GRAVITY INVESTIGATION OF THE TRIASSIC NEWARK BASIN AND ADJACENT PRECAMBRIAN HIGHLANDS IN THE VICINITY OF THE WATCHUNG MOUNTAINS

By JAMES BAMBRICK JR.

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Written under the direction of

Dr. Martha M. Hamil

of the Department of Geology

and approved by

Martha M. Hamil

Michael J. [illegible]

William Bonini

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ABSTRACT OF THE THESIS

Gravity Investigation of the Triassic Newark Basin and Adjacent Precambrian Highlands in the Vicinity of the Watchung Mountains

By JAMES BAMBRICK JR.

Thesis Director: Dr. Martha M. Hamil

A section of the Triassic Newark Basin and adjacent Precambrian highlands, which roughly coincides with the topographic extent of the Watchung Mountains, is investigated gravimetrically. The Bouguer anomaly map, graphical residual, second derivative and two dimensional models suggest a shallow basin with maximum depth on the order of 8000 feet. Although intrabasin structure related to the Watchung Mountains generally could not be resolved, significant anomalies associated with the Precambrian highlands appear. Similar work in other Triassic basins tends to support these results.

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INTRODUCTION

Gravity anomaly interpretation, although arbitrary by nature, finds usefulness in a variety of geologic problems in that it never conclusively resolves a problem but often sets limits on the extent of geologic models. This well known fact among gravity investigators is mentioned here because geophysical techniques have traditionally played a relatively minor role in the interpretation of Triassic geology, particularly in New Jersey. Past investigations of the Newark basin have generally been confined to paleontologic and sedimentologic aspects, primarily to determine an accurate time-rock scale and sedimentary environment respectively. Relatively little attention was given to structural geology; the simple half-graben model sufficed.

In light of modern tectonic theory, a large and diverse body of Triassic literature has developed. Several investigators have attempted to fit this body of data into a regional theory of Triassic basin formation and deformation. However, serious discrepancies have arisen. Of particular interest is the controversy over whether the Triassic basins of New Jersey and Connecticut were previously connected. In general, the "broad-terraine" hypothesis proposes an earlier link between the two basins. Consequently, depth is considerable and intrabasin deformation is extensive. The "isolated-basin" hypothesis requires a shallow basin depth with moderate to little deformation.

Any attempt to model the Newark basin in the context of regional tectonics must account for certain fundamental basin parameters such as type and extent of faulting and depth of basin.

A section of the Newark basin and adjacent highlands, which roughly coincides with the topographic extent of the Watchung Mountains, was selected for this study (Figure 1). Detailed Bouguer anomaly, graphical residual and second derivative maps are presented and interpreted with respect to current geologic data. Comparison with similar surveys in other Triassic basins is also presented. Two dimensional modeling along a traverse through the center of the basin, is included in an attempt to set limits on basin configuration which may aid in resolving the broad-terraine vs. isolated-basin controversy.

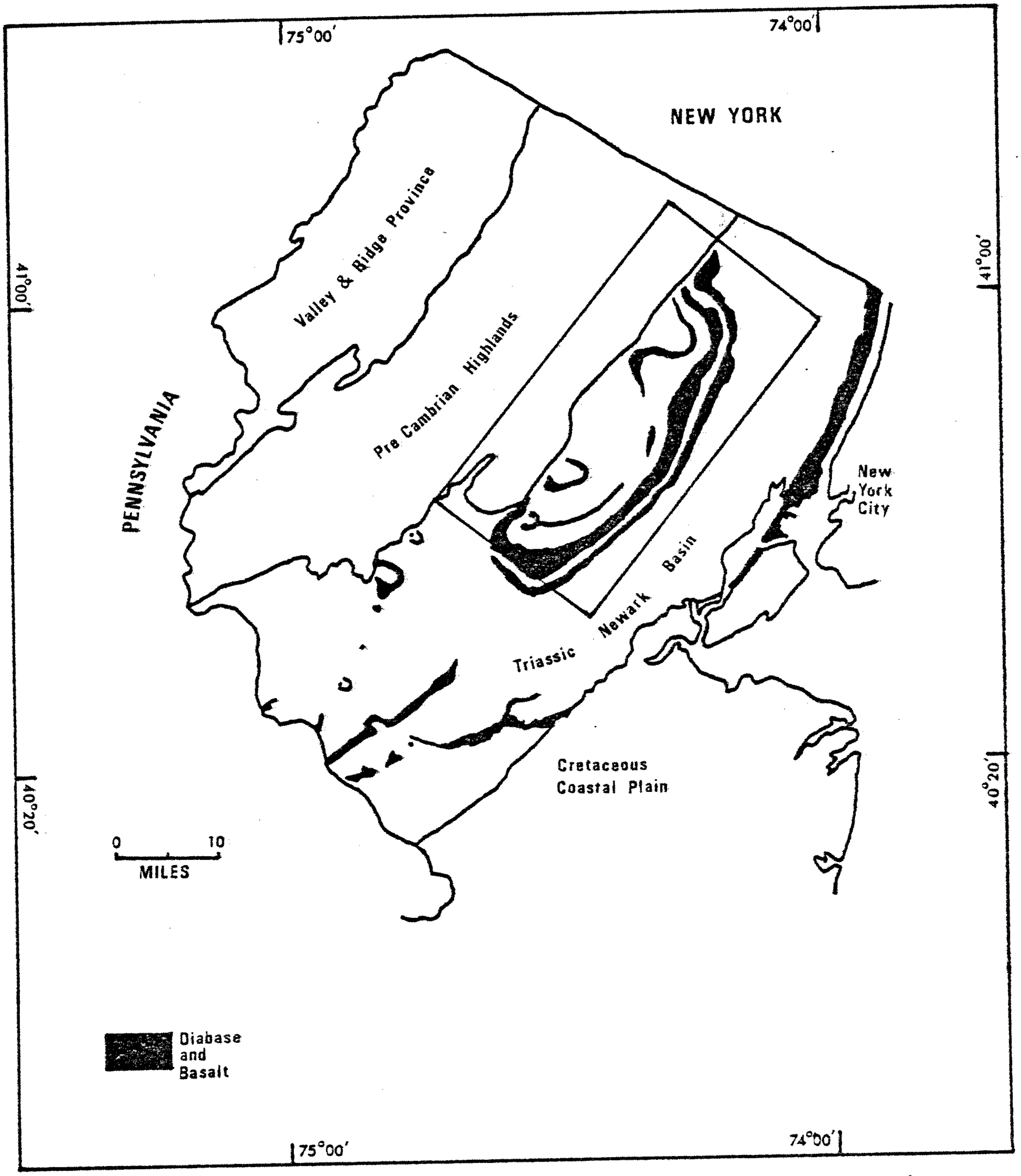


FIGURE 1. Regional map of New Jersey (modified after Bonini, 1965) The rectangular area outlines the study area.

TECTONIC DEVELOPMENT OF THE NEWARK BASIN

The tectonic development of the Newark basin has been a matter of controversy for nearly 100 years. Within this time, two distinctly opposed schools of thought have arisen. Proponents of the "isolated-basin" theory argue that the Newark and Connecticut basins have always been separate. Strata in each basin generally dips toward the border fault with little intrabasin deformation and sediment thickness. Proponents of the "broad-terraine" theory argue that the two basins were formerly connected through an anticline which has subsequently eroded exposing the intervening crystalline rocks and leaving the basins as remnants.

Earlier investigation of the northern end of the Newark basin led to the interpretation that the Palisade Sill became discordant and transected most of the overlying sediment. This agreed well with those who believed in a uniform northwest dip. However, reinterpretation of this area in light of detailed structural data (Sanders, 1974) shows that the strike of the surrounding sedimentary layers swings around and becomes perpendicular to the fault near Haverstraw, New York. Only minor discordancy is observed. This structural configuration is interpreted by Sanders to be the consequence of a transverse anticline (Danbury Anticline) which gently folded the sill and surrounding sediments into a synform.

DeBoer's (1968) study of thermal remnant magnetism in the Newark and Connecticut basalt flows indicate that all three Watchung flows are equivalent to the middle (Holyoke) flow in Connecticut. This indicates a comparatively short igneous period in the Newark basin which makes simple time-stratigraphic correlation unreasonable.

Perhaps the strongest evidence in favor of the isolated-basin theory comes from paleocurrent analysis and radiometric dating of sediment particles. Detailed analysis of paleoflow structures (Klein, 1969) indicates that the Newark basin filled from all sides, as did the Connecticut and several other Triassic basins. Radiometric dates on sediment from the northern part of the Newark basin (Abdel-Monem and Kulp, 1968) indicate a source area to the east. It is argued that this precludes an eastward extension of the basin much beyond its present limits.

This evidence, however, is not without opposition. Sanders (1974) comments that although sediment may have been derived from the east, paleoflow structures and radiometric dating give no indication of how far to the east. Possibly these sediments came from the opposing wall of the graben. Ratcliffe (1971) also reports on a fabric analysis of Precambrian and lower Paleozoic rocks at the extreme northern end of the Ramapo fault. Based on cataclastic effects in the Precambrian and mylonite zones in the lower Paleozoic rocks, he concludes that the Ramapo fault may have been active since the late Precambrian. He further proposes that the border fault "system" may be part of a deep seated crustal fracture system. This would tend to support the broad-terraine theory.

GEOLOGIC SETTING

Non-marine Newark Group sediments and associated igneous rocks generally dip 15 to 20 degrees northwest where they terminate against the Ramapo fault (Figure 2). The Ramapo fault is normal with reported dips ranging from 30 to 60 degrees or greater. Movement is generally assumed to be syndepositional since the non-marine sediments thicken toward the fault (Van Houten, 1969). The upthrown side of the Ramapo fault, within the study area, consists of Precambrian crystalline rocks exposed through extensive erosion.

Non-marine Newark Group sediments comprise basal conglomerates and fanglomerates (Stockton Formation) followed by lacustrine deposits (Lockatong Formation) and extensive red shales and mudstones (Brunswick Formation). East of the study area, along the Hudson River (Figure 1), the Stockton Formation crops out with a thickness of approximately 1300 feet. Cropping out within the Stockton, in this area, is the Palisade Sill which dips conformably toward the fault. The subsurface extent and thickness of the sill in a northwesterly direction is not known, but is inferred to be considerable based on its northernmost outcrop pattern and exposures of related intrusives in the southern part of the basin.

The Lockatong Formation appears as a thick sequence where it is exposed south of the study area, but is not present along the Hudson River. This indicates considerable thinning to the north with the possibility of its complete absence in the central part of the basin.

Igneous rocks of Newark age also include the Watchung basalt

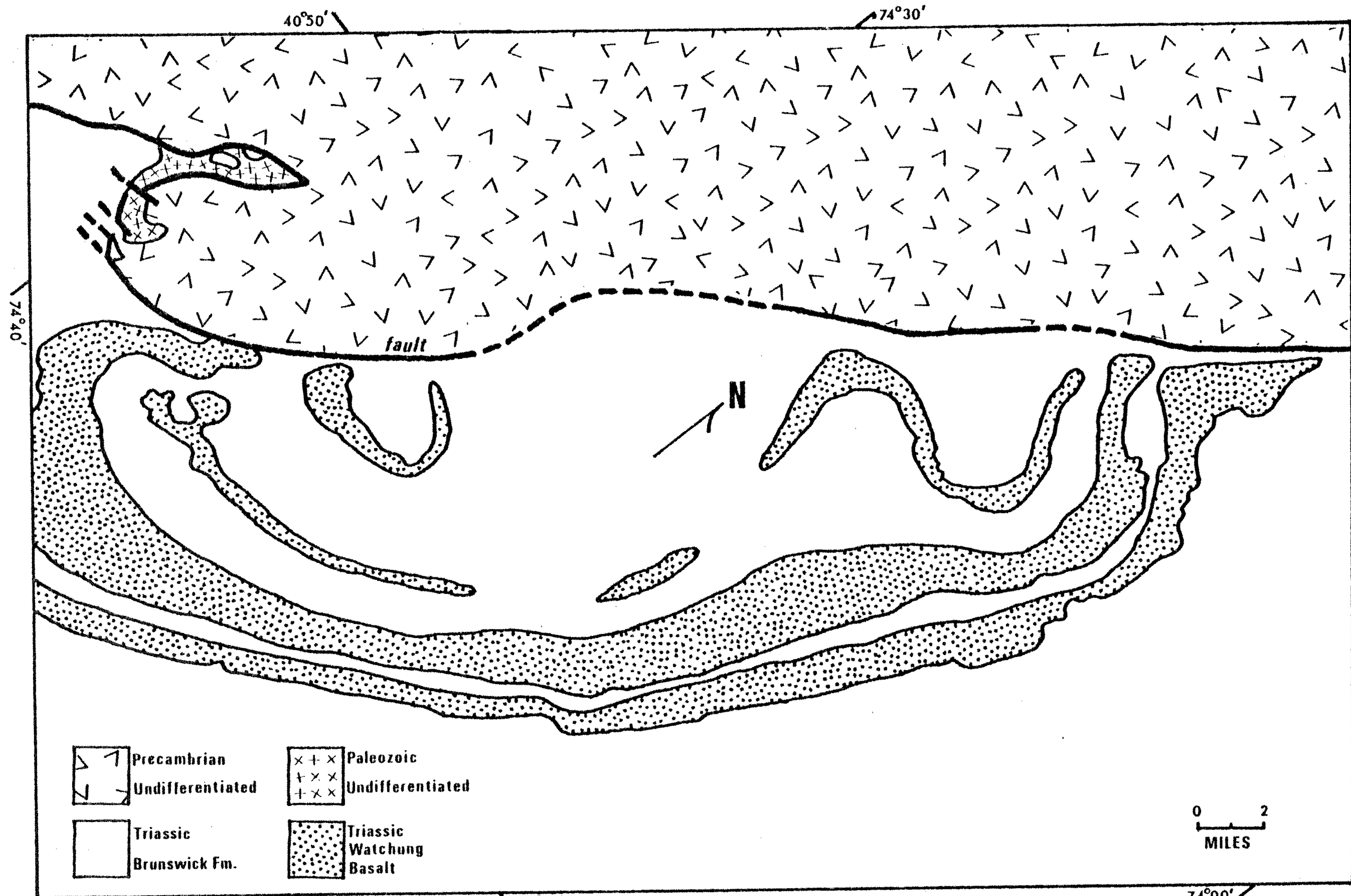


FIGURE 2. Generalized geologic setting of the study area (see Figure 1 for location).

flows. Three separate units, each a composite of at least two separate flows lie conformably in the upper Brunswick shale. The unusual outcrop pattern of curved and recurved limbs is the result of intrabasin deformation which has warped the flows and surrounding shale into open anticlines and synclines with fold axis roughly perpendicular to the fault. Wheeler (1939) proposed that these warps are associated with salients and re-entrants on the fault surface which produce differential drag during slippage.

BOUGUER GRAVITY ANOMALY MAP INTERPRETATION

The Bouguer anomaly gravity map* of the study area, contoured at a 1 milligal interval, shows that, generally, the physiographic outline of the basin is not defined by the gravity contours (Figure 3). In spite of this, several trends and features may be examined. Some gravity features shown on Figure 3 may be correlated with local geology (Figure 2).

Significant changes in the anomaly pattern are evident upon comparison of the 1 milligal interval map with the earlier 5 milligal map (Appendix 2). An earlier high (principal high) defined by the closed -25 isogal line is seen in Figure 3, to be confined to the adjacent highlands with a peak value of -24 milligals. This is significant in that it is the largest anomaly seen and is definitely connected with subsurface features in the Precambrian crystalline rocks. Inspection of the detailed geologic map of the Precambrian highlands presented by Smith (1969) reveals a significant clustering of amphibolite rich units in this area (Figure 4). Although Smith admittedly exaggerated the outcrop extent of these units for illustrative purposes, this does not affect their usefulness in this study, as local density contrasts are of primary concern. Vreeland (1965) studied Precambrian rocks farther west, in the Jenny Jump Mountain area, where amphibolite is much less common, and reports an average density of 2.71 gr./cm^3. Because the density range of amphibolite is 2.79 to 3.14, (Clark, 1966), it is concluded that this contrast is sufficient to produce at least

* Details of the gravity survey and subsequent reduction of data are given in Appendix 1.

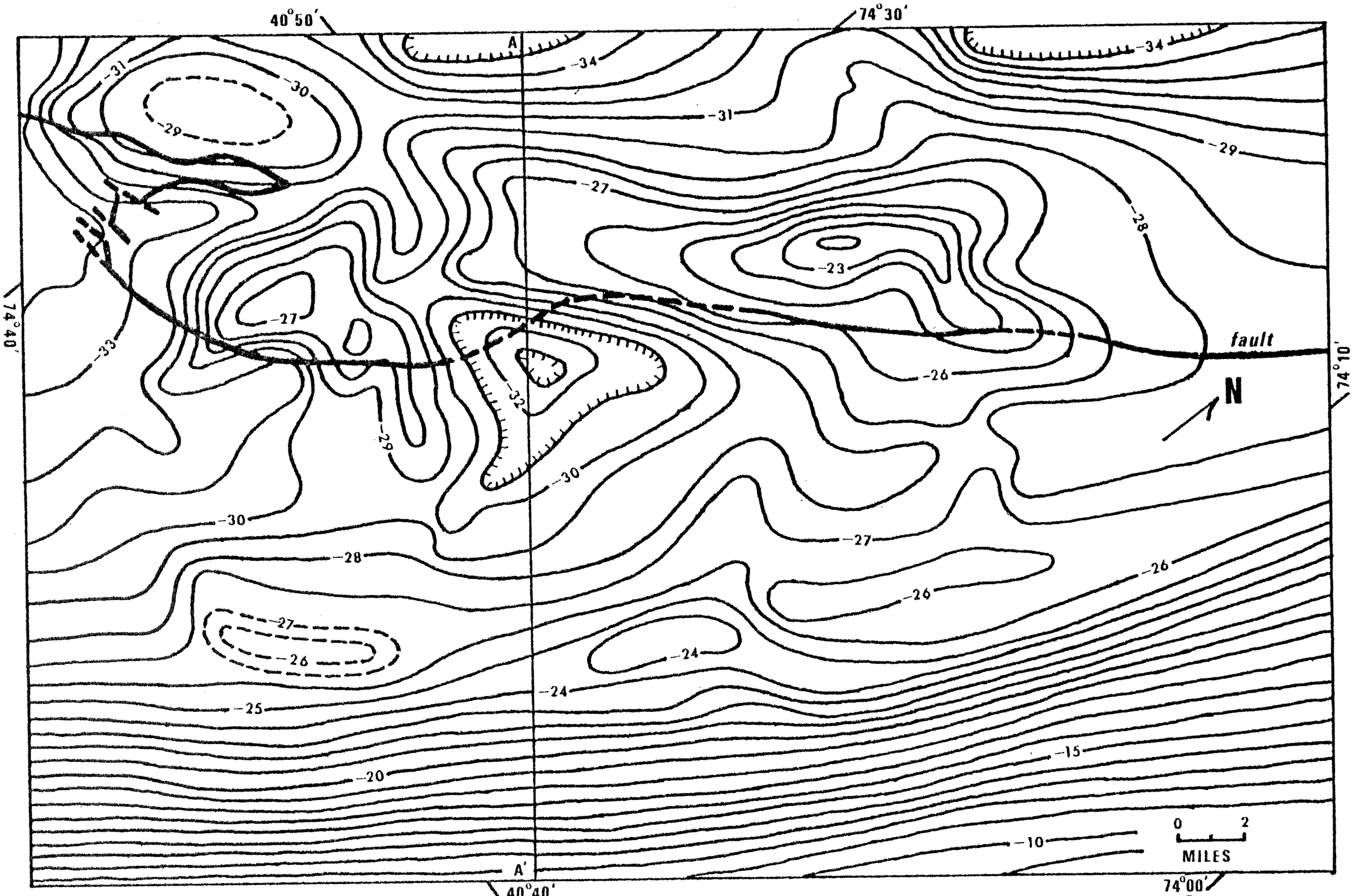


FIGURE 3. Bouguer anomaly gravity map of the study area contoured with a 1 milligal interval.

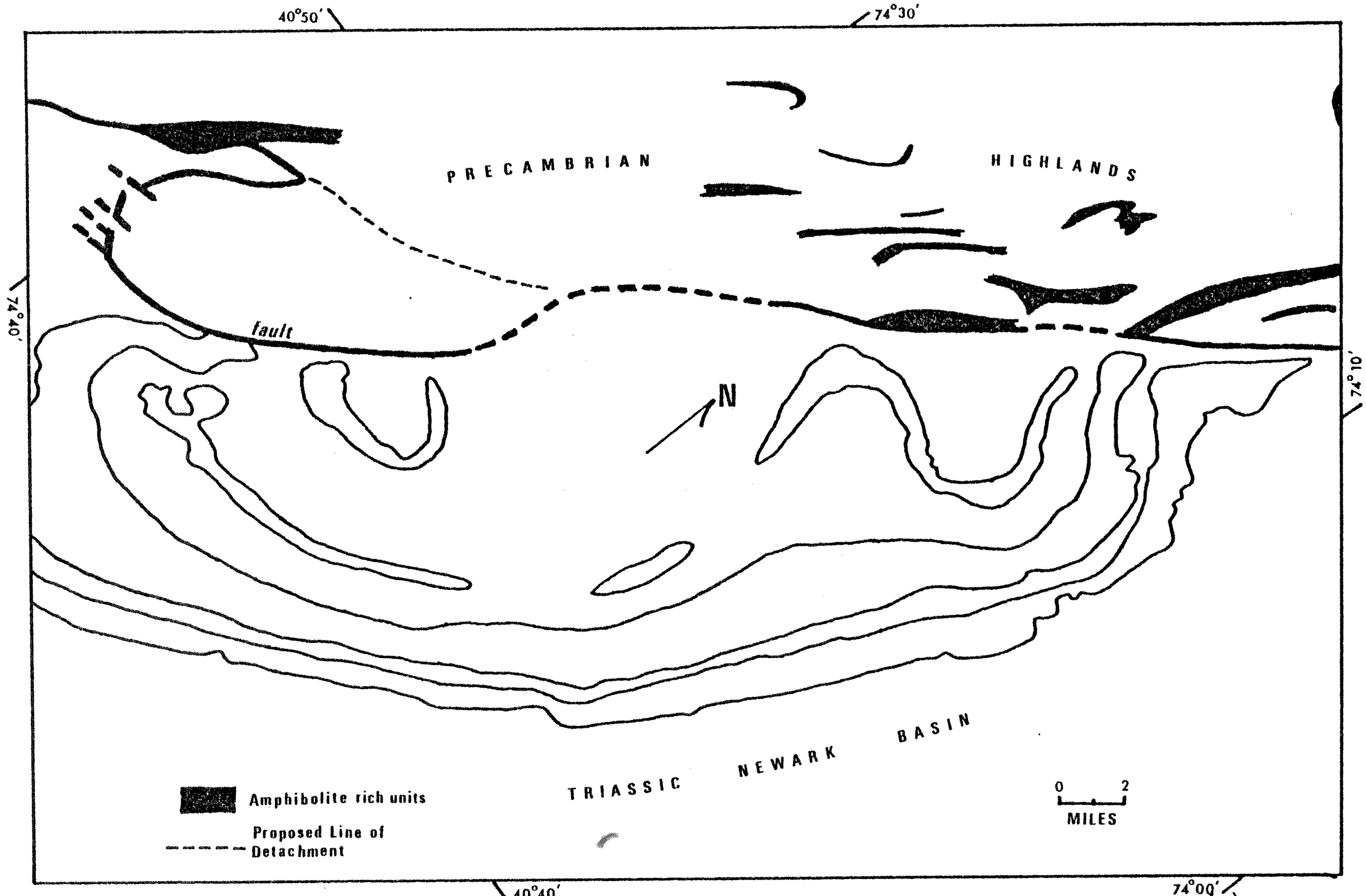


FIGURE 4. Location of amphibolite rich units mapped by Smith (1969), (modified after Smith, 1969).

part of the observed anomaly. Figure 4 also shows a large amphibolite rich unit located in the highlands adjacent to the Paleozoic sediments (Peapack Valley). If the above interpretation is correct, then the gravity high seen in this area should also be related to higher concentrations of amphibolite-rich rocks.

Southward along the fault, the principal gravity high gradually dies out but the gradient between the adjacent gravity low (principal low), increases. This can be interpreted as a steepening of the border fault in this area which agrees with Wheeler's (1939) interpretation of salients and re-entrants on fault surfaces. An alternative interpretation is that the gradient change is a reflection of the absence of near-surface basalt in this area. As the Bouguer anomaly map shows very little correlation with the surface expression of the basalt flows, the former interpretation is preferred.

The principal gravity low has not significantly changed in position over the 5 milligal version, but attains a peak value of -33 milligals. As this feature is the largest observed gravity low, it is interpreted to be located over the deepest part of the basin. Part of this anomaly, however, may be due to the absence of basalt. Another reason for interpreting this area to be the deepest part of the basin, is its coincidence with the axis of the Watchung syncline. Northward along the fault, the principal low dies out in a manner analogous to the principal high described above. Because the gradient between the highlands and basin is much broader in this area, the fault dip can be interpreted to become less steep or alternatively we are seeing the effect of the third Watchung flow.

At the southernmost end of the Ramapo fault proper, another previously unrecognized gravity high appears with a peak value of -27 milligals. This anomaly is particularly interesting because it is centered over an irregular lobe (named here, the Peapack Lobe) which protrudes outward into the basin. The surrounding saddle-like pattern of isogals bears remarkable resemblence to the Colon cross structure (Mann and Zablocki, 1961) which separates the Sanford and Durham basins in North Carolina. The saddle-like pattern surrounding the Peapack Lobe extends from the south through the Peapack Valley (Paleozoic sediment with minor Triassic conglomerate) and connects with another saddle-like pattern which separates the gravity high centered over the Peapack Lobe from the trailing southern end of the principal high. This suggests that the Peapack Lobe is partially detached from the main stem of the Ramapo Fault at depth. This interpretation also seems reasonable in light of Smith's (1969) geologic map which shows an offset of the Precambrian units in this area.

The three closed isogals appearing in the center of the basin are generally centered over the first and second Watchung Mountains. They appear as a broadening of the gradient to the west of the Trans New Jersey Gravity High (Bonini, 1965). These features are interpreted here merely as local expressions of the Watchung Mountains and, as such, are not related to basement structure. Aside from these rather small anomalies, there is no noticeable expression of the basalt flows.

The average Bouguer anomaly values in this part of the Newark basin are considerably higher than values south of the Peapack Lobe (-24 to -32 milligals as opposed to high -40's to -50 milligals). This effect is probably due to basin depth increasing to the south. The Watchung basalt flows probably do not mask basin depth very much as intrusive rocks of similar density are found in the southern part of the Newark basin along with much thicker sequences of Lockatong and Stockton.

RESIDUAL GRAVITY ANOMALY INTERPRETATION

In any choice of regional field, the underlying assumption should be that only those features not related to those of interest will be removed. Smoothing the five milligal contours on The Bouguer Anomaly Map of New Jersey (Bonini, 1965), yields the regional field (Appendix 3) which shows that the basin features have been adequately removed. Subtraction of this regional field from the Bouguer anomaly map yields the residual anomaly map (Figure 5).

The previously defined principal high retains its characteristic pattern and has a peak residual value of +8 milligals. The other highs centered over the Peapack Lobe and highlands adjacent to Peapack Valley have peak residual values of +5 milligals and do not change significantly in orientation over the Bouguer anomaly map. The principal low, previously interpreted to be the deepest part of the basin, remains the largest negative anomaly although its peak residual value is only -2 milligals.

Unfortunately, all of these observations, including the saddle-like anomalies, can just as easily be seen on the Bouguer anomaly map.

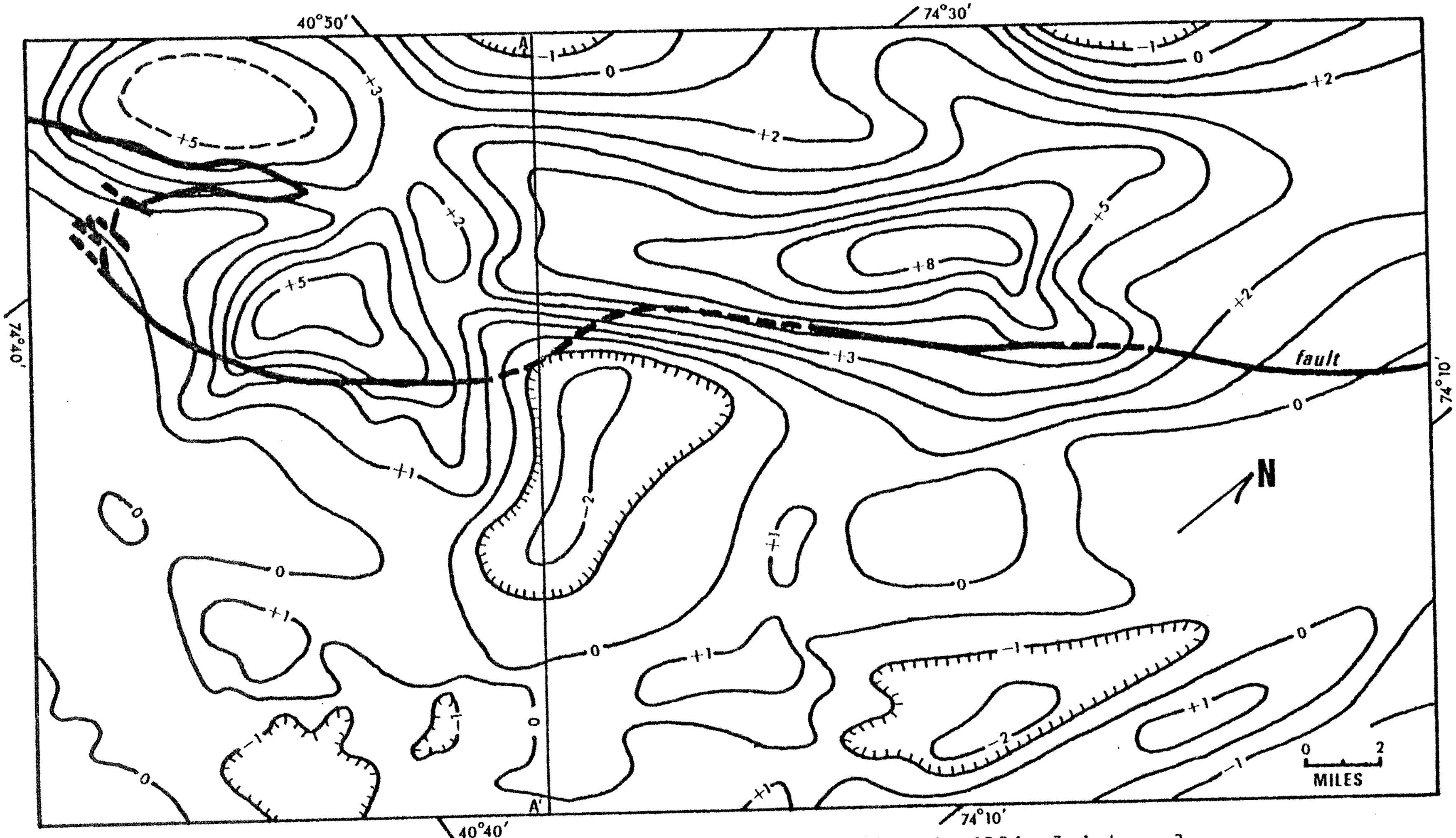


FIGURE 5. Residual anomaly map of the study area contoured with a 1 milligal interval.

In fact, the residual map shows even less about the Watchung Mountains than the Bouguer anomaly map. In general, the irregular pattern of isogals in the basin shows very little relief. This can be interpreted in either of two ways. The effect of the total basin may be relatively small compared to deeper features or alternatively, the effect of a relatively poor density contrast is dominant. Although the latter interpretation is preferred, slightly different regional fields might enhance intrabasin structure.

A second derivative map of the study area obtained by using Elkins' fifteenth equation (Elkins, 1951), was prepared to obtain residual information independent of an arbitrary regional field (Figure 8). Because of the magnitude of the numerical calculations inherent in any multi-ring second derivative operation, the contoured values at specific grid points were obtained by use of the computer program listed in Appendix 4. A multi-ring equation was selected because it tends to be more effective where irregular data are present (Nettleton, 1953).

Comparison of the second derivative map with the Bouguer anomaly map also shows a strong correlation between the two. All three gravity highs remain in the same relative position with no unexpected change in the magnitude of the anomalies. The principal high has a maximum residual value of +6 c.g.s. units whereas the other two gravity highs have residual values of +4 c.g.s. units. The residual anomaly over the principal low appears more sharply defined than in the graphical residual with a peak value of -5 c.g.s. units. As the second derivative map also shows very little relief within the basin, finer structures related to the Watchung Mountains remain unresolved. The second

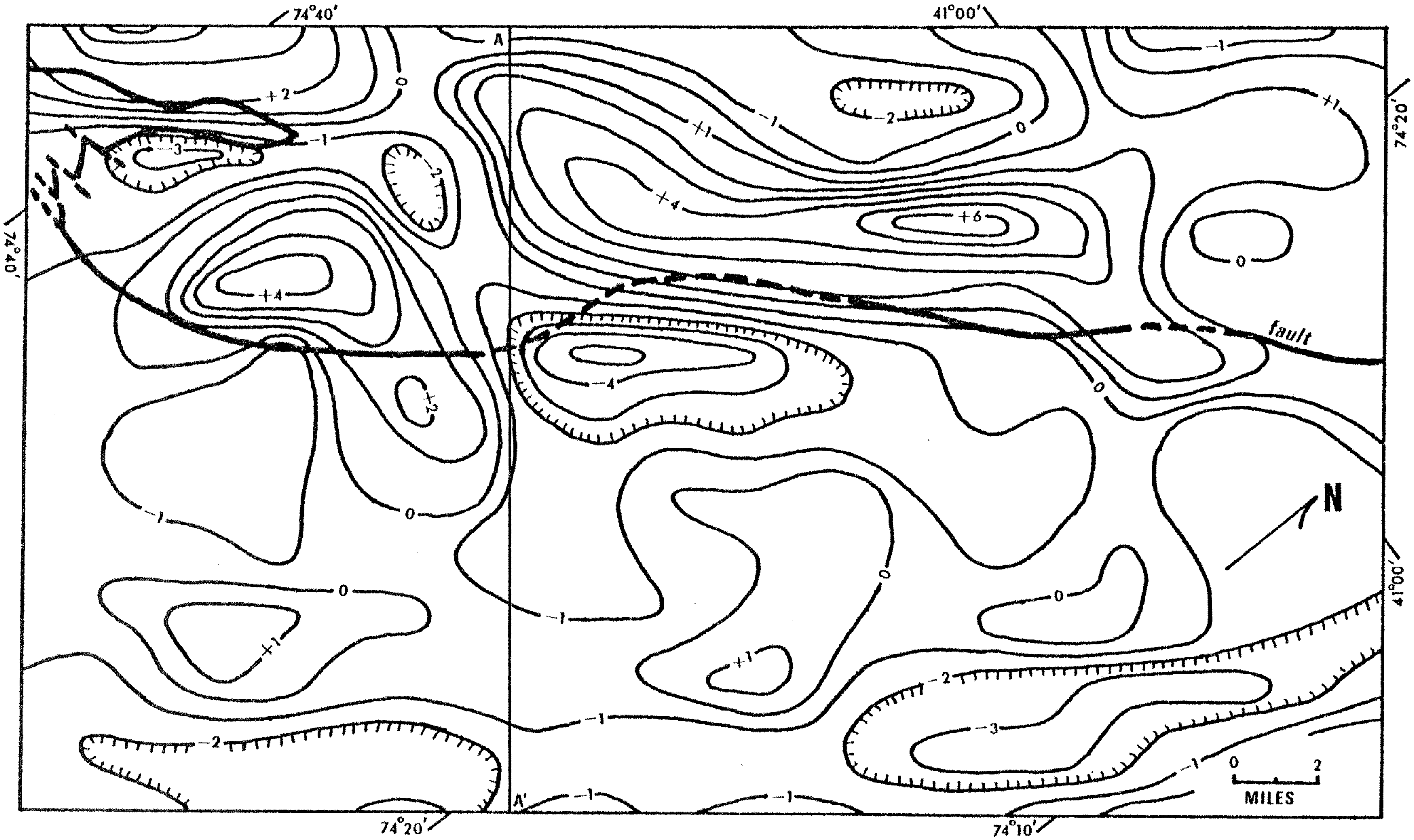


FIGURE 6. Second derivative map of the study area drawn with a contour interval of 1 x 10^{-11} c.g.s.u.

derivative technique, then, simply reinforces earlier conclusions based on Bouguer anomaly interpretation.

TWO-DIMENSIONAL MODELS

Two dimensional modeling along profile A - A' (Figures 3, 5, 6), to obtain more specific information on basin configuration, yields two distinctly different models. In each of the two models, the trailing end of the principal high was modeled as an amphibolite rich unit with density 2.80 gr./cm^3. The density of the Brunswick shale was taken from Eaton and Rosenfeld (1960); the density of the Watchung basalt was averaged from Bayley et. al. (1914); and the density of the Precambrian reference was taken from Vreeland (1965). Thicknesses of the Watchung basalt units are from Van Houten (1969). Modeling was carried out by use of the computer program "Polygon IV" (refined from Talwani, et. al., 1959) supplied by W. E. Bonini.

Model 1, (Figure 7), illustrates how poorly a long held notion of basin structure fits. This model was constructed as if all sedimentary and igneous units dipped uniformly 15 degrees toward the Ramapo Fault (60 degree dip of fault surface) from a hinge line located on Staten Island where the Stockton Formation is in contact with serpentine. Assuming that the residual anomaly curve adequately reflects the overall basin configuration, model 1 suggests that this type of basin configuration is unrealistic. The observed values differ from the computed by more than 10 milligals over the basin. The amphibolite unit presented in this, and the following model, was not

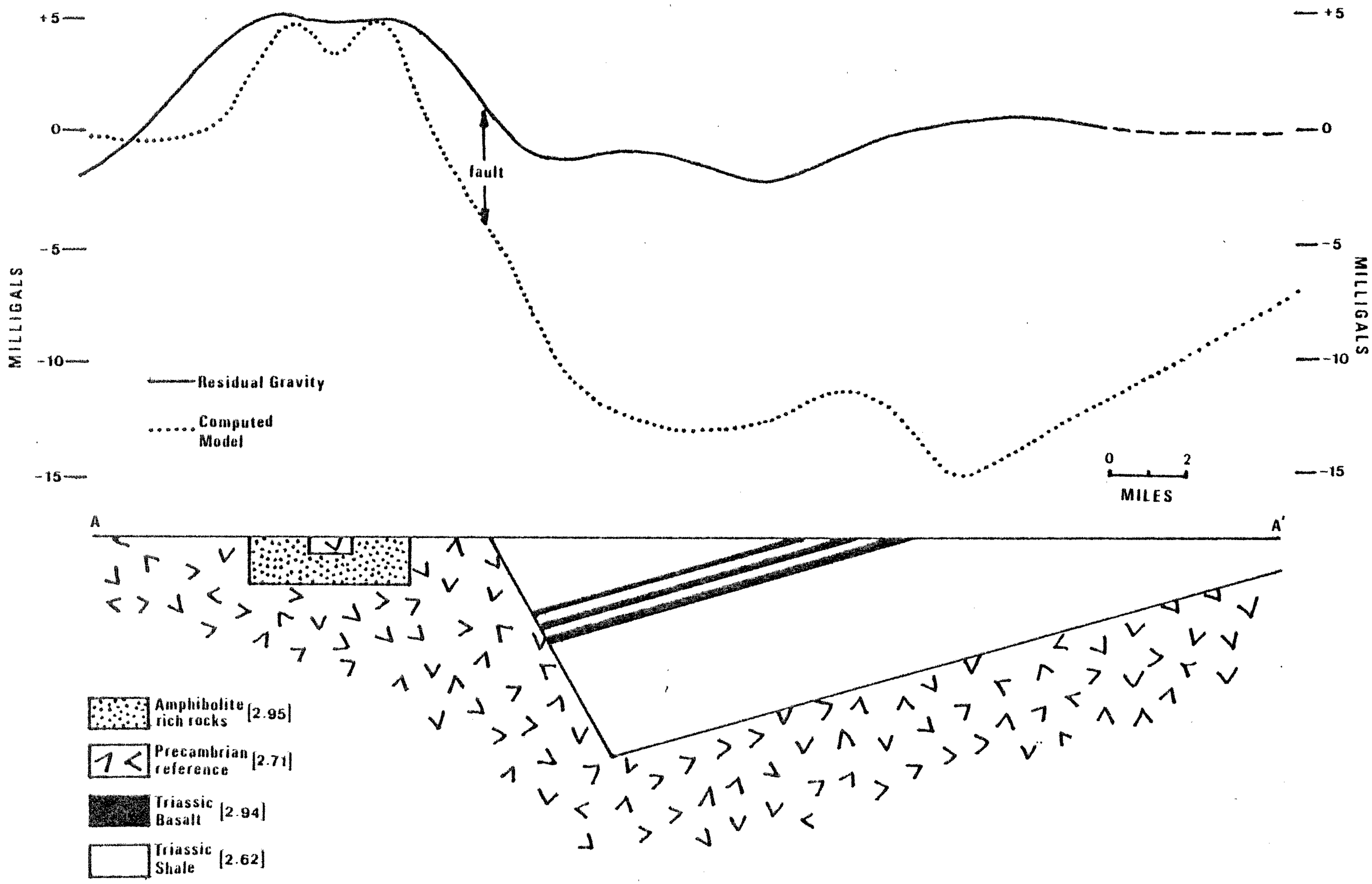


FIGURE 7. Model 1 showing simple westward dip of 15 for all units (no vertical exaggeration)

included in an attempt to satisfy the observed curve but rather to illustrate that amphibolite rich rocks at shallow depth can account for most of the principal high.

Model 2, (Figure 8), is the "best fit" attempt to match the observed values. In this model the fault dip is 45 degrees and the Watchung basalt flows are assumed to have a near surface dip of 15 degrees but flatten out as they approach the fault. The maximum basin depth is 7000 feet (1.36 mile). In prototype models of this configuration, a prominent low appeared just east of the First Watchung Mountain. This effect was probably due to the absence of basalt and was largely resolved by bringing the basement up to just over 1000 feet which gives the basin a full-graben configuration. This interpretation may be unreasonable but the only other alternative is to include the Palisade Sill which, for the purpose of these models, is assumed to be removed in the regional. Aside from the expected deviation over the principal high, the computed model differs from the observed only by about 3 milligals. Models which include a relatively shallow basement, fit the observed data much better.

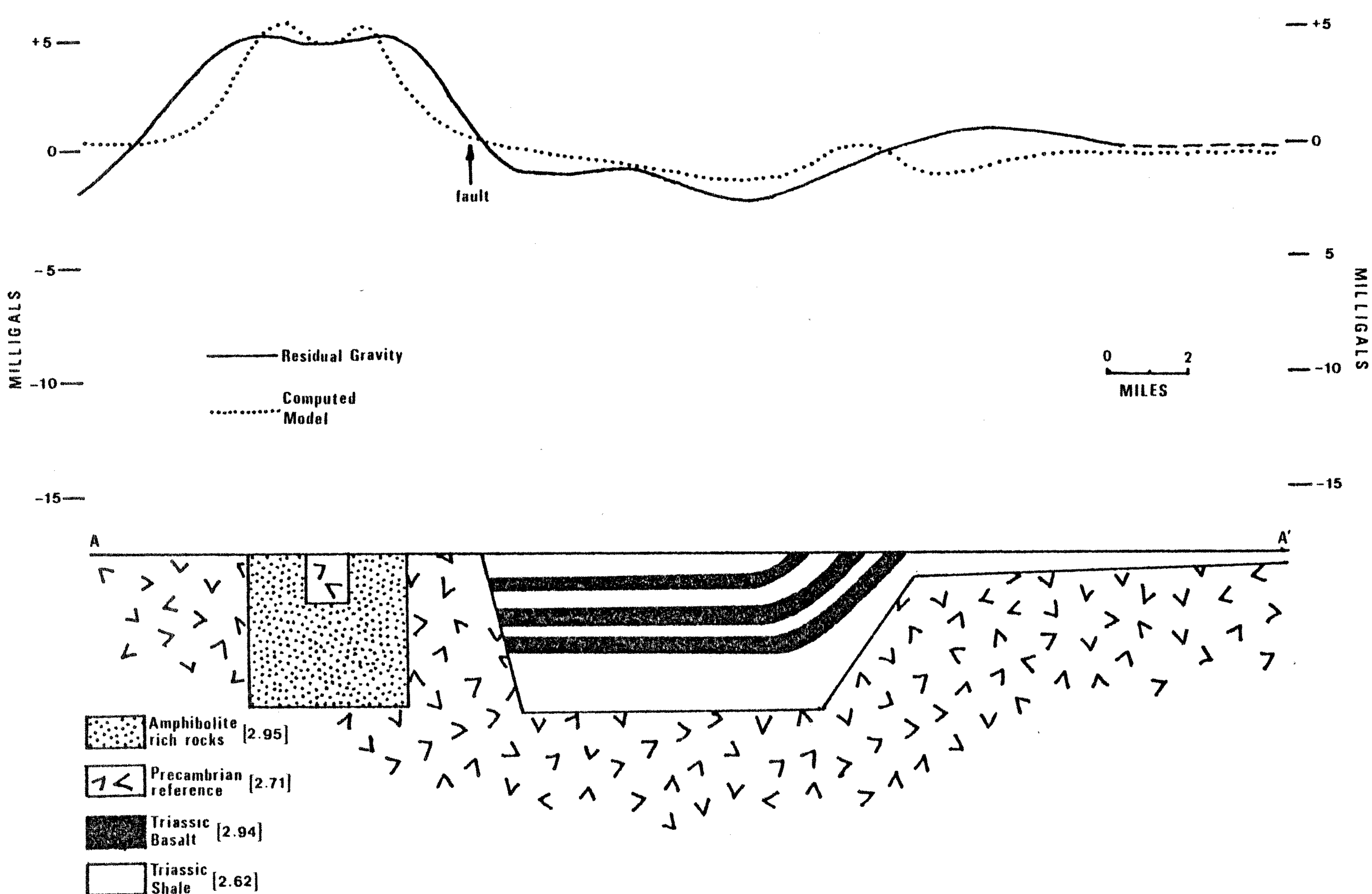


FIGURE 8. Model 2 showing a full-graben type configuration (vertical exaggeration = 3).

COMPARISON OF GRAVITY DATA FROM THE NEWARK BASIN WITH SIMILAR DATA FROM THE CONNECTICUT, GETTYSBURG AND NORTH CAROLINA BASINS

Detailed geophysical work has now been done in most of the Triassic basins from Nova Scotia to South Carolina. In general, comparison of gravity data from the Connecticut, Gettysburg and North Carolina basins agrees well with that obtained in the Newark basin.

Eaton and Rosenfeld (1960) surveyed the Connecticut basin along 3 traverses which extended into the adjacent highlands. Their general analytical estimate of 7500 feet maximum basin depth agrees with the proposed shallow depth of the Newark basin in the study area. They also propose the existence of intrabasin faults based on discontinuities in the residual gravity profile. As the detailed gravity data obtained in the Newark basin show little, if any, intrabasin structure other than gross features, I must suspect that the faults Eaton and Rosenfeld see (1.0 - 2.0 milligal anomalies) may well be simple near surface effects.

Recent gravimetric work in the Gettysburg and southern Newark basin by Sumner (1975) generally agree with data from the study area, however, these two areas are structurally dissimilar in several ways. Sumner reports a residual relief of 20 milligals compared to about 8 milligals relief in the study area. Basement depth estimates, for the Gettysburg basin, based on minimum density contrasts, gave values on the order of 2.2 to 3.0 kilometers (7181 to 9821 feet) which is reasonable in light of the earlier conclusion that the depth of the Newark basin increases south of the study area. Of particular interest is his conclusion that steep gradients on the southern margin of the

Gettysburg basin indicate "step faulting", which rule out the half-graben - southern border onlap theory. Model 2 would indicate a similar situation if one accepts the full graben interpretation. Two dimensional modeling of the Gettysburg basin in the vicinity of the Gettysburg diabase sheet also shows a basin depth of 0.7 to 1.0 kilometer (2282 to 3274 feet), which is interesting when compared to model 2.

The gravity survey of the North Carolina Triassic basins (Mann and Zablocki, 1961), encountered the same problem of residual interpretation as were encountered in the Newark basin, namely, residual anomalies mirrored Bouguer anomalies. Bouguer isogals in the North Carolina basins also failed to outline the basin. The Colon cross structure (anticlinal warp), which separates the Sanford and Durham basins, is very similar to the Peapack Lobe in New Jersey. Near the Colon cross structure the maximum anomaly of 2.5 milligals is reported to give a basin depth estimate of 2000 feet whereas the maximum basin depth for the whole basin was only 8000 feet. Mann and Zablocki (1961) further suggested that the Durham basin may locally have a graben-like configuration.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The Bouguer anomaly map presented in this paper yielded more information on the geology of the Precambrian highlands than was anticipated. A density contrast on the order of 0.1 gr./cm^3 corresponding to rocks rich in amphibolite can account for the observed gravity highs. The Peapack Lobe of the highlands is considered to be partially detached at depth. This may be a reflection of splaying in this area since the linear trend of the Ramapo Fault becomes seriously disrupted just south of the lobe.

Intrabasin structure can only be resolved to the extent of locating the deepest part of the basin. Basin depth in the vicinity of the Ramapo Fault near the axis of the Watchung syncline probably does not exceed 8000 feet. Although no definite expression of Wheeler's (1939) salients and re-entrants were seen, the principal low (deepest part of the basin) is considered to be located over the major re-entrant responsible for the broad Watchung syncline. The Watchung syncline should be thought of as a shallow bowl structure which gently plunges toward the fault. No other interpretation can reasonably account for the recurved southern limb of the second Watchung Mountain and the very low gravity profile.

Residual techniques generally showed nothing more than that already seen on the Bouguer anomaly map. The failure to resolve intrabasin structure is concluded to be a combination of low density contrasts and partial masking by regional features.

Two dimensional models of a basin which uniformly dips approximately 15 degrees toward the fault are not consistent with the observed data. However, a shallow basin model with a full-graben configuration gives a reasonably good fit to the observed data.

Further geophysical work in the Newark basin should include magnetic modeling as well as an attempt to see if a slightly different regional field will improve residual anomaly interpretation. Seismic reflection or refraction used to locate the top of the third Watchung basalt sheet at several locations would give a needed boundary condition for two dimensional modeling.

APPENDIX 1

GRAVITY SURVEY TECHNIQUE AND PRINCIPAL FACTS

One hundred fourteen measurements were taken with Princeton University's Lacoste and Romberg gravity meter (no. G-133) at predetermined locations where data was needed and elevation control was available. The majority of station elevations were taken from 1:200 scale aerial topographic sheets, state highway design planes and Bench Marks, giving a control of ± 1 foot. Less than 10 station elevations were based on careful interpolation between parallel contour lines on 1:24,000 scale topographic sheets.

Gravity meter units were reduced to milligals and Bouguer anomaly values with the computer programs "Milligal Convert" and "Prifac II" supplied by W. E. Bonini. These stations were combined with approximately 100 earlier stations used to produce the Bouguer Anomaly Map of New Jersey (W. E. Bonini, 1965), and contoured at a 1 milligal interval. The elevation error and drift of the gravity meter are considered to be very small (under 0.1 milligal). Earth-tide effects were also determined to be negligible (approximately 0.1 milligal). Terrane corrections were made on a number of points, particularly over the Watchung Mountains. Areas of greatest topographic relief showed correction values which fell in the range of 0.2 - 0.3 milligals. Stations more than 2 miles from the Watchung Mountains showed correction values on the order of 0.05 - 0.1 milligals. The Bouguer anomaly map presented in this paper was contoured with allowances made for the terrane correction. The following principal facts do not include terrane corrected values.

GRAVITY TIE PRINCIPAL FACTS

PU-GUY: Princeton University base station located in the center of the corridor between rooms 13 and 15, Guyot Hall.

RU-GEO: Rutgers University base station located in the center of the front porch under the light, Geology Hall.

H-BASE: Home base station used by the author for all readings taken in this survey. H-BASE is located in the center of the front porch under the light at 36 Oakwood Ave., Livingston, N. J.

date: 11-14-75

Station	Time	Average Meter Reading
PU-GUY	0955	3635.170
RU-GEO	1110	3662.189
H-BASE	1230	3664.355
RU-GEO	1335	3662.205
PU-GUY	1430	3635.318
RU-GEO	1510	3662.294
H-BASE	1615	3664.434
RU-GEO	1715	3662.179
PU-GUY	1745	3635.199

PU-GUY earth-tide corrected average meter value: 3635.270

RU-GEO earth-tide corrected average meter value: 3662.271

H-BASE earth-tide corrected average meter value: 3664.417

Milligal conversion factor: 1.0433 milligal/scale division

Final Tie Values

PU-GUY: 980.1766 milligals (Wollard and Rose, 1963)

RU-GEO: 980.2058 milligals

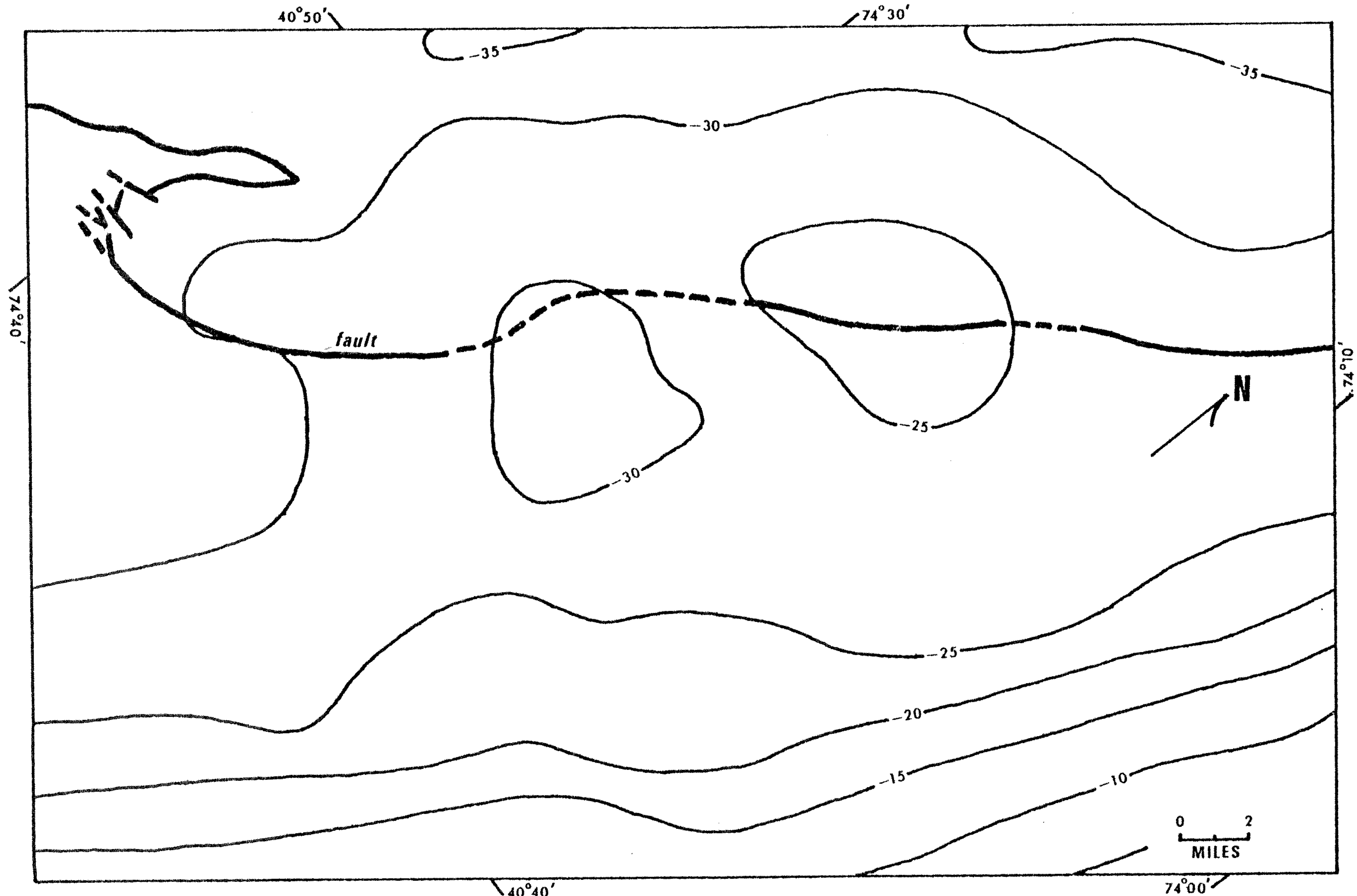
H-BASE: 980.2080 milligals

STA.	LAT.	LONG.	ELEV. FEET	OBS. GRAV.	B.A. 2.67	F.A. 0.0
HBASE	N40 46.75	74 18.45W	293.0	980.20820	-24.1	-14.1
RU0001	N40 47.29	74 15.39W	614.0	980.19081	-23.0	-2.1
RU0002	N40 47.51	74 15.76W	476.0	980.19907	-23.4	-7.1
RU0003	N40 47.57	74 16.17W	370.0	980.20491	-24.0	-11.4
RU0004	N40 47.57	74 16.39W	471.0	980.19798	-24.8	-8.8
RU0005	N40 47.73	74 17.08W	534.0	980.19580	-23.5	-5.3
RU0006	N40 47.92	74 17.70W	472.0	980.19956	-23.7	-7.6
RU0007	N40 47.81	74 17.94W	421.0	980.20198	-24.2	-9.9
RU0008	N40 47.83	74 18.32W	330.0	980.20689	-24.8	-13.5
RU0009	N40 47.72	74 18.74W	321.0	980.20641	-25.6	-14.7
RU0010	N40 47.64	74 19.45W	327.0	980.20496	-26.6	-15.5
RU0011	N40 47.75	74 20.97W	208.0	980.21004	-28.8	-21.7
RU0012	N40 47.98	74 21.58W	177.0	980.21260	-28.5	-22.4
RU0013	N40 51.52	74 18.75W	173.0	980.21907	-27.5	-21.6
RU0014	N40 51.10	74 18.40W	180.0	980.21843	-27.1	-21.0
RU0015	N40 51.02	74 17.81W	185.0	980.21839	-26.7	-20.4
RU0016	N40 50.72	74 17.16W	310.0	980.21057	-26.6	-16.0
RU0017	N40 50.41	74 16.80W	394.0	980.20576	-25.9	-12.5
RU0018	N40 50.12	74 15.93W	451.0	980.20173	-26.1	-10.7
RU0019	N40 50.12	74 15.06W	410.0	980.20410	-26.2	-12.2
RU0020	N40 49.54	74 14.26W	426.0	980.20358	-24.9	-10.4
RU0021	N40 49.43	74 13.57W	449.0	980.20212	-24.8	-9.5
RU0022	N40 54.95	74 22.25W	235.0	980.22104	-26.9	-18.9
RU0023	N40 53.56	74 24.94W	372.0	980.21195	-25.7	-13.0
RU0024	N40 51.04	74 25.57W	289.0	980.20734	-31.6	-21.7
RU0025	N40 48.95	74 26.74W	256.0	980.20444	-33.3	-24.6
RU0026	N40 48.34	74 27.34W	274.0	980.20335	-32.4	-23.1
RU0027	N40 46.08	74 29.40W	288.0	980.20291	-28.7	-18.9
RU0028	N40 45.83	74 30.31W	286.0	980.20184	-29.5	-19.7
RU0029	N40 45.25	74 31.56W	326.0	980.20103	-27.0	-15.9
RU0030	N40 44.66	74 31.94W	292.0	980.20031	-28.9	-19.0
RU0031	N40 44.01	74 32.42W	259.0	980.19587	-34.4	-25.5

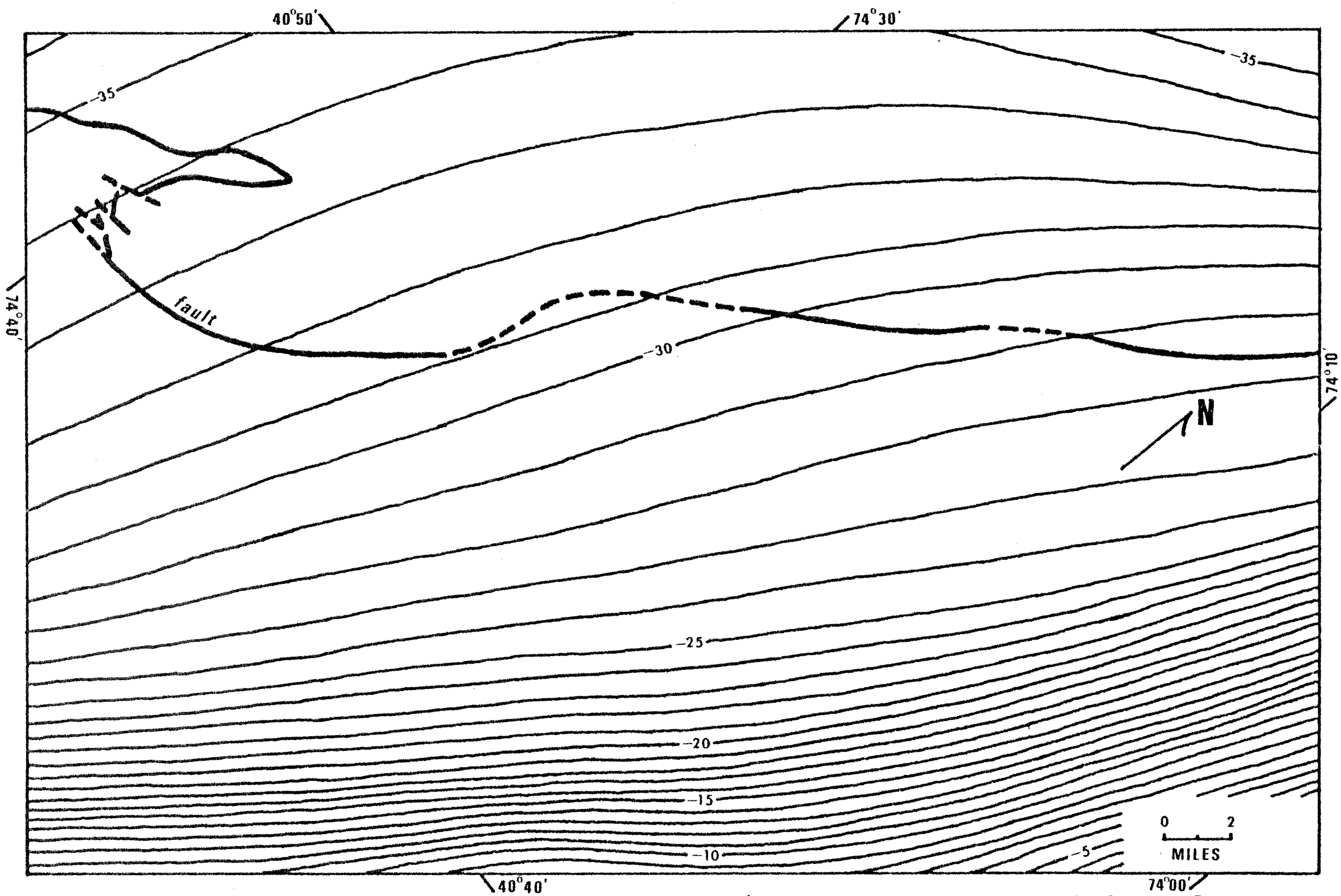
STA.	LAT.	LONG.	ELEV. FEET	OBS. GRAV.	B.A. 2.67	F.A. 0.0
RU0032	N40 43.31	74 32.83W	304.0	980.19399	-32.5	-22.2
RU0033	N40 44.34	74 22.35W	185.0	980.20785	-27.3	-21.0
RU0034	N40 44.43	74 22.95W	234.0	980.20458	-27.8	-19.8
RU0035	N40 44.83	74 23.81W	247.0	980.20307	-29.1	-20.7
RU0036	N40 45.26	74 24.49W	206.0	980.20572	-29.6	-22.5
RU0037	N40 45.54	74 25.07W	253.0	980.20280	-30.1	-21.5
RU0038	N40 45.97	74 25.89W	373.0	980.19546	-30.9	-18.2
RU0039	N40 46.47	74 26.50W	383.0	980.19545	-31.0	-18.0
RU0040	N40 47.97	74 30.14W	355.0	980.19922	-31.2	-19.1
RU0041	N40 47.77	74 30.68W	485.0	980.19203	-30.2	-13.7
RU0042	N40 47.54	74 31.78W	353.0	980.20012	-29.7	-17.7
RU0043	N40 47.30	74 33.13W	368.0	980.19713	-31.5	-18.9
RU0044	N40 47.24	74 33.85W	496.0	980.19178	-29.0	-12.2
RU0045	N40 47.08	74 34.50W	584.0	980.18710	-28.2	-8.3
RU0046	N40 46.98	74 35.21W	556.0	980.18801	-28.8	-9.9
RU0047	N40 46.54	74 36.10W	616.0	980.18094	-31.6	-10.7
RU0048	N40 48.12	74 21.58W	188.0	980.21195	-28.7	-22.3
RU0049	N40 48.41	74 22.51W	213.0	980.21113	-28.4	-21.2
RU0050	N40 48.60	74 22.90W	230.0	980.20992	-28.9	-21.1
RU0051	N40 48.71	74 23.62W	293.0	980.21070	-24.5	-14.5
RU0052	N40 49.14	74 24.23W	177.0	980.21188	-30.9	-24.9
RU0053	N40 49.37	74 24.94W	204.0	980.21099	-30.5	-23.6
RU0054	N40 49.70	74 25.81W	265.0	980.20672	-31.6	-22.6
RU0055	N40 50.13	74 26.75W	276.0	980.20594	-32.4	-23.0
RU0056	N40 50.65	74 27.82W	366.0	980.20368	-30.0	-17.6
RU0057	N40 51.07	74 28.42W	452.0	980.20208	-27.1	-11.7
RU0058	N40 51.55	74 29.44W	678.0	980.19008	-26.2	-3.1
RU0059	N40 51.71	74 29.97W	705.0	980.18866	-26.3	-2.3
RU0060	N40 52.13	74 30.85W	597.0	980.19532	-26.7	-6.4
RU0061	N40 52.25	74 31.24W	666.0	980.19244	-25.6	-3.0
RU0062	N40 59.84	74 28.48W	947.0	980.18390	-28.6	3.6
RU0063	N40 59.33	74 28.40W	1073.0	980.17375	-30.5	6.1

STA.	LAT.	LONG.	ELEV. FEET	OBS. GRAV.	B.A. 2.67	F.A. 0.0
RU0064	N40 58.51	74 28.20W	990.0	980.17727	-30.7	3.0
RU0065	N40 57.78	74 27.62W	820.0	980.18633	-30.7	-2.8
RU0066	N40 57.41	74 26.38W	750.0	980.19332	-27.4	-1.9
RU0067	N40 56.40	74 25.79W	530.0	980.20888	-23.5	-5.5
RU0068	N40 56.24	74 24.38W	598.0	980.20557	-22.5	-2.2
RU0069	N40 56.27	74 23.73W	650.0	980.20101	-24.0	-1.9
RU0070	N40 57.03	74 23.03W	645.0	980.20193	-24.5	-2.6
RU0071	N40 57.87	74 22.09W	650.0	980.20303	-24.4	-2.2
RU0072	N40 58.22	74 21.32W	674.0	980.20348	-23.0	-0.0
RU0073	N40 59.05	74 20.90W	697.0	980.20066	-25.7	-1.9
RU0074	N40 59.45	74 20.73W	496.0	980.21212	-26.9	-10.0
RU0075	N40 54.55	74 15.77W	186.0	980.22290	-27.4	-21.1
RU0076	N40 55.06	74 16.02W	204.0	980.22272	-27.3	-20.3
RU0077	N40 55.88	74 16.45W	244.0	980.22142	-27.4	-19.1
RU0078	N40 56.77	74 16.45W	231.0	980.22365	-27.3	-19.4
RU0079	N40 57.64	74 17.00W	180.0	980.22727	-28.0	-21.9
RU0080	N40 59.11	74 18.25W	226.0	980.23009	-24.6	-16.9
RU0081	N40 57.14	74 19.30W	193.0	980.22818	-25.6	-19.0
RU0082	N40 56.45	74 20.56W	250.0	980.22427	-25.0	-16.5
RU0083	N40 55.23	74 19.91W	330.0	980.21605	-26.6	-15.4
RU0084	N40 45.30	74 32.34W	390.0	980.19681	-27.5	-14.2
RU0085	N40 45.97	74 33.31W	444.0	980.19449	-27.6	-12.4
RU0086	N40 45.39	74 33.34W	425.0	980.19524	-27.1	-12.6
RU0087	N40 46.50	74 31.44W	585.0	980.18675	-27.6	-7.7
RU0088	N40 48.90	74 31.13W	425.0	980.19967	-27.9	-13.4
RU0089	N40 49.05	74 32.99W	790.0	980.17556	-30.3	-3.4
RU0090	N40 49.45	74 34.55W	900.0	980.16972	-30.2	0.5
RU0091	N40 50.66	74 36.43W	1000.0	980.16437	-31.3	2.8
RU0092	N40 50.01	74 42.61W	640.0	980.18273	-33.6	-11.8
RU0093	N40 49.50	74 43.17W	643.0	980.18052	-34.9	-12.9
RU0094	N40 48.19	74 42.87W	756.0	980.17365	-33.0	-7.2
RU0095	N40 47.00	74 41.94W	846.0	980.16968	-29.8	-1.0

STA.	LAT.	LONG.	ELEV. FEET	OBS. GRAV.	B.A. 2.67	F.A. 0.0
RU0096	N40 46.81	74 42.68W	853.0	980.16930	-29.5	-0.4
RU0097	N40 43.13	74 40.72W	360.0	980.18999	-32.9	-20.6
RU0098	N40 43.21	74 44.03W	411.0	980.18807	-31.9	-17.9
RU0099	N40 42.22	74 39.67W	227.0	980.19549	-34.0	-26.3
RU0100	N40 40.75	74 39.02W	198.0	980.19454	-34.5	-27.8
RU0101	N40 42.22	74 35.67W	278.0	980.19431	-32.1	-22.7
RU0102	N40 41.54	74 34.71W	304.0	980.19345	-30.4	-20.1
RU0103	N40 44.01	74 34.64W	630.0	980.18136	-26.6	-5.2
RU0104	N40 43.20	74 33.52W	366.0	980.19221	-30.4	-17.9
RU0105	N40 44.43	74 24.60W	361.0	980.19508	-29.7	-17.4
RU0106	N40 44.13	74 25.19W	281.0	980.20041	-28.7	-19.1
RU0107	N40 42.14	74 25.68W	224.0	980.20169	-27.9	-20.2
RU0108	N40 41.29	74 26.18W	215.0	980.20111	-27.7	-20.4
RU0109	N40 40.45	74 26.40W	253.0	980.19992	-25.4	-16.8
RU0110	N40 39.33	74 28.70W	275.0	980.19537	-27.0	-17.6
RU0111	N40 40.17	74 28.97W	225.0	980.19768	-28.9	-21.2
RU0112	N40 42.16	74 28.56W	235.0	980.19901	-29.9	-21.9
RU0113	N40 43.97	74 29.29W	246.0	980.20239	-28.6	-20.2
RU0114	N40 44.76	74 25.80W	287.0	980.19968	-30.0	-20.2



APPENDIX 2. Bouguer Anomaly Map of the study area contoured at a 5 mgal. interval (Bonini, 1965).



APPENDIX 3. Regional field (produced by contour smoothing) used to produce the residual anomaly map.

APPENDIX 4

```
      dimension q(26,17),secder(22,13)
      call open(10,'sdv','input')
      read(10,*)((q(i,j),j=1,17),i=1,26)
      do10 i=3,24
      do10 j=3,15
      h0=q(i,j)
      h1=(q(i-1,j)+q(i,j+1)+q(i+1,j)+q(i,j-1))/4.0
      h2=(q(i-1,j-1)+q(i-1,j+1)+q(i+1,j+1)+q(i+1,j-1))/4.
      a=q(i-2,j-1)+q(i-2,j+1)+q(i-1,j+2)+q(i+1,j+2)
      b=q(i+2,j+1)+q(i+2,j-1)+q(i+1,j-2)+q(i-1,j-2)
      h3=(a+b)/8.0
      g=2.58e-13
      l=i-2
      n=j-2
      secder(l,n)=g*((44.*h0)+(16.*h1)-(12.*h2)-(48.*h3))
   10 continue
      write(6,20)((secder(i,j),j=1,13),i=1,22)
   20 format(13e10.2)
      call close(10)
      stop
      end
```

The program listed above was written by the author to facilitate computation of second derivative values. The program is designed for use with Elkins 15th equation (Elkins, 1951):

$$\frac{\partial^2 g}{\partial z^2} = \frac{1}{62\,k^2 r^2}\left[44\,\overline{H}(0) + 4H'(s) - 3H'(s\sqrt{2}) - 6H'(s\sqrt{5})\right]$$

Data input is in matrix form where each element Q(i,j) is an interpolated value taken from a 1 cm^2. grid overlaid on the Bouguer anomaly map. h0 is the center point value, h1, h2 and h3 are numerical averages along circles of radius 1 cm., $\sqrt{2}$ cm. and $\sqrt{5}$ cm., respectively. $g = 1/62.k^2 r^2$ where k is the map scale and r is the grid spacing (1 cm.). The output matrix (secder (l,n)) is self-explanatory but will be somewhat smaller than the input matrix due to the nature of the calculations.

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