A GRAVITY SURVEY OF THE BOSTON BASIN REGION

by

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Submitted to the Department of Geology and Geophysics on October 10, 1959, in partial fulfillment of the requirements for the degree of Master of Science in Geology and Geophysics.

ABSTRACT

One hundred sixty eight gravity stations were occupied in the Boston Basin area, and Bouguer anomalies were ascertained for the purpose of determining or corroborating facts about the geology and structure of the basin and surrounding region. The relative accuracy of the anomaly determinations is 0.22 milligals.

The Bouguer anomaly contour map bears out some of the known phenomena in the region outside of the Boston Basin, but fails to indicate others. Three predominant highs are associated with the occurrence of Salem gabbro-diorite - the rock of greatest density in the region. Hence, it is concluded that the situation and thickness of the Salem throughout the region is the primary cause for the pattern of the gravity contours.

Over the main part of the Boston Basin, the gravity contour lines trend east-west. The gradient of over +2 milligals to the north is greater than, and nearly perpendicular to, the regional trend of the area. In the southwest corridor of the basin, a gravity ridge is seen to be in correlation with the stratified formations which are of greater density than the bordering igneous rocks of the area. Hence, the Boston Basin is manifested by the iso-anomaly map.

Two profiles, taken in a general north-south direction across the main portion of the Boston Basin, are approximately "U"-shaped, with the low centered over the Quincy granite, which borders the basin on the south. It was found that the profiles could best be interpreted by considering the flanks of each profile "U" separately. The right flanks indicate that the density contrast between the Salem gabbro-diorite and, to the north, the Dedham granodiorite and Quincy granite extends to a maximum depth of over 4400 feet. The left flanks show manifestations of two of the three principal structural units of the basin: the central anticline and southern shingle-block zone.

The contour map indicates a gentle plunging of the Boston Basin sediments to the east, corroborating the findings of geologic investigators. But the contours also indicate a sharp upswing of dense basement rocks in Boston Bay. This contradicts the belief of certain investigators.

A northern boundary fault is implied by s-shaped offsets of the gravity contour lines. The fault may be continuous from Lynn to Natick, although the s-shaped offset pattern is not apparent between Arlington and Waltham. The northern boundary fault is also manifested slightly on one of the north-south profiles. No conclusive evidence is found for the presence of a southern boundary fault.

Interpretation is hampered by the low density contrast between the major rock formations of the region - only 0.3 gm/cm^3 separates the densities of the rocks of greatest and least density - and is also hampered by a thin layer of low density glacial deposits of undertermined thickness, the total effect of which is not definitely known.

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TABLE OF CONTENTS

	Page
I. INTRODUCTION	5
1. Location of Area	5
2. Purpose of Study	5
3. Previous Studies	5
4. Reference to Previous Reports	7
II. GEOLOGY	8
1. Formulation of Geological Map	8
2. Stratigraphy	8
3. Structure	11
4. Problems	13
III. THE SURVEY	15
1. Field Procedure and Calculations	15
2. Determination of Bouguer Anomaly	16
3. Presentation of Data	18
4. Error in Determining Complete Bouguer Anomaly	18
IV. DENSITY OF LITHOLOGIC UNITS	20
V. INTERPRETATION AND ANALYSIS OF THE BOUGUER ANOMALIES	24
1. The Gravity Map	24
i. Limitations	24
ii. General Discussion	26
iii. Relation of Contour Pattern to Situation of Salem Gabbro-diorite	29
2. Consideration of Local Gravity Phenomena Outside the Boston Basin	30
i. Holliston Ridge	30
ii. Wayland High	31
iii. Westwood Area and Randolph High	32
3. The Boston Basin	32
i. Profiles A-A" and B-B"	32
(a) Causes at Depth: the Sphere and Horizontal Cylinder	33
(b) Horizontal Cylinder Representation Applied to Density Contrast between Salem and Less Dense Rocks	34
(c) Horizontal Half-Cylinder Representation	35
ii. Profiles A-A" and B-B": Consideration of the Flanks of the "U"	37
(a) The Right Flanks	38
(b) The Left Flanks	41
iii. The Contour Map	46
(a) The Main Part of the Boston Basin	46
(b) The Southwestern Portion of the Boston Basin	47
4. Expression of the Boundaries of the Boston Basin	48
i. Northern Boundary Fault	48
ii. Southern Boundary Fault	49

		Page
VI.	SUMMARY AND CONCLUSIONS	51
VII.	SUGGESTIONS FOR FURTHER WORK	53
	APPENDIX I	55
	BIBLIOGRAPHY	66
	ACKNOWLEDGMENTS	69

TABLES

TABLE I - Densities of Lithologic Units	23

ILLUSTRATIONS

FIGURE 1.	Area Covered by this Report	6
FIGURE 2.	Density Profiles for Roxbury Conglomerate	22
PLATE I	Geological Map of Boston Area	In Pocket.
PLATE II	Bouguer Anomaly Contour Map of Boston Basin Area	In Pocket.
PLATE III	Profile and Geologic Cross-Section A-A"	In Pocket.
PLATE IV	Profile and Geologic Cross-Section B-B"	In Pocket.

I. INTRODUCTION

1. Location of Area

The gravity survey was made of an area between the latitudes of 42°07.5' and 42°30.0' and the longitudes of 70°45.0' and 71°30.0' (Fig. 1). The area, which comprises 18 Geologic Survey $7\frac{1}{2}$ minute quadrangles, is about 39 miles long and 26 miles wide. Much of the northeastern sector of the area is under water. Gravity stations, which were all confined to the mainland, were spaced about 2 miles apart.

2. Purpose of Study

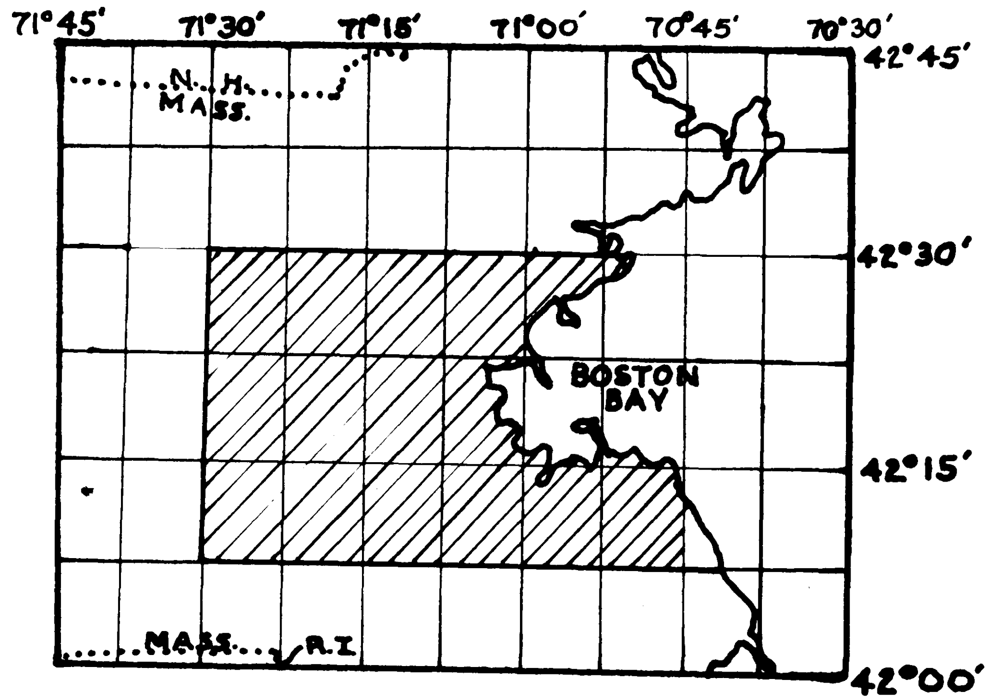
The purpose of this study is to supplement existing knowledge of the geology and structure of the Boston area, and in particular the Boston Basin.

This paper is a continuation of an earlier thesis by the author (Ginsburg, 1958), and is based on the data collected during the summer of 1958. In the present paper a more thorough analysis of the data is offered.

3. Previous Studies

Longwell (1943) undertook an extensive reconnaissance gravity study of southern New England and the Hudson River Valley in the early 1940's. Woollard made several studies in various areas throughout New England in 1943, 1944, and 1946. A review of other gravity surveys in New England performed before 1948 has been given by Woollard (1948).

More detailed surveys have been carried out in New England since 1948. In 1950 William Diment, a Harvard doctoral candidate made several surveys in portions of New Hampshire and Vermont, northwestern Massachusetts, and eastern New York. Bean (1953) studied an area comprising eastern New York, central Vermont, and central New Hampshire. Joyner (1958) surveyed Maine, Area Covered by This Report



SCALE

1 inch = 15.4 miles

Figure 1.

New Hampshire, and northeastern Massachusetts. His area of study includes the northeastern portion of the Boston Basin area.

Coryell and King (1958) made a detailed survey in the Malden and Medford, Massachusetts area. Their purpose was to locate a hypothetical thrust fault bounding the Boston Basin on the north. However, results of the survey were negative due to the negligible density contrast between the igneous rocks north of the proposed fault and the sediments south of it.

4. Reference to Previous Reports

In order to facilitate the reading of this report, certain chapters and sections from the author's earlier report (Ginsburg, 1958) have been incorporated, in total, in part, or with slight revisions, in the present report. They include the sections on field procedure and calculations, determination of the Bouguer anomaly, determination of the error involved in finding the Bouguer anomaly, and the problems encountered by geologists in the region. Also included in the present report is the chapter "Density of Lithologic Units" which appeared in the previous paper.

II. GEOLOGY

1. Formulation of Geological Map

The geology of the Boston Basin area is complex. Certain parts of the area have been examined in detail by several investigators; but their opinions vary as to the nature and location of formation contacts. Other parts of the area have been studied only in a reconnaissance manner, and published reports of the much larger areas give little detailed information.

The accompanying geological map (Plate I) represents the author's compilation based on the findings of various investigators. The geology of the Boston Basin and the regions to the north and northeast has been discussed by Bell (1948) and La Forge (1932). The more immediate Boston area has been investigated by Billings (1929). Billings, Loomis, and Stewart (1939) have described the geology in the vicinity of the Boston Bay south shore line. The geology of the igneous rocks which predominate north and northeast of Boston has been studied by Clapp (1921). The geology of the Blue Hills area and the area south of the Blue Hills has been described by Loughlin (1911) and Chute (1940), respectively. The geology of the Holliston and Medfield areas has been investigated by Dowse (1948). The geology of the Maynard area is included in a report by Hanson (1956). For the geology of the areas not covered by the aforementioned authors, Emerson's (1917) report on the geology of Massachusetts and Rhode Island was used in the compilation.

2. Stratigraphy

The rocks in the surveyed region can be subdivided into four categories: the sedimentary rocks of the Boston Basin; the igneous and metamorphic rocks which form the highlands to the north and south of the basin and which are believed by all investigators to underlie the basin sediments; the igneous and metamorphic rocks which are prevalent in the extreme western portion of the area and which may or may not be related to the aforementioned igneous rocks and metamorphics; and the sediments of the extreme north-eastern portion of the Norfolk Basin, which cuts across the Medfield, Norwood, and Blue Hills areas.

The principal igneous and metamorphic rocks which bound the Boston Basin on the north and south are the Westboro quartzite, Marlboro formation, Salem gabbro-diorite, Dedham granodiorite, Quincy granite, and Lynn-Mattapan volcanics. The Westboro quartzite is, for the purposes of this report, a minor metamorphic formation believed to be Lower Cambrian in age. The Marlboro formation consists mainly of basaltic volcanic flows and is thought by most investigators to be of Cambrian age, although Hanson (1956) considers the formation to be as young as Carboniferous on the basis of evidence found west of Framingham. The Marlboro formation is sparsely exposed north of Boston, but is more prevalent in the western part of the area where its thickness exceeds 2500 feet. The Salem and Dedham batholiths are two intrusives in the sequence of intrusions from a particular disturbance which may have occurred at any time from the late Siberian to the Devonian. The Salem is the more sub-alkaline and older formation of the two. The Salem and Dedham are widely distributed over the entire area as can be seen from Plate I. The Lynn-Mattapan volcanics erupted on the weathered surfaces of the Salem and Dedham, most probably in the Devonian. Although they are generally grouped with the igneous rock which underlies and are different from the Boston Basin sediments, the Lynn-Mattapan is categorized with the basin sediments by Dowse (1948) in her discussion of the western segment of the basin in the Holliston and Medfield areas. Billings (1929) cites that the Lynn-Mattapan attains a thickness of over 2000 feet in some portions of the basin area, notably Hyde Park. According to Clapp (1921) and La Forge (1932), the Quincy granite is the second phase of an igneous activity cycle, the first phase of which was the eruption of the volcanics. This would make the Quincy younger than the Lynn-Mattapan, contrary to the belief of most of the other investigators of the area. Although the Quincy or related formations appear in the highlands north of Boston, they predominate in the Blue Hills region just south of the basin sediments.

To the west, the Milford granite is the predominant igneous rock in the southwestern portion of the region. It is believed to be of the same age as the Dedham, although it is more alkaline. The Nashoba formation, comprised mainly of quartz-biotite gneiss, is found in the northwestern portion of the area under examination. The Nashoba borders on a small portion of the western extremityh of the Boston Basin in the Natick area. According to Hanson (1956), its thickness exceeds 5000 feet and its age is Carboniferous. The Assabet quartz-diorite intrusive underlies a broad area in the Maynard area according to Hanson (1956). Its age is Permian to Triassic.

The predominant sediment of the Norfolk Basin is the Wamsutta conglomerate, composed of coarse red and gray pebbles, which lies south and southwest of the Blue Hills with a segment at West Hanover. The Wamsutta, whose age is Carboniferous, may be as thick as 3000 feet.

The principal sediments of the Boston Basin are the Roxbury conglomerate and the Cambridge siltstone. The former is a coarse, massive, poorly sorted sediment which may attain a thickness of 5000 feet within the basin. In some areas it lies conformably upon the Lynn-Mattapan volcanics, but along the south shore of Boston Bay it lies unconformably on the Dedham formation. The Cambridge formation, a massive siltstone, may also exceed a thickness of 5000 feet. Investigators such as Emerson (1917), Billings (1929), and Dowse (1948) place the age of the Roxbury and Cambridge as Carboniferous, but La Forge (1932) and Bell (1948) believe the age of the two formations to be Devonian.

There is no disagreement in the belief that the deposition of the Roxbury preceded that of the Cambridge. The Brighton volcanics formation, which appears in Needham, is an extrusive formation which is interstratified with the Roxbury, and is unimportant for the purposes of this report.

Minor basic dikes, probably of Triassic age, are found throughout the area, but these are unimportant in the gravity survey.

During the Pleistocene, the New England area was subjected to glacial advances which left great deposits of outwash and ground moraine and formed many eskers and drumlins throught the eastern Massachusetts area. These deposits, as well as marshes and tidal flats, greatly obscure pre-glacial outcrops and structure of the Boston area. There have been comparatively few actual measurements in the basin area of the thickness of the glacial deposits, but according to drill-hole data compiled by the Boston Society of Civil Engineers, the greatest thickness is 256 feet (Journal of the Boston Society of Civil Engineers, October 1950).

3. Structure

Most investigators concur with Billings (1929), who divides the main part of the Boston Basin into three structural units. The northern unit is a syncline in which the Cambridge siltstone is the youngest formation. The syncline is marked by broad folds and low dips, except in the vicinity of the Boston Basin's northern boundary. Here the Cambridge dips steeply to the south and at some locations steeply to the north. South of the syncline, a broad anticline makes up the central structural unit of the main part of the basin. Both the central anticline and northern syncline plunge gently toward the east. The third structural unit, termed a "shingle block" zone by Billings (1929), lies south of the central anticline. It is characterised by the steep north and south dips of the sedimentary formations and by thrust faults which are overthrust toward the north;

the throws may be measured in thousands of feet. The traces of these faults, which strike east-west, extend for ten or more miles. In the narrow southwestern segment of the basin, the stratified formations are tightly folded and dip steeply to the north. Great tear faults strike in a general north-south direction. These faults appear in both the main part and southwestern portion of the basin and are indicated on the geologic map, Plate I.

It is widely believed that the basin rocks are overridden by two great overthrust blocks from the north and the south. Many investigators (Clapp, 1921; Billings, 1929; La Forge, 1932; Dowse, 1948; Bell, 1948; and others) have found evidence for the existence of a northern boundary fault which thrusts over the sediments of the main part of the basin from the north. However, in this area, the actual fault contact has never been found, either through geological or geophysical (Powell and Schwartz, 1956; Coryell and King, 1958) investigations. The northern boundary fault may extend to the southwestern end of the basin in the Natick vicinity. Evidence for a southward thrusting or echelon boundary fault on the north side of the basin in this area has been found by Dowse (1948), and she cites the actual discovery of the fault in an aqueduct tunnel by I. B. Crosby in the latter part of the 19th century. Whether such a fault is an extension of the northern boundary fault to the east has not been established.

A southern boundary fault in the main part of the basin between the Quincy granite and the basin stratified formations is obscure. However Loughlin (1911) discovered a fault contact in that area and estimated that the Quincy was thrust northward over the basin sediments by a distance of at least 2000 feet. The southernmost northward thrust along the Bay's south shore may be an extension of the aforementioned thrust or an extension of one of the thrusts of the shingle-block zone. However, evidence of boundary faults along the shore line is very sparse. The contact between the Dedham granodiorite and the Lynn-Mattapan volcanics - in and to the west of Dedham where the Lynn-Mattapan formation is included with the basin sediments - is believed to be a northward thrusting fault. In the southwestern segment of the basin, however, Dowse feels that the contact between these same two formations is not a fault.

The northwest and southeast boundaries of the Norfolk Basin sediments are both believed to be northward thrusting faults according to Chute (1940) and Loughlin (1911). But Loughlin states that the northern boundary of the basin which separates Wamsutta conglomerate from Quincy granite is an unconformity.

The areas of igneous and metamorphic rocks which surround the main part of the Boston Basin are of greater elevation than the basin itself. To the north, the upland rocks are marked by broad folds plunging gently toward the east. A bold escarpment, which may be associated with a hypothetical northern boundary fault, is the predominant physical feature north of the basin. It extends from Natick to Lynn, and its height varies from 100 to 300 feet. To the south, the most predominant featuresare the Blue Hills, which include Great Blue Hill, at 635 feet above sea level, the highest feature in the surveyed area.

The two main structural features in the northwestern part of the region, in the Maynard area, are a large synclinorium and, just southeast of it, a large anticline.

4. Problems

Because of the scarcity of outcrops in the Boston Basin area, there are many questions about the basin which cannot be answered by descriptive geologic methods alone.

The stratigraphic sequence of the basin sediments is a question mark because it is nowhere entirely exposed. Consequently, the correlation of stratigraphic horizons and determination of the structure of the sediments is uncertain (Bell, 1948). Investigators are in general agreement with the major structural divisions of Billings (1929) - a northern syncline, central anticline, and southern "shingle block" zone - but they may disagree on some of the minor aspects of the major divisions (Bell, 1948; Dowse, 1948). A case in point is what Billings (1929) calls the Watertown Faulted Anticline, which occurs in Newton. Bell (1948) disagrees with Billings' conclusion that the presence of Roxbury conglomerate in an area where Cambridge siltstone is predominant denotes a tightly folded anticline. The uncertainty about basin structure precludes uncertainty about the thickness of the basin sediments.

The extent of the basin to the southwest and in Boston Bay is undetermined. The nature of the basin's borders is not known. In some places, notably the southwest portion of the basin, the exact location of the borders is undetermined.

III. THE SURVEY

1. Field Procedure and Calculations

A total of 168 stations were occupied in the region. Their locations are listed in Appendix I and illustrated on Plate II.

Worden Gravity Meter No. 11, a product of Houston Technical Laboratories, was used in making the survey. The Worden does not measure the force of gravity directly, but gives a difference in scale division readings between two stations. This scale difference must be multiplied by a constant, which is determined by the instrument's construction, to obtain the difference in units of gravitational force. The constant for the particular instrument used is 0.3694 milligals per unit of scale division. The instrument may be read to one tenth of a scale division.

The reading at any one station changes with time, this "drift" being caused by tidal effects, atmospheric conditions, and movement of the component parts of the instrument. The drift is considered linear over a maximum period of six hours. Extent of drift was determined by taking two readings within six hours of each other at one of three base stations. Corrections were applied to the readings at stations occupied between the times of the base station readings. All observed drift was positive. The maximum was 0.1 milligal per hour, determined over a period of 5 hours.

In order to establish the elevation above sea level of each station, readings were taken within approximately 300 feet of elevation stations established by the United States Coast and Geodetic Survey. Required elevation accuracy was 0.5 foot. Differences in elevation between gravity stations and U.S.C.G.S. elevation stations were determined with hand-level and stadia rod.

A gravity net was established for each of the three base stations. These stations were in turn tied in with a main base at South Station, Boston. The force of gravity at South Station was taken as 980,399.9 milligals. This value was established in two surveys undertaken by the United States Navy Hydrographic Office in 1952 and 1953. The surveys originated at the U.S. Coast and Geodetic Survey gravimeter station at the Commerce Building in Washington, D.C.

2. Determination of Bouguer Anomaly

Determination of the Bouguer anomaly necessitates correcting all observed gravity readings to a common datum - in this case mean sea level.

Free Air Correction. The basis for the free air correction is that the force of gravity at a point outside the earth or on the earth's surface is inversely proportional to the second power of the distance from the point to the earth's center. However, the correction can be closely approximated as a linear function of elevation above (or below) sea level: 0.09406 milligals per foot.

Bouguer Correction. The plateau correction accounts for the gravitational attraction of an infinite slab of mass of uniform density and thickness between the station and sea level. The gravitational effect of an infinite slab of uniform density and thickness at a point outside the slab is $2\pi\gamma\rho h$ where ρ is the density, h the thickness and γ the gravitational constant, 6.67×10^{-8} $cm^3/gr\text{-}sec^2$. The density ρ is taken as 2.67, which is the average density of the earth's crust (Nettleton, 1940). For this value, the topographic correction term is .03407 milligals per foot. This term is always subtracted from g_s if the station is above sea level, because moving from the station to sea level effectively takes away the attraction of the plateau.

Topographic Correction. The topographic correction accounts for the unevenness of the topography. The graphical method described by Nettleton (1940), pp. 144-148, was used in determining the topographic effects at each station. A template consisting of concentric circles was constructed for use on a topographic map. The areas between successive circles are divided into various compartments. The center of the template is placed at the map location of the station. The difference between the station's elevation and a compartment's average elevation determines the gravitational effect of the compartment. United States Geologic Survey maps of the scale 2 inches = 1 mile were used. The map method was applied to compartments from 175 to 14,662 feet from each station. Average elevations of compartments from 6.6 to 175 feet from each station were visually estimated by the author at the time the station was occupied. The effect of the first compartment, which comprises the area within a circle 6.6 feet in radius, is neglected because the terrain was generally level in the immediate vicinity of each station. Nettleton's tables were the basis of determining terrain connections. However, as his tabulations were calculated for a crustal density of 2.0, his listed corrections were multiplied by 2.67/2.00 to obtain the appropriate corrections for this survey. One adds the effects of compartments of average elevation lower than that of the station, because they represent a mass deficiency in the plateau, the effect of which was subtracted. One also adds the effects of compartments of average elevation greater than that of the station, because they represent a "pulling up" on the gravity meter. This causes a lower reading than would be obtained if such elements of mass were not present.

Theoretical Gravity. The theoretical gravity of any point at sea level is a function of latitude. The gravity is given by the Cassini Formula (or International Gravity Formula):

$$g_c = 978,049.0(1 + 0.0052884 \sin^2\phi - 0.0000059 \sin^2 2\phi) \text{ mgals.}$$

where ϕ is the latitude. The latitude of each station was determined by accurately locating the position of the associated bench mark on the U.S.G.S. maps. No station was greater than 300 feet from the bench mark. One-tenth of a minute is a little over 600 feet. Thus, the latitude of each station is correct within 0.05 minutes.

Bouguer Anomaly. The Bouguer anomaly is determined by subtracting the theoretical value of gravity from the observed value of gravity, corrected for free air, plateau and terrain effects:

Complete Bouguer Anomaly = Observed gravity
+ Free Air Correction
- Plateau Correction
+ Topographic Correction
- Theoretical Gravity

3. Presentation of Data

The observed value of gravity for each station, corrected for drift and compared with the South Station value, is tabulated in Appendix I. Appendix I also lists for each station: its latitude and longitude to a tenth of a minute; its elevation; the theoretical gravity at sea level for a station of the same latitude and longitude; the topographic correction in milligals and the complete Bouguer anomaly.

4. Error in Determining Complete Bouguer Anomaly

The instrument is a possible source of two errors. The scale reading is only accurate to 0.1 scale division. Linear drift corrections are also only accurate to 0.1 scale division. One-tenth of a scale division is equivalent to approximately 0.037 milligals. These errors arise in determining the actual gravity value at a station.

The elevation at each station is accurate only to 1/2 foot, due to the inaccuracies in determining elevation by the hand-level and stadia method. The combined free air and Bouguer correction effect for an assumed crustal density of 2.67 is 0.05999 or about 0.06 milligals per foot. Thus, correcting a gravity reading to sea level introduces a possible 0.03 milligal error from the combined free air and Bouguer correction effect.

Determining the topographic correction is another source of error. It is the opinion of the writer that an inaccuracy of 0.02

milligals results from both the combined visual and template determination of topographic effects and the utilization of the corrective multiplicative factor needed to modify Nettleton's tabulated corrections.

The latitude of a gravity station may be inaccurate by a maximum of 0.05 minutes, as noted before. This introduces an approximate error of 0.075 milligals in determining the correct theoretical gravity at sea level in the New England latitudes. However, the Cassini Formula, as listed by Nettleton (1940), is significant only to 0.1 milligal. Thus, an actual 0.075 milligan discrepancy results in a possible error of 0.1 milligal in determining theoretical gravity from the Cassini Formula.

The maximum possible error in determining the complete Bouguer anomaly at a station is the sum of the errors previously mentioned. This is:

$$\pm (0.037 + 0.037 + 0.030 + 0.020 + 0.100)$$

$$\text{or} \pm 0.22 \text{ milligals.}$$

The standard deviation is the square root of the sum of the squares of each possible error. This is:

$$\pm \sqrt{(0.037)^2 + (0.037)^2 + (0.030)^2 + (0.020)^2 + (0.100)^2}$$

$$\text{or} \pm 0.12 \text{ milligals.}$$

IV. DENSITY OF LITHOLOGIC UNITS

The densities of 9 lithologic units were determined from various sources and by various methods.

Joyner (1958) determined the densities of the Salem gabbro-diorite and Quincy granite from measurements on samples of these rocks. He also lists the densities of the Dedham granodiorite and the Salem gabbro-diorite as determined by Clapp (1921).

Dowse (1948) tabulated the mineral composition of each of 36 samples of Dedham granodiorite, 17 samples of Salem gabbro-diorite, 22 samples of Marlboro formation, and 23 samples of Milford granite. To determine the densities of these rocks for the purposes of this report, the average composition of each rock type was obtained by a numerical averaging of the composition of all samples of that rock. Then, the density of each mineral was multiplied by the percentage of that mineral in the rock. The products were added to determine the final density. Following is a list of the minerals and their respective densities used in such calculations (Nettleton, 1940; Birch, Shairer and Spicer, 1942; Dana, 1952; Dobrin, 1952):

albite:	2.63
anorthite:	2.76
apatite	3.21
augite:	3.4
biotite:	2.93
chlorite:	2.8
epidote:	3.40
hornblende:	3.2
ilmenite:	4.67
K-feldspar:	2.57
magnetite:	5.08
microcline:	2.56
orthoclase:	2.57
pyrite:	5.018
quartz:	2.65
sericite:	2.93
sphene:	3.48

Coryell and King (1958) determined the Cambridge siltstone density as 2.72 by directly measuring several samples. They also determined the density of the Lynn-Mattapan volcanics as 2.75 by performing a density profile survey described by Nettleton (1939).

The writer performed similar profile surveys on the Roxbury conglomerate (See Figure 2) and determined its density as 2.62.

Determination of the density of glacial deposits was attempted by a density profile survey. The resulting density was found to be too great to be that of till. Proximity of bedrock - possibly Cambridge siltstone - to the surface is the probable cause of this. The density of the till is assumed to be 2.15 (Birch, Shairer and Spicer, 1942; Heiland, 1946; Coryell and King, 1958).

The densities of most of the formations are probably correct within 0.05 gr/cm^3. However, the densities determined by the profile method may only be correct within 0.1 gr/cm^3.

The densities of the lithologic units and the sources of the density determinations are listed in Table I.

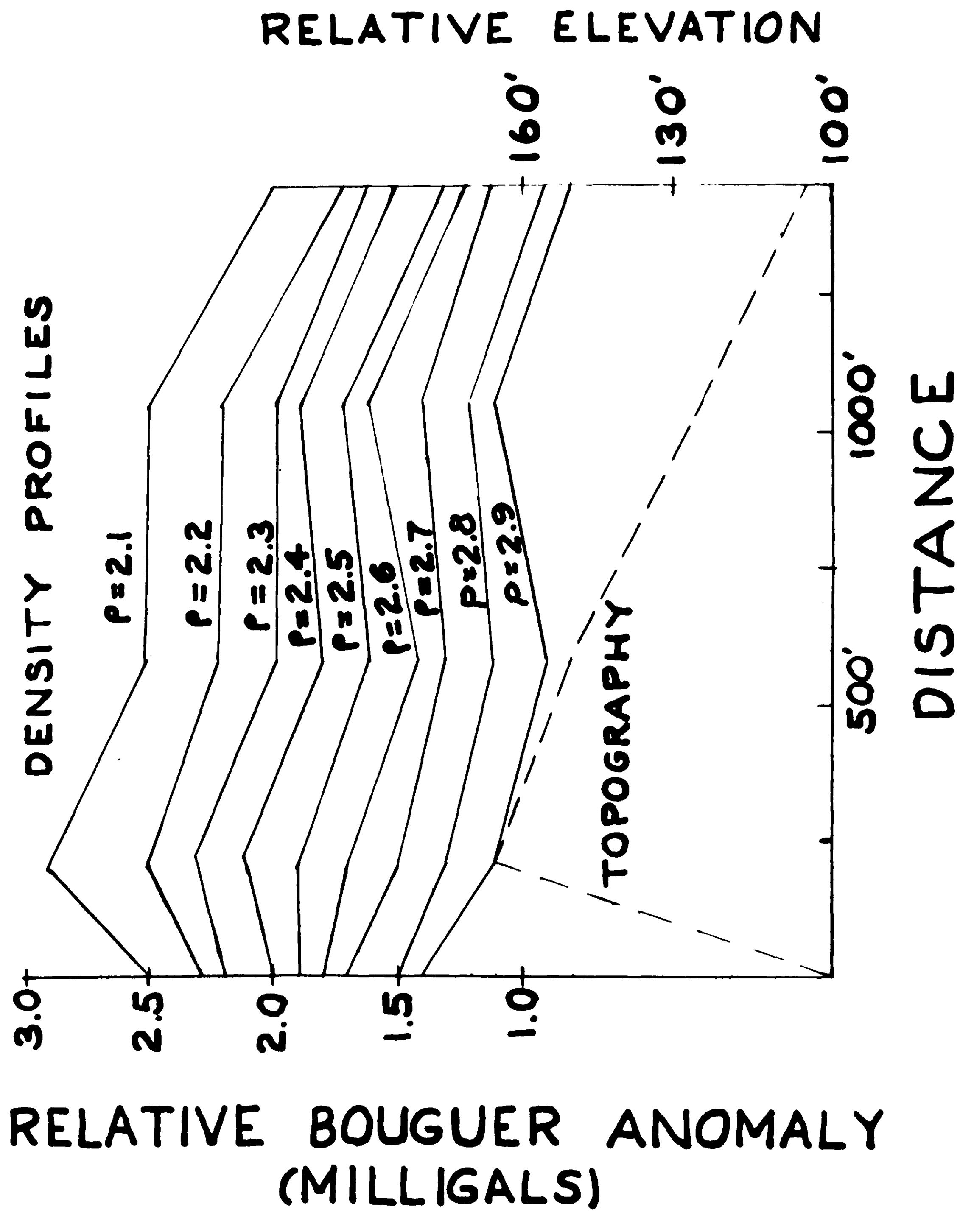


Figure 2. Density Profiles for Roxbury Conglomerate

Table I. Densities of Lithologic Units

Formation	Density	Source(s)
Igneous rocks		
Salem gabbro-diorite	2.92	Dowse and Numerical Calculations, Joyner-direct measurements
Marlboro formation	2.81	Dowse and Numerical Calculations
Lynn-Mattapan volcanics	2.75	Coryell and King - density profile
Quincy granite	2.66	Joyner-direct measurements
Dedham grano-diorite	2.65	Dowse and Numerical Calculations
Milford granite	2.64	Dowse and Numerical Calculations
Sedimentary rocks		
Cambridge siltstone	2.72	Coryell and King - direct measurements
Roxbury conglomerate	2.62	Writer - density profile
Glacial Till	2.15	Birch, Shairer and Spicer; Heiland; Coryell and King.

V. INTERPRETATION AND ANALYSIS OF THE BOUGUER ANOMALIES

1. The Gravity Map

i. Limitations

Before discussing the interpretation of the gravitational anomaly contour map, it is well to point out the limitations of such a procedure.

It must be remembered that the anomaly contour map (Plate II) shows the results of a regional reconnaissance survey covering an area of approximately 750 square miles. Hence, detailed interpretation should not be expected. Thus, although the gravity data may delineate the shingle-block zone of thrust faults in the southern part of the Boston Basin, it cannot be expected to accurately locate each of the thrust faults. Also, a disagreement between Billings (1929) and Bell (1948) (Ginsburg, 1958) as to the presence of a faulted anticline in Watertown - prompted by Billings' discovery of an exposure of Roxbury conglomerate in the vicinity - cannot be resolved by a survey of this general nature.

The contouring on the gravity map (Plate I) was performed independently of the geology of the area - that is, no attempt was made to correlate the iso-anomaly contours to known of anticipated geologic and structural phenomena. Instead, the path of each contour line was determined almost solely by linear interpolation between the anomaly values at the various gravity stations. Although interpretation must be based on the particular contour map shown in this report, the author certainly acknowledges the possibility of a different pattern of contours, resulting from the collected data. It is believed, however, that differences in the pattern will be so minor that the final interpretation would not be at variance with that which is presented here.

Another factor hampering interpretation is the prevalence of flacial till in the Boston Basin area. The density of the till is assumed to be 2.15 gm/cm^3 (Ginsburg, 1958), which is from 0.47 to 0.77 c.g.s. units less than the density of any of the other rock formations in the area. Hence, the presence of till instead of bedrock at a station location would make the gravimeter reading less than that obtained if the till were replaced by bedrock. This would be the main effect of the till in areas of low elevation - like the Boston Basin itself - where the Bouguer correction would be negligible. However, where the Bouguer correction is appreciable, the usage of an average rock density of 2.67 instead of the correct density of 2.15 would tend to nullify the effect of taking the reading on a rock formation of low density because the Bouguer correction is subtracted from the measured value at a particular station (Ginsburg, 1958).

From the Bouguer formula, $g_z = 2\pi\rho\gamma h$, where g_z is the vertical gravitational force and γ is the gravitational constant - it can be determined that $h = 78.4/\rho$, where h is the thickness in feet and ρ is the density contrast in c.g.s. units of a slab which will produce a one milligal anomaly. Assuming a density contrast of 0.6 between the till and the average density of the rock formations in the area under consideration, the thickness of till required to produce a -1 milligal anomaly is 130 feet, while that required to produce a -2 milligal anomaly is 260 feet. The maximum known thickness of till in the Boston Basin is 256 feet. Thus, the presence of till is unimportant in consideration of local gravity highs, as lack of till would tend to accentuate the highs. But it may be an important factor in areas of lows. The location of centralized drill holes depicting depths to bedrock of greater than 130 feet are indicated on Plate I.

Interpretation is also hampered by the low density contrast of the rock formations of the area. With the exception of the glacial till, the maximum density contrast of the other rocks is only about 0.3 c.g.s. (See Table I). Particularly noteworthy is the practically neglibible contrast between the Cambridge siltstone and Lynn-Mattapan volcanics, and that between the Roxbury conglomerate, Milford granite, Dedham granodiorite, and Quincy granite. The determined densities are believed accurate to within .05 with the exception of that of the Roxbury conglomerate, which is accurate to 0.1 units due to its being determined by Nettleton's (1939) density profile method.

ii. General Discussion.

The complete Bouguer anomaly map appears on Plate II.

An area of marked gravity lows occurs in the southwestern portion of the anomaly map, while an area of marked highs appears in the northeastern section. This suggests a regional trend increasing toward the northeast. The inaccuracy inherent in determining the magnitude and exact direction of the regional trend from the contour map is obvious. The writer has assumed a regional trend of +1.37 milligals per mile in a direction N. 65° E. This compares favorably with the regional trend for this area found by Longwell (1943) in an areal gravity survey of southern New England. Longwell's Bouguer anomaly map indicates a regional trend of +1.52 milligals per mile increasing in a N. 84° E. direction.

The general anomaly pattern points up some of the geologic conditions, which are believed to prevail in the area, while it fails to indicate others. The area of pronounced lows in the southwest is centered at two locations: Framingham and Medway. However, a ridge of higher values through Holliston cuts the pattern of lows. An area of less pronounced relative lows is centered in the general area of the Assabet quartz-diorite in the Maynard vicinity. This low is probably due to the density relationship between the Assabet and Nashoba formations. Another low occurs in Milton and seems to be associated with the granite which forms the Blue Hills. This particular low will be subsequently discussed.

Relative gravity lows in Arlington and Winchester appear to be associated with exposures of Marlboro formation (2.81) in the midst of Salem (2.92). A discussion of these lows will be included later during a consideration of north-south profiles which cut across the Boston Basin.

The most pronounced gravity highs occur in the extreme northeastern corner of the region. A high anomaly value of 44.9 milligals appears at Salem. Joyner (1958) has considered this phenomenon and concluded that the cause is probably an intrusion of Salem gabbro-diorite which is exposed at Salem Harbor and which, he postulates, extends to a depth of about 11,000 feet. However, because of the general lack of correlation of geology and gravity data in the Boston area, Joyner makes some reservations on his interpretation.

A relative gravity high occurs in Lexington in the midst of exposures of the dense Salem and Marlboro formations. Indications of another gravity high area appear at Randolph. The contour lines bend around the vicinity where the Salem formation comprises the bedrock. In the area, the Salem is surrounded by the less dense Dedham granodiorite.

A local relative high appears at Dedham where the Dedham granodiorite is believed to have thrust over the Lynn-Mattapan formation of the basin. The high does not correspond with the surface geology.

A large area with little gravity relief occurs in the vicinity of Westwood, south of the Dedham high. Again, there is no correlation between geology and gravity data because the Salem formation is exposed in the Westwood area implying the occurrence of gravity highs.

The prevalent non-correlation between gravity and geology holds true in the general area of the main part of the Boston Basin. One would expect that the gravity profile and geologic cross-section along a plane perpendicular to the long dimension of a sedimentary basin would show gravity highs over the igneous and metamorphic rocks which border the edges of the basin and a low centered over the middle of the basin where the less dense sediments are at their greatest thickness. Two such profiles and geologic cross-sections AA" and BB", taken in an approximate north-south direction across the basin, are shown in Plates III and IV. The profiles do show gravity highs to the north and south with a marked low between. However the low is centered not over the Boston Basin, but over the Blue Hills which border the basin to the south. Over the basin a northerly increasing local gradient of over 2 milligals per mile occurs. Such a trend is in a direction approximately perpendicular to the regional trend. Thus the Boston Basin is delineated by the gravity data. The same thing may be said for the northern boundary faults. Both the matter of the basin and its borders as pointed up by the contour map and gravity profiles will be considered later on in this report.

Another local trend which does not in general parallel the regional trend occurs between the Maynard low and the Lexington high where the gravity gradient increases to the southeast at about 2.5 milligals per mile. The phenomenon is apparently due to the density contrast between the Salem gabbro-diorite and the lower density formations of the Maynard and Concord areas. However, this area is unimportant as far as aspects of the Boston Basin are concerned.

At the shore line in Boston, the contour lines, whose directions run due east-west across the Boston Basin, swing to the southeast. From there, their paths roughly follow the shape of the Boston Bay shoreline, with the gradient increasing toward the Bay to the northeast and north. However, the gravity stations along the central and south shore areas are sparse, and no measurements were taken in Boston Bay. Hence the contour pattern in this area is at best only slightly reliable, although the increase of the gravity values toward the Bay is definitely established.

iii. Relation of Contour Pattern to Situation of Salem Gabbro-diorite.

The general gravity and geologic picture reveals that two of the three predominant highs - in Lexington and Randolph - are associated with the Salem gabbro-diorite, while the remaining high, in Salem Harbor, most probably is also related to the Salem. Since the Salem, as well as the Dedham granodiorite crops out as bedrock at numerous locations throughout the region of this report, and since the Salem is the most dense formation in the area - 0.11 grams per cubic centimeter greater than the Marlboro, 0.17 grams per cubic centimeter greater than the Lynn-Mattapan volcanics, and 0.2 to 0.3 grams per cubic centimeter greater than any other formation in the area - the gravity pattern is probably more dependent upon the situation of Salem formation than that of any other formation. This is, where there is a predominance of Salem gabbro-diorite, occurring either as bedrock or at depth, a local high should be expected to result. A low, however, would result from a lack of Salem at a location: this deficit pervading to a considerable depth. Such a deficit could occur from a stock of one of the less dense, granitic intrusive rocks. Should the Salem appear as bedrock with no corresponding expression by the gravity data, as in the Westwood area, the most probable solution would be that the exposed Salem does not extend to an appreciable depth, but is rather in the form of thin inclusions. If a 0.3 density contrast is assumed between the Salem and Dedham in Westwood, the application of the formula

$$h = \frac{78.4}{\rho}$$

indicates that about 260 feet of Salem formation would be required to cause a relative anomaly of +1 milligal. Thus a block of Salem which is less than 260 feet thick would hardly manifest itself on the gravity map.

Otherwise, if no gravity high exists where Salem is exposed in an area of lower density rock, the cause may be that the lighter formation only forms a thin veneer over a preponderance of the heavier formation.

According to Woollard (1948), the regional gravity increase of 1.37 milligals per mile in a N. 65^{o} E. direction may be due to either lithologic variations in the basement rocks which affect the density, or deep-seated crustal structural phenomena. The latter explanation is favored because the crust is expected to thin as the shore and continental shelf area is approached. Thus, the rocks of higher density in the lower crust are brought relatively closer to the surface.

2. Consideration of Local Gravity Phenomena Outside the Boston Basin

Some of the local phenomena shown on the contour map will now be considered.

i. Holliston Ridge.

There is no correlation of the ridge of highs, which passes through Holliston between the Framingham and Medway lows, with the surface geology. The lows are almost surely caused by a great thickness of the low density Milford granite.

The trend of the ridge appears to be a continuation of the trend of the Boston Basin formations in the area, particularly the Lynn-Mattapan volcanics (2.75), which are more dense than the bedrock at Holliston, the Milford granite (2.64). Because the Milford and Dedham are older than the basin rocks, it is unlikely that the basin rocks continue to prevail beyond their extreme southwestern exposure beneath a thin layering of Milford and/or

Dedham. Of course, a post-Carboniferous thrust fault could have thrust the igneous formations northeastward over the basin formations, but Dowse (1948) has found no evidence for a thrust in the Holliston area and has found no evidence for northeasterly thrusting anywhere in the Holliston and Medfield general regions.

A dike of high density material could cause the Holliston high, but its width would have to greatly exceed the small widths of the surface dikes observed by Dowse in the area to give rise to a relative high of the magnitude of that which occurs.

The gravity ridge is probably caused by a considerable mass of one of the more dense formations of the area situated at depth. The Marlboro formation (2.81) occurs in five large belts and many small belts within the Holliston and Medfield areas. A belt, long in the north-south direction, appears in the Holliston area, but its orientation does not correspond with the trend of the ridge. It is likely that the Marlboro exposure is a comparatively thin block and thus does not manifest itself on the gravity pattern. The ridge, however, may be due to the situation of Marlboro formation at depth surrounded by lighter formations. As expected, the Salem crops out throughout the area and also appears as inclusions in the younger formations. Hence the gravity ridge may be caused by the occurrence of Salem formation.

The gravity pattern in this area is not apparently related to the effects of the Boston Basin.

ii. Wayland High

A similar argument as that for the Holliston high may be made for the ridge of highs that passes through Wayland and points toward the west. It could be associated with the presence of Salem formation at depth or may be associated with the Marlboro formation (2.81), which crops out along the ridge and which is of greater density than the surrounding rocks in the area.

iii. Westwood Area and Randolph High.

In the Westwood area, there are several exposures of Salem gabbro-diorite, including a large belt at Medfield (Dowse, 1948). Yet, no gravity highs occur. As explained earlier, this phenomenon may be due either to a thin cover of Dedham (2.65), which is absent in certain locations where the Salem crops out, or to thin fragments of Salem appearing in an area predominated by the Dedham rocks. In either case gravity highs would not appear.

Between the Medway low and the Westwood flat zone there is a gravity gradient of about 3 milligals per mile increasing in a north-easterly direction. This far exceeds the regional trend and leads to the conclusion that the rocks of low density - the Milford and Dedham - are thicker where they crop out in the Medway area than they are where they crop out in the Westwood area.

Moving southeast from the Westwood flat zone, one encounters a flat zone over the Wamsutta conglomerate of the Norfolk basin, and then a rapid increase in the anomaly values toward Randolph.

The extent and nature of the Randolph high over an area where Salem formation is exposed as bedrock indicates, when compared to the Westwood flat zone, that in the Westwood area the Salem is not the principal bedrock formation. Rather, the less dense Dedham granodiorite is the main bedrock formation, and the Salem, where it is exposed in the area, occurs as thin inclusions.

3. The Boston Basin

We turn now to a discussion of the Boston Basin.

i. Profiles A-A'' and B-B''.

To study the gravity results over the Boston Basin, it will be advantageous to consider two north-south gravity profiles, A-A'' and B-B'', taken across the main part of the basin. (See Plates I, II, III and IV). Profile A-A" lies $2\frac{1}{2}$ to $3\frac{1}{2}$ miles to the east of profile B-B". The geologic cross-sections that accompany the profiles were compiled from the papers of La Forge (1932), Chute (1940) and Bell (1948).

Both profiles show a marked "U" shape, with a low, centered over the Quincy granite, between two highs to the north and south. This is the Blue Hills. Whereas an argument can be made for the right flank of the "U" corresponding to the surface geology in both profiles, there seems to be no corroboration between surface geology and the left flanks of the respective profiles. Thus, a first investigation is made to ascertain if the shapes of the profiles can be explained by a density contrast occurring at a great depth.

(a) Causes at Depth: The Sphere and Horizontal Cylinder. The half-width principal may be employed to determine the approximate depth of the contrast. In each profile, the value at the extreme right side is arbitrarily chosen as the normal value for the area - that is, the value that would be measured throughout the area if no anomalous mass were present. Actually the left flank of each profile rises to a higher value than that of the right. However, taking the extreme right-hand value as the "normal" value is accurate enough to give an approximate estimate of the depth of a possible source for the "U" shaped curve. The half-width, then, is that horizontal distance between the points on the left and right flanks where the Bouguer anomaly value is midway between the normal value and the minimum value.

The half-widths of each profile are taken from Plates III and IV. For profile A-A", X_h, the half-width, is 23,200 feet, while for profile B-B", X_h is 26,800 feet.

If the source of the "U" profile is best represented by a sphere, the depth to center is $Z_c = 1.3\ X_h$. From profile B-B", which cuts across the center of the Blue Hills low area,

Z_c = 34,800 feet. Profile A-A'' does not cut across the center. Hence, it is unimportant under the assumption of a spherical source.

The sphere is the deepest source that will produce a given anomaly.

For a horizontal cylinder source, $Z_c = X_h$. Thus Z_c is 23,200 feet based on profile A-A'', and is 26,800 feet based on profile B-B''.

(b) Horizontal Cylinder Representation Applied to Density Contrast between Salem and Less Dense Rocks. In line with the earlier conclusion that the anomaly contour pattern is probably dependent in great measure upon the prevalence of Salem gabbro-diorite, it would be instructive to determine if it is feasible to explain the "U" shape by the density contrast between the Salem and the lighter sedimentary and igneous rocks of the area.

The cropping out of the Salem on the northern and southern extremes of cross-sections A-A'' and B-B'' implies that the lighter rocks fill a bowl, the basement of which would be the Salem formation. The horizontal cylinder representation may be applied here, but it must be used with caution for the assumption being dealt with is not that of a low density cylinder at depth but that of low density material which appears at the surface and which fills a bowl, the thickest portion of which occurs at the low point of the "U" profile. Still the horizontal cylinder representation can lend a fairly good approximation of the depth of the bowl, under that particular assumption.

Nettleton (1940) has listed a formula relating the magnitude of a gravity low or high to the radius of a horizontal cylinder and the density contrast involved. The formula is

$$K' = \frac{12.77\sigma R^2}{Z},$$

where K' is the magnitude of the high or low in milligals, R is the radius of the cylinder in feet, σ is the density contrast in c.g.s. units, and Z is the depth to the center of the cylinder in feet.

The less dense rocks in the immediate vicinities of profiles A-A'' and B-B'' are the Lynn-Mattapan (2.75), Cambridge (2.72), Quincy (2.66), Dedham (2.65), and Roxbury (2.62) formations. An average density contrast between the Salem (2.92) and the above formations considered as one group is about 0.25 grams/cm^3.

For profile A-A'', K = 11.4 milligals and Z = 23,200 feet. Thus R = 9,100 feet. Hence the depth to the bottom of the bowl - that is, the depth to the Salem basement in the vicinity of profile A-A''- is R + Z = 32,300 feet. For profile B-B'', K = 15 milligals, Z = 26,800 feet, and R is calculated at 11,100 feet. Hence the depth of the bowl in the vicinity of profile B-B'' is 37,900 feet.

Both of the depths calculated above seem excessive. Certainly the estimated thicknesses of the sediments of the area do not imply so great a thickness of low density formations. However, as was pointed out before, the contents of the bowl also include the low density igneous rocks. Since no estimates have been made on the thickness of such formations as the Dedham and Quincy, there is no basis for doubting that the low density rocks could extend to the depths calculated above, in the Blue Hills region.

(c) Horizontal Half-Cylinder Representation. A perhaps more appropriate approximation to the source of the "U" shaped curves is a horizontal half-cylinder, with the axis along the length of the cylinder parallelling the trend of the Boston Basin sediments. The length of the half-cylinder would extend to infinity in both the east and west directions. The plane dividing the cylinder into two halves corresponds to the surface of the ground. Here, the half-cylinder is assumed to be made up of the less dense rocks of the area, while the surrounding material is assumed to be Salem gabbro-diorite (2.92). A density contrast of 0.25 $grams/cm^3$ is again used.

Since the long dimension of the cylinder is infinite in both directions, a two-dimensional technique may be applied to profiles A-A'' and B-B'' to determine the approximate depth of density contrast at the thickest part of the half-cylinder bowl. Recourse is made to the formula upon which the Jung graticule is constructed:

$$g_z = 2\gamma\sigma\,(\text{Cos}\ \theta_2 - \text{Cos}\ \theta_1)\,(r_2 - r_1),$$

where g_z is the gravitational force, γ is the gravitational constant, and σ is the density contrast. The angles θ_1 and θ_2 and the distances r_1 and r_2 are taken with respect to the point on the surface at which the anomalous effect is being determined. The θ's and the r's define, in polar coordinates, the outline of the two-dimensional body, or the outline of a segment of that body, whose effect is desired. The angles are measured from the horizontal surface to the right of the point in question, with θ_2 the smaller angle; the distance r_2 is the greater of the two distances.

To determine the gravitation of a half-cylinder, the Jung formula is applied to a half-circle. Thus,

$$\theta_2 = 0 \qquad \text{Cos}\ \theta_2 = 1$$
$$\theta_1 = \pi \qquad \text{Cos}\ \theta_1 = -1$$
$$r_1 = 0$$
$$r_2 = r = \text{the radius of the half-cylinder}$$

Hence, the Jung formula reduces to:

$$g_z = 4\gamma\sigma r.$$

Since we have been dealing with γ and σ expressed in the c.g.s. system, the Jung formula gives g_z in gals if r is expressed in centimeters. In order to express g_z in milligals, a factor of 10^3 must be applied to the right side of the Jung formula. To be able to express r in the more workable unit of feet, a factor of

30.48 (cm/ft) is also applied to the right side of the Jung formula. Hence the formula becomes

$$g_z = 8.15 \times 10^{-3} \sigma r$$

where g_z is in milligals, σ in grams per cubic centimeter, and r in feet. As before, a density contrast of 0.25 grams/cm^3 is taken between the less dense rocks of the area and the basement rock - the Salem.

Considering first the profile A-A", g_z is taken to be the magnitude of the gravity low: 11.4 milligals. Hence, r is found to be about 5,600 feet. From profile B-B", g_z is taken as 15 milligals, and r is determined as 7,400 feet. Since from both profiles the maximum values of the magnitude of the low were used, the values of r, calculated above, represent the maximum depth of the half-cylindrical bowl at its thickest part. Such depths are certainly reasonable considering the order of thicknesses of the sedimentary formations in the area. However, it is questionable if the horizontal half-cylinder is an adequate representation of the structural relationship between the Salem gabbro-diorite and the less dense rocks. If the "U" shape curve were entirely due to such a relationship, one would expect the gradient of both flanks of the "U" to be much greater than is indicated by either profile.

Yet the horizontal half-cylinder gives a much more reasonable value of the probable maximum depth of density contrast in the Blue Hills - at the low point of each profile - than does the representation of the sphere at depth and horizontal cylinder depth.

ii. Profiles A-A" and B-B": Consideration of the Flanks of the "U"

It is the author's opinion that separate considerations of each flank of the "U" of the profiles give a more accurate picture of Boston Basin geology. Definite correlation can be made between the right flanks of each profile and surface geology, while certain aspects of the left flanks of each profile can also be correlated with some of the structural phenomena in the area over which the left flanks lie.

(a) The Right Flanks. The right flank of the "U" can be correlated with the surface geology in both profiles A-A" and B-B". The right flanks are at their high value to the right over an area predominated by the high density Salem formation (2.92) and then uniformly decrease to their low points over the low density Quincy granite (2.66). The right flank is the type of profile one would expect over an approximately vertical contact between a higher density formation to the south and a lower density formation to the north. The Dedham formation (2.65) also appears in the area, cropping out just north of the Salem and also underlying the Wamsutta conglomerate. Hence the vertical contact is not necessarily between the Salem and the Quincy, but is more likely between the Salem and the Dedham. It should be noted that the Dedham (2.65) and Quincy (2.66) have densities so similar, in comparison with the density of the Salem, that for the purposes of interpreting gravity data, the Dedham and the Quincy can be considered equivalent.

To determine the approximate extent of the density contrast between the Salem and the "Quincy-Dedham", the Bouguer correction formula

$$g_p = 2\pi\gamma\sigma h$$

where γ is the gravity constant and σ is the density contrast. If γ and σ are expressed in c.g.s. units and h is expressed in feet, this formula becomes $g_p = 0.01276\,\sigma h$ milligals. This formula is especially useful in determining the extent of an approximately vertical contact between two different rock types when that contact appears on the surface.

Profile A-A'' will be considered first. On the right, the extreme value of profile A-A'' is 10 milligals, and this decreases to -1.4 milligals over the Blue Hills. The decrease is fairly uniform, but there is a noticeable decrease in the rate of decrease at the approximate southern extreme of the Wamsutta formation. South of the Wamsutta-Dedham contact, the profile's gradient is -2.8 milligals per mile, while north of the contact, the gradient is -1.2 milligals per mile. However, since the gradient continues to decrease until well over the Quincy formation, the presence of the Wamsutta may be neglected in making an approximate estimate of the depth of the density contrast between the Salem and the Dedham-Quincy. Applying the Bouguer correction formula, and using a density contrast of 0.265, which is the difference between the density of the Salem and the average density of the Quincy and Dedham, the depth of the density contrast is ascertained as 3,370 feet at the Salem-Dedham contact in Braintree. This figure represents a maximum depth which is based on the maximum difference between the profile's right flank high and the low over the Quincy granite.

The right flank, however, seems to level off just to the right of the point where its value is 9 milligals. And, as already pointed out, the gradient on the north portion of the flank is noticeably different from that on the south portion. Thus, a closer estimate of the depth of the density contrast may be had by taking g_p in the Bouguer correction formula to be the difference between 9 milligals and 0 milligals, where the latter value of 0 milligals is the approximate mid-value between the high and low values of the north portion of the right flank. Thus, taking g_p as 9 milligals and σ as 0.265 grams/cm^3, h is calculated to be 2,660 feet.

We examine now profile B-B''. The right flank of profile B-B'' decreases from a maximum value of +12.0 milligals in the south to a minimum of -3.0 milligals just south of the Quincy granite - Cambridge siltstone contact in Hyde Park. Over the south portion of the flank, the gradient is about -2.6 milligals per mile. In the vicinity of the Wamsutta conglomerate, there is an almost imperceptible flattening of the profile, but it is not as marked as the change of gradient in a similar location on profile A-A'', and hence is not deemed important in determining the depth of density contrast. The Bouguer correction formula is again applied with

$$g_p = 12-(-3) \text{ milligals} = 15 \text{ milligals}$$

$$\text{and } \sigma = 0.265 \text{ grams/cm}^3$$

The depth, h, is determined as 4,440 feet. This figure represents the maximum depth of the boundary between the Salem and the Dedham in the Braintree area.

Since the extreme south portion of flank B-B'' flattens out, and since there is a small amount of flattening in the north portion, a truer picture of the depth of density contrast may be made by taking g_p to be the difference between +11.0 milligals, the approximate value at which the south portion starts to flatten out and -1.0 milligals, the approximate mid-value of the northern portion of the flank. Thus, with g_p = 12 milligals and σ = 0.265 grams/cm^3, the depth, h, is calculated as 3,550 feet.

The density contrast is thus seen to extend to a greater depth to the west than to the east. If the assumption is made that the Salem underlies the less dense formations, then the above calculations indicate that the Salem ascends in an easterly direction.

Although the right flanks of the profiles can give a clue to the extent of the density contrast between the Salem and the Dedham-Quincy formations, they can give no indication of the nature of the contact in Braintree. The Bouguer correction formula can be used to determine the exact depth extent of density contrast only when the contrast is the result of a vertical fault. In this ideal case, the change in the magnitude of the profile will be abrupt and will occur over the trace of the fault.

(b) The Left Flanks. The left flanks of profiles A-A" and B-B", especially in that area over the Boston Basin, show very little correlation with the surface geology or with the supposed structure indicated in cross-sections A-A" and B-B". However, by taking certain local trends into account, some major features of the basin are pointed up by the gravity data.

The left flank of profile A-A" brings out some of the features of the Boston Basin much better than does that of profile B-B".

The local trend is represented by the dotted line NML, shown on Plate III. NML is a modified southward extension of the gradient north of N. The gradient of the local trend MN is +1.5 milligals per mile to the north; the gradient of local trend LM is +1.07 milligals per mile.

Figure III-A, which appears on Plate III, represents the residual profile between points N and L with the local trend taken out. Two separate highs appear at "a" and "b". The maximum value of anomaly "a" is +1.5 milligals, while that of anomaly "b" is nearly +0.5 milligals.

The southern edge of anomaly "a" occurs about 0.2 miles south of the contact between the Quincy granite and the Boston Basin sediments in the Blue Hills area. The northern edge occurs over the Roxbury conglomerate south of Jamaica Plain. Anomaly "a" thus forms a blanket over all of the shingle block zone, and may very well be a manifestation of this zone. Such a manifestation would be expected to be a small relative high because the thrusts in the shingle block zone bring up to the surface the Lynn-Mattapan volcanics (2.75) which is more dense than the major basin sediments, the Cambridge (2.72) and the Roxbury (2.62) formations.

Anomaly "b" is seen to blanket the central anticline of the Boston Basin. The south edge of the anomaly occurs 1 mile south of the apparent apex of the anticline (See cross-section A-A"), while the north edge of the anomaly occurs about $1\frac{1}{4}$ mile north of the apex. Hence, anomaly "b" is conceivably a manifestation of the central anticline, caused by the underlying Lynn-Mattapan formation being closer to the surface.

Within the basin, highs of the magnitudes of anomalies "a" and "b" can be occasioned by the topography of the bedrock (2.67 average) underlying a cover of glacial till (2.15), the surface of which is approximately level. For instance, if the bottom surface of a several hundred foot layer of till were interrupted by a 65 foot hill of bedrock, a +0.5 milligal relative high - such as anomaly "b" - would result. A similarly caused 200 foot deficiency of till would result in a +1.5 milligal relative high - the same magnitude as anomaly "a". However, since anomalies "a" and "b" do correlate with the probable geologic structure and since localized deficiencies of till - especially a deficiency as great as 200 feet -- are unlikely, though possible, it is assumed that the residual anomalies are due to the structure of the basin, which is indicated by the surface exposures. Unfortunately, depth to bedrock data for this portion of the basin is scant. The complexity of the geology, as well as the low density contrast of the formations in the area involved, prevents the use of anomalies "a" and "b" to determine anything quantitative.

To the north of point N, the value of the left flank of profile A-A" increases with a gradient of about 2.2 milligals per mile. The profile then tends to flatten out over Somerville, in an area where Cambridge siltstone (2.72) is exposed in the northern syncline portion of the basin. Over Arlington, the gravity values drop 1.2 milligals in a distance of about half a mile. The ascent of the gravity values then resumes with a very shallow slope which tends to further flatten out over the Salem, north of Winchester.

The first rise of the slope, just north of point N, does not correlate with the structure shown in cross-section A-A'', and thus may be attributed to the same cause as that of the general local trend of the left flank. The flattening out over Somerville could be due to a rising of the Roxbury conglomerate (2.62) on the north arm of the syncline.

The sharp drop over Arlington, however, correlates almost exactly with the northern boundary of the basin and is indicative of a fault in which a less dense formation - the Dedham (2.65) - lies to the north of a heavier formation - the Cambridge (2.72). Since the Dedham is older than the basin sediments, the fault is a thrust if the contact dips to the north. This is the case, according to most geologists.

Because the Roxbury (2.62) which underlies the Cambridge (2.72) is less dense than the Dedham (2.65) and the Cambridge, and because the Dedham is less dense than the Cambridge, the unknown relative locations of the three formations in the area of the contact would make meaningless any determination of the amount of throw of the fault from the profile data. However, if the Roxbury is considered to be of the same density as the Dedham, 2.65 grams/cm^3, we can estimate the approximate thickness of the Cambridge formation in the immediate vicinity of the basin's border. Again, the Bouguer correction formula

$$g_p = 2\pi\gamma\sigma h$$

is applied. Taking g_p to be 1.2 milligals, σ to be 2.72 - 2.65 = 0.07 grams/cm^3, h is ascertained as 1,340 feet. The Cambridge is undoubtedly thicker to the south, in the center of the northern syncline, but thins out to approximately the above figure because of the curvature of the syncline.

The apparent flattening of the gravity profile in the area north of the basin border where igneous rocks predominate, and the pronounced flattening over the Salem north of Winchester indicates that the local trend of the left flank is caused by a change in the relative depth to the Salem formation. The depth to the Salem is greatest beneath the southern shingle block zone, and steadily decreases to the north. Evidently this steady rate of decrease is not changed in those areas where the structure of the basin sediments implies an abrupt change in the depth to the Salem. Such areas would be the central anticline, in which the depth to the Salem would decrease, and the northern syncline zone, in which this depth would decrease. Igneous rocks of lower density are probably involved in these structural phenomena, however. The relief of the Salem is apparently less severe beneath the Dedham granodiorite in Arlington and Winchester. The shape of the profile in the Winchester area indicates a gradual thinning of the Dedham formation, which covers the Salem, until the Salem predominates north of Winchester. This situation is not shown by cross-section A-A''.

We turn now to a discussion of the left blank of profile B-B''. The left flank of profile B-B'' shows less correlation with its corresponding cross-section than does the left flank of profile A-A''.

As seen from the geologic map (Plate I), the geology of the southern part of the Boston Basin is very complex in that area where the basin is cut by cross-section trace B-B-B''. There is little or no manifestation on the profile of this southern zone which is represented on cross-section B-B'' as a westward extension of the shingle-block zone.

North of the extension, a local trend, represented by the dotted line QP, is inferred, with a gradient of +1.6 milligals per mile to the north. A residual profile, with trend QP taken out, is shown in Figure IV-A, which is also shown in Plate IV. The maximum amplitude of the residual profile is +0.6 milligals. It blankets the central anticline zone, extending northward to the contact between the Roxbury and the Cambridge formations in Newton. The residual profile is probably a manifestation of the central anticline because of the profile's location and because its amplitude is about the same as the amplitude of anomaly "b" of Figure III-A, which is a manifestation of the central anticline on profile A-A". However, it should be pointed out that the choosing of the local trend QP is much more arbitrary in this case than it was in the case of the left flank of profile A-A".

North of point Q, there is a slight flattening of the profile over the northern syncline in the Charles River area. In this area, the thickness of the Cambridge siltstone (2.72) increases at the expense of depressing the less dense Roxbury formation (2.62). Hence, the slope of the profile would be expected to increase to the north instead of flatten. Thus the flattening may be due to a relative lessening of the northwardly rise of the surface of the Salem formation. The flattening may also be due to the partially compensating effect of glacial till in the vicinity of the Charles River. In any event, the flattening is apparently not caused by the structure of the basin sediments.

There is a slight increase in the northwardly slope of the profile in the Watertown area. The zone of increase is centered over a postulated thrust fault (Billings, 1929). But, since the thrust would bring the Roxbury (2.62) closer to the surface at the expense of a thinning of the Cambridge (2.72), one would expect a relative flattening of the profile in relation to the slope south of the Watertown fault. That just the opposite is observed may indicate that structure at depth instead of near the surface influences the nature of the profile in the Watertown vicinity.

In Arlington, there is again a relative flattening of the profile.

But more important, there is no indication of the boundary between the basin sediments and the Marlboro (2.81) and Salem (2.92) rocks to the north. Because of the interplay of igneous rocks of different densities at depth below the basin sediments, there would be no point in using the trend of the profile in the Newton, Watertown, and Arlington areas to make any depth or thickness calculations.

The flattened shape of the profile north of Arlington, in an area where the Salem formation is predominantly exposed on the surface, is probably due to the interplay at relatively shallow depth of the various igneous rocks.

iii. The Contour Map.

Further information on the structure in the immediate vicinity of the Boston Basin can be ascertained from an examination of the contour map of Plate II.

(a) The Main Part of the Boston Basin. The Bouguer anomaly contours extend approximately east-west over the main part of the Boston Basin, specifically over the areas of the northern syncline and the central anticline. That is, an east-west profile taken across this portion of the basin would be practically level until the shoreline were reached, at which point the profile would rise sharply.

If there were no anomalous bodies in the tract of such a profile, we should expect the profile to increase to the east because of the northeasterly regional trend. The easterly increase would amount to about +1.5 milligals based on Longwell's (1943) determination of a regional trend of +1.52 milligals per mile in a direction N. 84° E. The easterly trend would be +1.24 milligals per mile based on the regional trend, determined from the contour map of Plate II, of +1.37 milligals per mile in the direction N. 65° E.

The actual level profile across the basin indicates that there is some phenomenon which "cancels out" the easterly trend. That is, if the easterly trend were disregarded, an east-west profile across the basin would decrease to the east at a rate of from 1.2 to 1.5 milligals per mile. Such a circumstance certainly bears out the believed eastern pitch of the basin's central anticline and northern syncline, and indicates that the surface of the heavier basement formation - presumably the Salem gabbro-diorite - also dips to the east.

The apparent increase to higher anomaly values in Boston Bay indicates that the Salem, or perhaps some other dense rock type, takes a marked upswing and gets nearer the surface of the Bay's floor. This is in marked disagreement with La Forge (1932) who feels the eastward plunge of the basin continues well out to sea.

The outcrops observed on some of the islands in the Bay are not helpful in determining the extent of the basin's easterly plunge. The Cambridge siltstone crops out on most of the islands, but the magnitude and direction of the dips are very irregular as is the distribution of outcrops of the same orientation throughout the Bay.

(b) The Southwestern Portion of the Boston Basin. The southwestern segment of the Boston Basin is subtly depicted by the gravity data. In the Wellesley area, a ridge of highs points to the south and then bears to the southwest (See Plate II). This is to be expected, since the Lynn-Mattapan volcanics (2.75) are the prominent basin formation, and they are bound on the northwest and southeast by the lighter Dedham formation (2.65). However, it is presumed that the interplay of the various igneous and metamorphic formations in this area - the Salem (2.92), Marlboro (2.81), Dedham (2.65), Milford (2.64) - and below the basement sediments, prevents exact correlation of the gravity data with presumed geology. It is obvious that the gravity data and the surface geology are respectively irregular and complicated in the Wellesley-Natick-Dedham area.

4. Expression of the Boundaries of the Boston Basin

i. Northern Boundary Fault. The most striking expression of the northern boundary on the contour map occurs in the Melrose and Medford areas. In the Melrose area, a trench of lows points toward the east. To the south in the Medford area, a ridge of highs points toward the west. The presumed northern boundary fault lies between and roughly parallel to the ridge and trench in this area. Both the trench and ridge are within three-quarters of a mile from the basin border. This type of anomaly contour expression - which is best described as an s-shaped offset - is what would be expected across a fault. However, in the Melrose area, the Lynn-Mattapan volcanics (2.75) border the Cambridge formation (2.72) to the north. The relative low north of the border may be due to a predominance of Dedham granodiorite (2.65) which lies beneath a thin cover of Lynn-Mattapan. The Dedham does border the basin west of Melrose.

There seems to be no gravity expression of the northern border from Arlington southwest to Waltham, supposedly due to the far-reaching effects of the phenomenon, discussed earlier, causing the Lexington high.

Southwest of Waltham, the border trends southwest, but more to the south than to the west. Once again, the border coincides with an s-shaped offset. To the east a ridge of highs, trending southward, is about a mile from the border. To the west, a trench of lows, trending northward, is within a half-mile from the border. The ridge of highs, through Wellesley, has been discussed in relation to the southwestern portion of the Boston Basin. The relative drop in anomaly values from east to west across the border in the Wellesley area can be explained by the positions of the Lynn-Mattapan formation (2.75) which is associated with the relative high in the basin east of the border and the less dense Dedham (2.65) which lies west of the border.

The s-shaped offset continues, in general, to parallel the northern boundary southwest of Wellesley into South Natick. However, in the latter area, the gravity ridge moves closer to the border and almost coincides with it, while the trench of lows moves farther away from the border. This phenomenon may be caused by the density contrast between the basin stratified formations and the Nashoba formation which borders the basin on the northwest in the South Natick vicinity.

The contour pattern in the tract of the northern border is certainly what one would expect if the border were a fault, but could also be the result of some other phenomenon.

In conclusion then, the gravity contours add some credence to, but are certainly not conclusive proof of, the prevalent theory that the Boston Basin is bounded on the north by a fault. However, there is no corroboration whatsoever of Dowse's (1948) contention that the border is one continuous fault from the Boston Bay shore to the South Natick vicinity, because the gravity contour pattern indicative of a fault does not exist along the tract of the basin's border between Arlington and Waltham. This should not be taken as strong evidence that the basin's border is not a fault in the Arlington - Waltham vicinity, however, since some other phenomenon might possibly cause a contour pattern that would completely overshadow the fault pattern.

ii. Southern Boundary Fault.

Neither profile A-A" nor profile B-B" indicates anything conclusive about the nature of the southern boundary of the Boston Basin. The contour data add little more.

West of Milton, through Dedham, to Milford, there is little or nothing in the contour pattern which would indicate a fault. North of Milford, a trench of lows parallels the southeastern border. However, the trench appears to be a remnant of the Medway low phenomenon which is prevalent about 9 miles to the southwest of the southwestern tip of the basin.

Along the south shore of Boston Bay, in the southeastern portion of the region considered by this report, the contour pattern shows no sharp irregularities which would indicate the southern boundary thrust fault which Billings, Loomis, and Stewart (1939) believe to exist in the area. However, it must be remembered that gravity data is relatively scarce in the south shore vicinity.

Immediately west of Milton, a northeast trending gravity trench parallels the border between the Quincy granite (2.66) and the Cambridge siltstone of the basin. The apex of the trench lies within a half-mile south of the basin's border. No corresponding gravity ridge appears within a mile of the border to the north. Thus, no s-shape offset pattern is developed. Yet, the trench correlates with what one would expect when passing from the area of Cambridge formation to the area of less dense Quincy granite, and is a possible indication of an abrupt fault contact.

Hence, the gravity data are seen to give no conclusive evidence of the presence of a southern boundary fault.

VI. SUMMARY AND CONCLUSIONS

Throughout the surveyed region, there is lack of correlation between surface geology and gravity data in some areas, and excellent correlation in other areas. One of the controlling factors in the gravity interpretation is how the gravity data are influenced by the distribution, thickness, and depth of the Salem gabbro-diorite, which is the most dense rock in the region.

Areas of gravity highs and lows bear out some of the surface observations in the uplands of igneous and metamorphic rocks surrounding the basin sediments.

Within the main portion of the basin, a small gravity high corresponds with the shingle-block zone and central anticline. The anomaly map delineates to some degree the southwestern portion of the basin. There is evidence from both a profile and the plan view anomaly contour map that a northern boundary fault exists. However, there is no conclusive evidence in support of the existence of a southern boundary fault.

The sharp northerly increase of anomaly values over the main portion of the basin indicates a lessening of the thickness of the sedimentary basin and the bringing of the heavier basement rocks closer to the surface as the northern border of the basin is approached.

If the general northeast trend of the region is attributed to phenomena deep within the crust, the gravity data indicate a thickening of the basin sediments toward the east in the main part of the basin . . . . and this corroborates the presumed eastward pitch of the basin's northern syncline and central anticline. However, in the Boston Bay area, the gravity data indicate a sharp upswing to the east of the dense basement rocks.

Because of the complexity of the geology of the region, and because of the small density contrast of the rocks involved, there are few opportunities to determine any quantitative information from the gravity data.

VII. SUGGESTIONS FOR FURTHER WORK

It is doubtful whether further gravity investigations in the region covered by this report would be fruitful, except in those areas where structure is relatively simple. Most essential to any gravity investigation of the Boston Basin is a knowledge of the distribution of the igneous formations in the heterogeneous basement beneath the sediments. The depth of surficial deposits should also be known if the results of a gravity survey are to be useful. However, there is a relatively small amount of data on till thickness throughout most of the region. Further investigations in Boston Bay and its islands, however, could be helpful in determining the eastward extent of the basin sediments.

The nature of the contour patterns in the western part of the region indicates that further investigations to the west, northwest, and southwest of the region of this report would be of value in determining structure in those areas.

Magnetic surveys could be helpful, depending upon the relative susceptibilities of the igneous and metamorphic rocks of the region. Unfortunately, such a survey is not feasible in the area where it would be the most enlightening - over the main portion of the basin where it could ascertain the relation and distribution of the igneous formations of the basin - because of the abundance of culture.

Magnetic surveys could prove valuable in determining the location and nature of the basin's borders in the areas where there is little man-made construction. Such surveys may also denote the relationships of the igneous and metamorphic rocks in the sparsely populated areas in and beyond the western portion of the region.

Seismic surveys may be utilized in sparsely populated areas also. However, they would be most valuable in areas predominated by stratified formations. Obviously these methods can't be employed in Boston, but they could prove useful in determining the relationship of the stratified formations in the southwestern corridor of the Boston Basin. A seismic survey would probably be most useful in Boston Bay where it could determine the plunge of the basin by the thickness of the Cambridge siltstone. Of course, high operational cost limits the use of the seismic method, unless some economic return can be expected.

APPENDIX I

PRESENTATION OF GRAVITY DATA: MEASURED AND COMPUTED

APPENDIX I

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
1A-1	42°28.7'	71°24.9'	136.9'	980,395.7	980,402.1	.05	+ 1.9
1A-2	42°25.4'	71°28.5'	182.8'	980,390.9	980,397.1	.15	+ 5.9
1A-3	42°25.8'	71°26.4'	220.6'	980,388.5	980,397.8	.01	+ 4.0
1A-4	42°24.9'	71°23.8'	144.2'	980,393.1	980,396.4	.05	+ 5.4
1A-5	42°23.0'	71°24.9'	182.5'	980,393.1	980,393.6	.05	+ .6
1A-6	42°29.3'	71°30.0'	273.5'	980,391.0	980,403.0	.03	+ 4.5
1A-7	42°27.9'	71°28.0'	205.3'	980,390.3	980,400.9	.03	+ 1.8
1A-8	42°27.3'	71°23.3'	151.8'	980,390.4	980,400.0	.03	- .5
2A-1	42°25.1'	71°21.9'	122.4'	980,391.2	980,396.7	.21	+ 2.1
2A-2	42°22.7'	71°16.9'	99.3'	980,399.5	980,393.1	.12	+12.5
2A-3	42°29.9'	71°15.4'	112.4'	980,402.5	980,403.9	.09	+ 5.4
2A-4	42°29.0'	71°18.0'	127.4'	980,398.4	980,402.6	.04	+ 3.5
2A-5	42°28.3'	71°21.0'	118.7'	980,395.4	980,401.5	.05	+ 1.1
2A-6	42°26.9'	71°16.2'	201.7'	980,396.5	980,399.4	.01	+ 9.2
2A-7	42°27.0'	71°19.3'	159.9'	980,393.7	980,399.6	.03	+ 3.8
2A-8	42°26.8'	71°21.6'	138.7'	980,390.1	980,399.3	.01	- .8
2A-9	42°25.8'	71°18.9'	236.7'	980,392.0	980,397.8	.12	+ 8.5
2A-10	42°25.3'	71°16.3'	175.7'	980,401.3	980,397.1	.33	+ 15.1
2A-11	42°23.9'	71°19.0'	168.6'	980,395.0	980,394.9	.04	+ 10.3
3A-1	42°24.4'	71°14.4'	333.6'	980,391.6	980,395.7	.40	+ 16.4

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
3A-2	42°23.7'	71°09.5'	13.1'	980,408.1	980,394.6	.01	+ 14.3
3A-3	42°23.0'	71°12.5'	49.9'	980,403.2	980,393.6	.05	+ 12.7
3A-4	42°26.7'	71°10.0'	324.3'	980,403.2	980,399.1	.48	+ 16.4
3A-5	42°28.3'	71°09.7'	42.7'	980,414.4	980,401.5	.09	+ 15.6
3A-6	42°27.5'	71°12.3'	206.3'	980,405.2	980,400.3	.00	+ 17.2
3A-7	42°28.7'	71°13.0'	170.2'	980,407.0	980,402.1	.05	+ 15.9
3A-8	42°27.7'	71°14.3'	186.1'	980,404.6	980,400.6	.09	+ 15.3
3A-9	42°25.2'	71°13.9'	266.6'	980,400.3	980,396.8	.05	+ 19.5
3A-10	42°25.5'	71°10.6'	109.4'	980,406.0	980,397.3	.15	+ 15.3
3A-11	42°29.5'	71°09.3'	106.0'	980,415.6	980,403.3	.00	+ 18.6
3A-12	42°22.6'	71°14.2'	63.0'	980,398.9	980,392.9	.01	+ 9.7
3A-13	42°25.4'	71°08.9'	7.5'	980,409.6	980,397.1	.12	+ 13.1
4A-1	42°24.1'	71°03.8'	11.1'	980,411.1	980,395.2	.16	+ 16.7
4A-2	42°22.5'	71°02.0'	12.2'	980,406.6	980,392.8	.00	+ 14.6
4A-3	42°25.0'	71°00.5'	27.0'	980,414.0	980,396.6	.04	+ 19.1
4A-4	42°25.3'	71°02.5'	49.4'	980,412.8	980,397.0	.03	+ 18.8
4A-5	42°26.2'	71°04.3'	45.4'	980,412.4	980,398.3	.12	+ 16.9
4A-6	42°23.7'	71°01.7'	10.6'	980,410.1	980,394.6	.11	+ 16.2

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
4A-7	42°22.5'	71°05.0'	18.9'	980,406.4	980,392.8	.03	+ 14.8
4A-8	42°25.1'	71°06.6'	11.8'	980,412.1	980,396.7	.04	+ 16.2
4A-9	42°26.6'	71°07.3'	222.5'	980,401.7	980,498.9	.21	+ 16.3
4A-10	42°27.9'	71°07.2'	152.0'	980,409.1	980,400.9	.09	+ 17.4
4A-11	42°29.6'	71°06.3'	128.8'	980,413.8	980,403.5	.00	+ 18.0
4A-12	42°29.8'	71°04.4'	88.8'	980,420.3	980,403.8	.03	+ 21.9
4A-13	42°28.0'	71°04.2'	63.2'	980,415.3	980,401.0	.03	+ 18.1
4A-14	42°28.2'	71°01.8'	56.7'	980,416.5	980,401.3	.07	+ 18.7
4A-15	42°26.4'	71°00.9'	28.4'	980,415.0	980,401.3	.07	+ 18.7
4A-16	42°23.5'	71°07.3'	29.2'	980,407.8	980,394.3	.00	+ 15.1
5A-1	42°28.4'	70°59.5'	48.4'	980,419.6	980,401.7	.16	+ 21.0
5A-2	42°28.7'	70°57.7'	82.0'	980,422.3	980,402.1	.04	+ 25.2
5A-3	42°29.7'	70°58.3'	104.8'	980,423.1	980,403.5	.08	+ 25.9
5A-4	42°29.9'	70°53.2'	17.6'	980,447.3	980,403.8	.35	+ 44.9
5A-5	42°28.2'	70°53.9'	22.6'	980,429.3	980,401.3	.07	+ 29.4
5A-6	42°27.4'	70°56.1'	13.7'	980,423.6	980,400.1	.03	+ 24.3
5A-7	42°25.4'	70°59.1'	9.6'	980,417.4	980,397.1	.04	+ 20.9
5A-8	42°23.2'	70°58.6'	22.4'	980,411.1	980,393.8	.13	+ 18.7

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
6A-1	42°29.3'	70°50.2'	47.0'	980,430.7	980,403.0	.08	+ 30.6
1B-1	42°17.9'	71°24.3'	204.9'	980,371.6	980,385.9	.03	- 2.0
1B-2	42°17.9'	71°26.5'	184.2'	980,368.5	980,385.9	.03	- 6.3
1B-3	42°16.3'	71°24.1'	160.9'	980,373.4	980,383.5	.00	- .4
1B-4	42°18.8'	71°25.9'	206.1'	980,373.4	980,387.3	.01	- 1.5
1B-5	42°21.6'	71°26.5'	182.4'	980,380.4	980,391.5	.12	0
1B-6	42°16.6'	71°25.7'	168.3'	980,364.5	980,384.0	.03	- 9.4
1B-7	42°15.7'	71°29.0'	203.7'	980,353.3	980,382.6	.21	- 16.9
1B-8	42°22.5'	71°27.5'	173.2'	980,380.5	980,392.8	.03	- 1.9
2B-1	42°15.5'	71°15.6'	117.2'	980,379.9	980,382.4	.08	+ 4.7
2B-2	42°17.9'	71°22.1'	150.9'	980,376.1	980,385.9	.03	- .8
2B-3	42°18.2'	71°19.8'	162.1'	980,380.7	980,386.3	.01	+ 4.1
2B-4	42°15.5'	71°22.4'	179.3'	980,373.1	980,382.4	.33	+ 1.9
2B-5	42°21.3'	71°15.9'	71.3'	980,396.7	980,391.0	.17	+ 10.1
2B-6	42°20.6'	71°18.4'	228.6'	980,385.4	980,389.9	.00	+ 9.1
2B-7	42°20.1'	71°20.5'	218.4'	980,383.4	980,389.2	.12	+ 7.7
2B-8	42°22.3'	71°17.6'	158.6'	980,394.1	980,392.5	.13	+ 11.6
2B-9	42°16.3'	71°18.9'	119.9'	980,381.1	980,383.5	.07	+ 4.9

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
2B-10	42°22.5'	71°22.3'	125.0'	980,387.7	980,392.8	.04	+ 2.0
2B-11	42°22.0'	71°20.3'	164.3'	980,391.1	980,392.0	.00	+ 8.9
2B-12	42°19.2'	71°17.6'	306.5'	980,375.8	980,387.9	.12	+ 6.5
2B-13	42°17.9'	71°16.7'	138.2'	980,383.7	980,385.9	.11	+ 6.2
3B-1	42°17.7'	71°14.8'	91.7'	980,384.2	980,385.6	.05	+ 4.2
3B-2	42°15.2'	71°12.4'	279.2'	980,370.7	980,381.9	.51	+ 7.2
3B-3	42°17.6'	71°09.8'	119.7'	980,381.9	980,385.5	.08	+ 3.6
3B-4	42°18.4'	71°08.8'	184.8'	980,381.1	980,386.6	.08	+ 5.6
3B-5	42°19.8'	71°09.4'	138.6'	980,388.3	980,388.8	.11	+ 8.0
3B-6	42°20.0'	71°14.6'	100.3'	980,392.9	980,389.0	.20	+ 10.1
3B-7	42°21.0'	71°12.9'	51.8'	980,398.9	980,390.6	.15	+ 11.6
3B-8	42°21.5'	71°09.7'	13.4'	980,401.8	980,391.3	.03	+ 11.3
3B-9	42°15.8'	71°09.4'	135.3'	980,373.6	980,382.8	.00	- 1.1
3B-10	42°19.8'	71°11.5'	141.5'	980,389.1	980,388.8	.07	+ 8.9
3B-11	42°16.9'	71°13.2'	176.2'	980,376.4	980,384.4	.09	+ 2.6
4B-1	42°15.0'	71°01.6'	97.4'	980,376.4	980,381.6	.07	+ .8
4B-2	42°16.7'	71°00.8'	12.6'	980,391.8	980,384.1	.03	+ 8.5
4B-3	42°18.3'	71°05.0'	116.9'	980,383.4	980,386.5	.01	+ 3.9

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
4B-4	42°19.9'	71°03.2'	17.8'	980,395.5	980,388.9	.00	+ 7.7
4B-5	42°21.1'	71°06.7'	8.0'	980,400.1	980,390.7	.11	+ 10.0
4B-6	42°19.9'	71°07.1'	23.5'	980,394.2	980,388.9	.04	+ 6.8
4B-7	42°15.4'	71°06.9'	50.3'	980,378.2	980,382.1	.19	- .8
4B-8	42°16.2'	71°04.1'	22.6'	980,386.5	980,383.3	.13	+ 4.6
4B-9*	42°21.1'	71°03.3'	18.4'	980,399.9	980,390.7	.00	+ 10.3
4B-10	42°20.4'	71°04.4'	9.7'	980,397.7	980,389.7	.00	+ 8.8
4B-11	42°17.2'	71°07.2'	41.9'	980,384.1	980,384.9	.05	+ 1.8
5B-1	42°21.7'	70°58.3'	10.3'	980,412.1	980,391.6	.01	+ 21.1
5B-2	42°15.6'	70°59.7'	32.8'	980,389.0	980,382.5	.01	+ 8.5
5B-3	42°16.1'	70°57.4'	26.1'	980,395.3	980,383.2	.03	+ 13.7
5B-4	42°15.7'	70°53.7'	10.4'	980,397.8	980,382.6	.07	+ 15.8
6B-1	42°15.6'	70°50.7'	10.3'	980,399.4	980,382.5	.04	+ 17.6
6B-2	42°16.7'	70°52.1'	15.2'	980,401.2	980,384.1	.03	+ 18.0
1C-1	42°14.4'	71°24.9'	182.2'	980,361.2	980,380.7	.19	- 8.3
1C-2	42°12.6'	71°25.6'	178.2'	980,364.1	980,378.0	.07	- 3.1
1C-3	42°10.5'	71°26.7'	239.4'	980,353.3	980,374.2	.01	- 6.5

(*) - South Station base station.

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
1C-4	42°08.9'	71°29.2'	253.6'	980,343.1	980,372.4	.03	- 14.1
1C-5	42°07.9'	71°26.8'	202.5'	980,343.0	980,371.0	.00	- 15.9
1C-6	42°08.8'	71°26.1'	282.2'	980,340.6	980,372.3	.12	- 14.6
1C-7	42°08.3'	71°23.2'	139.5'	980,349.1	980,371.5	.07	- 14.1
2C-1	42°14.0'	71°19.8'	119.8'	980,371.7	980,380.1	.11	- 1.0
2C-2	42°12.4'	71°21.2'	122.3'	980,363.7	980,377.7	.09	- 6.6
2C-3	42°11.3'	71°20.1'	125.2'	980,364.1	980,376.0	.13	- 4.3
2C-4	42°09.4'	71°22.4'	197.9'	980,350.0	980,373.2	.03	- 11.3
2C-5	42°09.5'	71°19.9'	122.5'	980,362.0	980,373.3	.13	- 3.8
2C-6	42°07.7'	71°19.9'	192.7'	980,351.8	980,370.6	.04	- 7.2
2C-7	42°08.3'	71°16.9'	235.4'	980,355.4	980,371.5	.03	- 2.0
2C-8	42°10.4'	71°17.5'	166.4'	980,365.7	980,374.7	.24	+ 1.2
2C-9	42°14.3'	71°22.0'	175.2'	980,370.6	980,380.6	.04	+ .6
2C-10	42°14.7'	71°16.9'	149.6'	980,374.4	980,381.1	.01	+ 2.3
2C-11	42°12.6'	71°18.9'	181.1'	980,366.4	980,378.0	.04	- .6
2C-12	42°11.2'	71°18.5'	167.1'	980,367.0	980,375.9	.04	+ 1.2
2C-13	42°09.0'	71°15.6'	167.2'	980,361.2	980,372.6	.23	- 1.1

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
3C-1	42°13.8'	71°13.6'	188.7'	980,371.1	980,379.8	.07	+ 2.7
3C-2	42°14.4'	71°11.3'	199.6'	980,369.2	980,380.7	.35	+ .9
3C-3	42°13.1'	71°10.9'	92.1'	980,375.3	980,378.7	.07	+ 2.2
3C-4	42°11.6'	71°13.0'	255.2'	980,362.4	980,376.5	.07	+ 1.3
3C-5	42°10.0'	71°12.6'	79.4'	980,369.8	980,374.1	.15	+ .6
3C-6	42°07.6'	71°14.8'	186.6'	980,356.7	980,370.5	.03	- 2.5
3C-7	42°08.7'	71°13.1'	274.6'	980,353.9	980,372.2	.11	- 1.7
3C-8	42°07.4'	71°10.8'	302.7'	980,348.7	980,370.2	.03	- 3.4
3C-9	42°07.8'	71°07.7'	154.1'	980,363.6	980,370.8	.04	+ 2.1
3C-10	42°08.9'	71°09.7'	151.9'	980,364.4	980,372.4	.19	+ 1.3
3C-11	42°10.4'	71°10.5'	104.0'	980,369.2	980,374.7	.00	+ .7
3C-12	42°11.9'	71°09.2'	47.9'	980,373.2	980,376.3	.01	+ 1.3
3C-13	42°08.9'	71°07.8'	144.1'	980,366.0	980,372.4	.05	+ 2.2
4C-1	42°12.7'	71°01.2'	146.3'	980,371.6	980,378.1	.09	+ 2.4
4C-2	42°10.5'	71°02.1'	137.6'	980,375.2	980,374.9	.13	+ 8.7
4C-3	42°08.3'	71°02.4'	228.0'	980,370.1	980,371.5	.00	+ 12.3
4C-4	42°08.8'	71°06.6'	165.2'	980,367.4	980,372.3	.11	+ 5.1
4C-5	42°12.5'	71°07.2'	193.9'	980,362.2	980,377.8	.75	- 3.3

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
4C-6	42°11.5'	71°03.6'	171.3'	980,368.7	980,376.4	.00	+ 2.6
4C-7	42°13.9'	71°06.9'	115.2'	980,369.8	980,379.9	.05	- 3.2
4C-8	42°14.4'	71°06.6'	108.9'	980,371.3	980,380.7	.08	- 2.8
4C-9	42°14.7'	71°04.2'	114.1'	980,372.7	980,381.1	.04	- 1.6
4C-10	42°08.1'	71°05.5'	324.0'	980,361.0	980,371.3	.05	+ 9.3
5C-1	42°14.6'	70°57.9'	13.6'	980,388.9	980,381.0	.03	+ 8.8
5C-2	42°13.0'	70°53.1'	40.9'	980,387.2	980,378.6	.00	+ 11.0
5C-3	42°12.6'	70°55.8'	78.0'	980,381.8	980,378.0	.04	+ 8.6
5C-4	42°12.1'	70°58.2'	115.1'	980,374.1	980,377.2	.00	+ 3.8
5C-5	42°09.2'	71°00.0'	202.7'	980,367.6	980,372.8	.00	+ 6.9
5C-6	42°10.0'	70°58.6'	168.0'	980,368.1	980,374.1	.01	+ 4.1
5C-7	42°10.7'	70°56.1'	110.5'	980,373.6	980,375.1	.03	+ 5.2
5C-8	42°10.9'	70°54.1'	150.8'	980,370.5	980,375.5	.01	+ 4.1
5C-9	42°08.2'	70°55.2'	141.7'	980,365.3	980,371.4	.01	+ 2.4
5C-10	42°08.6'	70°57.0'	144.2'	980,367.4	980,372.0	.00	+ 4.0
5C-11	42°07.6'	70°57.8'	188.8'	980,364.7	980,370.5	.04	+ 5.6
6C-1	42°14.7'	70°52.2'	39.5'	980,394.1	980,381.1	.01	+ 15.4
6C-2	42°14.7'	70°46.0'	17.5'	980,397.3	980,381.1	.11	+ 17.4

APPENDIX I (Continued)

Station	Latitude	Longitude	Elevation	Measured Gravity (Milligals)	Theoretical Gravity (Milligals)	Topographic Correction (Milligals)	Complete Bouguer Anomaly
6C-3	42°09.6'	70°51.4'	127.7'	980,367.6	980,373.5	.01	+ 1.8
6C-4	42°08.0'	70°50.0'	58.2'	980,368.2	980,371.1	.00	+ .6
6C-5	42°08.4'	70°48.2'	148.7'	980,365.4	980,371.7	.03	+ 2.7
6C-6	42°09.9'	70°47.0'	54.6'	980,374.9	980,374.0	.00	+ 4.2
6C-7	42°10.4'	70°45.3'	8.4'	980,381.6	980,374.7	.03	+ 7.4
6C-8	42°11.4'	70°46.7'	82.4'	980,376.2	980,375.9	.01	+ 5.3

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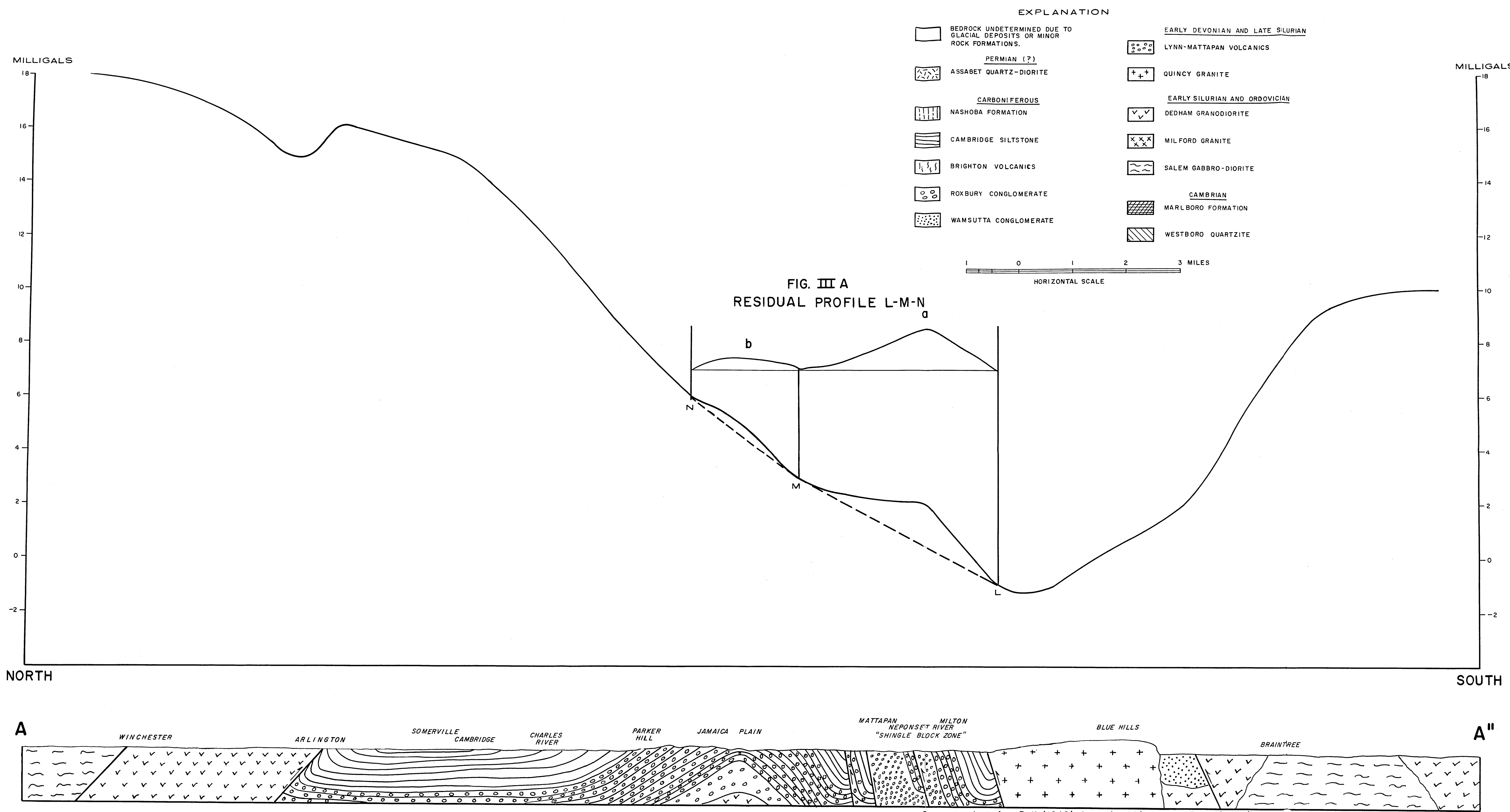
M. S. Ginsburg

Cambridge, 1959.

PLATE I
GEOLOGICAL MAP OF BOSTON AREA

PLATE II
BOUGUER ANOMALY CONTOUR MAP OF BOSTON BASIN AREA



Cross-section after Bell (1948), Chute (1940), and La Forge (1932)

Vertical Scale and Topography shown schematically

PLATE III

PROFILE AND GEOLOGIC CROSS-SECTION A-A"

Cross-section after Bell (1948), Chute (1940), La Forge (1932).

Vertical Scale and Topography shown schematically

PLATE IV

PROFILE AND GEOLOGIC CROSS-SECTION B-B''