BOUGUER GRAVITY ANOMALY MAP OF

NEW JERSEY

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DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

BOUGUER GRAVITY ANOMALY MAP OF NEW JERSEY

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Trenton, New Jersey

1965

CONTENTS

ILLUSTRATIONS

(Plates are in pocket)

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ABSTRACT

A Bouguer Gravity Anomaly Map of New Jersey (scale 1:250,000) is presented. It is based on over 4000 gravity observations, half of which were previously unpublished. Contour interval is 5 milligals and the map is translucent, so that it can be used as an overlay on the State Geologic Map. A cross-section from Phillipsburg, New Jersey, to Barnegat Bay is given with Bouguer and isostatic anomalies shown. The trans-New Jersey gravity high is a marked positive Bouguer and isostatic anomaly and is related to basement or sub-basement density excess. The trans-New Jersey high is part of a series of gravity highs running from Georgia to Vermont and generally associated with the Piedmont Province south of New Jersey.

INTRODUCTION

Scope and Purpose

Over 4000 gravity observations have been made in New Jersey and in nearby areas of New York and Pennsylvania. G. P. Woollard (1943a) published a regional gravity map based on 1000 stations of the middle Atlantic states which covered New Jersey, as well as Delaware, Connecticut, southern New York, and eastern Pennsylvania. He further reports the results of a detailed gravity survey consisting of 700 gravity observations in a 5-mile wide section between Barnegat Bay and Phillipsburg, New Jersey. Steenland and Woollard (1952) report the results of a gravity study of the Courtlandt Complex near Peekskill, New York, based on 185 stations. J. B. Hersey (1944) has made a gravity map of an area west of Phillipsburg, New Jersey, based on 700 stations. Faculty and students at Princeton University in unpublished detailed studies have added over 2000 new gravity observations to this published data. About 1700 of these new measurements have been reported in six theses in the Department of Geological Engineering (Bonini, 1949; Meier, 1949; Johnson, 1956; Stewart, 1962; Vreeland, 1965; and Wofford, 1962).

The purpose of this geologic report is to present the revised gravity anomaly map of New Jersey and surrounding area compiled from both the published and unpublished data. For those not familiar with gravity anomalies, there is a brief section on anomalies and their interpretation in New Jersey.

ACKNOWLEDGEMENTS

George P. Woollard, Director, Institute of Geophysics, University of Hawaii, kindly supplied a copy of his revised 1943 data. John E. Hardaway and John H. Vreeland, while students at Princeton University, provided considerable assistance both in the field and in preparation of the gravity map. Princeton University supplied the vehicle and gravity instrument for the field work. The Higgins Fund of Princeton University and the National Science Foundation provided partial support for the field work and office compilation of the data. The writer is grateful to Kemble Widmer, New Jersey State Geologist, for his encouragement with respect to preparation of the map and for making possible its publication as a translucent overlay for the State Geologic Map.

GRAVITY DATA

This section refers only to the Princeton University data, since Hersey (1944), Woollard (1943a), and Steenland and Woollard (1952), have covered the following items with respect to their observations.

Observed Gravity Values

Values for observed gravity are based on the absolute value (980.1776 gals)[1] in the center of Room 14[2], Guyot Hall, Princeton University, and all field stations are tied to this value. The Guyot Hall value has been established by measurements between it and the fundamental gravity station in Washington, D. C., by Bonini and Woollard (1957).

1) The gal is the unit of gravitational acceleration and is equal to an acceleration of one centimeter per second squared. The milligal (mgal) is one-thousandth of a gal and is the most frequently used unit.

2) In 1964 this room was converted into a corridor to permit access to a new wing. The original site is otherwise unchanged and is in the center of the corridor in the old part of the building between Rooms 13 and 15.

The general plan of gravity observations was to establish field base stations related to Guyot Hall by measuring short-time closed loops between them. Local observations were then made relative to the field bases, with station reoccupations every two to four hours for instrumental drift control.

Elevation and Position Control

Elevations were determined either by altimeters tied to benchmarks, or by interpolation from U. S. Geological Survey topographic maps contoured on a 20 foot interval. In general, the elevation errors are estimated to be less than five feet, producing an estimated error in the gravity anomalies caused by elevation errors of less than 0.3 mgal. Stations were located on topographic sheets at known points, or based on mileage from such points. On traverses by foot, positions were located by pace and compass between known points.

Data Reductions

Theoretical values of gravity at sea level were determined according to the 1930 International Gravity Formula (U. S. Coast and Geodetic Survey, 1942). The combined Bouguer (mass) and free air correction value, 0.06 mgal/ft above sea level, was used for all reductions assuming a density of 2.67 gm/cc for material above sea level. Terrain corrections were applied only to stations where the effect was greater than 0.4 mgal.

Instruments and Calibration

A Worden Gravimeter, W-57, was used for all measurements except those of Bonini (1949) and Meier (1949), on which the Humble X-type meter was employed. The Worden calibration was determined by comparison with pendulum and gravimeter data by others (see Bonini, 1963, fig. 1). The Humble calibration was determined by comparison with U. S. Coast and Geodetic Survey pendulum stations in the eastern United States in 1948.

Accuracy of Gravity Data

Observed gravity values are considered to be accurate to 0.2 mgal. Bouguer anomaly values, in which observed gravity, latitude, and elevation are important, should be accurate within 0.5 mgal.

The Gravity Anomaly Map

Bouguer gravity anomalies are contoured on a 5 mgal interval on the basis of the stations indicated. Reference is made to the sources of detailed and regional data. Although most of the regional data is derived from Woollard (1943a), further regional stations were added by John E. Hardaway and John H. Vreeland of Princeton University in areas of poor control or questionable data. A small geologic map of New Jersey and an abbreviated gravity anomaly map overlay (both scales approximately 1:1,000,000) are provided in the rear pocket. For more detailed studies, a large gravity map is also included. It is drawn on a scale of 1:250,000, and is suitable as an overlay on the New Jersey Geologic Map which can be purchased for $3.00 from the following source:

Map and Publication
Sales Office
P. O. Box 1889
Trenton, New Jersey 08625

SIGNIFICANCE OF GRAVITY ANOMALIES

General

The gravity anomaly at a given location is the difference between the value observed at that point and the predicted theoretical value. In the calculation of a theoretical gravity value two things must be considered: (1) the latitude of the station and (2) its elevation with respect to sea level.

The theoretical value of gravity at sea level at a given latitude is determined according to the 1930 International Gravity Formula (U. S. Coast and Geodetic Survey, 1942), which considers the non-spherical shape of the earth and the effects of the centrifugal force. The "latitude effect" in New Jersey is approximately 1.2 mgal/mile, increasing northward.

The second theoretical consideration concerns the elevation of a station with respect to sea level, since the International Gravity Formula predicts gravity at sea level. If a station is 100 feet above sea level, it is 100 feet further from the earth's center and the theoretical value of gravity there will be less than that given by the Formula. If one considers only the change in elevation between the station and sea level (as would be the case in a tall building), this effect is 0.094 mgal/ft decreasing upward from sea level. This is called the free air effect. On the other hand, for field observations when one is at 100 ft elevation, there is mass (rock) between the station and sea level, and this mass in theory would increase the gravitational attraction by an amount determined by the elevation and the density of the material. This effect is called the Bouguer, or mass, effect. Using a density between the station and sea level of 2.67 gm/cc, this effect is 0.034 mgal/ft, increasing with increase in elevation. This assumes that there is no topography near the station, i.e., that the station is in this case on a plain 100 feet above sea level. For detailed work where there is considerable topography, terrain corrections must be made.

Normally, the free air effect and the Bouguer, or mass, effect are combined as follows for elevation above sea level:

Free air effect	-0.094 mgal/ft
Bouguer (mass) effect	+0.034 mgal/ft
Combined effect	-0.060 mgal/ft

The theoretical result is a decrease in gravity with an increase in elevation. Therefore a correction has to be made for elevation.

When these elevation effects are taken into consideration, we can predict a theoretical value for gravity for any given location. The difference between the theoretical and observed gravity values is the anomaly. If both the free air and Bouguer (mass) corrections are applied, the resulting anomaly is the "Bouguer anomaly." This is the anomaly of interest to geologists, since the Bouguer anomaly is related more directly to subsurface mass distribution. If the subsurface mass distribution were uniform everywhere, the anomaly would be uniform. In general, a positive Bouguer anomaly indicates an excess of mass beneath the station and a negative Bouguer anomaly, a deficiency.

An isostatic anomaly is derived by applying one further theoretical correction. Simply stated, the theory of isostasy says that the major topographic features of the earth are associated with mass irregularities, i.e., mountainous areas have roots of lower mass, and mountains tend to "float" in equilibrium in the earth's crust, much as an iceberg does in water. The isostatic correction takes into account the lower mass of the root and therefore lower observed gravity to be expected if the area is in perfect isostatic equilibrium. There are several ways of correcting for isostasy, but an isostatic anomaly indicates a departure from the ideal isostatic condition. A positive anomaly indicates an excess of mass and a negative anomaly, a deficiency. The Appalachian Mountains have a 50 mgal negative isostatic anomaly (Woollard, 1943b), indicating a deficiency of mass at depth, or too much root for the size of the mountain. The primary use of isostatic anomalies is to give an indication of just how well adjusted the earth's crust is to the large topographic features. Both isostatic and Bouguer anomalies are shown on cross-section C-D.[3] For New Jersey, isostatic adjustment has not been perfect, since the trans-New Jersey high is notably positive and the Newark Triassic Basin on this line of profile is negative. For a more complete discussion of gravity anomalies, see Dobrin (1960) or Woollard (1941).

DETAILED SURVEYS AND SUMMARIES OF RESULTS

Fall line Studies

The work of Meier (1949) and Bonini (1949) was directed toward interpreting residual gravity anomalies in terms of basement density variations. Meier's area covered that part of the coastal plain in which Woollard (1943a) and Ewing, Woollard, and Vine (1939) outlined the so-called "Plainsboro Triassic fault block."[4] Gravity and magnetic highs are considered to be associated with basement rocks, basalt and gabbro. Bonini's area was in the Trenton prong of the Piedmont Province. He showed that there were minor (3-5 mgal) high gravity anomalies associated with gabbro and 3 mgal lows associated with the infolded Cambrian Chickies quartzite. Both showed northeast-trending residual gravity anomalies which are parallel or sub-parallel to the general grain of Piedmont rocks.

Trans-New Jersey Gravity High

Johnson (1956) concentrated his work in outlining a section of the gravity high extending across the New Jersey Coastal Plain. He found that basement topography might

3) The isostatic corrections used in calculation of the isostatic anomalies were from data supplied by Dr. U. A. Uotila, Department of Geodetic Science, Ohio State University, for a value of T=30 km on the Airy-Heiskanen System.

4) This "fault block" was found not to exist by Fiske and Bonini (1956), since the gravity anomalies and seismic time offset reported earlier were found to be associated with pre-Triassic and Triassic rocks in a normal relationship.

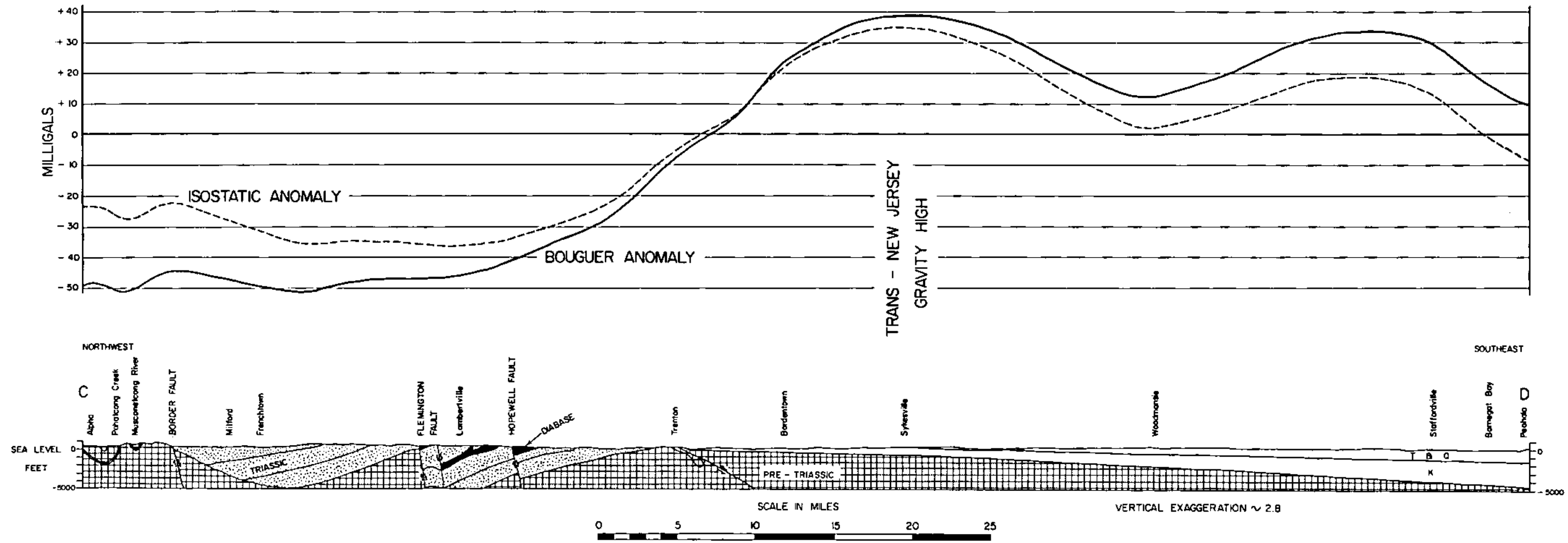

FIGURE 1. CROSS-SECTION FROM PHILLIPSBURG TO BARNEGAT BAY SHOWING BOUGUER AND ISOSTATIC ANOMALIES. GEOLOGY IS MODIFIED FROM SECTION C-D OF THE NEW JERSEY GEOLOGIC MAP.

explain residual anomalies on the order of 1 or 2 mgals on the crest of the high, but that most of the high trend itself was caused by high density basement or sub-basement rocks.

Rocky Hill Diabase

Stewart (1962) further outlined the residual gravity high associated with the Rocky Hill diabase, confirming the earlier work of Woollard (1943a) on this body.

Round Valley

Wofford (1962) investigated the diabase of Cushetunk Mountain, site of the Round Valley Reservoir. This data, in addition to later work by the author and his students, confirm the original estimate that the diabase dips up to 80^{o} outwardly from Round Valley on the northeast limb, and more gently (around 30^{o}) on the southwest limb (see Widmer, 1960). Magnetic anomalies also confirm this estimate.

Sanford (1963) indicates that the Cushetunk material is a flow and structurally an anticline. Based on detailed geological studies in this area by the New Jersey Geological Survey, Widmer (personal communication) indicates that the petrologic classification of the Cushetunk material is diabase and the attitude of the surrounding Brunswick shale indicates that the diabase is intrusive and probably in the form of a cone sheet.

REGIONAL FEATURES

In general, the gravity anomaly trends are parallel to sub-parallel to the structural trends of the Piedmont and Appalachians.

The most prominent feature in New Jersey is the trans-New Jersey gravity high, on which there is a peak Bouguer value of +42 mgals. It crosses the state in a northeast direction, from near Wilmington, Delaware, through Skyesville, New Jersey, just east of Staten Island and into Manhattan and Queens, New York (see map and cross-section). Woollard (1943a) shows a continuation into Connecticut and Massachusetts on the northeast and southward less prominently through Washington, D. C. A lesser group of highs is located near Cedar Grove and Millville, New Jersey, and the trend is nearly parallel to the trans-New Jersey high. In gross aspect, the trans-New Jersey high is part of a series of gravity highs running from Georgia to

Vermont. Although it occurs over the New Jersey Coastal Plain, it is clearly associated with the Piedmont south of New Jersey, and north of New Jersey it is over the basement on the western edge of the Connecticut Valley in Connecticut and Massachusetts. Longwell (1943) has made an analysis of gravity anomalies in Connecticut and eastern New York and their relationship to the Connecticut Triassic Basin.

Woollard (1943a) has discussed the trans-New Jersey gravity high in detail (p. 804-805 and p. 815) and concludes that the source of the anomaly is rather deep. Assuming a density contrast of 0.5 gm/cc using values for granite of 2.67 gm/cc and gabbro of 3.15 gm/cc - the maximum one might expect - he calculates the maximum depth to the center of mass of the source to be 16 miles (26 km) with its top near 11 miles (8 km). The source could be shallower, however, by adjusting the density contrast and size of the body. It should be noted that Ewing, Woollard, and Vine (1939) report high seismic velocities up to 22,000 ft/sec (6.71 km/sec) near the trans-New Jersey gravity high, suggesting that pre-Cretaceous basement rock may be of gabbroic composition.

The main features of the Coastal Plain gravity picture are related to pre-Cretaceous basement or sub-basement density variations, similar to results of investigations on the Atlantic Coastal Plain further south (Bonini and Woollard, 1960).

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PLATE I

BOUGUER GRAVITY ANOMALY CONTOUR MAP OF NEW JERSEY

Prepared by William E. Bonini
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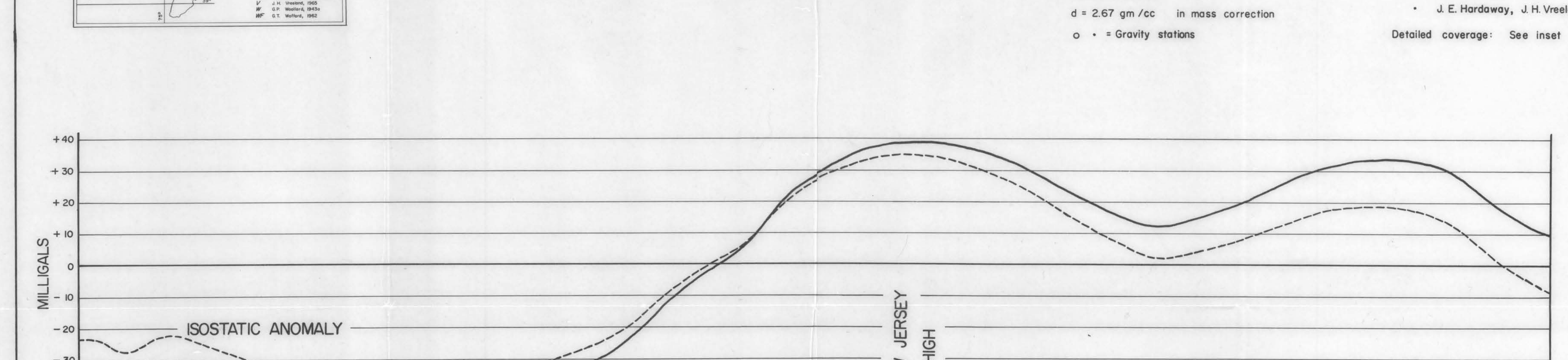
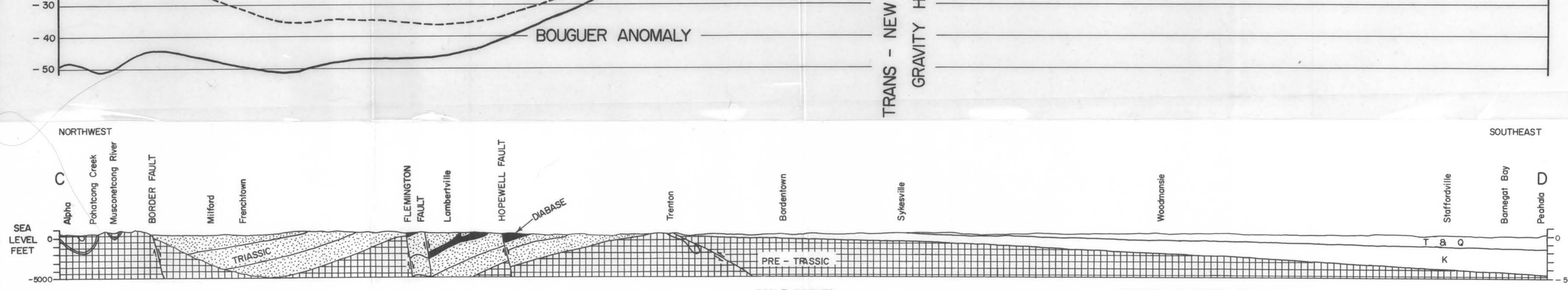
1965

Scale in miles
0 5 10 15 20 25

Contour interval: 5 milligals
Sea level datum
d = 2.67 gm/cc in mass correction
o • = Gravity stations

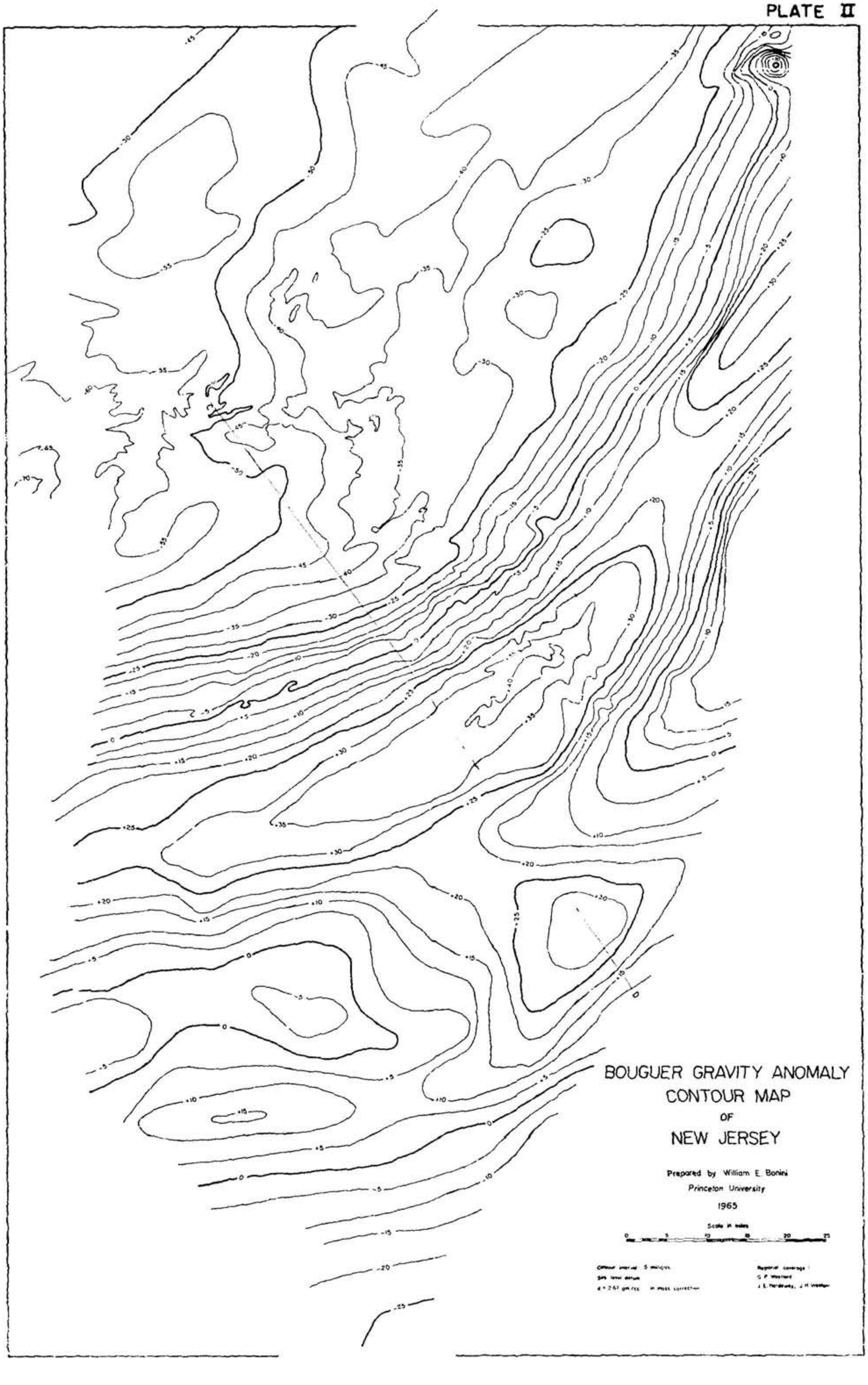
Regional coverage:
o G. P. Woollard, 1943a
• J. E. Hardaway, J. H. Vreeland
Detailed coverage: See inset





CROSS-SECTION FROM PHILLIPSBURG TO BARNEGAT BAY SHOWING BOUGUER AND ISOSTATIC ANOMALIES. GEOLOGY IS MODIFIED FROM SECTION C-D OF THE NEW JERSEY GEOLOGIC MAP

PLATE II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