UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Bouguer gravity map of the Northeastern United States and adjacent Canada

Compiled by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards.

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Introduction

A new Bouguer gravity map of the Northeastern United States and adjacent areas in Canada has been compiled from all the gravity data available to us at this time. Plates 1 and 2, which may be joined to form a single map, display the Bouguer anomaly field of this region at a 5 milligal contour interval. Plates 3 and 4 show the locations of the gravity observations used in the preparation of this map.

The Data Set

Our data file consists of approximately 40,000 U.S. gravity observations both onshore and offshore. The bulk of these were obtained from the gravity data banks maintained by the National Oceanic and Atmospheric Administration (NOAA) and the Defense Mapping Agency (DMA). A list of the contributors to these data banks is available from NOAA. Additional observations filling in many gaps were supplied by the numerous individuals listed in Appendix A. These additional observations are being added to the NOAA and DMA data banks. The index map prepared by Y. W. Isachsen for Hildreth (1979) displays the areal extent of the studies found in the NOAA data files.

Some 46,000 gravity observations covering portions of Canada to the north and east, were supplied by The Canadian Gravity Data Centre, Earth Physics Branch, Department of Energy, Mines and Resources, 1 Observatory Crescent, Ottawa, Canada, K1A 0Y3.

Observed gravity values have been adjusted to conform to the International Gravity Standardization Net of 1971 (Morelli, 1974). For the older surveys, this required the subtraction of 13.7 milligals (DMA convention) from the observed gravity values. Theoretical gravity values were calculated using the 1967 Geodetic Reference System formula (International Association of Geodesy, 1971). At these latitudes, the combined effect of using the 13.7 milligal datum shift and the 1971 theoretical formula is that Bouguer anomaly values are from 2.4 to 4.8 milligals lower than those calculated using the old reduction system. Bouguer anomaly values onshore and offshore were calculated from the standard formulae used by the DMA, which assume a reduction density of 2.67 g/cc. These formulae are given in the DMA format description sheets which accompany their data, and which are reproduced in Appendix B.

Terrain corrections have been applied to the U.S. onshore stations for zones from 0.895 km out to 166.7 km using the automatic terrain correction program of Plouff (1977) and 30" interval digitized terrain data for the region. The terrain data was originally digitized by the DMA, and is available through the NOAA Data Center.

No terrain corrections have been applied for the zones closer than 0.895 km (Hammer zones A-F), but in most cases, errors resulting from this omission are thought to be substantially less than 1.0 mgal. Note, however, that inner zone corrections can reach 6 milligals in parts of the northeast (O. H. Muller, personal communication). Only one percent of the stations had outer terrain corrections greater than 2 milligals.

The consistency between different data sets is generally quite good. Stations from the early survey of Bean (1953) were spot checked and were found to be reproducible to within 2 milligals when the meter correction suggested by Joyner (1963) was applied to Bean's data. All of the Bean data in the DMA file was corrected in this manner. When new surveys have been merged into the master set, repeat stations and nearby stations have always been examined, and the agreement is usually better than 2 milligals at worst, and often better than 1 milligal. This consistency leads us to believe that ± 2 milligals is a reasonable and conservative estimate of the accuracy of most of the land gravity stations in our data set. Marine gravity measurements have inherently larger errors. We estimate the marine stations to generally have an accuracy of ± 5 milligals, though some of the marine areas have contours which suggest inconsistencies in the data in excess of 5 milligals.

Map Preparation

From the gravity data file we prepared a rectangular grid of gravity values with grid points 2.5 km apart. This grid of regularly spaced values is necessary as input into our contouring program. The gridding program, written by M. Webring, is based on a minimum curvature algorithm (Briggs, 1974) which fits a surface to the originally irregularly spaced data points and then uses this surface to estimate gravity values at the regularly spaced grid points.

The 44,800 data points displayed on Plates 3 and 4 are those forming the subset of the total data set actually used in preparing the contour map. Actual density of stations in some areas is much greater and not easily plotted at this scale on our plotting devices.

The contour interval is 5 milligals, which is more than twice the estimated uncertainty in our land data points. Highs and lows defined by a single data point should always be suspect without corroborating data. Several dozen obviously bad data points were edited from our file in the preparation of this map. Unfortunately, we cannot guarantee that other errors do not remain.

Acknowledgments

We wish to thank the National Oceanic and Atmospheric Administration, the Defense Mapping Agency, The Canadian Gravity Centre, and all of the many people who generously offered us their data.

Tom Hildenbrand, Bob Kucks, Mike Webring, Ron Sweeney, and Danny Dansereau gave substantial help in the computations. Ruth Kolpanen, Pat Hill, and Dan Michalski assisted in editing and drafting these maps.

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Bean, R. J., 1953, Relation of gravity anomalies to the geology of central Vermont and New Hampshire: Geological Society of America Bulletin, v. 64, p. 509-537.

Briggs, I. C., 1974, Machine contouring using minimum curvature: Geophysics, v. 39, p. 39-48.

Hildreth, C. T., 1979, Bouguer gravity map of northeastern United States and southeastern Canada, onshore and offshore: New York State Museum Map and Chart Series, no. 32, scale 1:1,000,000.

International Association of Geodesy, 1971, Geodetic Reference System 1967: International Association of Geodesy Special Publication, no. 3, 116 p.

Joyner, W. B., 1963, Gravity in north-central New England: Geological Society of America Bulletin, v. 74, p. 831-857.

Morelli, C., (ed.), 1974, The International Gravity Standardization Net 1971: International Association of Geodesy Special Publication, no. 4, 194 p.

Plouff, D., 1977, Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-file report 77-534, 45 p.

APPENDIX A

Data Sources

Principal Sources

National Oceanic and Atmospheric Administration
National Geophysical and Solar-Terrestrial Data Center (D62)
Boulder, CO 80302

Defense Mapping Agency
St. Louis Air Force Station
St. Louis, MO 63118

Energy, Mines and Resources of Canada
Earth Physics Branch
Gravity and Geodynamics Division
1 Observatory Crescent
Ottawa, CANADA K1A 0Y3

Published Data added to Master Data Files

Abbey, D. A., 1972, Gravity study of several Maine coastal plutons, southeastern Maine: SUNY at Buffalo M. S. thesis, 77p.

Anderson, R., 1978, Northern termination of the Massabessic gneiss, New Hampshire: Dartmouth College M. S. thesis, 111 p.

Bothner, W. A., 1977, Gravity study of Cape Cod Bay: U.S. Geological Survey Open-file report 77-497.

Bothner, W. A., and Harrower, K. L., 1973, Gravity survey of the Cape Neddick Complex and associated offshore anomaly in southern Maine: Geological Society of America Abstracts with Programs, v. 5, p. 140.

Bothner, W. A., and Brace, R-L. D., compilers, 1978, Principal facts for gravity stations in the State of Connecticut: U.S. Geological Survey Open-file report 78-804, 46 p.

Bromery, R. W., Davis, M. and Ahmad, F., 1972, Simple Bouguer anomaly map of Connecticut: U.S. Geological Survey Open-file report.

Fitzpatrick, J. C., 1978, Interpretation and significance of a major positive gravity anomaly in central Massachusetts: University of Massachusetts, Amherst, M.S. Thesis, 45 p.

Ginsburg, M. S., 1959, A gravity survey of the Boston Basin region: Massachusetts Institute of Technology M.S. thesis, 68 p.

Nielson, D. L., Clark, R. G., Lyons, J. B., Englund, E. J., and Borns, D. J., 1976, Gravity models and mode of emplacement of the New Hampshire Plutonic Series: Geological Society of America Memoir 146, p. 301-318.

Osberg, P. H., Wetterauer, R., Rivers, M., Bothner, W. A., and Creasey, J. W., 1978, Feasibility study of the Conway Granite as a possible geothermal energy source: Dept. of Energy Contract No. EY-76-S-02-2686, 184 p., 10 pls.

Simpson, R. W., and LaPierre, P., 1978, Principal facts for gravity profiles at Orrington and Waterville, Maine: U.S. Geological Survey Open-file report 78-849, 6 p.

______1979, Principal facts for gravity profiles near South Penobscot, Maine: U.S. Geological Survey Open-file report 79-767, 13 p.

Sweeney, J., 1972, Detailed gravity investigation of shapes of granitic intrusives, south-central Maine, and implications regarding their mode of emplacement: SUNY at Buffalo Ph.D dissertation, 117 p.

Weston Geophysical Research, Inc., 1977, Models of White Mountain Series intrusives based on gravity and magnetic data: Report BE-SG-7701 (Revision I, March 1977), prepared for Boston Edison Co.

Unpublished data:

Bothner, W. A., FAY 23 cruise, Gulf of Maine; Ossipee and Belknap Complexes, N.H.; Rhode Island.

Hodge, D. S. - Eastern Maine.

Kane, M. F. - Merrymeeting Complex, N.H.; Pawtuckaway and Mad River Plutons, N.H.

Revetta, F. A. - Central New York State; Clarendon-Lindon Fault Region, western New York; St. Lawrence Valley, northern New York and Canada.

Urban, T. C., and Diment, W. H. - Pennsylvania, New Jersey, and New York.

APPENDIX B

Defense Mapping Agency
Gravity Format and Formulae

GRAVITY STATION DATA FORMAT

1 August 1976

DoD Gravity Library

Explanation of DoD Gravity Library Station Data Format.

I. Definitions and Notation

II. Formulas used in Computing Free-Air and Bouguer Anomalies

III. Gravity Coding Sheet

A graphic representation of the Gravity Station Data Format showing the position of the data fields and also a listing of the codes for each data field. This sheet is used to code gravity source documents for keypunching.

I. DEFINITIONS

1. Observed (or measured) Gravity (g) is the value of gravity at the site of the gravity instrument referenced to a recoverable base reference station.

2. Theoretical Gravity: The approximation of the closed form of the Gravity Formula 1967 is used for theoretical gravity (γ) at sea level. Reference: "Geodetic Reference System 1967," International Association of Geodesy, Special Publication, No. 3.

$$\gamma = 978031.85 (1 + 0.005278895 \sin^2\phi + 0.000023462 \sin^4\phi) \text{ mgals.}$$

3. Units of Gravity: The mgal is the unit for our gravity data.

4. Free-Air Anomaly: To reduce gravity to sea-level, we use the normal gradient of gravity or "free-air" correction: +0.3086h mgal; h is in meters and positive down to the geoid. The second order terms of the elevation correction will be applied when they are of the magnitude of 0.1 mgal or more. The free-air anomaly is derived from Δg_f (mgal) = $g + 0.3086h - \gamma$.

5. Simple Bouguer Anomaly: The simple Bouguer Anomaly is derived from Δg_B (mgal) = $g + 0.3086h - 0.1119h - \gamma$.

The term 0.1119h is the attraction of an infinite flat plate, thickness h and with standard density $p = 2.67 cm^3$.

6. Standard Deviation (Error): Connotes that there is a 68% probability that the free-air or Bouguer anomalies will fall between the indicated + and - value: e.g., if the free-air anomaly is 10 mgal with a ± 2 mgal error or standard deviation, then there is a 68% probability that the value lies between 8 and 12 mgals.

7. The computations of free-air and Bouguer Anomalies with various modes of n observation types of terrain are given in the Anomaly Computation Chart.

II. Formulas Used in Computing Free-Air and Bouguer Anomalies

1. Symbology

Symbol	Definition	Units
Δg_f	Free-Air Anomaly	milligals
Δg_B	Bouguer Anomaly	milligals
ϕ	Latitude of Observation	degrees, minutes
γ	Theoretical Gravity	milligals
g	Observed Gravity	milligals
h	Elevation (Col 23-29) of surface of land, ice or water; depth of ocean (positive downward) elevation types 3, 4, and 5. + = above SL; - = below SL.	meters
d	Supplemental Elevation (col 31-35) = Depth of Ocean, lake, ice or instrument (positive downward).	meters

2. Anomaly Computations

See following pages:

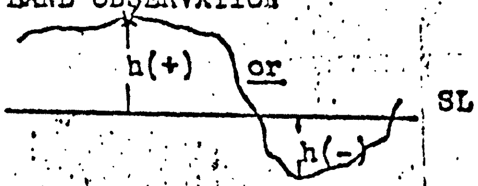
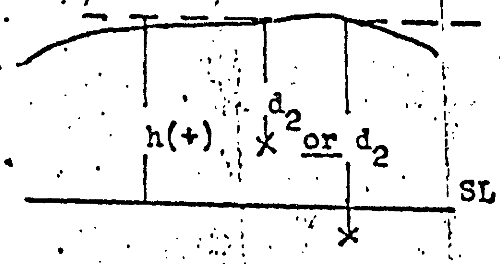
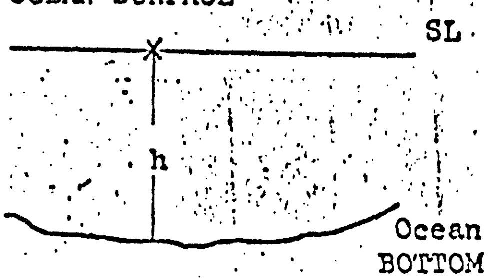
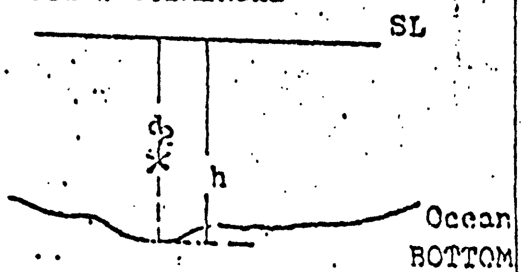
b = Bouguer Correction Factor

$= 2\pi k\rho = 0.04191\rho$

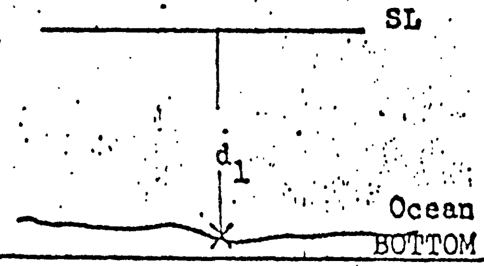
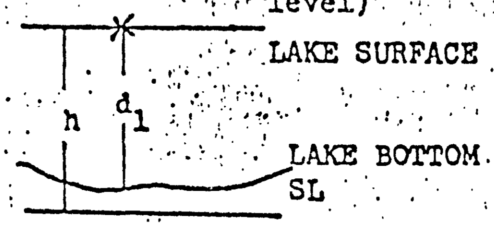
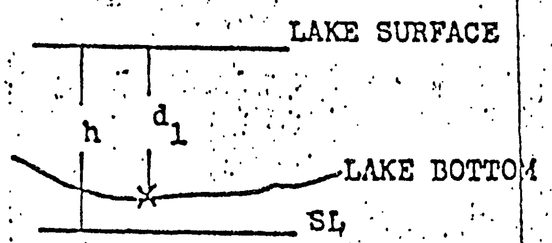
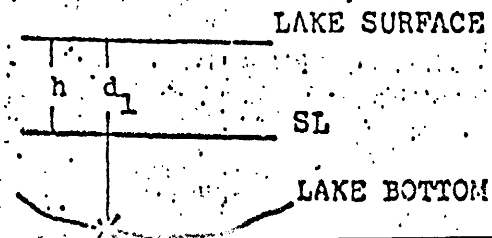
ρ = Density Used in Computations

Substance	ρ	$b = 2\pi k\rho$
Fresh Water	1.0	0.04191
Salt Water	1.027	0.04304
Ice	0.917	0.03843
Land	2.67	0.1119
Land-Fresh Water	1.67	0.06999
Land-Salt Water	1.643	0.06886
Land and Ice	1.753	0.07347

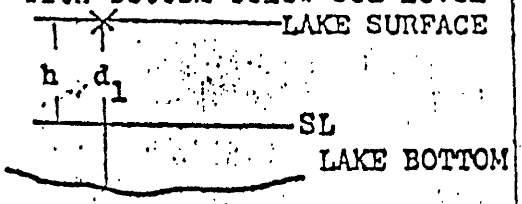
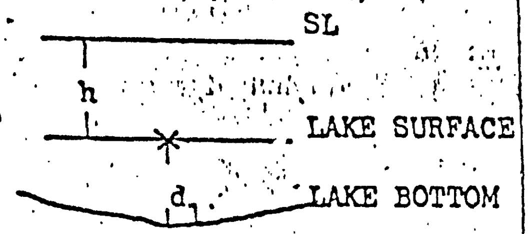
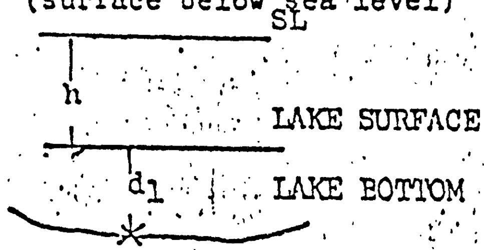
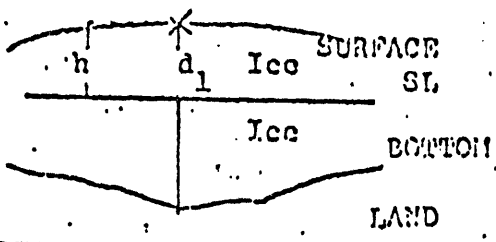
ANOMALY COMPUTATION CHART (p. 1)

Elev. Type Col.21	SITUATION	FREE-AIR ANOMALY COMPUTATION	BOUGUER ANOMALY COMPUTATION
1	LAND OBSERVATION 	$\Delta g_f = g + 0.3086h - \gamma$	$\Delta g_B = \Delta g_f - 0.1119h$
2	SUBSURFACE 	$\Delta g_f = g + 0.2238d_2 + 0.3086(h-d_2) - \gamma$ NOTE: d_2 = depth of instrument	$\Delta g_B = \Delta g_f - 0.1119h$
3	OCEAN SURFACE 	$\Delta g_f = g - \gamma$	$\Delta g_B = \Delta g_f + 0.06886h$ NOTE: h = depth of ocean positive downward from surface
4	OCEAN SUBMERGED 	$\Delta g_f = g - 0.2225d_2 - \gamma$ NOTE: d_2 = depth of instrument positive downward	$\Delta g_B = \Delta g_f + 0.06886h$ NOTE: h = depth of ocean positive downward

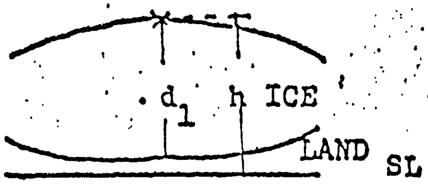
ANOMALY COMPUTATION CHART (p. 2)

Elev. Type Col.21	SITUATION	FREE-AIR ANOMALY COMPUTATION	BOUGUER ANOMALY COMPUTATION
5	OCEAN BOTTOM 	$\Delta g_f = g - 0.2225d_1 - \gamma$ NOTE: d_1 = depth of ocean positive downward	$\Delta g_B = \Delta g_f + 0.06886d_1$
6	LAKE SURFACE (above sea level) 	$\Delta g_f = g + 0.3086h - \gamma$	$\Delta g_B = \Delta g_f - 0.04191d_1 - 0.1119(h-d_1)$ NOTE: d_1 = depth of lake positive downward
7	LAKE BOTTOM (above sea level) 	$\Delta g_f = g + 0.08382d_1 + 0.3086(h-d_1) - \gamma$	$\Delta g_B = \Delta g_f - 0.04191d_1 - 0.1119(h-d_1)$
8	LAKE BOTTOM (below sea level) 	$\Delta g_f = g + 0.08382d_1 + 0.3086(h-d_1) - \gamma$	$\Delta g_B = \Delta g_f - 0.04191h - 0.06999(h-d_1)$

ANOMALY COMPUTATION CHART (p. 3)

Elev. Type Col. 21	SITUATION	FREE-AIR ANOMALY COMPUTATION	BOUGUER ANOMALY COMPUTATION
9	LAKE SURFACE (above sea level) with bottom below sea level 	$\Delta g_f = g + 0.3086h - \gamma$	$\Delta g_B = \Delta g_f - 0.04191h - 0.06999(h-d_1)$
A	LAKE SURFACE (below sea level) 	$\Delta g_f = g + 0.3086h - \gamma$	$\Delta g_B = \Delta g_f - 0.1119h + 0.06999d_1$ <u>NOTE:</u> d_1 = depth of lake positive downward
B	LAKE BOTTOM (surface below sea level) 	$\Delta g_f = g + 0.3086h - 0.2248d_1 - \gamma$ <u>NOTE:</u> d_1 = depth of lake positive downward	$\Delta g_B = \Delta g_f - 0.1119h + 0.06999d_1$
C	ICE CAP (bottom below sea level) 	$\Delta g_f = g + 0.3086h - \gamma$	$\Delta g_B = \Delta g_f - 0.03843h - 0.07347(h-d_1)$ <u>NOTE:</u> d_1 = depth of ice positive downward

ANOMALY COMPUTATION CHART (p. 4)

Elev. Type Col.21	SITUATION	FREE-AIR ANOMALY COMPUTATION	BOUGUER ANOMALY COMPUTATION
D	ICE CAP (bottom above sea level) 	$\Delta g_f = g + 0.3086h - \gamma$	$\Delta g_B = \Delta g_f - 0.03843d_1 - 0.1119(h-d_1)$ NOTE: d_1 = depth of ice