800	r	6300	'		enter 24.2
		01	u	0400	'		enter 24.2
		02	m	0000	'		carriage return
		03	i	0000	'		enter data
		04	u	0000	'		enter alpha num.
,0000003		05	4040	h460	'		print headings
		06	20e4	1040	'		print headings
		07	4000	0000	'	X	print headings
		08	1c	0014	'		set counter
		09	1e	0000	'		set counter
		10	1i	0002	'		set counter
		11	16	5104	'	$H(b_n h)$	
		12	1m	5002	'	C_n	$C_n\ H(b_n h)$
		13	a	5000	'	$\Sigma C_n H(b_n h)$	$\Sigma C_n H(b_n h)$
		14	h	5000	'		hold
		15	1z	4811	'	X	loop
		16	6	5100	'	h	
		17	z	0001	'		print h
		18	d	0000	'		tab
		19	b	5102	'	H_o	
		20	s	5000	'	$\Sigma C_n H(b_n h)$	E
		21	z	0002	'		print E
		22	m	0006	'		carriage return
		23	z	0000	'	X	stop
		24	b	5000	'	$\Sigma C_n H(b_n h)$	
		25	s	5000	'		$\Sigma C_n H(b_n h) = 0$
		26	h	5000	'		hold
		27	u	4803	'		to next case
.0004800		28			'		
		29			'		
		30			'		
		31			'	X	

X. VITA

Edwin J. Ballantyne, Jr. was born January 6, 1934, in Springfield, Missouri, the son of Edwin J. and Grace M. Ballantyne. He received his elementary and high school education in Springfield.

In September 1951 he enrolled in the University of Missouri School of Mines and Metallurgy. He entered the United States Navy as a Naval Aviation Cadet in November 1953. In June 1955 he graduated as a Naval Aviator and was commissioned a Second Lieutenant in the United States Marine Corps Reserve. After serving a tour in North Carolina and one in the Far East, he was discharged from active duty as a First Lieutenant in November 1957.

In February 1958 he returned to the School of Mines and Metallurgy and completed the requirements for a B.S. degree in Mining Engineering, Mining Geology option, in January 1960. At that time he enrolled in the graduate school in the Department of Mining Engineering. During the school year of 1960-61 he was employed as a graduate assistant in the Mining Department.

On September 19, 1959 he was united in marriage to Evelyn E. Hodges of Rolla, Missouri.

He is a member of Sigma Gamma Epsilon, The European Association of Exploration Geophysicists, and Lambda Chi Alpha, an associate member of Sigma Xi, and a student member of the Society of Exploration Geophysicists and the American Institute of Mining Engineers.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF MISSOURI
GEOLOGICAL SURVEY AND WATER RESOURCES
THOMAS R. BEVERIDGE, STATE GEOLOGIST

SELMORE QUADRANGLE
MISSOURI—CHRISTIAN CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1952. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Missouri coordinate system, central zone

TRUE NORTH — MAGNETIC NORTH 7°
APPROXIMATE MEAN DECLINATION, 1955

SCALE 1:24000

1 — ½ — 0 — 1 MILE

1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET

1 — .5 — 0 — 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLORADO OR WASHINGTON 25, D. C.
AND BY THE MISSOURI GEOLOGICAL SURVEY, ROLLA, MISSOURI
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

MISSOURI
QUADRANGLE LOCATION

ROAD CLASSIFICATION

Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

SELMORE, MO.
N3652.5—W9307.5/7.5
1955

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF MISSOURI
GEOLOGICAL SURVEY AND WATER RESOURCES
THOMAS R. BEVERIDGE, STATE GEOLOGIST

CHADWICK QUADRANGLE
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7.5 MINUTE SERIES (TOPOGRAPHIC)

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Topography from aerial photographs by multiplex methods
Aerial photographs taken 1952. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Missouri coordinate system, central zone

APPROXIMATE MEAN DECLINATION, 1955

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty — Light-duty
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THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

CHADWICK, MO.
N3652.5—W9300/7.5
1955

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF MISSOURI
GEOLOGICAL SURVEY AND WATER RESOURCES
EDWARD L. CLARK, STATE GEOLOGIST

MISSOURI
BRADLEYVILLE QUADRANGLE
15-MINUTE SERIES

Mapped by the Geological Survey
1936, 1937, and 1943

APPROXIMATE MEAN DECLINATION, 1937

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1000 500 0 1000 2000 3000 4000 5000 6000 7000 Yards

1000 0 3000 6000 9000 12000 15000 18000 Feet

1 .5 0 1 2 3 4 5 Kilometers

Contour interval 20 feet

Datum is mean sea level

Polyconic projection. 1927 North American datum
5000 yard grid based on U.S. zone system, C
10000 foot grid based on Missouri (Central) rectangular coordinate system

ROAD CLASSIFICATION
1945

Dependable hard-surface heavy-duty road — Dry weather roads — U. S. Route 15
Secondary hard-surface all weather road — Loose-surface graded — Unsurfaced, graded — Dirt road — State Route 26
More than two lanes indicated along road with tick at point of change 3 LANE | 4 LANE

BRADLEYVILLE, MO.
Edition of 1945

N3645-W9245/15

THE TOPOGRAPHIC MAPS OF THE UNITED STATES

The United States Geological Survey is making a series of standard topographic maps to cover the United States. This work has been in progress since 1882, and the published maps cover more than 47 percent of the country, exclusive of outlying possessions.

The maps are published on sheets that measure about 16½ by 20 inches. Under the general plan adopted the country is divided into quadrangles bounded by parallels of latitude and meridians of longitude. These quadrangles are mapped on different scales, the scale selected for each map being that which is best adapted to general use in the development of the country, and consequently, though the standard maps are of nearly uniform size, the areas that they represent are of different sizes. On the lower margin of each map are printed graphic scales showing distances in feet, meters, miles, and kilometers. In addition, the scale of the map is shown by a fraction expressing a fixed ratio between linear measurements on the map and corresponding distances on the ground. For example, the scale $\frac{1}{62,500}$ means that 1 unit on the map (such as 1 inch, 1 foot, or 1 meter) represents 62,500 of the same units on the earth's surface.

Although some areas are surveyed and some maps are compiled and published on special scales for special purposes, the standard topographic surveys and the resulting maps have for many years been of three types, differentiated as follows:

1. Surveys of areas in which there are problems of great public importance—relating, for example, to mineral development, irrigation, or reclamation of swamp areas—are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{31,680}$ (1 inch = one-half mile) or $\frac{1}{24,000}$ (1 inch = 2,000 feet), with a contour interval of 1 to 100 feet, according to the relief of the particular area mapped.

2. Surveys of areas in which there are problems of average public importance, such as most of the basin of the Mississippi and its tributaries, are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{62,500}$ (1 inch = nearly 1 mile), with a contour interval of 10 to 100 feet.

3. Surveys of areas in which the problems are of minor public importance, such as much of the mountain or desert region of Arizona or New Mexico, and the high mountain area of the northwest, are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{125,000}$ (1 inch = nearly 2 miles) or $\frac{1}{250,000}$ (1 inch = nearly 4 miles), with a contour interval of 20 to 250 feet.

The aerial camera is now being used in mapping. From the information recorded on the photographs, planimetric maps, which show only drainage and culture, have been made for some areas in the United States. By the use of stereoscopic plotting apparatus, aerial photographs are utilized also in the making of the regular topographic maps, which show relief as well as drainage and culture.

A topographic survey of Alaska has been in progress since 1898, and nearly 44 percent of its area has now been mapped. About 15 percent of the Territory has been covered by maps on a scale of $\frac{1}{500,000}$ (1 inch = nearly 8 miles). For most of the remainder of the area surveyed the maps published are on a scale of $\frac{1}{250,000}$ (1 inch = nearly 4 miles). For some areas of particular economic importance, covering about 4,300 square miles, the maps published are on a scale of $\frac{1}{62,500}$ (1 inch = nearly 1 mile) or larger. In addition to the area covered by topographic maps, about 11,300 square miles of southeastern Alaska has been covered by planimetric maps on scales of $\frac{1}{125,000}$ and $\frac{1}{250,000}$.

The Hawaiian Islands have been surveyed, and the resulting maps are published on a scale of $\frac{1}{62,500}$.

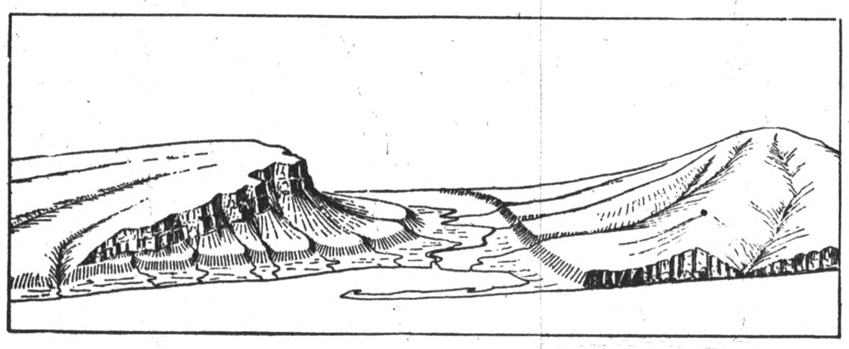
A survey of Puerto Rico is now in progress. The scale of the published maps is $\frac{1}{30,000}$.

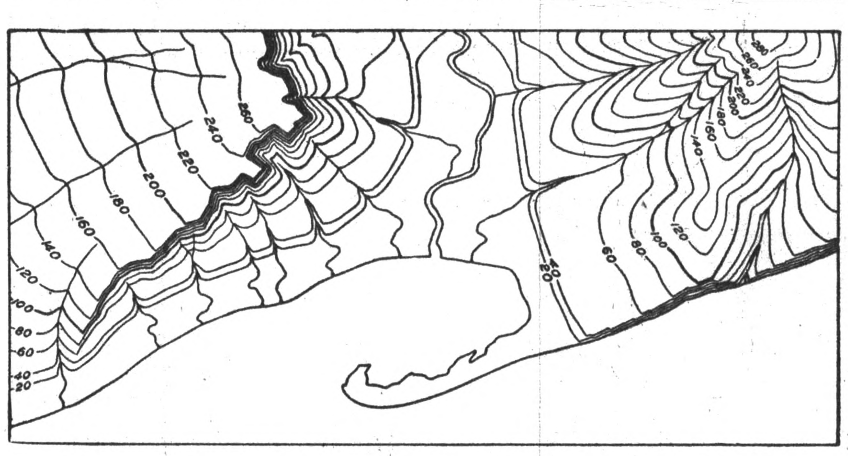
The features shown on topographic maps may be arranged in three groups—(1) water, including seas, lakes, rivers, canals, swamps, and other bodies of water; (2) relief, including mountains, hills, valleys, and other features of the land surface; (3) culture (works of man), such as towns, cities, roads, railroads, and boundaries. The symbols used to represent these features are shown and explained below. Variations appear on some earlier maps, and additional features are represented on some special maps.

All the water features are represented in blue, the smaller streams and canals by single blue lines and the larger streams by double lines. The larger streams, lakes, and the sea are accentuated by blue water lining or blue tint. Intermittent streams—those whose beds are dry for a large part of the year—are shown by lines of blue dots and dashes.

Relief is shown by contour lines in brown, which on a few maps are supplemented by shading showing the effect of light thrown from the northwest across the area represented, for the purpose of giving the appearance of relief and thus aiding in the interpretation of the contour lines. A contour line represents an imaginary line on the ground (a contour) every part of which is at the same altitude above sea level. Such a line could be drawn at any altitude, but in practice only the contours at certain regular intervals of altitude are shown. The datum or zero of altitude of the Geological Survey maps is mean sea level. The 20-foot contour would be the shore line if the sea should rise 20 feet above mean sea level. Contour lines show the shape of the hills, mountains, and valleys, as well as their altitude. Successive contour lines that are far apart on the map indicate a gentle slope, lines that are close together indicate a steep slope, and lines that run together indicate a cliff.

The manner in which contour lines express altitude, form, and grade is shown in the figure below.





The sketch represents a river valley that lies between two hills. In the foreground is the sea, with a bay that is partly enclosed by a hooked sand bar. On each side of the valley is a terrace into which small streams have cut narrow gullies. The hill on the right has a rounded summit and gently sloping spurs separated by ravines. The spurs are truncated at their lower ends by a sea cliff. The hill at the left terminates abruptly at the valley in a steep scarp, from which it slopes gradually away and forms an inclined tableland that is traversed by a few shallow gullies. On the map each of these features is represented, directly beneath its position in the sketch, by contour lines.

The contour interval, or the vertical distance in feet between one contour and the next, is stated at the bottom of each map. This interval differs according to the topography of the area mapped: in a flat country it may be as small as 1 foot; in a mountainous region it may be as great as 250 feet. In order that the contours may be read more easily certain contour lines, every fourth or fifth, are made heavier than the others and are accompanied by figures showing altitude. The heights of many points—such as road intersections, summits, surfaces of lakes, and benchmarks—are also given on the map in figures, which show altitudes to the nearest foot only. More precise figures for the altitudes of benchmarks are given in the Geological Survey's bulletins on spirit leveling. The geodetic coordinates of triangulation and transit-traverse stations are also published in bulletins.

Lettering and the works of man are shown in black. Boundaries, such as those of a State, county, city, land grant, township, or reservation, are shown by continuous or broken lines of different kinds and weights. Public roads suitable for motor travel the greater part of the year are shown by solid double lines; poor public roads and private roads by dashed double lines; trails by dashed single lines. Additional public road classification if available is shown by red overprint.

Each quadrangle is designated by the name of a city, town, or prominent natural feature within it, and on the margins of the map are printed the names of adjoining quadrangles of which maps have been published. More than 4,100 quadrangles in the United States have been surveyed, and maps of them similar to the one on the other side of this sheet have been published.

Geologic maps of some of the areas shown on the topographic maps have been published in the form of folios. Each folio includes maps showing the topography, geology, underground structure, and mineral deposits of the area mapped, and several pages of descriptive text. The text explains the maps and describes the topographic and geologic features of the country and its mineral products. Two hundred twenty-five folios have been published.

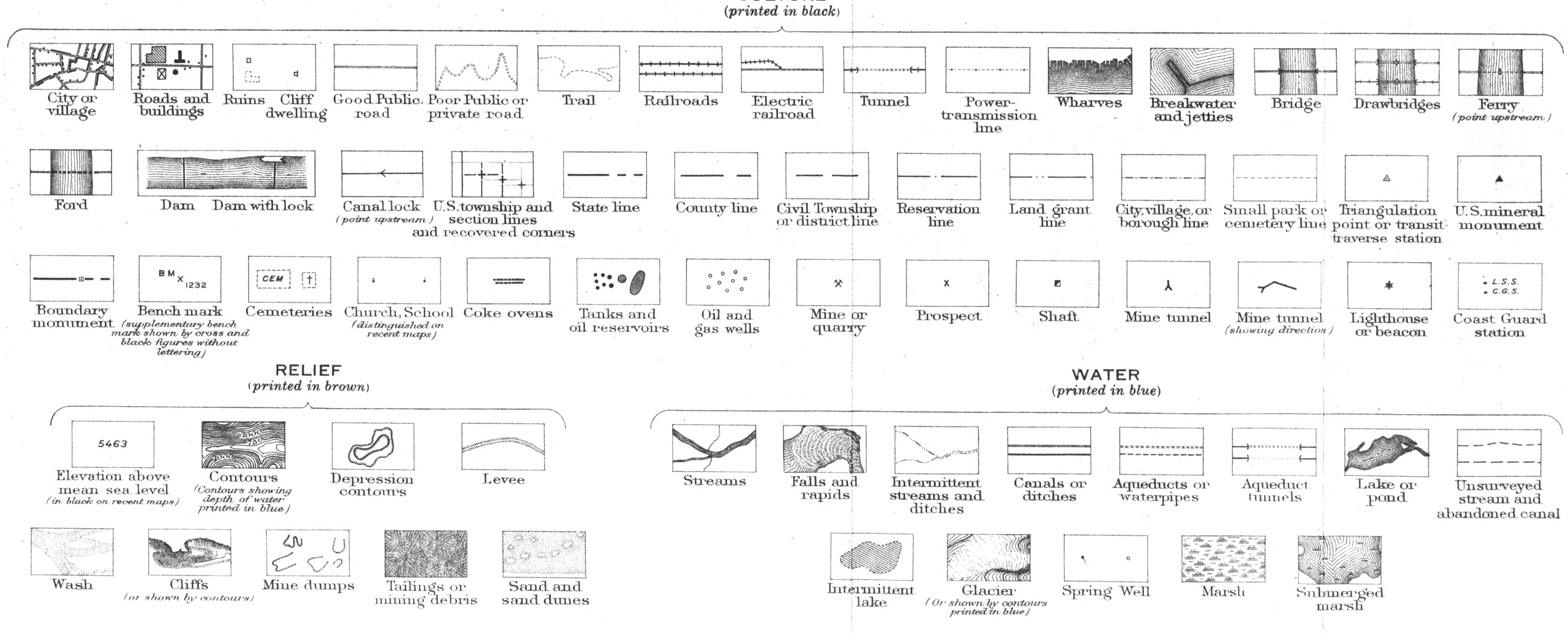
Index maps of each State and of Alaska and Hawaii showing the areas covered by topographic maps and geologic folios published by the United States Geological Survey may be obtained free. Copies of the standard topographic maps may be obtained for 10 cents each; some special maps are sold at different prices. A discount of 40 percent is allowed on an order amounting to $5 or more at the retail price. The discount is allowed on an order for maps alone, either of one kind or in any assortment, or for maps together with geologic folios. The geologic folios are sold for 25 cents or more each, the price depending on the size of the folio. A circular describing the folios will be sent on request.

Applications for maps or folios should be accompanied by cash, draft, or money order (not postage stamps) and should be addressed to

THE DIRECTOR,
United States Geological Survey,
Washington, D. C.

November 1937.

STANDARD SYMBOLS



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF MISSOURI
GEOLOGICAL SURVEY AND WATER RESOURCES
H. A. BUEHLER, STATE GEOLOGIST

MISSOURI
FORDLAND QUADRANGLE
15-MINUTE SERIES

Topography by J. B. Leavitt, W. R. Broaddus, C. D. Mitchell, S. D. Farmer, L. E. Williams, and L. H. Bray
Surveyed in 1932–1933, 1936–1937, and 1939

TRUE NORTH — MAGNETIC NORTH 7°
APPROXIMATE MEAN DECLINATION, 1939

Scale $\frac{1}{62500}$

Contour interval 20 feet
Datum is mean sea level

ROUTES USUALLY TRAVELED
HARD IMPERVIOUS SURFACES
OTHER SURFACE IMPROVEMENTS
1942
U. S. ROUTE — STATE ROUTE

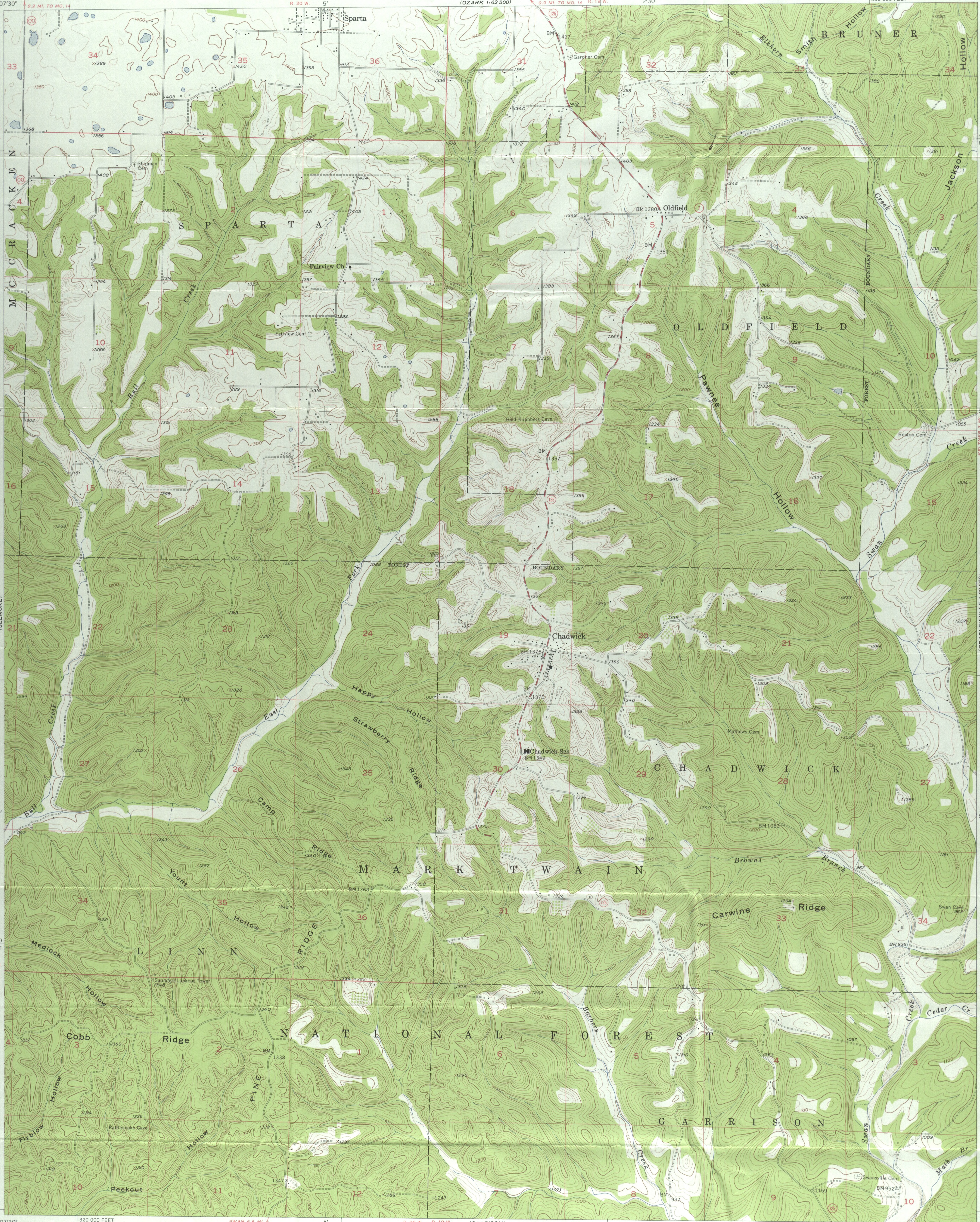
Polyconic projection. 1927 North American datum
5000 yard grid based on U. S. zone system, C
10000 foot grid based on Missouri (Central) rectangular coordinate system

FORDLAND, MO.
N3700—W9245/15

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF MISSOURI
GEOLOGICAL SURVEY AND WATER RESOURCES
THOMAS R. BEVERIDGE, STATE GEOLOGIST

CHADWICK QUADRANGLE
MISSOURI-CHRISTIAN CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



36°52'30"
93°07'30"
320 000 FEET
SWAN 6.6 MI.
5'
R. 20 W. R. 19 W.
(GARRISON)
2'30"
GARRISON 2.7 MI.
27 MI. TO U.S. 160
INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1956—NS
M R-3319
36°52'30"
93°00'
(DAY)
(BRADLEYVILLE 1:62 500)

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1952. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Missouri coordinate system, central zone

7°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1955

SCALE 1:24000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

MISSOURI
QUADRANGLE LOCATION

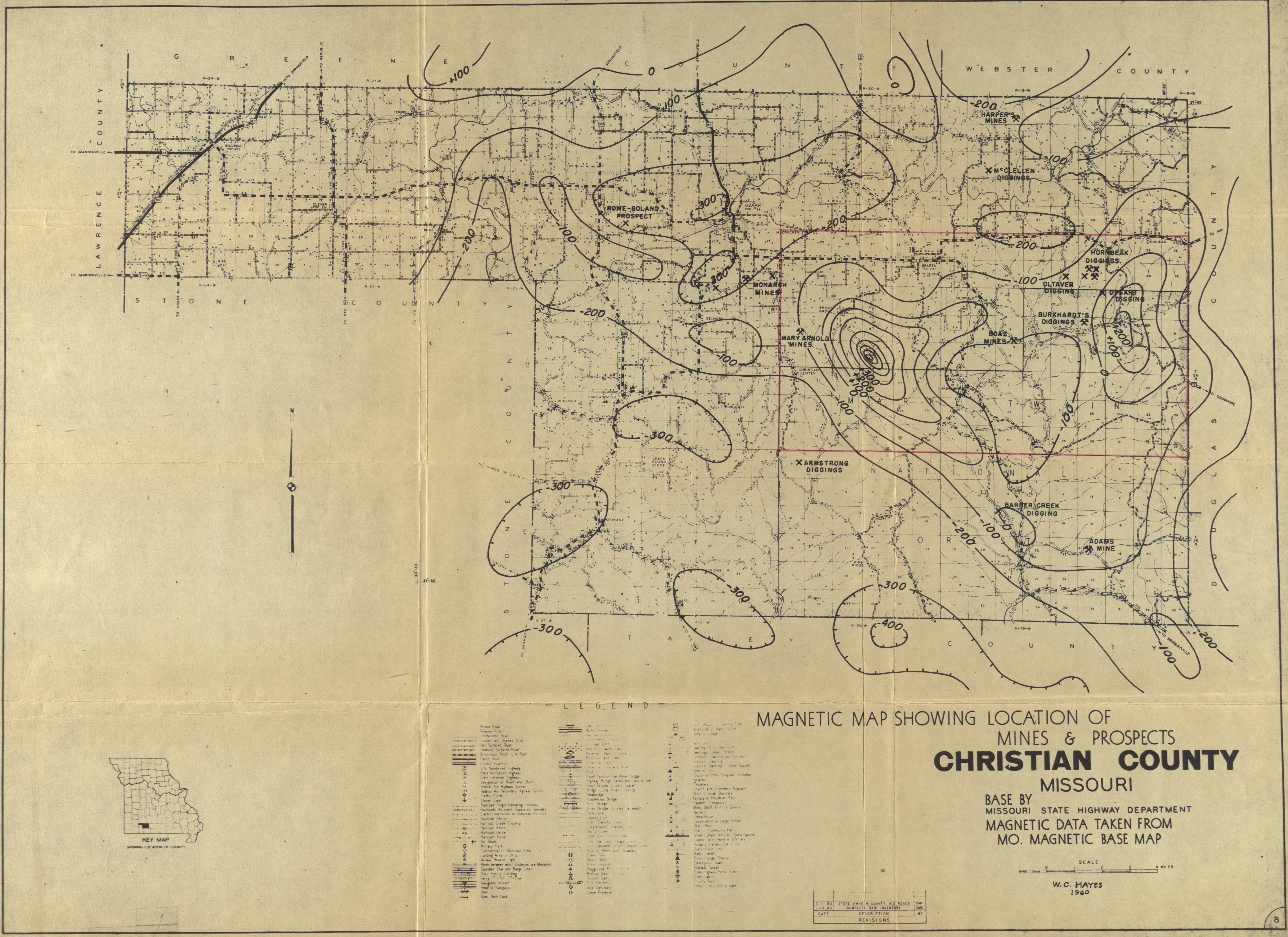
ROAD CLASSIFICATION

Heavy-duty .... Light-duty ....
Medium-duty Unimproved dirt
U. S. Route State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLORADO OR WASHINGTON 25, D. C.
AND BY THE MISSOURI GEOLOGICAL SURVEY, ROLLA, MISSOURI
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

CHADWICK, MO.
N3652.5—W9300/7.5

1955


MAGNETIC MAP SHOWING LOCATION OF
MINES & PROSPECTS
CHRISTIAN COUNTY
MISSOURI
BASE BY
MISSOURI STATE HIGHWAY DEPARTMENT
MAGNETIC DATA TAKEN FROM
MO. MAGNETIC BASE MAP
SCALE
4 MILES
W. C. HAYES
1960
7-1-53 STATE HWYS & COUNTY AID ROADS CMD
COMPLETE NEW INVENTORY CMD
DATE DESCRIPTION BY
REVISIONS
LEGEND
KEY MAP
GREENE COUNTY
WEBSTER COUNTY
LAWRENCE COUNTY
STONE COUNTY
TANEY COUNTY
DOUGLAS COUNTY
MARK TWAIN NATIONAL FOREST
HARPER'S MINES
McCLELLEN DIGGINGS
ROME-BOLAND PROSPECT
MONARCH MINES
HORNBEAK DIGGINGS
OLTAVER DIGGING
DEPAW DIGGING
BURKHARDT'S DIGGINGS
BOAZ MINES
MARY ARNOLD MINES
ARMSTRONG DIGGINGS
BARBER CREEK DIGGING
ADAMS MINE
TO MARIONVILLE
TO SPRINGFIELD
TO REPUBLIC
+100
0
-100
-200
-300
-400
+200
8

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF MISSOURI
GEOLOGICAL SURVEY AND WATER RESOURCES
EDWARD L. CLARK, STATE GEOLOGIST

MISSOURI
OZARK QUADRANGLE
15-MINUTE SERIES

Mapped by the Geological Survey
1933, 1936, 1937 and 1943

SELMORE 2.5 MI.
BRANSON 35 MI.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1937

Map of the Galloway quadrangle, scale 1:24,000, contour interval 10 feet, from a more detailed survey of the north-west quarter of this quadrangle, is available

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1000 500 0 1000 2000 3000 4000 5000 6000 7000 Yards

1000 0 3000 6000 9000 12000 15000 18000 Feet

1 .5 0 1 2 3 4 5 Kilometers

Contour interval 20 feet
Datum is mean sea level

OLDFIELD 1.9 MI.
BRADLEYVILLE 22 MI.

ROAD CLASSIFICATION
1945

Dependable hard-surface heavy-duty road	Dry weather roads	U. S. Route 15
Secondary hard-surface all weather road	Loose-surface graded	
	Unsurfaced, graded	
	Dirt road	State Route 26

More than two lanes indicated along road with tick at point of change 3 LANE 4 LANE

Polyconic projection. 1927 North American datum
5000 yard grid based on U.S. zone system, D
10000 foot grid based on Missouri (Central) rectangular coodinate system

OZARK, MO.
Edition of 1945

N3700—W9300/15

THE TOPOGRAPHIC MAPS OF THE UNITED STATES

The United States Geological Survey is making a series of standard topographic maps to cover the United States. This work has been in progress since 1882, and the published maps cover more than 47 percent of the country, exclusive of outlying possessions.

The maps are published on sheets that measure about 16½ by 20 inches. Under the general plan adopted the country is divided into quadrangles bounded by parallels of latitude and meridians of longitude. These quadrangles are mapped on different scales, the scale selected for each map being that which is best adapted to general use in the development of the country, and consequently, though the standard maps are of nearly uniform size, the areas that they represent are of different sizes. On the lower margin of each map are printed graphic scales showing distances in feet, meters, miles, and kilometers. In addition, the scale of the map is shown by a fraction expressing a fixed ratio between linear measurements on the map and corresponding distances on the ground. For example, the scale $\frac{1}{62,500}$ means that 1 unit on the map (such as 1 inch, 1 foot, or 1 meter) represents 62,500 of the same units on the earth's surface.

Although some areas are surveyed and some maps are compiled and published on special scales for special purposes, the standard topographic surveys and the resulting maps have for many years been of three types, differentiated as follows:

1. Surveys of areas in which there are problems of great public importance—relating, for example, to mineral development, irrigation, or reclamation of swamp areas—are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{31,680}$ (1 inch = one-half mile) or $\frac{1}{24,000}$ (1 inch = 2,000 feet), with a contour interval of 1 to 100 feet, according to the relief of the particular area mapped.

2. Surveys of areas in which there are problems of average public importance, such as most of the basin of the Mississippi and its tributaries, are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{62,500}$ (1 inch = nearly 1 mile), with a contour interval of 10 to 100 feet.

3. Surveys of areas in which the problems are of minor public importance, such as much of the mountain or desert region of Arizona or New Mexico, and the high mountain area of the northwest, are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{125,000}$ (1 inch = nearly 2 miles) or $\frac{1}{250,000}$ (1 inch = nearly 4 miles), with a contour interval of 20 to 250 feet.

The aerial camera is now being used in mapping. From the information recorded on the photographs, planimetric maps, which show only drainage and culture, have been made for some areas in the United States. By the use of stereoscopic plotting apparatus, aerial photographs are utilized also in the making of the regular topographic maps, which show relief as well as drainage and culture.

A topographic survey of Alaska has been in progress since 1898, and nearly 44 percent of its area has now been mapped. About 15 percent of the Territory has been covered by maps on a scale of $\frac{1}{500,000}$ (1 inch = nearly 8 miles). For most of the remainder of the area surveyed the maps published are on a scale of $\frac{1}{250,000}$ (1 inch = nearly 4 miles). For some areas of particular economic importance, covering about 4,300 square miles, the maps published are on a scale of $\frac{1}{62,500}$ (1 inch = nearly 1 mile) or larger. In addition to the area covered by topographic maps, about 11,300 square miles of southeastern Alaska has been covered by planimetric maps on scales of $\frac{1}{125,000}$ and $\frac{1}{250,000}$.

The Hawaiian Islands have been surveyed, and the resulting maps are published on a scale of $\frac{1}{62,500}$.

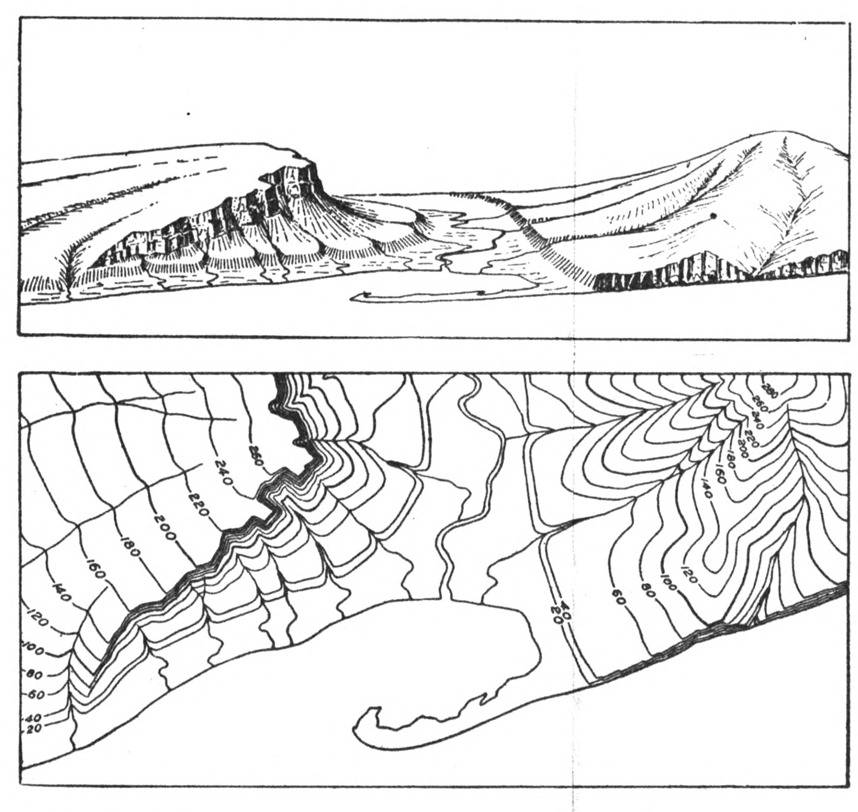
A survey of Puerto Rico is now in progress. The scale of the published maps is $\frac{1}{30,000}$.

The features shown on topographic maps may be arranged in three groups—(1) water, including seas, lakes, rivers, canals, swamps, and other bodies of water; (2) relief, including mountains, hills, valleys, and other features of the land surface; (3) culture (works of man), such as towns, cities, roads, railroads, and boundaries. The symbols used to represent these features are shown and explained below. Variations appear on some earlier maps, and additional features are represented on some special maps.

All the water features are represented in blue, the smaller streams and canals by single blue lines and the larger streams by double lines. The larger streams, lakes, and the sea are accentuated by blue water lining or blue tint. Intermittent streams—those whose beds are dry for a large part of the year—are shown by lines of blue dots and dashes.

Relief is shown by contour lines in brown, which on a few maps are supplemented by shading showing the effect of light thrown from the northwest across the area represented, for the purpose of giving the appearance of relief and thus aiding in the interpretation of the contour lines. A contour line represents an imaginary line on the ground (a contour) every part of which is at the same altitude above sea level. Such a line could be drawn at any altitude, but in practice only the contours at certain regular intervals of altitude are shown. The datum or zero of altitude of the Geological Survey maps is mean sea level. The 20-foot contour would be the shore line if the sea should rise 20 feet above mean sea level. Contour lines show the shape of the hills, mountains, and valleys, as well as their altitude. Successive contour lines that are far apart on the map indicate a gentle slope, lines that are close together indicate a steep slope, and lines that run together indicate a cliff.

The manner in which contour lines express altitude, form, and grade is shown in the figure below.



The sketch represents a river valley that lies between two hills. In the foreground is the sea, with a bay that is partly enclosed by a hooked sand bar. On each side of the valley is a terrace into which small streams have cut narrow gullies. The hill on the right has a rounded summit and gently sloping spurs separated by ravines. The spurs are truncated at their lower ends by a sea cliff. The hill at the left terminates abruptly at the valley in a steep scarp, from which it slopes gradually away and forms an inclined tableland that is traversed by a few shallow gullies. On the map each of these features is represented, directly beneath its position in the sketch, by contour lines.

The contour interval, or the vertical distance in feet between one contour and the next, is stated at the bottom of each map. This interval differs according to the topography of the area mapped: in a flat country it may be as small as 1 foot; in a mountainous region it may be as great as 250 feet. In order that the contours may be read more easily certain contour lines, every fourth or fifth, are made heavier than the others and are accompanied by figures showing altitude. The heights of many points—such as road intersections, summits, surfaces of lakes, and benchmarks—are also given on the map in figures, which show altitudes to the nearest foot only. More precise figures for the altitudes of benchmarks are given in the Geological Survey's bulletins on spirit leveling. The geodetic coordinates of triangulation and transit-traverse stations are also published in bulletins.

Lettering and the works of man are shown in black. Boundaries, such as those of a State, county, city, land grant, township, or reservation, are shown by continuous or broken lines of different kinds and weights. Public roads suitable for motor travel the greater part of the year are shown by solid double lines; poor public roads and private roads by dashed double lines; trails by dashed single lines. Additional public road classification if available is shown by red overprint.

Each quadrangle is designated by the name of a city, town, or prominent natural feature within it, and on the margins of the map are printed the names of adjoining quadrangles of which maps have been published. More than 4,100 quadrangles in the United States have been surveyed, and maps of them similar to the one on the other side of this sheet have been published.

Geologic maps of some of the areas shown on the topographic maps have been published in the form of folios. Each folio includes maps showing the topography, geology, underground structure, and mineral deposits of the area mapped, and several pages of descriptive text. The text explains the maps and describes the topographic and geologic features of the country and its mineral products. Two hundred twenty-five folios have been published.

Index maps of each State and of Alaska and Hawaii showing the areas covered by topographic maps and geologic folios published by the United States Geological Survey may be obtained free. Copies of the standard topographic maps may be obtained for 10 cents each; some special maps are sold at different prices. A discount of 40 percent is allowed on an order amounting to $5 or more at the retail price. The discount is allowed on an order for maps alone, either of one kind or in any assortment, or for maps together with geologic folios. The geologic folios are sold for 25 cents or more each, the price depending on the size of the folio. A circular describing the folios will be sent on request.

Applications for maps or folios should be accompanied by cash, draft, or money order (not postage stamps) and should be addressed to

THE DIRECTOR,
United States Geological Survey,
Washington, D. C.

November 1937.

STANDARD SYMBOLS