A STUDY OF BURIED BEDROCK VALLEYS NEAR SOUTH HAVEN, MICHIGAN, BY THE GRAVITY METHOD

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

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1964

ABSTRACT

A STUDY OF BURIED BEDROCK VALLEYS NEAR SOUTH HAVEN, MICHIGAN, BY THE GRAVITY METHOD

by John S. Klasner

A total of 358 gravity stations were observed in an area of 55 square miles at approximately one-quarter mile intervals along east-west section line roads. Two detail gravity profiles were located over the deepest known valley in the area at a station spacing of approximately 300 feet. A density of 2.15 gm/cc was determined for the glacial drift from a density profile.

Standard procedures were used for the reduction of the raw gravity data. The least squares profile method, the three dimensional least squares method, and the cross profile method were the interpretational techniques used to isolate the residual gravity anomalies. Each of the three methods gave essentially the same results although the magnitude of the residual anomalies varied as much as 54 per cent.

A quantitative examination of the source of the residual gravity anomaly minimums was made at four locations by comparing a theoretically-computed residual gravity anomaly with the observed residual gravity anomaly.

JOHN S. KLASNER

A topographic map of the bedrock surface, utilizing gravity and well-log data, shows three main bedrock valleys in the area. One valley trends north-south near the western edge of the area and the two other valleys lie on either side of a series of bedrock highs which trend diagonally across the area.

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By

John S. Klasner

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Geology

1964

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks to the following people and organizations:

To Dr. William J. Hinze for his unceasing interest and valuable technical guidance in the preparation of this manuscript.

To. Dr. H. B. Stonehouse and Dr. J. Zinn for reviewing the manuscript and for their helpful suggestions.

To the United States Geological Survey for the financial assistance in the gathering of the field data.

The Messrs G. Hendrickson, K. Vanlier, and P. Giroux of the Lansing branch of the U. S. Geological Survey for their encouragement and suggestions during the preparation of this paper.

To the Michigan State Highway Department for preparing a seismic profile in the area of this gravity study.

To Mr. D. L. Merritt for his valuable assistance in the programming of the gravity data for the digital computer.

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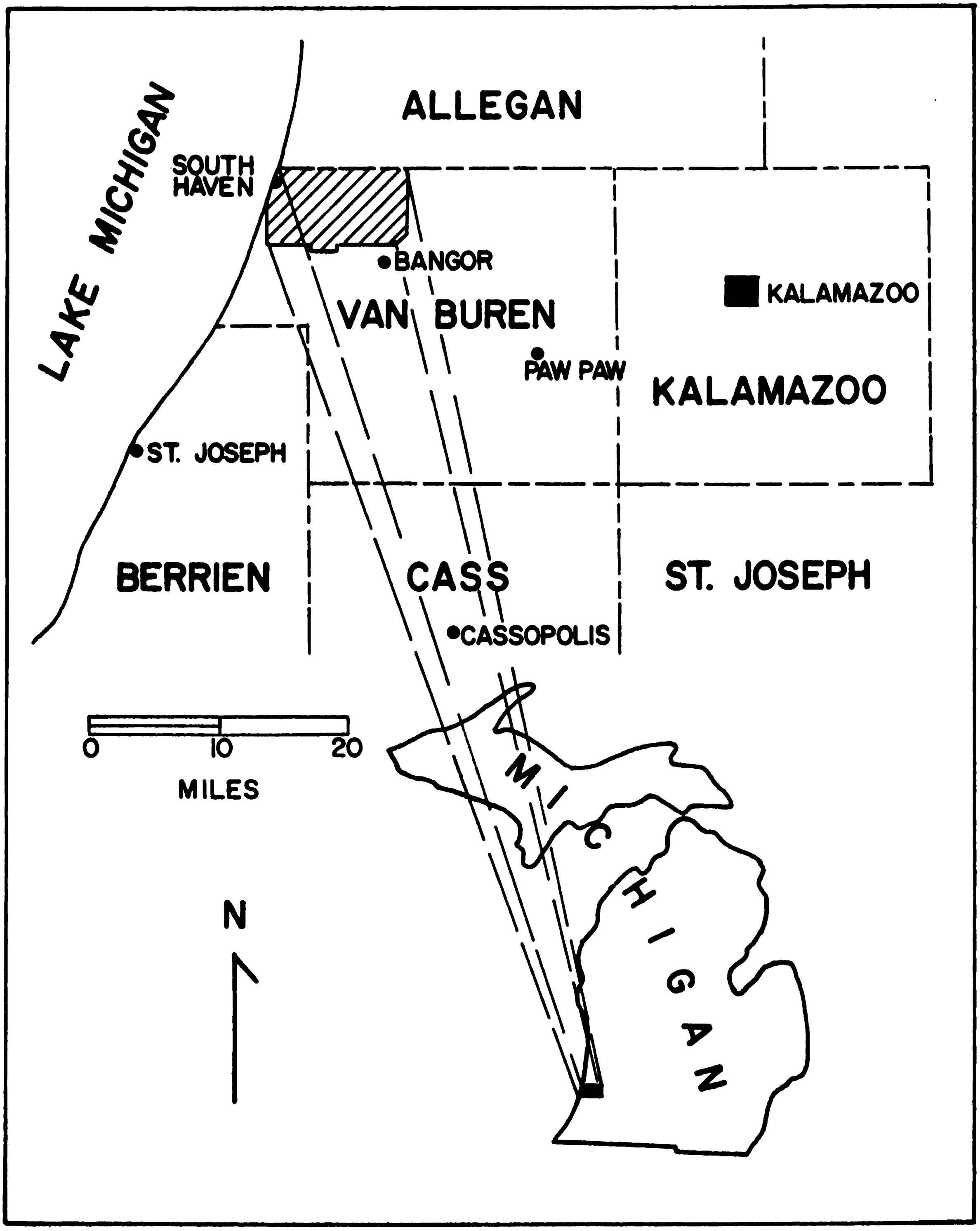
INTRODUCTION

The increasing demand for water has pointed out the importance of buried bedrock valleys as possible sites for ground water exploration in the glaciated areas of the midwestern United States. In areas of adequate well control, the bedrock valleys can be mapped from well-log data. However, in areas of inadequate well control, geophysical methods may serve as useful tools for mapping of the bedrock valley systems.

It is the purpose of this study to map the bedrock valley system in the northwestern part of Van Buren County by the gravity method, to test several methods for isolating the residual anomalies caused by the buried valleys, and to make a quantitative study of the source of the residual anomalies.

GEOGRAPHY OF THE AREA

The area under study, shown in Figure 1, is located in South Haven, Geneva, and parts of Columbia and Bangor townships of Van Buren County. It lies between latitudes 42° 19'N and 42° 25'N and longitudes 86° 05'W and 86° 16'W. Most of the area consists of privately owned farm land which is evenly divided by a network of section-line roads. Elevations range from the level of Lake Michigan, 579 feet above sea level, to a maximum of 760 feet above sea level. In general the area is relatively flat with local relief of 20 to 40 feet along the river valleys. The Black River and its tributaries constitute the main drainage system in the area.



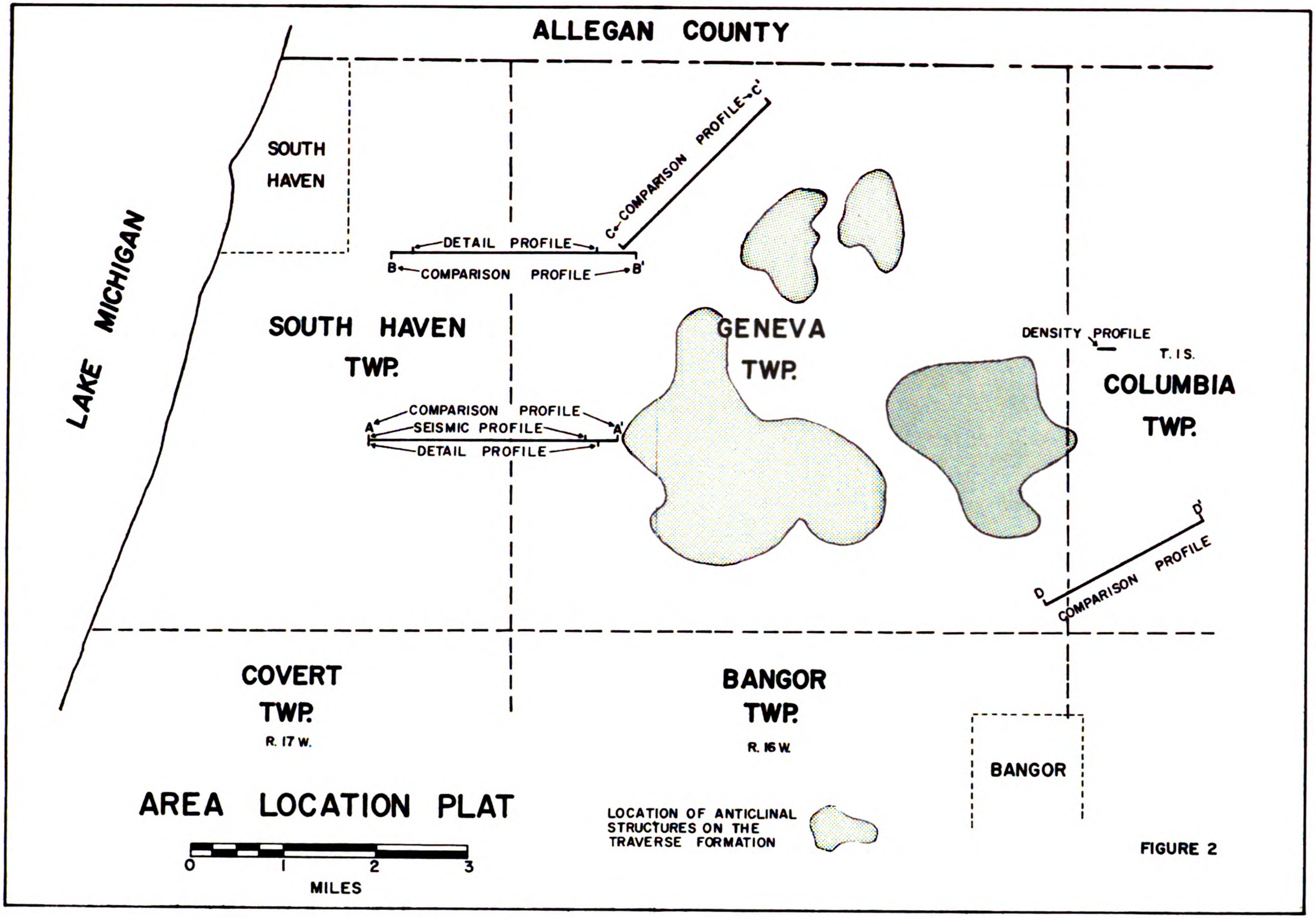
AREA OF INVESTIGATION

FIGURE I

GEOLOGY OF THE AREA

The area of investigation lies near the southwestern edge of the Michigan Basin. Coldwater shale forms the bedrock, and it is dissected by a system of bedrock valleys which have been mapped from well-log data (Terwilliger, unpublished map).

Information from oil well data indicates the presence of anticlinal structures within the sedimentary column. Specifically, there are three anticlinal structures in the Traverse formation at an approximate depth of 400 feet below sea level. The closure on these features is approximately 20 feet. Their location is shown in Figure 2 (Michigan Geological Survey, unpublished maps).


ALLEGAN COUNTY
LAKE MICHIGAN
SOUTH HAVEN
SOUTH HAVEN TWP.
C←COMPARISON PROFILE→C'
DETAIL PROFILE
B← COMPARISON PROFILE →B'
GENEVA TWP.
DENSITY PROFILE
T. I S.
COLUMBIA TWP.
COMPARISON PROFILE
A
SEISMIC PROFILE
A'
DETAIL PROFILE
D
COMPARISON PROFILE
D'
COVERT TWP.
R. 17 W.
BANGOR TWP.
R. 16 W.
BANGOR
AREA LOCATION PLAT
0
1
2
3
MILES
LOCATION OF ANTICLINAL STRUCTURES ON THE TRAVERSE FORMATION
FIGURE 2

FIELD WORK

Two exploration type gravimeters were used for this study. These are Worden meter number 99 and World Wide meter number 45. The respective calibration constants of these two meters are 0.0994(5) and 0.10094 milligals per scale division. The calibration constants for both meters were checked at the beginning of the survey to assure consistant results. Both meters read the relative acceleration of gravity to an accuracy of 0.01 milligals. The normal acceleration of gravity at the earth's surface is 980 gals. Thus, 0.01 mgals is approximately one part in one hundred million of the normal gravity of the earth.

Although the meters are temperature compensated and barometrically controlled, they are subject to time variations or drift. These time variations of the gravimeter readings are caused by temperature changes, tidal variations, spring fatique, and abrupt changes in the atmospheric pressure. In order to keep track of these variations, a check reading at one of a series of pre-established base stations was obtained at least once per hour during the course of the survey.

A series of gravity base stations were established throughout the area at easily accessible locations and tied to a primary base, located near the center of the area, by the base looping method.

Gravity readings were observed at approximately one-quarter mile intervals along the east-west section line roads and tied to the base stations by the hourly base-check readings.

Two detail profiles were located over the deepest known valley in the area. The location of these profiles is shown in Figure 2. The station spacing on these detail profiles are approximately 300 feet.

A density profile to determine the in situ density of the glacial drift was located over a surface feature with 20 feet of relief. A station spacing of 90 feet was used on this profile. Its location is shown in Figure 2.

Station elevations and east-west horizontal locations were surveyed with a Zeiss self-leveling level. Elevation control was established from three U. S. Geological Survey bench marks and two U. S. Coast and Geodetic Survey bench marks. All traverses closed to an accuracy of 0.34 feet or better. East-west horizontal distances were determined by stadia intervals, and the control was carried only from road intersection to road intersection to eliminate accumulative error.

REDUCTION OF DATA

Introduction

Corrections for the influence of known near surface and surface conditions must be applied to the raw gravity data before it is interpreted. These corrections are applied to each gravity stations and the resulting value is called the Bouguer gravity anomaly. The Bouguer gravity anomaly map is an expression of the horizontal variation in the density of the material within the earth which has not been accounted for in the Bouguer corrections.

The Bouguer gravity anomaly values were calculated on a digital computer according to the following formula:

$$G_b = g_o - g_l + g_f - g_m + g_t,$$

where:

G_b = Bouguer gravity anomaly

g_o = observed gravity

g_l = latitude correction

g_f = free-air correction

g_m = mass correction

g_t = terrain correction

Observed Gravity

The observed gravity values were determined by first correcting the meter readings for drift, and then multiplying these values by the calibration constant of the meter. The amount of drift for each gravity observation was determined from graphs of the hourly base-check readings. If the hourly drift exceeded one scale division, about 0.1 mgal, the stations that were occupied during that hour were repeated to insure drift correction accuracy.

Latitude Correction

The latitude correction takes into account the increase in gravity from the equator to the poles. In this case, latitude corrections were made from latitude 42° 19'N, the arbitrarily selected base latitude. Distances were measured in feet from the base latitude to each gravity station on U. S. Geological Survey, 7 1/2 minute, topographic quadrangles. The correction to be applied to each gravity station was determined by multiplying the latitude distance by a constant, K. According to Nettleton (1940), $K = 1.307 \sin 2\phi$ mgals per mile, where ϕ is the latitude of the area under study. In this area $K = 0.0002465$ mgals per foot.

Free-Air Correction

The free-air correction takes into account the decrease in gravity with an increase in elevation. This correction was calculated by multiplying the vertical gradient of gravity, 0.09406 mgals per foot, by the elevation differential between the gravity station and the datum.

Mass Correction

The mass correction takes into account the attraction of the material between the datum and the elevation of each gravity station. The formula to determine the mass correction is 0.01276 h mgals per foot, where: σ = density (2.15 gm/cc), and h = the elevation differential between the datum and the gravity station. In this correction both the choice of the datum and the density (σ) are critical factors.

A 600 foot datum was chosen for this study. This datum was chosen to minimize the effect on the mass correction of density variations within the glacial drift. Both lateral and vertical variations in the density of the glacial drift result from the heterogeneous nature of the glacial drift, and from fluctuations in the elevation of the water table. If the elevation differential (h) is kept at a minimum, any error in the density (σ) will be minimized in the mass correction.

The density used for the mass correction was 2.15 gm/cc. this value was obtained by a least squares reduction of the density profile by the method of Jung (1953). One of the disadvantages of density determination from a density profile is that in an area of little topographic relief, very accurate gravity values are needed to make an accurate density determination. Because this area is relatively flat, it was difficult to locate an accessible topographic feature of appreciable relief. However, this disadvantage is somewhat compensated because a larger error can be tolerated in areas of small relief (Nettleton, 1940). Also, the drift density that was determined from this density profile was geologically feasible and agrees with other values used in the reduction of gravity data observed in nearby areas.

Terrain Corrections

Because of the lack of appreciable relief in the area, the effect of variations in the elevation of the land surface on the acceleration of gravity was checked by computing terrain corrections for those gravity stations that were located in the areas of maximum relief. The maximum terrain correction, computed by Hammer's method (1939), was 0.04 mgals.

ACCURACY OF BOUGUER REDUCTIONS

The main factors that cause errors in the calculation of the Bouguer gravity anomaly are:

1. Errors in obtaining the observed gravity values.
2. Errors in elevations.
3. Errors in latitude measurements.
4. Errors in the density of the glacial drift.

An estimate of the accuracy of the gravimeter readings and the drift control was obtained by re-observing several stations. Nine stations were re-occupied on different days, and eight stations were re-read on the same day. The standard deviation for these repeated gravity observations is ± 0.02 mgals.

Errors in station elevations affect the free-air and mass corrections. The maximum misclosure on any of the surveyed loops was 0.34 feet. By combining the free-air and the mass effects, at a density of 2.15 gm/cc, a maximum error in elevation of 0.34 feet would cause a 0.02 mgal error in the calculation of the Bouguer gravity anomaly.

Errors in the latitude correction depend on the accuracy of the latitude measurements. Latitude measurements can be made to an accuracy of 150 feet or better from 7 1/2 minute U. S. G. S. topographic quadrangles. This gives a maximum error of 0.03 mgals at 0.0002465 mgals per foot.

The magnitude of the error due to an incorrect density value in the mass correction is mainly dependent on the amount of relief in the area. In this area the local relief is rarely as great as 40 feet. The hetrogeneous nature of the glacial drift makes it extremely difficult to estimate realistically the error caused by an incorrect value for the density of the glacial drift. If an average density error of, say, 0.2 gm/cc is assumed for the glacial drift, it would cause a constant error over a flat surface. However, in areas of local relief, this error could cause a critical distortion of the Bouguer gravity anomaly. Thus, it is reasonable to estimate the error for the density of the glacial drift on the basis of the maximum local relief of 40 feet. This error is:

$$E = 0.00128 \cdot \Delta\sigma \cdot \Delta h$$

where:

0.00128 = the magnitude of error in milligals per foot for each 0.1 gm/cc error in density.

$\Delta\sigma$ = error in drift density in gm/cc.

Δh = maximum local relief in feet.

The resulting error is $\pm$ 0.10 mgals. However, this error can often be identified because of its direct correlation with topography.

A combination of all sources of possible error gives a miximum possible error of ± 0.2 mgals. However, the coincidence in sign of all of these possible errors at one single station is unlikely.

DISCUSSION OF THE BOUGUER GRAVITY ANOMALY MAP

The Bouguer gravity anomaly map (Plate 1) shows an increase in regional gravity from 37.5 mgals in the southwest to 52.00 mgals in the northeast. A large gravity nose points diagonally across the area toward the southwest. This map shows excellent agreement with the regional gravity map of Michigan (Hinze, 1963). It lies on the southwest flank of a regional gravity high that has 13 mgals of closure.

Two anomalous areas that interrupt the regional gravity picture are readily apparent. One is the gravity low that trends in a north-south direction along the South Haven-Geneva township line. The other anomalous area lies about two miles north of the city of Bangor.

ISOLATION OF THE BEDROCK ANOMALIES

Introduction

The Bouguer gravity anomaly map illustrates the effect that the horizontal variations in the density of the material within the earth have on the acceleration of gravity. To determine the effects of the near surface features on the acceleration of gravity, the effect of the deep, broad, regional features must be removed from the Bouguer gravity anomaly. Three methods were used to remove the regional gravity effects. These are the least squares profile method, the three dimensional least squares method, and the cross profile method. The purpose of these three methods is to approximate the regional gravity anomaly. The residual gravity anomaly is then obtained by taking the difference between the observed Bouguer gravity anomaly and the regional gravity anomaly at each station.

Least Squares Profile Method

The principle of the least squares method is to pass a curve through a set of points so that the sum of the residual errors is a minimum (Smith, 1934).

To illustrate: $z' = a + bx = cx^2$ is the polynomial equation for a second degree curve that is to be passed through a set of points, (x, z), (x_2, z_2), ... , (x_n, z_n), where:

n = the number of points

x_i = the horizontal coordinate of the point.

z_i = the Bouguer gravity value of the point.

The sum of the squares of the residual errors ($\sum r^2$) is given as follows:

$$\sum r^2 = \sum(z-z') = \sum(z-a-bx-cx^2)^2$$

where:

z = the observed gravity value

z' = the regional gravity value

$r(x_i, z_i)$ = the residual gravity value at point i.

For the sum of the errors to be a minimum, the total differential of $\sum(z-z-bx-cx^2)^2$ is equal to zero.

Thus:

$$d(\sum r^2) = \frac{\partial(\sum r^2)}{\partial a} da + \frac{\partial(\sum r^2)}{\partial b} db + \frac{\partial(\sum r^2)}{\partial c} dc = 0,$$

or:

$$\frac{\partial(\sum r^2)}{\partial a} = \sum 2(z-a-bx-cx^2) = 0$$

$$\frac{\partial(\sum r^2)}{\partial b} = \sum 2x(z-a-bx-cx^2) = 0$$

$$\frac{\partial(\sum r^2)}{\partial c} = \sum 2x^2(z-a-bx-cx^2) = 0.$$

It then follows that:

$$\sum z = na + b\sum x + c\sum x^2$$

$$\sum xz = a\sum x + b\sum x^2 + c\sum x^3$$
$$\sum x^2 z = a\sum x^2 + b\sum x^3 + c\sum x^4.$$

To determine the coefficients (a, b, c), the three simultaneous equations can be solved by matrices as follows:

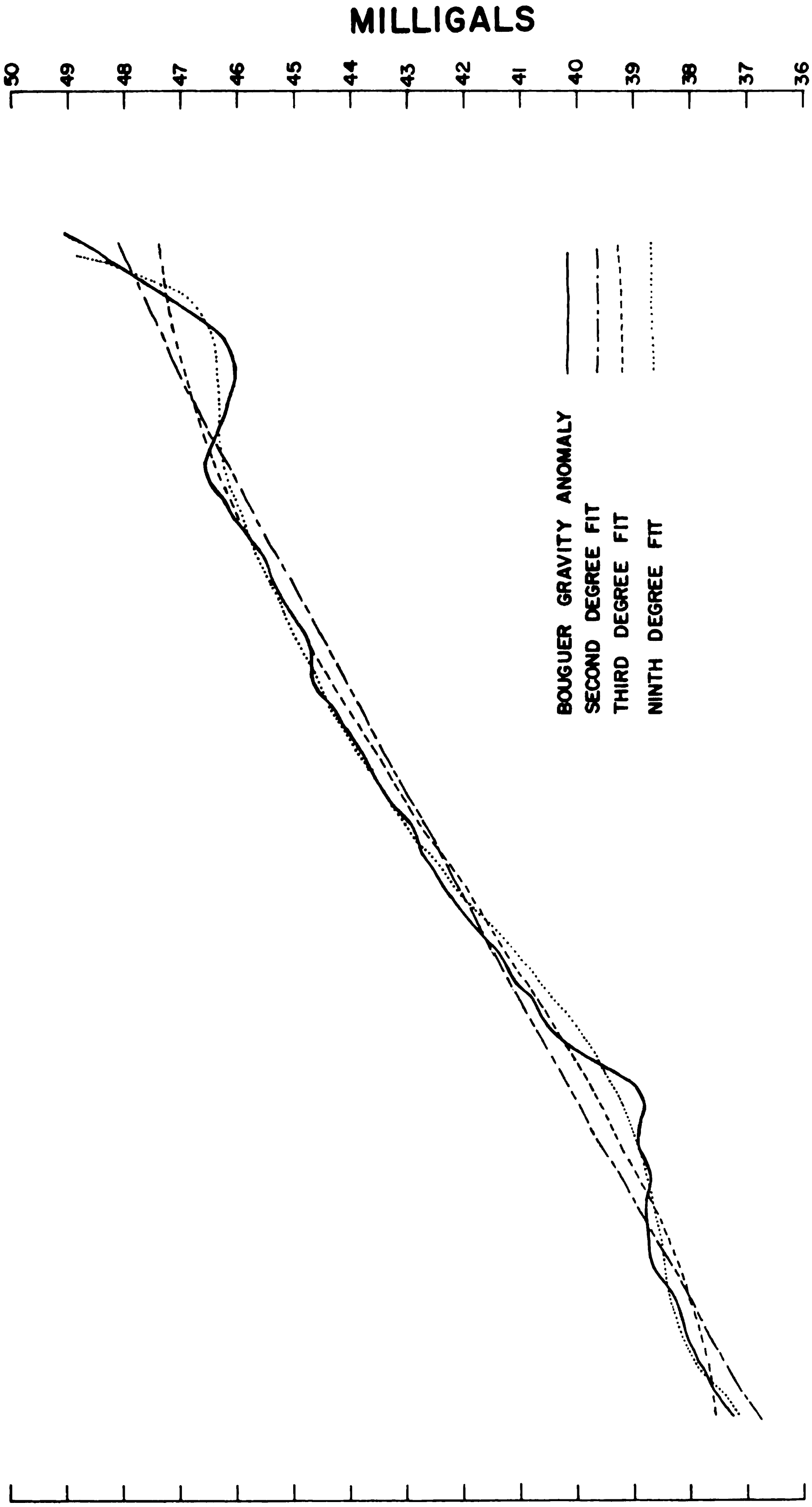
$$\begin{vmatrix} n & \sum x & \sum x^2 \\ \sum x & \sum x^2 & \sum x^3 \\ \sum x^2 & \sum x^3 & \sum x^4 \end{vmatrix} \qquad \begin{vmatrix} a & & \sum z \\ & = & \sum xz \\ c & & \sum x^2 z \end{vmatrix}$$

Then:

$$\begin{vmatrix} a \\ b \\ c \end{vmatrix} = \begin{vmatrix} n & \sum x & \sum x^2 \\ \sum x & \sum x^2 & \sum x^3 \\ \sum x^2 & \sum x^3 & \sum x^4 \end{vmatrix}^{-1} \begin{vmatrix} \sum z \\ \sum xz \\ \sum x^2 z \end{vmatrix}$$

In a similar manner higher degree equations can be computed to fit a set of gravity values. A digital computer was used to calculate least squares equations from the first to the twentieth degree. Figure 3 illustrates how the least squares curves of various degrees fit a Bouguer gravity anomaly profile. The third degree fit was chosen as the best approximation to the regional gravity anomaly.

Plate 2 shows the residual gravity anomaly map for the third degree fit. Three main residual gravity lows occur in the area. One trends in a north-south direction along the South Haven-Geneva township line. The two other residual lows lie on either side of a series of residual gravity highs which trend diagonally across the area in a



PROFILE OF BOUGUER GRAVITY ANOMALY WITH LEAST SQUARES FITS

FIGURE 3

northeast-southwest direction. Several tributary residual lows join these three gravity lows at various locations.

Three Dimensional Least Squares Method

The three dimensional least squares method is a technique by which the regional gravity anomaly is approximated by a three dimensional surface. In contrast to the least squares profile method which uses a system of two coordinates, $(x_1\ z_1)\ (x_2\ z_2),\ldots.(x_n\ z_n)$, the three dimensional least squares method utilizes a system of three coordinates, $(x_1\ y_1\ z_1)$, $(x_2\ y_2\ z_2),\ldots.(x_n\ y_n\ z_n)$, where x_i and y_i are the east-west and north-south horizontal coordinates of the gravity station, and z_i is the Bouguer gravity anomaly value of the station. The polynomial equations for the three dimensional least squares method were solved by matrices on a digital computer in a manner similar to the least squares profile technique.

Seven three dimensional least squares surfaces were computed to fit the Bouguer gravity anomaly. These involved equations of the first, third, fifth, seventh, ninth, eleventh, and thirteenth degree. After an examination of the various degree fits, the fifth degree surface was chosen as the best approximation to the regional gravity anomaly.

The residual gravity anomalies from the fifth degree surface are shown on Plate 3. A comparison with the results of the least squares profile method illustrates that the two methods give essentially the same results. The three main residual lows are present at the same locations, and the series of residual gravity highs trend diagonally across the area.

Plate 4 shows the residual gravity anomalies from the eleventh degree surface. In general this map is similar to the two previous interpretations. However, the size and configuration of the residual anomalies are changed appreciably.

Cross Profile Method

The cross profile method for the approximation of the regional gravity anomaly is a personal interpretation technique. It involves the selection of two series of Bouguer gravity profiles at right angles to each other. A regional gravity profile is drawn along each of the selected profiles from an examination of the Bouguer gravity anomaly. These regional profiles are inspected and adjusted wherever necessary so that the regional gravity values are equal at the points of intersection of any two profiles, and that the resulting regional gravity profiles are geologically reasonable. The residual gravity values are obtained by subtracting the value of the regional gravity anomaly from the value of the Bouguer gravity anomaly at each station.

Plate 5 shows the residual gravity map which was obtained from the cross profile interpretation. Similar to the two previously discussed methods, the cross profile technique gives the three main residual gravity lows and the series of residual gravity highs trending diagonally across the area.

Discussion of the Residual Gravity Maps

The residual gravity lows are attributed to bedrock valleys that are filled with glacial deposits. Because of its greater amount of pore space, the glacial material filling the bedrock valleys is less dense than the adjacent bedrock. This decrease in density in the bedrock valleys causes the acceleration of gravity to be less over the buried valleys. These deviations in the acceleration of gravity from the regional gravity anomaly are shown as residual lows on the residual gravity maps.

The three gravity highs that trend diagonally across the area in a northeast-southwest direction could be attributed to either structures within the sedimentary column of high areas on the bedrock surface. The large residual high that lies near the center of Geneva township appears to be related to a structural high in the Traverse formation as shown by comparing Figure 2 and Plate 6. The other gravity high that is located in the northeast corner of Geneva township does not appear to be related to a structural high in the Traverse formation. Both of these residual gravity highs, however, do correspond to high areas on the bedrock surface as shown on Plate 6. It thus appears that the residual gravity highs are the results of the effects from both the bedrock surface and deeper structures within the sedimentary column.

COMPARISON PROFILES OF OBSERVED AND THEORETICAL RESIDUAL ANOMALIES

Talwani (1959) has outlined a method for the computation of the acceleration of gravity due to two dimensional bodies. These are bodies which have finite dimensions only in one direction; the dimension normal to the finite dimension is considered to be infinite. By approximating the shape of the two dimensional body with a vertical polygon, analytical expressions can be obtained for the gravitational attraction of the polygon. The computed gravitational attraction of the two dimensional body is compared with the observed gravitational attraction of the body. The closeness of the comparison depends on how closely the dimensions and depth of the theoretical body corresponds to those of the actual body, and on how accurately the density contrast between the body and the host rock is estimated.

By logarithmic potential, the gravitational attraction for a two dimensional body is equal to $2G\,\rho\oint z\,d\phi$ which is the line integral taken along the periphery of the body. In the above formula G is the gravitational constant, ρ is the density of the body, and z and ϕ are the respective distance and angle parameters to define the dimensions of the body. By setting up a coordinate system to locate the ground points at which the gravity is being computed, and to define the location of the vertices of the polygon, Talwani developed a method by which the above integral can be solved on a digital computer. The formula for the gravitational attraction due to the whole polygon at any point along the profile is:

$$v = 2G\rho \sum_{i=1}^{n} z_i,$$

where:

G and ρ are the same as above,

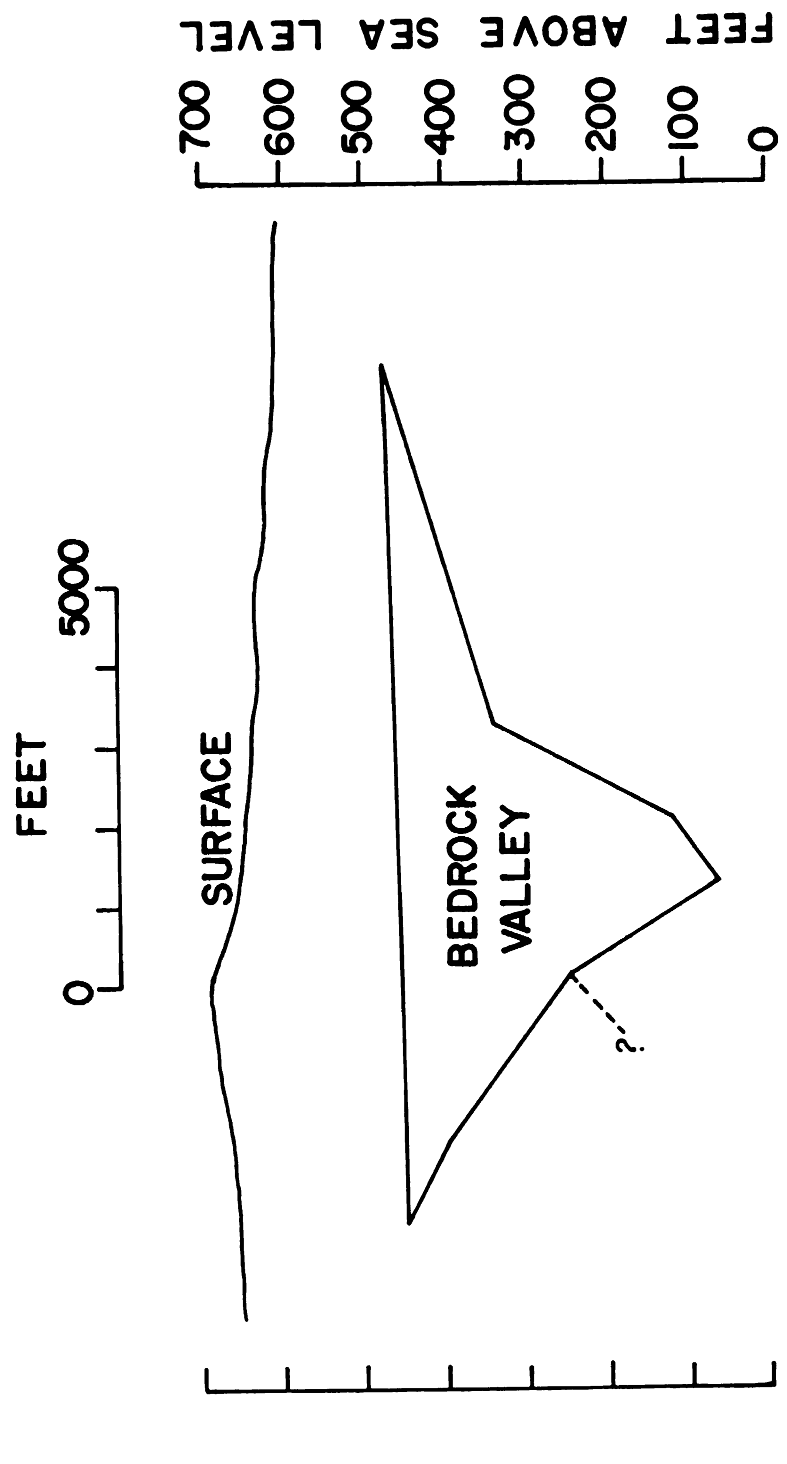
z_i = the results of the evaluation of the line integral over the ith side of the polygon,

n = the number of the sides of the polygon

v = the total gravitational effect of the polygon.

Four comparison profiles were drawn across the bedrock valleys. The locations of the comparison profiles are shown in Figure 2. All four profiles were located in areas of depth control. Three of the comparison profiles were selected over oil well locations, and the other profile was located over a seismic profile which was observed by the Michigan State Highway Department (Figure 4).

These profiles involved a comparison between an observed residual gravity profile, taken from the cross profile interpretation, and the residual profile computed from a two dimensional body by the method outlined above. The



BEDROCK VALLEY FROM
SEISMIC PROFILE INTERPRETATION

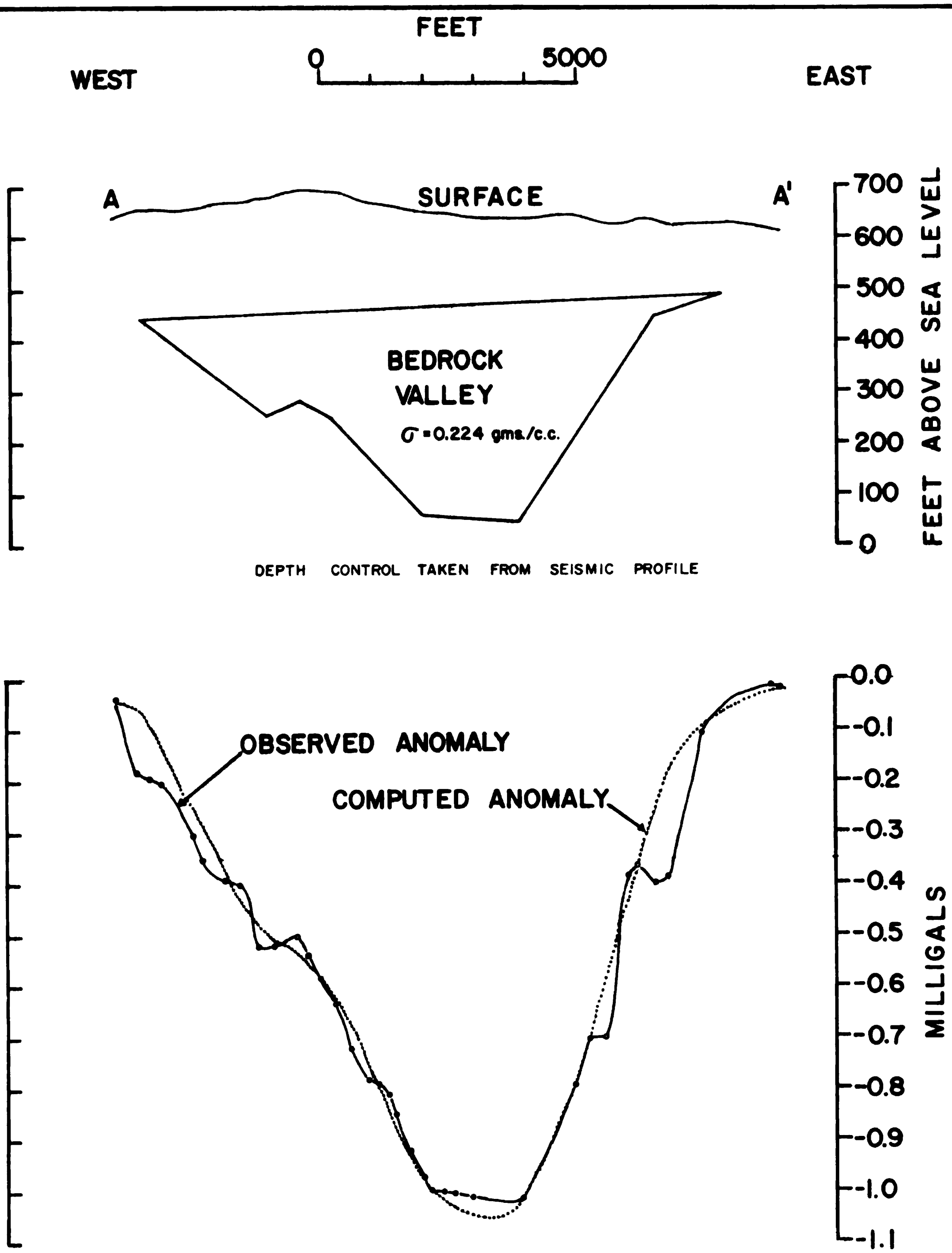
AFTER MICHIGAN STATE HIGHWAY DEPARTMENT, UNPUBLISHED DATA

FIGURE 4

observed residual anomalies were taken from the cross profile interpretation because the residual anomalies of interest are clearly defined and are not subject to smoothing effects in the cross profile method as they are in the least squares methods.

Comparison profile A-A' (Figure 5) was selected at the location of coincident seismic and detail gravity profiles. The first approximation for the shape and depth of the theoretical bedrock valley was made on the basis of the results of seismic data. To obtain the desired fit between the observed and computed gravity anomalies, the width of the body from the seismic interpretation was altered as shown by comparing Figures 4 and 5. The dashed line in Figure 4 illustrates an observed reversed seismic dip. Although this was unexplained in the seismic interpretation, it does support the presence of the bench on the west side of the bedrock valley as shown in Figure 5.

Control for the depth and general shape of the bedrock valley from the seismic profile permitted a reasonable estimate to be made of the density differential between the material filling the valley and the adjacent bedrock. This density differential was used as a guide in calculating the three remaining comparison profiles.



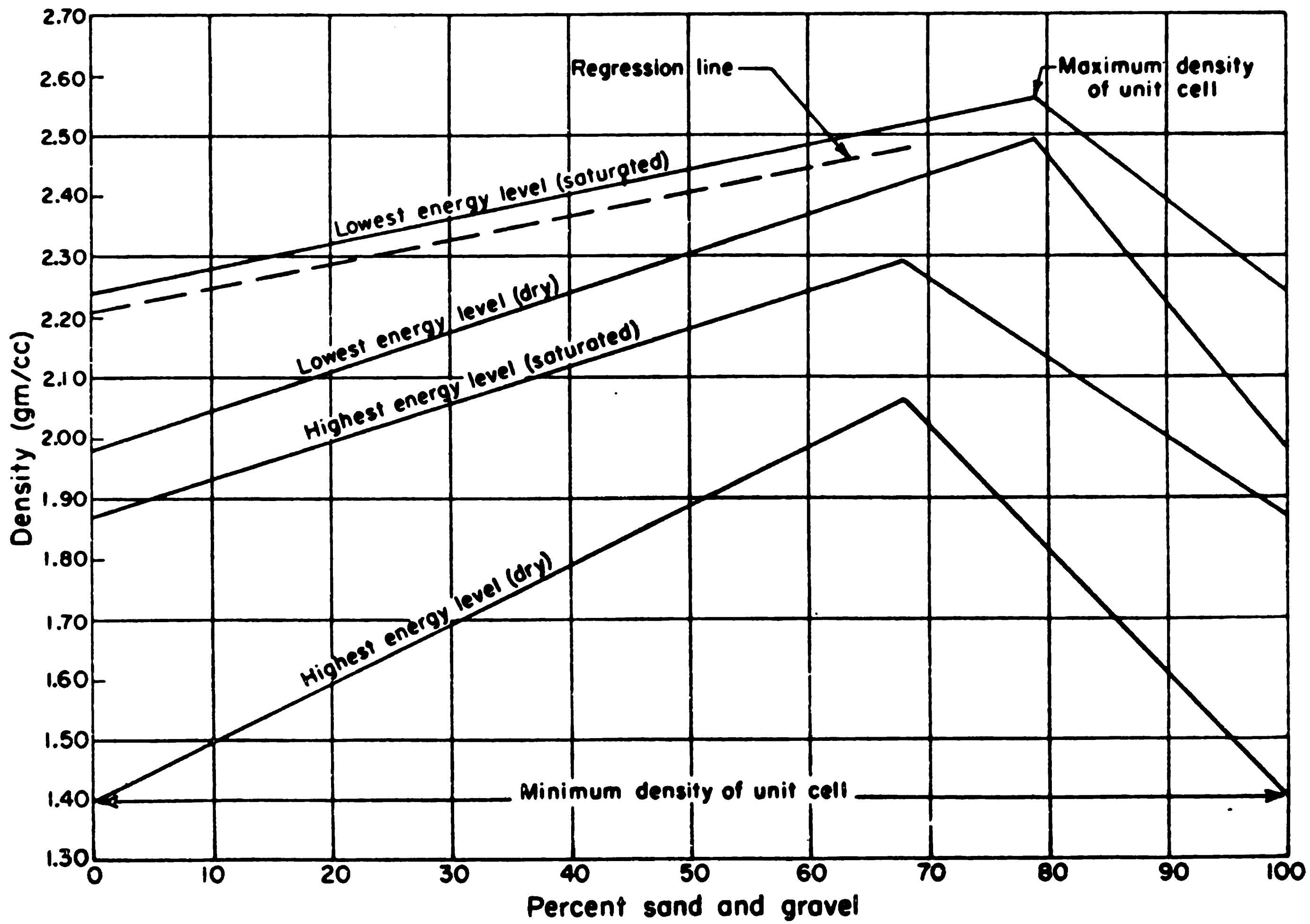
COMPARISON OF OBSERVED AND COMPUTED RESIDUAL GRAVITY ANOMALY

FIGURE 5

A density differential of 0.224 gm/cc was obtained from comparison profile A-A'. The density of the Coldwater shale is estimated at 2.65 gm/cc (Michigan State University, unpublished data). This gives 2.43 gm/cc as the density of the material filling the bedrock valley.

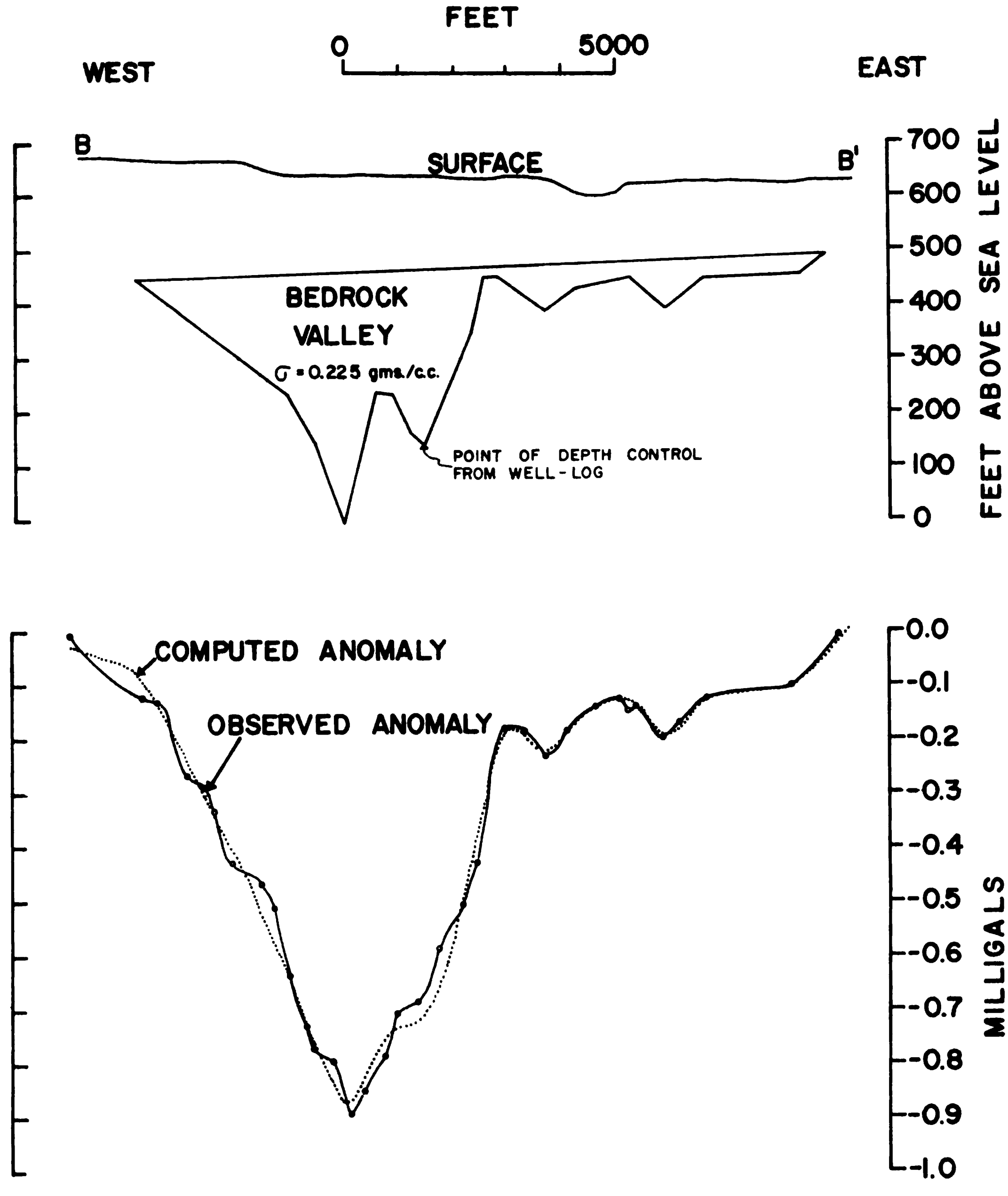
McGinnis, Kempton, and Heigold (1963) made a theoretical study of the density of the glacial drift, assuming spherical grains, as a function of percentage of sand and gravel. The study was made in connection with a gravity study of bedrock valleys in northern Illinois. In reference to their results as shown in Figure 6, a density of 2.43 gm/cc gives either 48 or 87 per cent sand and gravel for the saturated material in the bedrock valley. The energy levels in this diagram refer to the type of packing of the glacial material. The lowest energy level refers to the situation in which the spherical grains are packed to give the least amount of pore space. The highest energy level refers to the situation in which the spherical grains give the greatest amount of pore space. A value near the lowest energy level (saturated) was chosen for the material filling the valley since it is buried by several hundreds of feet of glacial drift.

Comparison profile B-B' (Figure 7) was located over a detail gravity profile two miles north of profile A-A'. The shape of the valley was determined through repeated



Theoretical drift densities versus percent sand and gravel. After McGinnis, Kempton, and Heigold, 1963

Figure 6



COMPARISON OF OBSERVED AND COMPUTED RESIDUAL GRAVITY ANOMALY

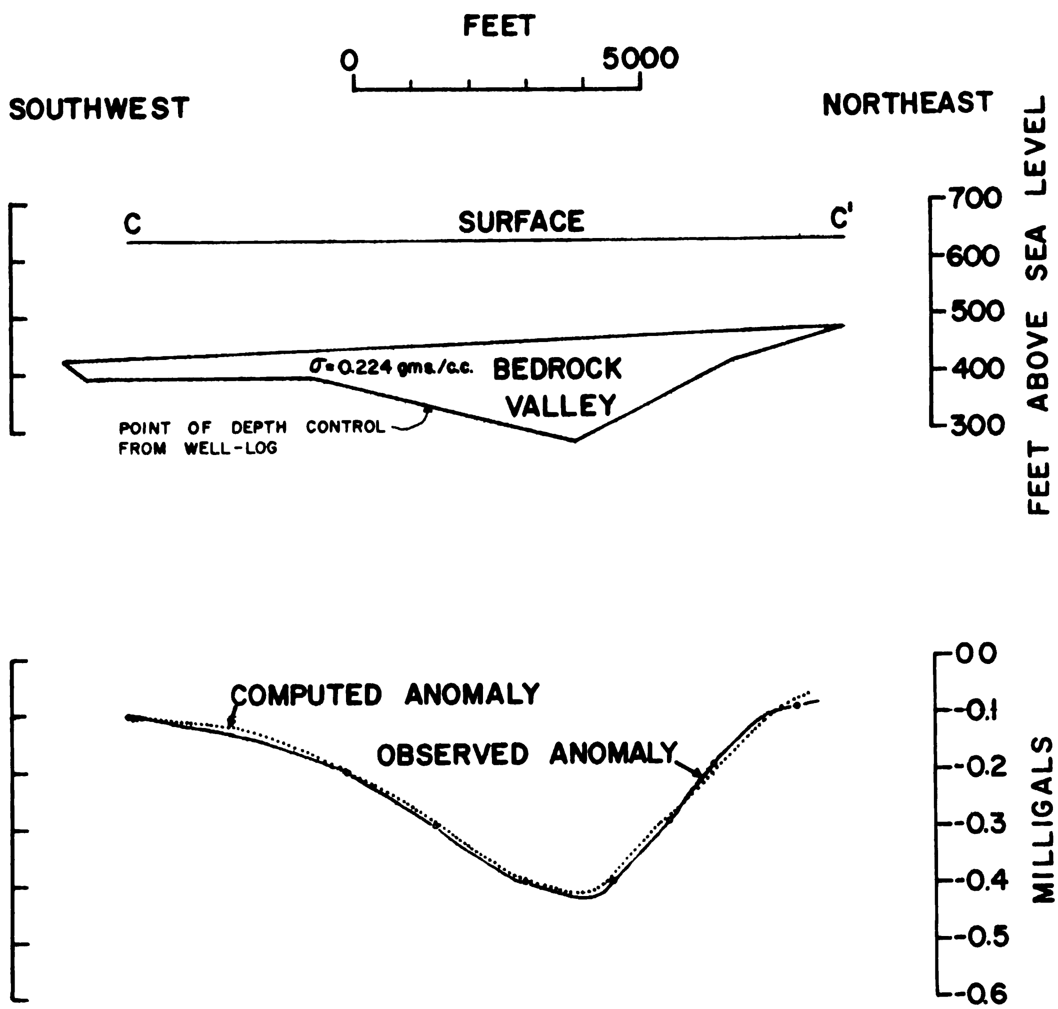
FIGURE 7

alterations of an initial, arbitrary approximation. A value of 0.225 gm/cc for the density differential was used in this approximation.

Profile C-C' (Figure 8) was located over the bedrock valley that trends in a northwest-southeast direction in the northwest corner of Geneva township. The shape of the valley was approximated in the same manner as profile B-B'. A value of 0.224 gm/cc was used as the density differential for the calculation of the theoretical valley.

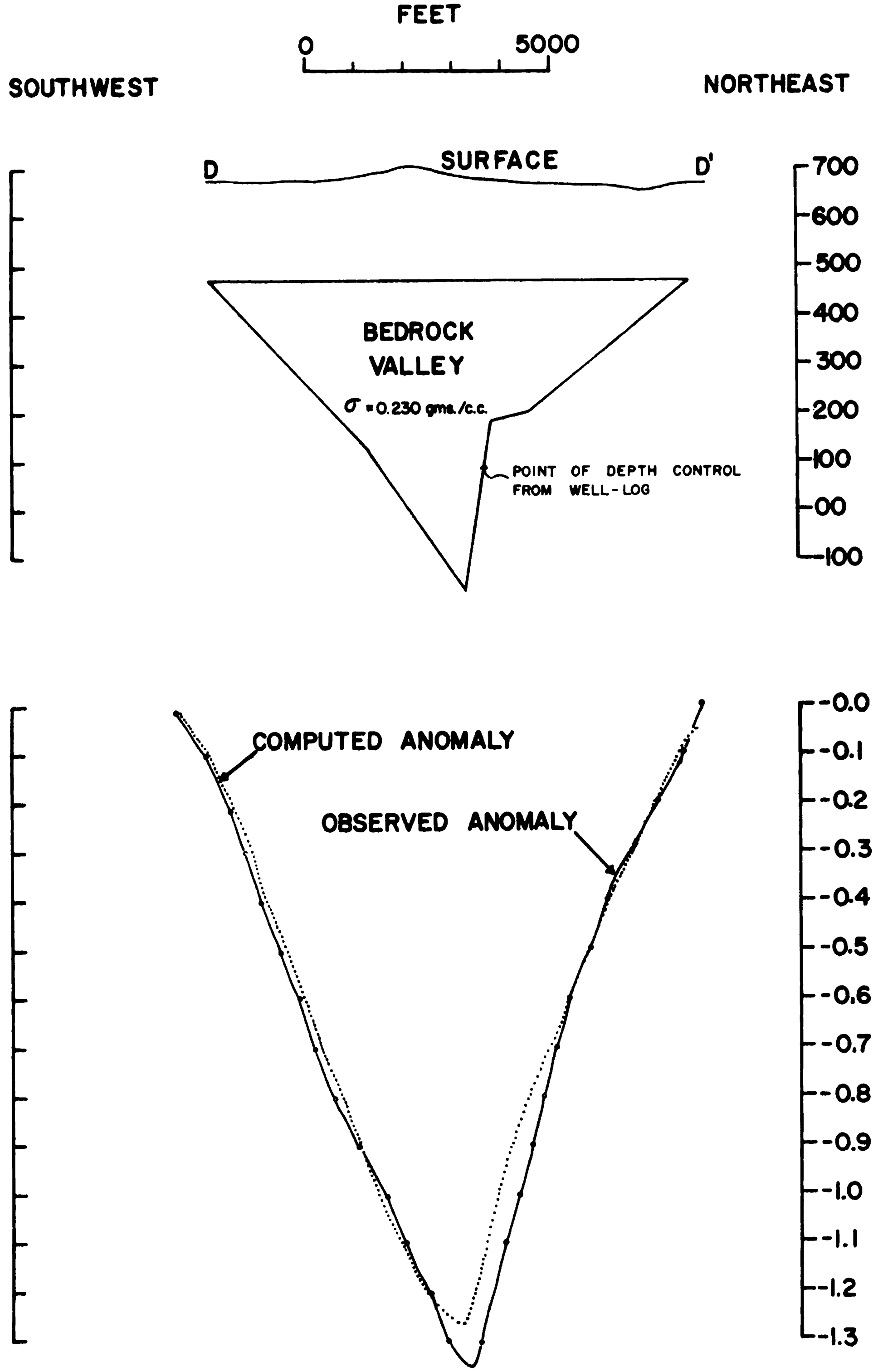
Profile D-D' was located in the southeast corner of the area across the northwest-southwest trending bedrock valley. The shape of the bedrock valley was approximated in the same manner as profiles B-B' and C-C'. Figure 9 illustrates the results that were obtained. The bench on the northeast side of the valley is based on a depth obtained from an oil well log. The observed residual anomaly appears to be incorrectly estimated because a reasonable comparison cannot be made with the well-log depth. The incorrect estimate of the magnitude of the residual anomaly is attributed to the fact that this is near the edge of the area of gravity control. In order to obtain a better estimate of the size of the residual anomaly, the gravity control would have to be extended outside of the present area of control.

Without the depth control that was available for each profile, a unique solution for the size and shape of



COMPARISON OF OBSERVED AND COMPUTED RESIDUAL GRAVITY ANOMALY

FIGURE 8



COMPARISON OF OBSERVED AND COMPUTED RESIDUAL GRAVITY ANOMALY

FIGURE 9

the bedrock valley could not be obtained. A series of theoretical valleys could be computed by changing one or more of the three variables, depth, size, and density. For example, if the theoretical valley for profile B-B' was lowered 40 feet, and the dimensions and density of the body were increased, a new comparison could be obtained between the observed and computed residual gravity anomalies. This process could be repeated at several different depths until the depth factor would make it impossible to attain an agreement between the computed and observed residual anomalies.

COMBINED INTERPRETATION FROM WELL-LOG DATA AND GRAVITY DATA

The residual gravity maps, discussed above, are not bedrock surface maps as such. They represent the effects of the near surface materials on the acceleration of gravity after the regional gravity effects have been removed from the Bouguer gravity anomaly. A map of the elevation of the bedrock surface was made from a combined interpretation of the gravity data and well-log data (Plate 6). In the areas of adequate well control, the gravity interpretation was supported by the well-log data, and in areas of poor well control the gravity data aided in the mapping of the bedrock surface.

There are three major bedrock valleys in the area. One of these valleys trends along the South Haven-Geneva township line. The two other valleys lie on either side of bedrock high which trends diagonally across the area in a northeast-southwest direction. A low area, or saddle, with about 150 feet of local relief joins these two oppositely trending valleys. The directions from which the tributary valleys enter the main valleys indicate the probable direction of former stream-flow in the bedrock valleys.

The depths of the bedrock valleys vary considerably. The north-south trending valley is a maximum of 400 feet deep. The valley which lies on the northwestern slope of the bedrock divide is approximately 180 feet deep at the location of profile B-B'. The valley which lies on the southwestern slope of the bedrock divide is of the order of 600 feet deep, however, an accurate depth approximation cannot be made at this location because it is near the edge of the area of gravity control.

SUMMARY

The bedrock valley system has been successfully mapped by the gravity method in the northwestern corner of Van Buren County. Three main bedrock valleys were delini-ated. These are a north-south trending valley along the South Haven-Geneva township line, and two valleys which lie on the opposite slopes of a northeast-southwest trending bedrock divide. A topographic map of the bedrock surface has been made from a combined interpretation of the gravity and well-log data.

The three interpretation techniques, the two least squares methods, and the cross profile method have successfully isolated the anomalies caused by the bedrock valleys. The least squares equations below the sixth degree approximate the regional gravity anomaly more closely than the higher degree equations.

A quantitative study of the residual gravity anomalies was made at four locations by the method of Talwani. Two profiles were calculated for the north-south trending valley, and a profile was computed for each of the two northwest-southeast trending anomalies. All of the comparison profiles were selected in an area of depth control so that unique solutions could be obtained for the dimensions of the bedrock valleys.

The quantitative studies of the shape and approximate density differentials of the bedrock valleys proved successful and were supported by the known geology in the areas.

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