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A GEOLOGICAL INTERPRETATION OF THE BOUGUER ANOMALY FIELD OF NEWFOUNDLAND

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GEOLOGICAL INTERPRETATION OF THE BOUGUER ANOMALY FIELD OF NEWFOUNDLAND

Abstract: During the summer of 1964, a Dominion Observatory field party occupied about 1,200 regional gravity stations on the Island of Newfoundland. The results are presented here in the form of a Bouguer anomaly map, accompanied by a geological interpretation of the major features.

The results reveal a major gravity gradient across a line that trends northeasterly over the southern part of the Great Northern Peninsula. This line may mark the boundary between the Grenville and Appalachian geological provinces. The anomalies north of this line average about 30 mgal less than the anomalies in the southern area. Seismic work suggests a thinner lower density crust in the north where the anomalies are negative, and a thicker higher density crust in the southern area where the anomalies are generally positive. Calculations show that the results are compatible with the gravity data if density variations in the upper mantle contribute to the gravity field. In neither area does there appear to be any dependence of Bouguer anomaly on elevation.

A correlation of the local Bouguer anomalies with the surface geology suggests that granite is the prime cause of the negative anomalies of Newfoundland. The sediments, most of which are metamorphosed, appear to have very little effect on the gravity field. Most of the positive anomalies of Newfoundland correlate with large bodies of diorite or with gabbroic and ultrabasic intrusions. It is suggested that many of the longer wavelength regional variations in the gravity field are produced by changes in the crustal parameters at depth.

Résumé: Au cours de l'été 1964, une équipe de l'Observatoire fédéral a procédé à des levés gravimétriques à quelque 1,200 endroits sur l'île de Terre-Neuve. L'auteur donne dans le présent rapport des résultats sous forme d'une carte des anomalies de Bouguer, avec interprétation géologique des principaux accidents.

Les résultats indiquent un gradient gravimétrique d'importance en travers d'une ligne à direction nord-est dans la partie sud de la Grande péninsule du Nord. Cette ligne peut servir de limite entre les provinces géologiques de Grenville et des Appalaches. Les anomalies au nord de cette ligne sont, en moyenne, inférieures de 30 milligals à celles de la région sud. Les travaux séismiques indiquent que la croûte est plus mince et de plus faible densité au nord où les anomalies sont négatives, et qu'elle est plus épaisse et de plus forte densité au sud où les anomalies sont généralement positives. Les calculs montrent que les résultats concordent avec les données gravimétriques si les variations de densité dans le mateau supérieur influencent le champ de gravité. Dans aucune région les anomalies de Bouguer ne semblent dépendre de la hauteur.

Une corrélation des anomalies de Bouguer locales avec la géologie de surface indique que le granite est la principale cause des anomalies négatives à Terre-Neuve. Les sédiments, dont la plupart est métamorphisée, semblent avoir peu d'effet sur le champ de gravité. La majeure partie des anomalies positives de Terre-Neuve correspondent à de grandes masses de diorite ou à des intrusions gabbroïques et ultrabasiques. Il se peut que plusieurs des variations régionales à grande longueur d'onde dans le champ de gravité proviennent de changements en profondeur dans les paramètres de la croûte.

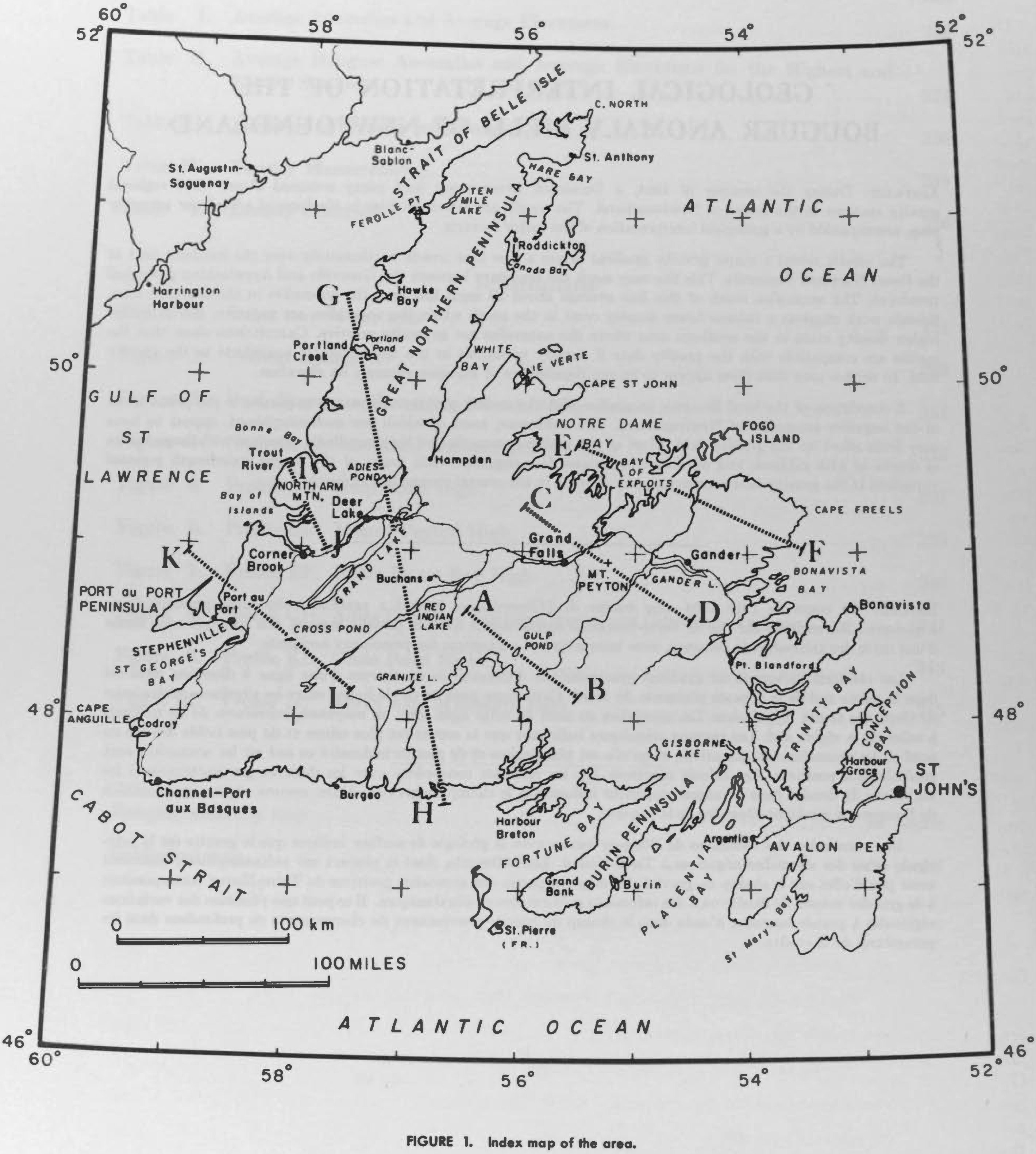


FIGURE 1. Index map of the area.

INTRODUCTION

During the summer of 1964 a Dominion Observatory field party, consisting of 16 men, conducted a regional gravity survey of the entire Island of Newfoundland and of parts of Quebec and Labrador. This report contains a Bouguer anomaly map of Newfoundland, at a scale of 1 inch = 20 miles, and a discussion of the most significant gravity anomalies and their implications. Bouguer anomaly maps at a scale of 1:500,000 with the individual station values shown will be published in the Gravity Map Series (Weaver, a, in press). Figure 1 is a general index map of the area covered by this report, showing the location of the various profiles that were studied in detail. All previously available geological and geophysical data are combined with the present work in arriving at the conclusions drawn in this report.

Transportation for the survey was provided by two Bell 47G2 helicopters and a float-equipped De Havilland Beaver aircraft. The Beaver was used mainly to set out gas caches for the helicopters and simultaneously to establish a gravity control network. A Canso aircraft was chartered to establish very large gas caches such as at base camps and to transport men and camp equipment between main bases. Operations in Newfoundland were carried out from a single base camp at the centrally located town of Buchans. In addition to the main camp, several fly camps were necessary since the aircraft could not always return to the main camp. The aircraft would remain for one or two nights at these camps which were normally at villages or towns where communication was readily available.

In order to obtain preliminary Bouguer anomaly values, all the data were reduced by hand in the field as the survey progressed. This method enabled the crew to check several suspected reading errors by re-observing the stations. Also, whenever time permitted, more closely spaced stations were placed in areas containing interesting anomalies.

REDUCTION OF DATA

Gravity Observations

All the connections between gravity control stations (except for a few of the excentre connections) were made by LaCoste and Romberg gravimeters, numbers G74 and G9. Most of the connections were made while establishing gas caches, and involved reading at one control station (A), flying to the second (B) and reading there, and then returning to read again at the first station (A), thereby forming an A–B–A connection. Many of the connections were initially single observations at successive stations A–B, with one or more A–B or B–A ties added later. Regardless of how they are made, the connections are entered into the control station network adjustment program as single ties. This type of network is possible because of the very small drift of the LaCoste and Romberg gravimeters. Most of the residuals after a least squares adjustment of the Newfoundland control network were less than 0.05 mgal. All excentres not connected with the LaCoste and Romberg gravimeters were established with Worden gravimeters using complete looping procedures (Nettleton, 1940). Nearly all the detail gravity stations at 6- to 8-mile intervals were established with the Worden gravimeters.

Errors in the observed gravity arise from four main sources: a small uncertainty (about one part in 2,000) in the scale constant for converting gravimeter readings to milligals, small errors (less than ±0.1 mgal) in the gravity values at the control stations, errors involved in reading the gravimeter at each station (about ±0.05 mgal) and uncertainties caused by assuming that the drift of the gravimeter is linear between control stations. The last of these is difficult to estimate but rarely exceeds ±0.1 mgal. It is difficult to estimate the overall error in the observed gravity values unless some stations are marked and reoccupied later at exactly the same spot, preferably using different control stations and a different instrument. This has been done in another area by Tanner (1961), who concluded that the observed gravity values had a standard error of 0.2 mgal. The values in Newfoundland are probably better because of more control stations, resulting in shorter time intervals over which the drift is calculated and a more accurate control network.

Elevation Measurements

Most of the elevations for the gravity stations were computed from altimeter readings taken concurrently with each gravity observation. Two Wallace and Tiernan altimeters were carried in each aircraft and were read at each gravity station. In reducing the barometric data, corrections were made for temperature, humidity, and for changes in barometric pressure. The latter were obtained by observations at points of known elevation and by assuming that the atmospheric pressure varied linearly with time. A station of known elevation was normally occupied at least once every hour.

Elevation control in Newfoundland was provided by sea-level, bench marks, and barometric elevations supplied by the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa. Sea-level observations along the coast of Newfoundland were not corrected for tidal effects, because the maximum variation in water level is only about 6 feet. The majority of the bench marks used are accurate to ±1 foot.

The elevations supplied by the Surveys and Mapping Branch are estimated to be accurate to ±20 feet.

The largest errors in the Bouguer anomalies are caused by errors in the elevations. Uncertainties in the known elevations, in the assumption of linear drift between known elevations especially during unsettled weather, and in the temperature and humidity corrections especially in rough topography, are the major factors contributing to the unreliability of the station elevations. In addition, there is a small error of about ±3 feet in the altimeter readings because of induced vibrations from the helicopter.

One method of obtaining an estimate of the uncertainty in the elevations obtained barometrically is to calculate the dispersion of the differences obtained for measurements between points of known elevation. An analysis of 279 altimeter connections made to sea-level in Newfoundland showed an r.m.s. difference of 15 feet, causing a corresponding error in the Bouguer anomalies of 0.9 mgal.

Determination of Position

Maps supplied by the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa, at a scale of 1:250,000 (approximately 4 miles to the inch) were available for the entire Island of Newfoundland. The latitude and longitude of the gravity stations were scaled from these maps with an accuracy of ±0.1 minute. This causes a corresponding error in the Bouguer anomalies of ±0.15 mgal.

Calculation of the Bouguer Anomalies

The Bouguer anomalies were reduced using the conventional density of 2.67 g/cm^3 for the crustal rocks, instead of 2.69 g/cm^3, the average density of all rock samples collected during the survey. The use of the higher density of 2.69 g/cm^3 in the reduction would alter the Bouguer anomalies by only 0.25 mgal per 1,000 feet of elevation. Terrain corrections have not been applied to the gravity data. Terrain effects were minimized by careful choice of station location by the observers during the course of the survey (*see* Tanner and McConnell, 1964). It is estimated that 60 to 80 per cent of the stations in Newfoundland require a terrain correction of less than one milligal, and that 95 per cent or more require a correction under 5 mgal.

Summary of Errors

A good estimate of the overall error in the Bouguer anomalies from these sources can be found from a study of repeat stations. On this survey 92 stations were repeated. Any station within 0.2 minute of latitude and 0.3 minute longitude of another was called a repeat in this analysis; however, most were actually closer than this. Since a repeat station was not read in exactly the same spot as the first station—the observers, in fact, were unaware that they were repeating a station—it would be expected that the elevation and the observed gravity values of any set of repeats would not exactly coincide. The Bouguer anomalies, however, should be the same, unless an extremely steep gradient were present in the area. Thus, repeat stations according to the above definition should give a good estimate of the overall errors in the Bouguer anomalies. The r.m.s. difference in Bouguer anomaly values between these repeat stations was only 0.7 mgal, indicating the general high quality of the data. However, the errors in the anomalies caused by the use of the conventional density of 2.67 g/cm^3 in the Bouguer reduction, and by the omission of terrain corrections would not be evident from repeat stations.

In summary it is believed that the error in the Bouguer anomaly values in Newfoundland is generally less than two milligals.

Principal Facts

The principal facts for all the gravity stations used in this report and location sketches of the control stations are available upon request from the Gravity Division, Dominion Observatory, Ottawa, Canada.

GENERAL DISCUSSION OF THE BOUGUER ANOMALY FIELD AND ISOSTASY

As can be seen from the anomaly map (in pocket) the Bouguer anomaly field of Newfoundland is extremely variable with areas of both large positive and large negative anomalies. Some of the anomalies are linear while others appear more circular in shape. The total range of the Bouguer anomalies in the map-area covered by this report is from −58.9 mgal (north of Harrington Harbour) to +52.0 mgal (on Exploits Island). The total range of the elevations is from sea-level (along the coasts) to 2,469 feet (just south of the Bay of Islands).

Table I gives some statistics for the gravity data.

TABLE I. AVERAGE ANOMALIES AND AVERAGE ELEVATIONS

	For the Whole Map-Area (1,444 Stations)	For the Area South of Lat. 50° (1,103 Stations) (Area S)	For the Area North of Lat. 50° (341 Stations) (Area N)
Average free-air anomaly (mgal)	+15	+23	−11
Average Bouguer anomaly (mgal)	−2	+ 5	−28
Average elevation (feet)	519	527	491

Major Gravity Gradient

On inspection of the anomaly map it is seen that, in general, the Bouguer anomalies of Newfoundland are positive or near zero with the exception of the Great Northern Peninsula, which shows predominantly negative anomalies. This change in anomaly level from positive to negative appears to be a major change because all of the Canadian Shield area north of the St. Lawrence River has generally negative anomalies (Weaver, b, in press), while the Appalachian areas of New Brunswick, Nova Scotia, and Prince Edward Island (Garland, 1953), along with Newfoundland south of latitude 50°, all have predominantly positive anomalies. Also, it should be noted that the rocks forming the plutonic core of the Great Northern Peninsula are Grenville in age, similar to those of the Shield area to the north. Thus, it was believed reasonable to divide the data into two groups as shown in Table I.

It should be noted that the line across which the gradient occurs cuts the 50° latitude line at about a 45° angle. However, for ease of averaging on the computer, the 50° latitude line was chosen. Thus, a few stations were averaged in the wrong group, but this would not significantly affect the results. For purposes of discussion, the area south of latitude 50°N is designated as "area S" while the area to the north is designated as "area N".

The change in level of the average Bouguer anomaly cannot be readily explained on the basis of the surface densities. The average density of the rocks collected for the area south of latitude 50° (area S) is 2.69 g/cm^3, while the average density of all the rocks collected on the remainder of the survey is also 2.69 g/cm^3. The "remainder of the survey" includes the present map-area north of latitude 50° (area N) as well as the other parts of the Shield area to the north and west where the Bouguer anomalies are also all negative (Weaver, b, in press). It must be remembered, however, that this is based on relatively few samples, and that the rock types were not necessarily sampled in proportion to their occurrence. Moreover, the change in density required is extremely small. For a crustal thickness of about 35 km a change in the average density of less than 0.02 g/cm^3 throughout the crust could cause the observed change in Bouguer anomaly level of about 33 mgal. For complete density information see Table IV.

Assuming that, for a large area, the effect of isostatic compensation is about equal to the attraction of the topography above sea-level, the difference in average elevation of these two areas of 36 feet (*see* Table I) corresponds to only about one milligal. Thus, the anomaly difference of 33 mgal does not correlate with any major change in the surface elevation.

Since the anomaly change appears to be a major one, it seems reasonable to suggest that it reflects a major change in crustal structure, and may in fact mark the boundary between the Grenville and Appalachian provinces. This change could be a variation in average crustal density as mentioned above, or a variation in depth to an intermediate layer or to the Mohorovičić discontinuity. It should be noted that a similar gradient occurs in the St. Anthony area at the northern tip of the Great Northern Peninsula. This may be the same gradient and the connection between the two may be offshore to the east where no measurements have yet been made. Thus, the Bouguer anomaly level east of the Great Northern Peninsula and north of Notre Dame Bay is probably similar to that of area S. It should be noted that this gradient in the St. Anthony area appears to bear no relation to the ultrabasic bodies there.

Isostasy

As indicated above, the difference in Bouguer anomaly level between the two areas does not seem to correlate with any change in mean elevation. Likewise, the Bouguer anomalies within each area do not depend on the elevations in that area. In order to show this, each area was divided into units of one degree latitude by two degrees of longitude. This unit was used for convenience as the data output from the computer is listed according to these units. For each unit, the Bouguer anomalies for all stations with the elevations 10 feet and under were listed and then the anomalies for the same number of stations with the highest elevations in that unit were listed. Finally, the two lists were averaged and the results are tabulated in Table II.

TABLE II. AVERAGE BOUGUER ANOMALIES AND AVERAGE ELEVATIONS FOR THE HIGHEST AND LOWEST STATIONS

Number of Stations	Average Elevation ft.	Average Bouguer Anomaly (mgal)	Standard Deviation of Average Bouguer Anomaly (mgal)
Area south of latitude 50° (Area S)			
215	10	+ 7	17
215	910	+ 7	15
Area north of latitude 50° (Area N)			
73	10	−22	18
73	944	−20	18

Thus, it is remarkable that within each area, even though the average elevation difference between the highest and lowest stations is over 900 feet (equivalent to over 30 mgal), the average Bouguer anomaly remains essentially the same. And yet between the two areas, the difference of nearly 30 mgal is evident for both the highest and lowest stations.

If one expects a Bouguer anomaly of zero for sea-level stations which are perfectly isostatically compensated and an anomaly of −.034 mgal per foot for other stations which are perfectly compensated for elevation, then the following picture is evident from Table II:

> For area S, the sea-level stations are undercompensated by 7 milligals. As the Bouguer anomaly at the high elevations is also +7 mgal, there is no compensation for the topography above sea-level. For area N, the sea-level stations are overcompensated by 22 mgal. Again, there is almost no change in Bouguer anomaly for the high elevations, and thus there is no change in compensation for these elevations.

Comparing Tables I and II, it is apparent that the average anomaly for each area when all the stations are included is more negative in each case than the values for the highest and lowest stations. Thus, the stations with intermediate elevations must show more negative anomalies than either the highest or lowest stations. The values would be +4 mgal for area S (for an average intermediate elevation of 572 feet), and −33 mgal for the northern area (for an average intermediate elevation of 504 feet). Thus with respect to the sea-level stations, there does appear to be a slight amount of compensation (more in the northern area) for the intermediate elevations but none for the highest elevations.

Another method of treating the data is to consider all the data in each area at once. Referring to Table I, it is seen that for area S, the average elevation is 527 feet and the average Bouguer anomaly is +5 mgal. Thus, the area is undercompensated by 23 mgal on the average. For the northern area, the average elevation is 491 feet, and the average anomaly is −28 mgal. Thus, the area is overcompensated by 11 mgal, on the average. These can be seen directly from the free-air anomalies.

Relation Between Bouguer Anomalies and Seismic Results

Recent seismic work in the area (Ewing, Dainty, Blanchard, and Keen, 1966) indicates that a thick crust with an intermediate layer is present beneath the area where the Bouguer anomaly level is positive, while a thin crust without an intermediate layer is present in the northern area where the anomaly level is negative. Furthermore, in areas with a thick crust, there is a high-velocity crustal layer present above the intermediate layer, and the upper mantle velocity is also high.

The seismic data show that the depth to the Mohorovičić discontinuity is about 45 km under the lower Gulf of St. Lawrence, and about 41 km near Cape Freels, east of Notre Dame Bay, with upper mantle velocities of 8.5 and 8.7 km/s respectively. Crustal thickness appears to be about 35 km near the eastern end of Anticosti Island, 30 km near the northern tip of the Great Northern Peninsula, about 33 km off the west coast of Newfoundland between the Port au Port Peninsula and Ferolle Point, and about 33 km off the east coast of Nova Scotia, with upper mantle velocities between 8.0 and 8.1 km/s in these areas. An intermediate layer with a velocity of 7.4 to 7.5 km/s is present under the Gulf at a depth of about 28 km, and under Cape Freels at a depth of 23 km. In addition, these two areas have a high-velocity major crustal layer (6.4 − 6.7 km/s) above the intermediate layer. The velocity of the major crustal layer in the other areas is about 6.1 km/s.

The above results agree with the conclusions drawn by Pakiser and Steinhart (from Odishaw, 1964) from seismic work in the United States. They find that low mean crustal and upper mantle velocities favour a thin crust while high mean crustal and upper mantle velocities favour a thick crust. They further state that if the density increases with seismic velocity, then the results are those expected for isostatic equilibrium. Thus, isostatic compensation is related to density variations in the crust and upper mantle as well as to changes in crustal thickness, and therefore any crustal studies by the analysis of gravity data is extremely complicated, and highly ambiguous. From gravity data alone if no other information is available, all one can say about the crust is that any area of predominantly positive anomaly has more mass nearer the surface than an area of predominantly negative anomaly. But it is not possible to say anything about the actual crustal structure without other information.

Woollard's (1964) velocity-density curves seem to indicate that the density of a given rock type always increases with seismic velocity but usually only a small amount. However, a different rock type with a much higher density may have similar velocity values. Table III shows typical examples, read from Woollard's graph. The seismic velocities found for the Appalachian area fall within the velocity ranges given in the table.

Table III. Variation of Density with Seismic Velocity (from Woollard, 1964)

Rock Type		Velocity Variation (km/s)	Approximate Density Variation (g/cm³)
Granite		5.8 – 6.8	2.65 – 2.66
Diorite		5.8 – 7.5	2.76 – 2.79
Gabbro		7.0 – 8.0	2.98 – 3.00
Pure dunite	continuous	7.7 – 8.0	3.19 – 3.28
Pure dunite	curve	8.0 – 8.7	3.28 – 3.48

As previously shown, the two areas of Newfoundland, N and S, are out of isostatic equilibrium with respect to each other. The average elevation of the two areas is essentially the same while the average Bouguer anomaly is about 33 mgal more negative in the northern area. Also, as the seismic data shows, the cause is not a simple thinning or thickening of the crust between the two areas. Figure 2 shows a model for both areas based on the Newfoundland seismic information, the measured surface densities, and Woollard's velocity-density curves. As will be demonstrated later, diorite in Newfoundland seems to be associated very often with positive anomalies, and thus the evidence from the seismic and gravity data suggests that the high-velocity major crustal layer in area S is dioritic. The intermediate layer is assumed to be gabbroic.

Considering each layer as a Bouguer slab, the attraction of model S disregarding the material below 41.5 km is nearly 14 mgal greater than the attraction of model N to the same depth. The observed difference is about 33 mgal, and thus the other 19 mgal must be due to the density variation in the upper mantle. This can be produced if the density of 3.3 g/cm³ for the upper mantle in model N grades into a density of 3.5 g/cm³ below the 41.5 km level. If the change were sharp, it would occur at a depth of about 43.5 km.

The gravitational attraction is very sensitive to changes in thickness or density of any of the layers, or to a combination of the two. Consider, for example, in model S, changing the thickness of the first layer to 12 km, that of the second layer to 11 km, and that of the intermediate layer to 19 km, making the total crustal thickness 42 km, instead of 41.5 km. Also consider changing the crustal thickness in model N to 30.5 km instead of 31 km. These slight changes are still within the limits of the accuracy of the seismic data. But now, the attraction of model S to 42 km depth is about 4 mgal less than that of model N to the same depth. Thus, in this case, all of the 33 mgal plus the deficient 4 mgal must be supplied by the upper mantle. This could be produced if the density of 3.3 g/cm³ in model N changes to 3.5 g/cm³ at a depth of about 46 km.

Thus, the variations in the gravity field must be caused partly by a greater average crustal density in areas with a thick crust and partly by a greater average upper mantle density in these areas. But, because the gravity field is affected so greatly by even small changes in any of the crustal parameters, one cannot say with any reliability how much the upper mantle actually contributes to the gravity field. More seismic data in Newfoundland and in the Shield area might help to resolve the problem here. However, the simple model and the discussion have shown that the gravity and seismic results are compatible, provided the upper mantle contributes to the gravity field.

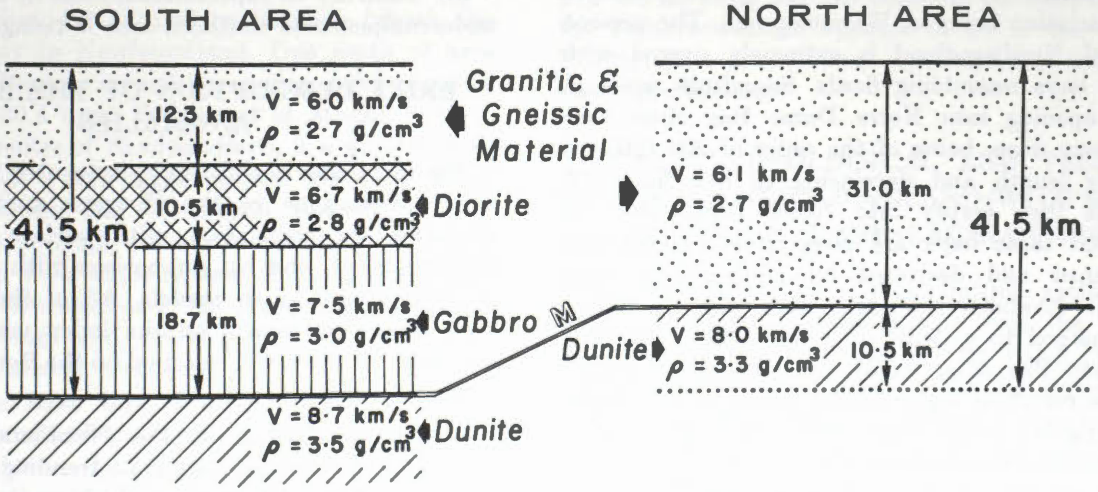


FIGURE 2. Crustal models.

Ewing *et al.* (1966) state that the thick crust may be associated with the areas deformed by the Taconic orogeny; the Gulf of St. Lawrence and Cape Freels are two such areas. The intermediate layer and the high velocity crustal layer above it may be associated with an intermixing of crust and mantle material. Basic and ultrabasic intrusions seem to be associated with the Taconic orogeny also and this again points to an upwelling of basic material. The east coast of Nova Scotia has a thin crust, but, although it is in the Appalachian province, it was not deformed during the Taconic orogeny. The west coast of Newfoundland and the St. Anthony area, both of which have a thin crust, are at or near the major gravity gradient discussed previously, and thus may mark the edge of the Taconic zone and the beginning of the Grenville area.

Another suggestion by Ewing *et al.* (1966) is that the thick crusts may be associated with sedimentary basins; the Gulf of St. Lawrence is a good example. The intermediate layer and the general apparent rise of basic material may compensate for the low-density sediments. The gravity data tends to favour the first hypothesis as most areas affected by the Taconic orogeny have generally positive anomalies, whether or not they are sedimentary basin areas.

The seismic results seem to indicate that the Appalachian system does not die away north of Notre Dame Bay. This lends support to the conclusion reached from the gravity data that the Bouguer anomaly level east of the Great Northern Peninsula and north of Notre Dame Bay is similar to that of area S (the main body of Newfoundland south of latitude 50°).

It is interesting to note that most of the land in the southern area where the Bouguer anomaly level is positive is rising, contrary to what one would expect from isostatic considerations. In Pleistocene times, evidence indicates that the whole island was glaciated, the last glaciation being of Wisconsin age. The present coastline of Newfoundland is extremely rugged with very deep bays resembling fiords. Soundings made in the bays opening into Notre Dame Bay show that they are very deep, being of the order of 200 fathoms along their length and decreasing to less than 100 fathoms as they empty into Notre Dame Bay. It appears that these bays are steep river valleys that were widened and deepened by glaciers and then submerged. Evidence indicates that the shorelines were submerged to a depth of around 800 feet along Notre Dame Bay after world-wide melting of glacial ice and the return of water to the oceans (Espenshade, 1937). Along the south coast, only about 150 feet of submergence has taken place. Since then, the land has been rising slowly, as shown by raised beaches. In the Great Northern Peninsula, raised beaches suggest a post-glacial recovery of about 250 feet. The Notre Dame Bay area seems to have risen about 200 feet. The south coast and the Bonavista Peninsula, however, appear to have risen only about 50 feet. These areas are still rising. However, the tide gauge at St. John's suggests a rate of sinking there at the present time of about 2 feet per century. A hinge line is believed to occur between the Avalon and Bonavista Peninsulas, passing through Trinity and Placentia Bays, (Jenness, 1963). Thus, there appears to be a general southeastward tilting of the island.

It is not clear why most of area S which is undercompensated is rising. Normally, such areas are sinking while overcompensated areas are rising.

Summary

In summary, the foregoing discussion has indicated the following:

(1) There is a major change in anomaly level across a line trending northeasterly across the 50° latitude line, and apparently reappearing in the St. Anthony area, which may represent the boundary between the Appalachian and Grenville provinces.

(2) There is little or no correlation between anomalies and elevations in the map-area.

(3) The southern area (the main body of Newfoundland) is generally undercompensated and the northern area is generally overcompensated.

(4) Considering the recent seismic studies, the anomaly difference between the two areas is probably due to density variations within the crust and upper mantle and to variations in crustal thickness. The upwelling of basic material to the south may be associated with the Taconic orogeny.

(5) Contrary to expectations, most of the land in the undercompensated southern area is rising.

BRIEF DESCRIPTION OF THE BOUGUER ANOMALIES

The remainder of this report is devoted to a discussion of the variations in the Bouguer anomalies in the map-area by correlation with surface geology and aeromagnetics, and by comparison with the anomalies of hypothetical earth models. All of the place names used below are shown on the index map (Figure 1), and many of them will be found on the Bouguer anomaly map (in pocket).

A striking feature of the Newfoundland gravity field is the fairly steep gradient trending northeasterly across the 50° latitude line, which appears to mark a major change in the average Bouguer anomaly from

+5 mgal in the south to −28 mgal in the north. This has already been discussed in the previous section along with the isostatic considerations. A more detailed inspection of this gradient shows that it is offset to the south near the east coast of the Great Northern Peninsula and then appears to extend out into White Bay. A gradient of about the same magnitude separates the positive anomaly in the St. Anthony area from the negative anomaly in the central part of the Great Northern Peninsula. It is suggested that the same feature causes both gradients, and that the connection between the two is just off the east coast where measurements have not yet been made. The maximum Bouguer anomaly in the St. Anthony high is +27.9 mgal and this value is nearest the ocean suggesting a more positive centre located offshore. The minimum anomaly for the Great Northern Peninsula Low of −57.6 mgal is centred near Ten Mile Lake.

South of the Great Northern Peninsula, the Bouguer anomaly field may be divided into five broad areas; the West Coast Low, the Central High, the Granite Lake Low, the Eastern High, and the St. John's Low. The West Coast Low is a long narrow band of negative anomalies ranging from 0 to −30 mgal, and extending along the west coast from the Great Northern Peninsula to the south coast. It may represent in part at least a broadened and modified extension of the major gradient previously discussed. Within this area of negative anomaly are two centres of positive anomaly—the Bay of Islands High with a peak anomaly of +30.8 mgal at North Arm Mountain, and the Port au Port Peninsula High with a maximum value of +19.7 mgal.

The broad Central High encompasses a large area around Notre Dame Bay with a narrow extension that follows the Long Range Complex to the south coast. Within this broad Central High are many centres of high positive anomaly, the most positive being that immediately surrounding Notre Dame Bay itself where the value reaches +52.0 mgal on Exploits Island, the highest anomaly in Newfoundland. Due south of here near Mount Peyton is another centre with a peak anomaly of +39.4 mgal. Southwest of Mount Peyton, almost in the centre of Newfoundland, is a small feature with a value of +32.5 mgal, termed the Gulp Pond High. Between the Bay of Islands and White Bay, the Adies Pond High shows a maximum anomaly of +36.3 mgal. Two major centres of positive anomaly occur between Buchans and the south coast. They are the Buchans High and Cross Pond High and both attain maxima of over +40 mgal.

The Granite Lake Low is a major feature of the central Newfoundland gravity field. The most negative centre of this low, −41.8 mgal, is near Granite Lake. One arm of the low trends northeasterly towards Cape Freels.

The Eastern High comprises four areas of positive anomaly, Bonavista Bay, the Burin Peninsula, the Harbour Breton area and the Avalon Peninsula with the last three joined to Bonavista Bay through a narrow band of positive anomaly trending north-south. The Bonavista Bay High shows the most intense anomaly with a maximum value of +38.1 mgal. The other three centres, Burin, Harbour Breton, and Avalon all have peak anomalies of over +30 mgal.

In the northeastern part of the Avalon Peninsula, the Bouguer anomalies become negative, with the minimum value being −17.7 mgal just southeast of St. John's. It appears that the centre of this St. John's Low may be offshore.

In general, the trends of all the major anomalies of Newfoundland are northeasterly. A close inspection of the map, however, will reveal that other trends are present. A northerly trend seems to separate the Adies Pond and Buchans Highs on the west from the Notre Dame Bay anomaly on the east. Furthermore, this trend is in line with the offset in the major gradient that separates the Great Northern Peninsula from the rest of Newfoundland. The Burin Peninsula High also trends northerly and the narrow band of positive anomaly that connects it and the Avalon High to the Bonavista Bay anomaly also strikes northerly over most of its length. There appears to be a northeasterly trend separating the Avalon High and the St. John's Low. Elsewhere in the map-area, there are suggestions of more north and northwest trends.

An interesting aspect of the gravity anomaly field is that major positive anomalies are associated with four of the larger bays of Newfoundland, namely, Notre Dame Bay, Bonavista Bay, Placentia Bay, and Fortune Bay. Also, as previously mentioned, the line across which a major gradient occurs trends into White Bay, and the dividing line between the St. John's Low and the Bonavista High appears to be in the middle of Trinity Bay. No obvious explanation is available for these associations.

GENERAL GEOLOGICAL AND TECTONIC HISTORY OF NEWFOUNDLAND (WITH MENTION OF ADJACENT APPALACHIAN AREAS)

The information for the generalized geological map (in pocket) was obtained mainly from the Geological Map of Newfoundland compiled by Baird (1954), and from various publications of the Geological Survey of Canada. The map is at a scale of 1 inch to 20 miles.

The Precambrian rocks of the Grenville province were stabilized 800 − 1,100 million years ago, and constituted a craton during the development of the

Appalachian geosynclinal system. The oldest rocks of Newfoundland are the Precambrian gneisses of the Long Range Complex which form the core of the Great Northern Peninsula. The gneiss is also intruded by Precambrian granite. The Precambrian rocks of the Fleur de Lys Group on the east side of White Bay are similar to those of the Great Northern Peninsula, but some were reworked during the Acadian orogeny.

A second resistant block in Newfoundland was the Avalon Peninsula where the Harbour Main Group of metamorphosed acid volcanic rocks have been intruded by the Holyrood granite batholith which has been dated as Grenville. The rocks of the Avalon Peninsula were refolded in the Acadian orogeny but not as extensively as those of central Newfoundland.

The Long Range Complex is overlain to the west by gently folded Lower Palaeozoic sediments, mainly limestone and shale. These rocks do not appear to have been folded during either the Taconic or Acadian orogenies.

The youngest rocks of Newfoundland are the coarse feldspathic sandstones of the Barachois Group which are of Pennsylvanian age. These are located in the Carboniferous basin in southwestern Newfoundland.

According to Neale, Beland, Potter, and Poole (1961), work in Russia has shown that the history of geosynclinal regions appears to be characterized by three stages of development. They are: (1) an early phase of volcanic rocks and associated sediments; (2) a middle phase of greywacke, shale, and carbonate rocks, with granitic intrusions; and (3) a late phase of conglomerate, sandstone, shale, carbonate, evaporites and coal. The Appalachian geosynclinal development seems to follow this pattern. The Ordovician rocks of Newfoundland which were folded during the Taconic orogeny represent the first phase. The Silurian and Devonian rocks of Newfoundland which were folded and intruded by granites during the Acadian orogeny represent the second phase, and the Carboniferous rocks folded and faulted in late Palaeozoic time represent the third phase.

The Taconic orogeny in middle to late Ordovician times seems to have affected most of the Eastern Townships of Quebec, the Gaspé Peninsula, New Brunswick, possibly Cape Breton Island, and all of central Newfoundland from the west coast eastward to Fortune and Bonavista Bays. Areas apparently not affected by the Taconic orogeny include mainland Nova Scotia, southern Newfoundland, and the Burin, Bonavista, and Avalon Peninsulas. Many ultrabasic intrusions are associated with the Taconic orogeny, but only a few very small granite batholiths of Ordovician age are known in the Canadian Appalachian area. Neale and Nash (1963) suggest that the granitic rocks of the Burlington Peninsula area of Newfoundland may be Ordovician.

The Acadian orogeny in Devonian time probably affected all parts of the Canadian Appalachian region except northern Gaspé and parts of the Eastern Townships of Quebec, the sedimentary and volcanic rocks of the Bay of Islands area on the west coast of Newfoundland and those at the northern tip of the Great Northern Peninsula, and the Grenville core of rocks of the Great Northern Peninsula. The evidence for the Acadian orogeny includes an angular unconformity between Carboniferous rocks and all older rocks and almost all granitic bodies except those of the Great Northern Peninsula either cut Devonian rocks or have been actually dated as Devonian by K/Ar dating. The Precambrian rocks of southeastern Newfoundland (Avalon and Burin Peninsulas) were also deformed during the Acadian orogeny.

The Appalachian orogeny in late Palaeozoic times affected a fairly narrow area from the Bay of Fundy region northeasterly through Cape Breton Island and through the two Carboniferous basins of Newfoundland. Metamorphism and intrusion did not accompany the Appalachian orogeny. In the area around the Bay of Fundy and Prince Edward Island a cratonic cover of Upper Pennsylvanian strata overlies the rocks folded during the Appalachian orogeny. They consist of sandstone, conglomerate, and coal beds. The last movement along the major fault zone of Newfoundland that extends from the southwestern coast in a northeasterly direction to Grand Lake and White Bay appears to be late Palaeozoic and may be due to the Appalachian orogeny. Other northeasterly trending faults in Newfoundland may be of the same phase.

Since the time of the Appalachian orogeny, the Island of Newfoundland has been mostly above sea-level, and has been an area of erosion.

INTERPRETATION OF THE BOUGUER ANOMALY FIELD OF NEWFOUNDLAND

Any detailed geology required for the interpretations that follow is presented with the interpretations.

Considering the anomaly map with regard to the geological map it is apparent that some of the anomalies show a good correlation with surface geology, while others show little or none at all. The Granite Lake Low appears to be associated with large granite masses and Ordovician sediments. The Bay of Islands High at North Arm and Table Mountain, and the Gulp Pond High, occur directly over known ultrabasic and gabbroic intrusions. The Mount Peyton High correlates exactly with the mapped diorite and hornblende granite. The Cross Pond and Buchans Highs appear to be associated with outcrops of gabbro and diorite. The most positive centre of the Notre Dame Bay High occurs on Exploits Island, and diorite is found there. Negative anomalies along the west coast appear to correlate with a sedimentary basin although, considering the densities of shale and limestone, it seems unlikely that the sediments in the Bay of Islands area can explain the entire anomaly. The negative anomaly in the Great Northern Peninsula may be caused by Cambrian sediments and Precambrian granite. The Eastern High may be associated partly at least with Precambrian volcanics. No obvious correlation with geology exists for most of the other anomalies. Neither is there any direct correlation between surface geology and the gradient across the line that trends northeasterly over the 50° latitude line. However, this gradient does occur near the place where Grenville gneisses are exposed.

During the survey, it was not possible to make detailed gravity traverses across any of the anomalies shown on the map, except the Bay of Islands High at North Arm Mountain. Consequently, all of the gravity profiles which follow were prepared by using the Bouguer anomaly values of the stations located on the profile and by taking the values from contours which cross the profile. The surface expression of the models represents the geology from the general geological map. Aeromagnetic information is available in Newfoundland for a 1-degree strip from 48 to 49° latitude and is published on maps at a scale of 1 inch to 1 mile. Because it is only used in a general way in this report, it was compiled into a map at a scale of 1 inch to 4 miles, using only the 500-gamma contours. Any aeromagnetic profiles shown with the gravity profiles that follow were obtained from the compiled map (which is not included in this report). The gravitational attractions of the mass distributions used were calculated by means of two computer programs, one for use with two-dimensional masses (Nagy, 1964) and one for right vertical circular cylinders (Nagy, 1965). A program for three-dimensional masses is also available but the regional spacing of the gravity stations and the lack of sufficient density data do not warrant its use here.

Determination of the Regional Gravity Field

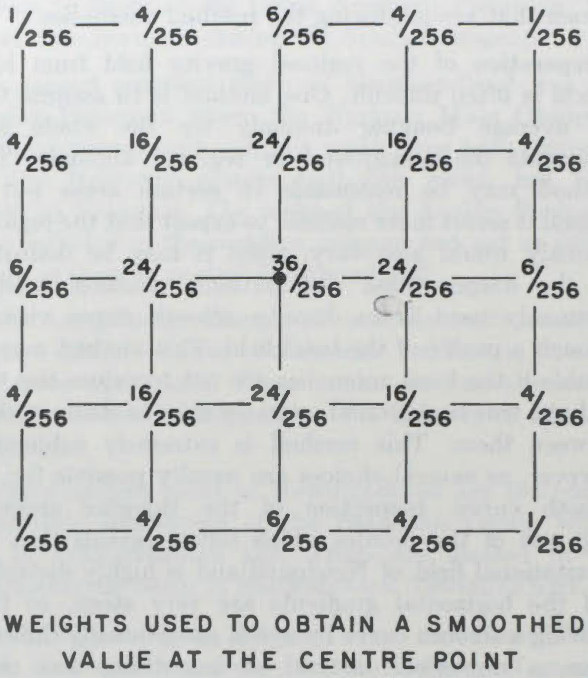
A Bouguer anomaly map will rarely show single anomalies that do not have superimposed on them the effects of smaller or larger disturbances. Such a map is very difficult to interpret unless one can somehow separate the near-surface features from the deeper ones. Usually this is done by choosing a regional or background anomaly with a gentle gradient and then subtracting this field from the original field to give a residual anomaly field, which consists of the local anomalies with fairly steep horizontal gradients. These are caused by near-surface mass distribution, and often find direct correlation with the surface geology. The regional anomaly field consists of the longer wavelength anomalies with smaller horizontal gradients, and are often due to deeper sources such as changes in crustal thickness or to deeper sections of the same anomalous masses that are producing the residual anomalies.

Separation of the regional gravity field from local effects is often difficult. One method is to assume that the average Bouguer anomaly for the whole area represents the background or regional anomaly. This method may be reasonable in certain areas but in general it seems more realistic to expect that the regional anomaly would also vary, since it may be disturbed by the deeper mass distributions. Another method commonly used is to draw a smooth curve visually through a profile of the total field. This method may be reliable if the local anomalies are not too close together so that a true background anomaly may be distinguished between them. This method is extremely subjective, however, as several choices are usually possible for the smooth curve. Inspection of the Bouguer anomaly map and of the profiles which follow reveals that the gravitational field of Newfoundland is highly disturbed and the horizontal gradients are very steep, so that drawing a smooth curve by eye is exceptionally difficult. Thus, a numerical method of smoothing was used, which was described by Holloway (1958), and first applied to gravity data in Wales by Griffiths and Gibb (1965).

Since the purpose of smoothing is to attenuate the short wavelength anomalies without significantly affecting the large wavelength anomalies, it is actually analogous to low-pass filtering of an electrical signal. The residual anomalies, which are obtained by subtracting the smoothed field from the total field, are equivalent to high-pass filtering. Various types of smoothing and filtering functions usually contain a series of weights which determine how much each observation contributes to the smoothed value. The normal smoothing function with weights made proportional to the ordinates of the normal probability curve and with the sum of the weights equal to unity has the most desirable properties for smoothing gravity data. The average value of the smoothed data remains the same as the original, and no polarity reversals or phase shifts occur in the smoothed values. The data may be smoothed any number of times by a smoothing function until the desired smoothing is obtained.

The above method was applied to the present gravity data as follows. A 16-mile-square grid was placed over the Bouguer anomaly map of Newfoundland, and the gravity values were sampled at each of the grid points.

A smoothed value at any grid point is found by using the appropriate weights on the values at the surrounding grid points. This gives an approximation to the normal smoothing function in two dimensions. Figure 3 shows the weights to be applied to obtain a smoothed value.



1/256	4/256	6/256	4/256	1/256
4/256	16/256	24/256	16/256	4/256
6/256	24/256	36/256	24/256	6/256
4/256	16/256	24/256	16/256	4/256
1/256	4/256	6/256	4/256	1/256

FIGURE 3. Grid diagram with weights for smoothing data.

According to the frequency response curve for a normal smoothing function, for a data interval of 16 miles as chosen, the smoothing process should attenuate to under 25 per cent of their original value all features having a wavelength (in profiles) of 60 miles or less and it should retain at about 75 to 100 per cent of their value all features having a wavelength of 130 miles or more. Most of the local features of interest in the Newfoundland gravity field seem to have a wavelength of 60 miles or less and thus would be attenuated on the regional map. Features of wavelength more than 130 miles would tend to show up only on the regional map. The features with sizes in between these would show up partly on the regional map and partly on the residual map. In these cases, the regional variations may be due to deeper parts of the same masses that are causing the residual anomalies or they may be due to something entirely different, such as changes in the crust-mantle boundary. One must use other control data, particularly geological and seismic, to make a decision in such cases. It may be worth pointing out here that it is always impossible, no matter how many smoothing operations are performed, to say anything about the exact depth to the source of the anomalies on either the residual or regional maps. From the gravity data alone, it is only possible to estimate the maximum depth to the top of the mass causing the anomaly. This maximum, of course, increases after each smoothing. But the exact depth to any body causing an anomaly depends on the density contrast and on the width and general shape of that body.

In the profiles which follow, it will be seen that whenever the gravity field is not too disturbed, the regional curve by this numerical method of smoothing is nearly the same as the one that might be determined by drawing a smooth curve visually. In other profiles, this choice of a smooth curve by the latter method is so ambiguous as to be almost meaningless. For the grid size of 16 miles as chosen, the numerical method cannot be used reliably to find regional values within 32 miles of the edges of the surveyed area. However, in the present case, it was applied to within 16 miles of the edges even though the outside row of data required was not available. However, the weights for the outside row are very small (*see* Figure 3) and thus the regional values determined without this row are probably still reasonably good, though not as reliable as the values found for points farther inland. To obtain the regional surface nearer the edges than 16 miles, the contours were projected visually.

The regional gravity field of Newfoundland prepared by the above method is shown in Figure 4. This field was subtracted from the observed field along the profiles in order to give the residual anomaly values. However, separate residual anomaly curves are not included in this report. A complete interpretation requires an explanation for both the residual and regional anomaly fields.

Density Information

During the survey, 114 rock samples were collected on the Island of Newfoundland. This is far fewer than had been planned, but it is difficult to combine good sampling with the gravity observations and maintain the survey schedules. The average density of all the samples collected was 2.69 g/cm^3 with a standard deviation of 0.11. In addition, densities were obtained for some areas from samples collected by the Geological Survey of Canada.

The samples were classified into various rock types, and Table IV gives the average density and standard deviation for each rock type. Rocks of which only one or two samples were collected, however, are not listed in the table. Unfortunately, some important rock types in Newfoundland such as diorite and anorthosite were not sampled, and it is necessary to rely on samples collected in the Canadian Shield area north of the

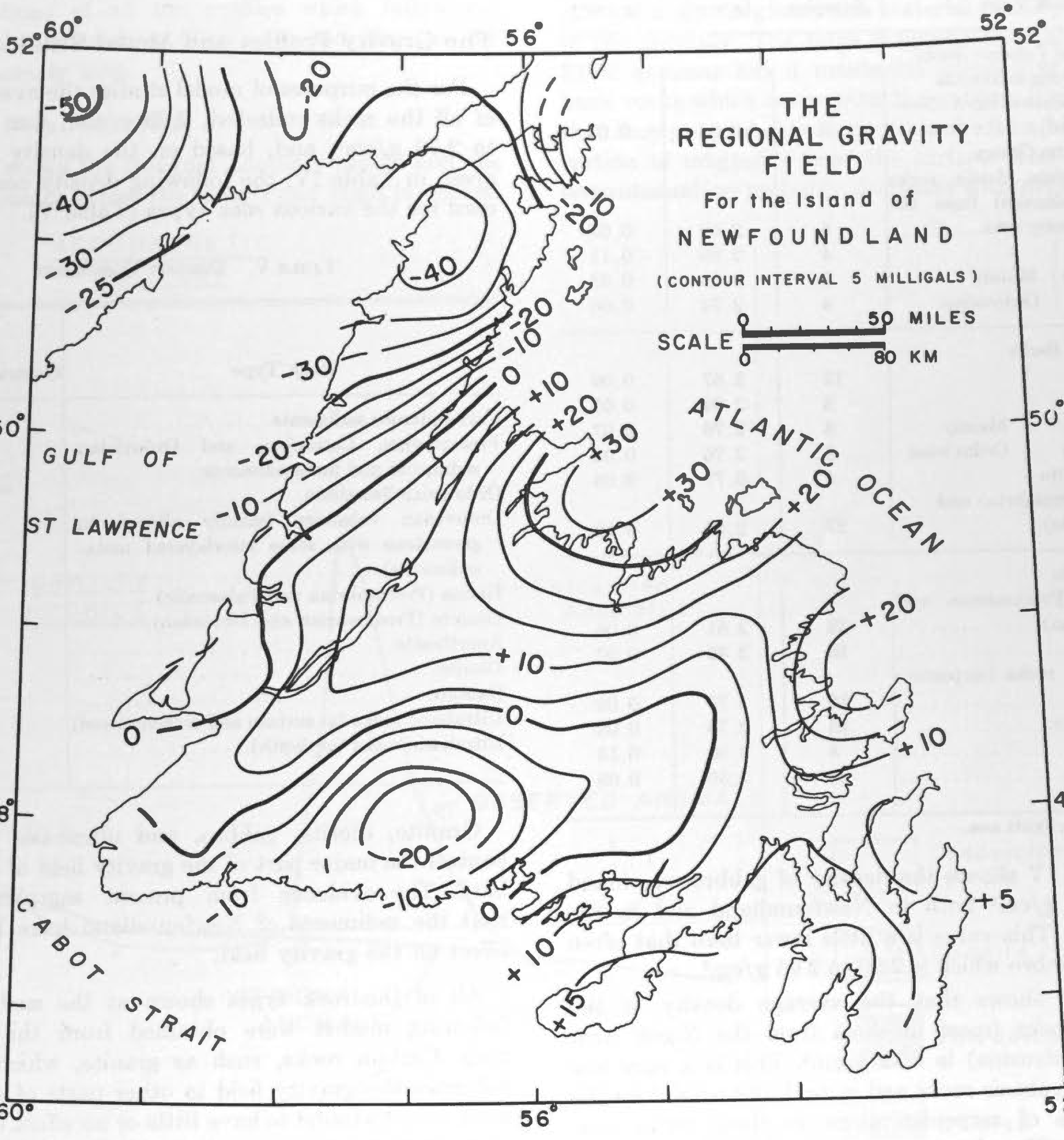


FIGURE 4. Numerically smoothed regional gravity map.

St. Lawrence River for representative densities of these rocks. The values are given in the table.

Table IV. Density Measurements

Rock Type	Number of Samples	Average Density (g/cm^3)	Standard Deviation (g/cm^3)
Sediments and Volcanic Rocks			
Carboniferous sediments (from southwestern Newfoundland)	8	2.64	0.03
Humber Arm Group (Ordovician clastic rocks with volcanics) from the St. Anthony area	6	2.69	0.03
Siltstone	4	2.69	0.11
Greywacke Mainly	9	2.69	0.07
Limestone Ordovician	4	2.74	0.06
Metamorphic Rocks			
Quartzite	12	2.67	0.09
Slate	8	2.69	0.05
Schist Mainly	8	2.76	0.07
Greenstone Ordovician	6	2.76	0.08
Meta-argillite	4	2.77	0.08
Gneiss (Precambrian and Palaeozoic)	27	2.69	0.10
Intrusive Rocks			
Granite (Precambrian and Devonian)	28	2.61	0.06
Gabbro	16	2.86	0.07
Ultrabasic rocks (serpentinized)	16	2.73	0.09
*Anorthosite	15	2.70	0.08
*Diorite	8	2.80	0.13
*Gabbro	20	2.86	0.09

* From Canadian Shield area.

As Table IV shows, the density of gabbro was found to be 2.86 g/cm^3 both in Newfoundland and in the Shield area. This value is a little lower than that often found for gabbro which is 2.90 to 2.95 g/cm^3.

Table IV shows that the average density of the ultrabasic rocks (most of them from the North Arm Mountain intrusion) is 2.73 g/cm^3. This is a very low value for ultrabasic rocks and is no doubt caused by the large degree of serpentinization in these rocks near the surface. The density must increase rapidly with depth, however, especially at the North Arm Mountain intrusion. Here, there is an extremely steep gravity gradient over the edge of the ultrabasic section and the maximum gravity anomaly occurs over the ultrabasic rocks. The change in density is no doubt gradational but in the models which follow, it is approximated by discrete layers. The average maximum density of the ultrabasic rocks is assumed to be 3.10 g/cm^3, although in local sections, they may be more dense.

Because of the inadequate sampling of all the various rock types, it is not possible to show how much the densities vary systematically from place to place within a rock type. Thus, the most reasonable compromise for interpretation is to accept the average densities listed above as representative of the various rock types.

The Gravity Profiles and Model Studies

For the purposes of model studies the average density of all the rocks collected, 2.69 g/cm^3, was rounded off to 2.70 g/cm^3, and, based on the density information given in Table IV, the following density contrasts were used for the various rock types (Table V).

Table V. Density Contrasts

Rock Type	Density Contrast (g/cm^3) (σ)
Carboniferous sediments	−0.06
Precambrian, Cambrian, and Ordovician sediments and metasediments	0.00
Ordovician limestone	+0.04
Ordovician volcanics (mainly altered to greenstone with some interlayered metasediments)	+0.06
Gneiss (Precambrian and Palaeozoic)	0.00
Granite (Precambrian and Devonian)	−0.09
Anorthosite	0.00
Diorite	+0.10
Gabbro	+0.16
Ultrabasic rocks (at surface and serpentinized)	+0.03
Ultrabasic rocks (at depth)	+0.40

Granite, diorite, gabbro, and ultrabasic rocks thus control the major part of the gravity field of Newfoundland. The evidence from present sampling suggests that the sediments of Newfoundland have little or no effect on the gravity field.

All of the rock types shown at the surface in the following models were obtained from the geological map. Certain rocks, such as granite, which normally influence the gravity field in other parts of Newfoundland, may be found to have little or no effect in a certain area. In this case, the rock is still shown in the model but as a very thin mass. An alternative explanation is that the density of the rock in that area is quite different from the average found for that rock type. But there is not sufficient density information to show whether or not this is true.

The main purpose of the following models is to give an indication of the distribution of anomalous mass required to produce the gravity anomalies. However, the exact shape of the masses used, particularly the shapes of the bottom surfaces, should not be taken as absolute. Slight density variations within the mass could give the same gravity effect as a change in shape of the bottom surface of a mass of uniform density. But the models can at least give a rough idea of the depth and extent of the various anomalous masses, based on all of the available information.

The locations of all the profiles which follow are shown on the index map (Figure 1) and also on the Bouguer anomaly map.

Profile AB, Gulp Pond High

Figure 5 shows the Bouguer anomaly profile and the regional anomaly across the Gulp Pond High in central Newfoundland. The same diagram also shows the structural model and the computed gravity values, taking the regional curve as the zero datum. The aeromagnetic data along the same profile are plotted also.

The model shown was obtained by considering the following facts. The maximum value of the observed gravity anomaly occurs over a surface exposure of gabbro, suggesting that this material is the prime cause of the anomaly. The large magnetic anomaly of about 2,000 gammas has a maximum value over the ultrabasic rocks which occur with the gabbro. This indicates that they are probably serpentinized with a high concentration of magnetite near the surface. The amount of serpentinization probably decreases with depth, and the

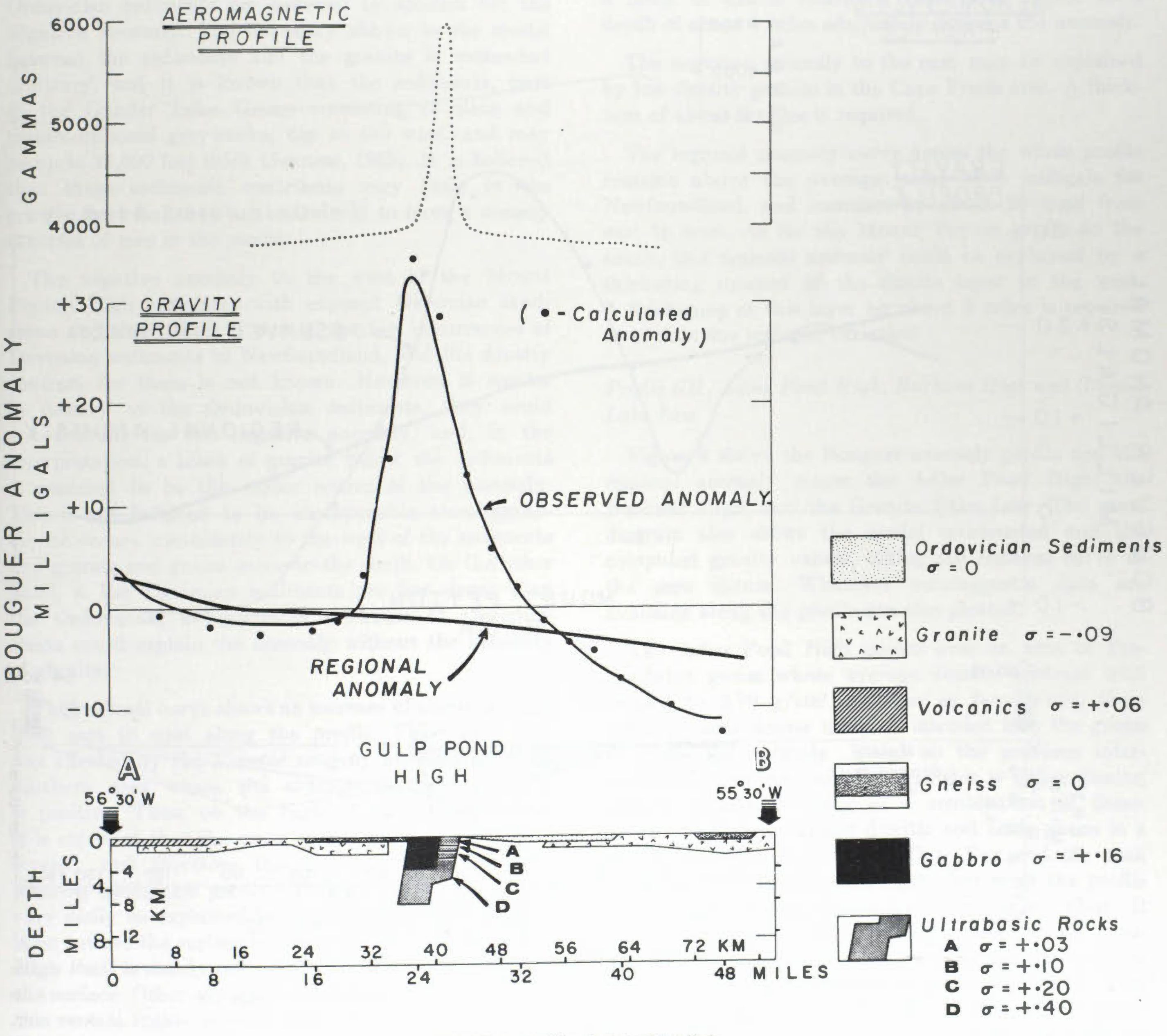


FIGURE 5. Profile AB, Gulp Pond High.

model shows the density contrast varying from +0.03 g/cm³ at the surface to +0.40 g/cm³ at depth. In other areas which are better mapped, such as the Bay of Islands (Smith, 1958), gabbro is underlain by ultrabasics and thus it is believed that the same situation probably exists at Gulp Pond. The final model illustrates that a gabbroic intrusion about 2.5 miles thick underlain by nearly 3 miles of ultrabasics could produce the anomaly. The boundary between the gabbro and the ultrabasic rocks at depth is very uncertain, and if more gabbro is used, the overall depth of the intrusion would be greater.

The small negative anomaly to the east is probably caused by Devonian granite as shown in Figure 5. Ordovician sediments, mainly slate, phyllite, and greywacke similar to the Gander Lake Group, overlie the granite in this area to the east, but their effect on the gravity field is negligible because their average density is close to 2.70 g/cm³.

The regional anomaly curve shows a decrease of about 10 mgal from west to east across the anomalous feature. This is probably caused by an increase in the thickness of granite to the east as the eastern arm of the Granite Lake Low is approached.

Profile CD, Mount Peyton High

Figure 6 shows the Bouguer anomaly profile and the regional anomaly across the Mount Peyton High south

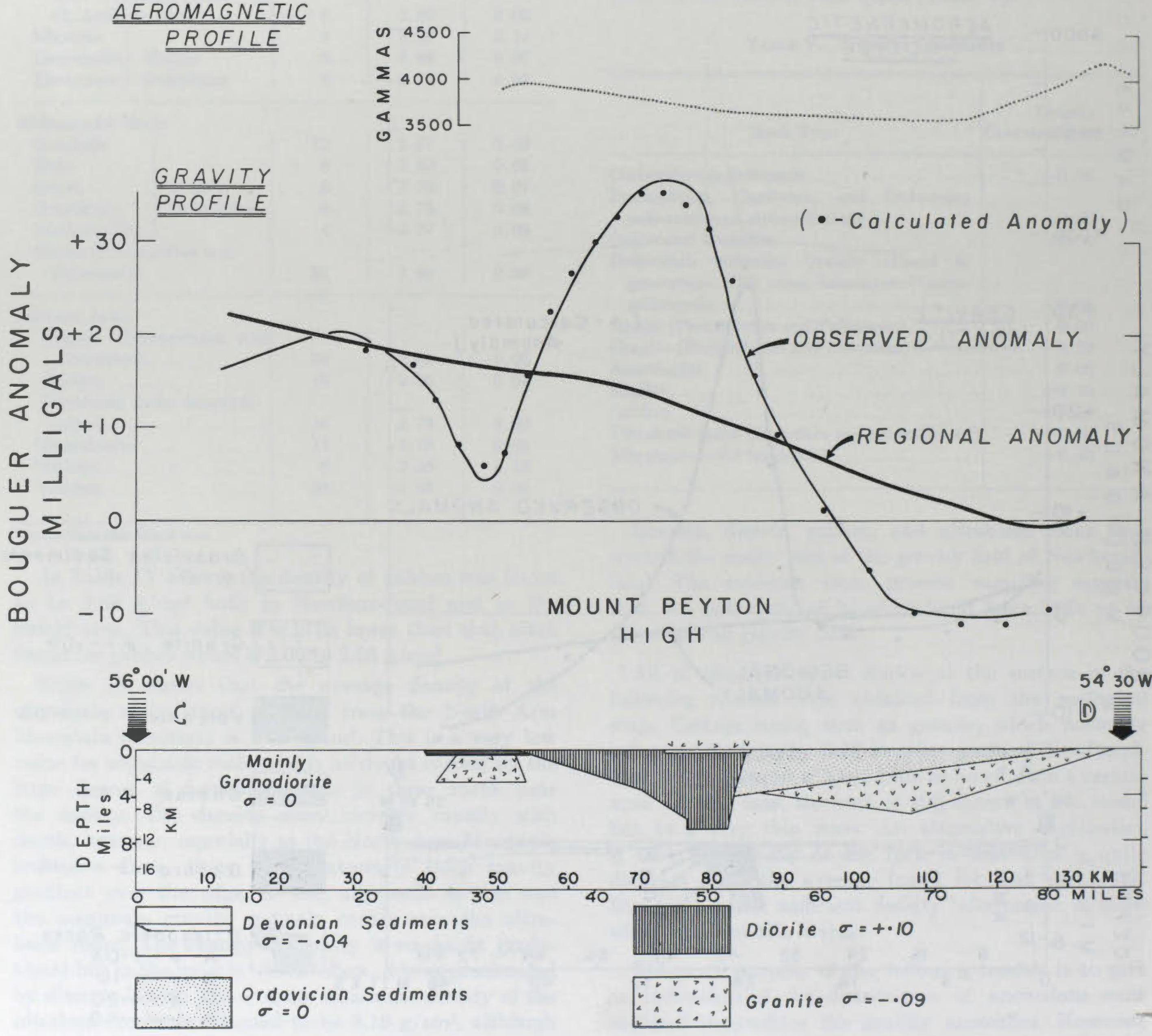


FIGURE 6. Profile CD, Mount Peyton High.

of Notre Dame Bay. The same diagram also shows the model constructed and the computed gravity values, taking the regional curve as the zero datum. The aeromagnetic data for the same profile are also given.

Here, the maximum value of the observed gravity anomaly correlates exactly with the occurrence of diorite and granite, but the granite appears to have little effect on the anomaly and therefore must be very thin as shown. The aeromagnetic data along this profile show little change in value over the anomalous feature. The final model shows a large block of diorite nearly 7 miles thick as a possible explanation of the anomaly. To the east, granitic rocks underlying the Ordovician sediments are believed to account for the negative anomaly. The boundary shown in the model between the sediments and the granite is somewhat arbitrary, but it is known that the sediments, part of the Gander Lake Group consisting of slate and metamorphosed greywacke, dip to the west, and may be up to 25,000 feet thick (Jenness, 1963). It is believed that these sediments contribute very little to the gravity field and they are considered to have a density contrast of zero in the model.

The negative anomaly to the west of the Mount Peyton High correlates with exposed Devonian sandstone and shale. This is one of the few occurrences of Devonian sediments in Newfoundland, and the density contrast for them is not known. However, if similar in density to the Ordovician sediments, they could not account for the negative anomaly, and, in the interpretation, a block of granite below the sediments is assumed to be the major source of the anomaly. This is not believed to be unreasonable since granodiorite occurs immediately to the west of the sediments and granite and gneiss occur to the south. On the other hand, if the Devonian sediments are less dense than the Ordovician, a reasonable thickness of Devonian strata could explain the anomaly without the necessity of granite.

The regional curve shows an increase of about 20 mgal from east to west along the profile. This whole area was affected by the Taconic orogeny and also is in the southern area where the average Bouguer anomaly is positive. Thus, on the basis of earlier discussions, it is expected that the crust would be thick and multilayered, and therefore the increase in the regional anomaly along this profile CD from east to west could very easily be explained by a thickening of the dioritic layer toward the surface to the west. The Mount Peyton High itself is merely one point where the diorite reaches the surface. Other exposures of diorite occur throughout this central region as well, and it is probable that the area was affected to a greater extent by the Taconic orogeny than the area to the east and south where the surface material is mainly granite.

Profile EF, Notre Dame Bay High

Figure 7 shows the Bouguer and regional anomaly profiles across the Notre Dame Bay High, and the suggested interpretation.

As mentioned in the discussion of the last profile, diorite seems to occur frequently in the vicinity of Notre Dame Bay. In fact, diorite occurs on Exploits Island where the most positive centre of the Notre Dame Bay High occurs. Thus, diorite is believed to be responsible for the positive anomaly; in the model, a block of diorite extending from near surface to a depth of about 4 miles adequately explains the anomaly.

The negative anomaly to the east may be explained by low density granite in the Cape Freels area. A thickness of about 2 miles is required.

The regional anomaly curve across the whole profile remains above the average value of 5 milligals for Newfoundland, and increases by about 20 mgal from east to west. As for the Mount Peyton profile to the south, this regional anomaly could be explained by a thickening upward of the diorite layer to the west. A thickening of this layer by about 3 miles is required to explain the regional variation.

Profile GH, Adies Pond High, Buchans High and Granite Lake Low

Figure 8 shows the Bouguer anomaly profile and the regional anomaly across the Adies Pond High, the Buchans High, and the Granite Lake Low. The same diagram also shows the model constructed and the computed gravity values, taking the regional curve as the zero datum. Whatever aeromagnetic data are available along the profile are also plotted.

The Adies Pond High occurs over an area of Precambrian gneiss whose average density contrast with respect to 2.70 g/cm^3 is taken as zero. Thus, there must be some denser material intruded into the gneiss to cause the anomaly. Based on the previous interpretations, one may assume that this is either diorite, gabbro, ultrabasic rocks, or a combination of these. Baird (1960) has mapped dioritic and basic gneiss in a small area west of southern White Bay and the peak value of the Adies Pond High (which is off the profile shown) occurs directly over this material. Thus, it seems reasonable to suppose that a basic dioritic intrusion is the cause of this anomaly. Its exact depth below the gneiss along the profile is uncertain but it must be fairly near surface. The top was placed at a depth of about 0.75 mile in the model. Also, gabbro is shown

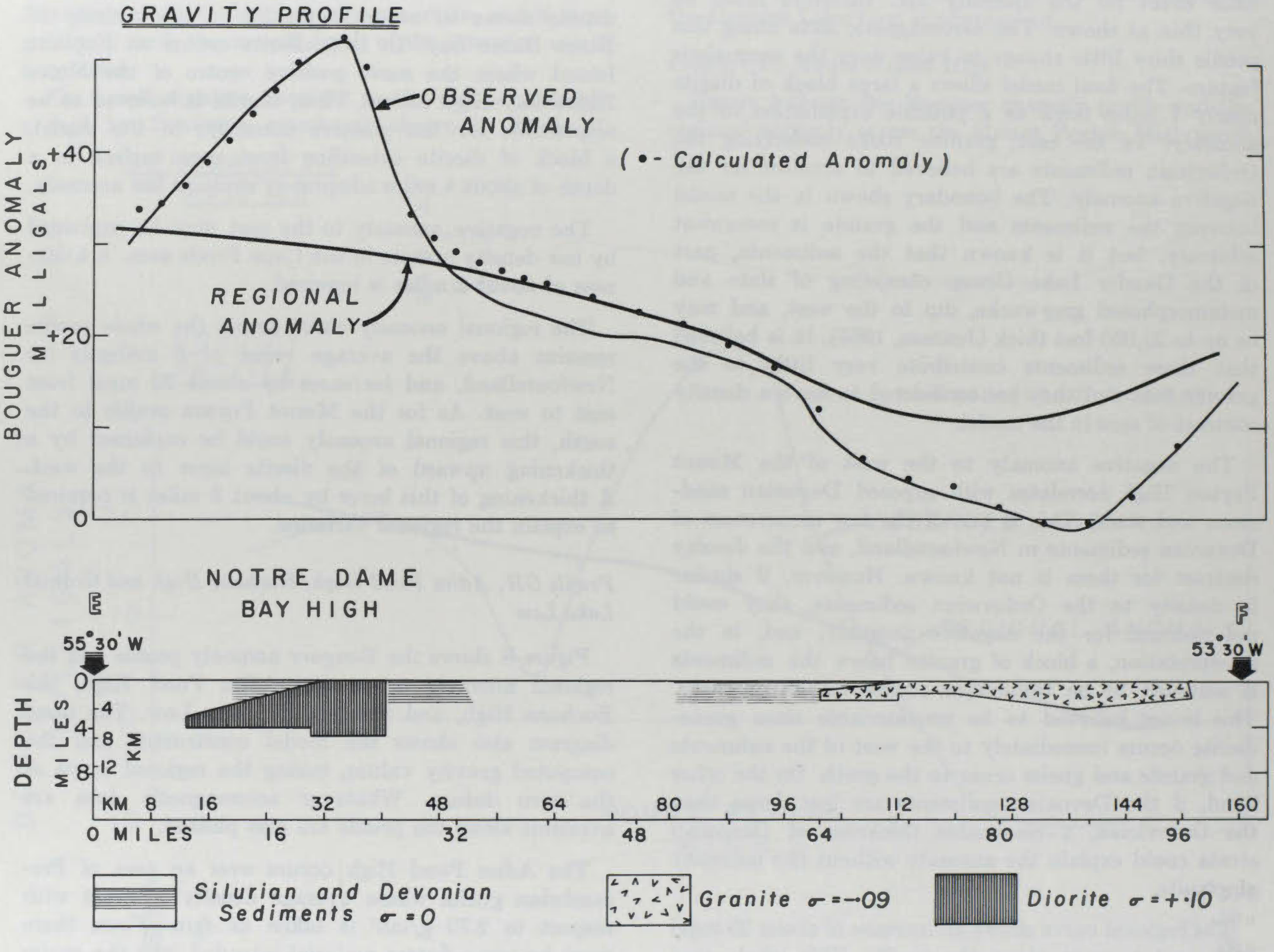


FIGURE 7. Profile EF, Notre Dame Bay High.

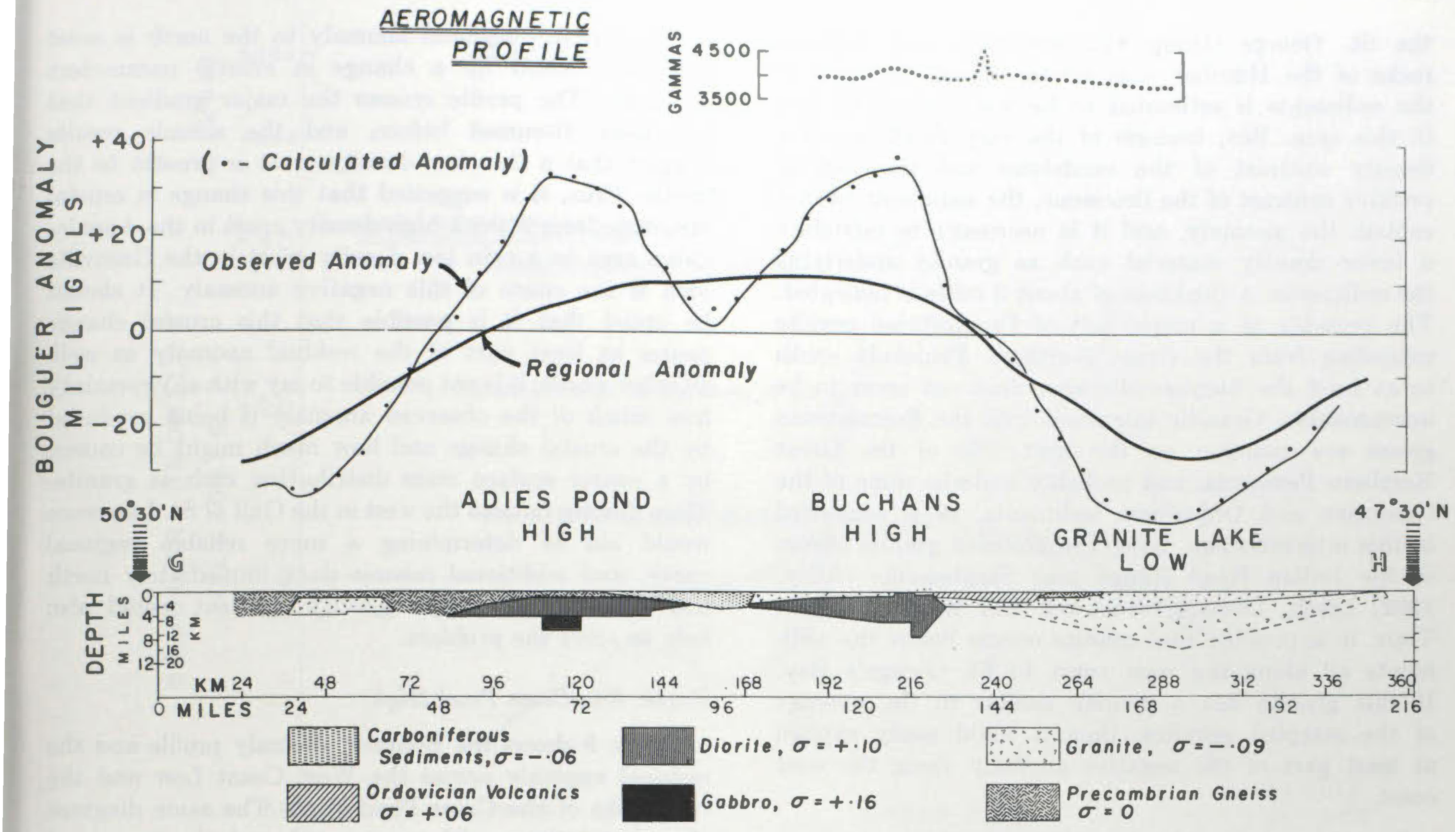


FIGURE 8. Profile GH, Adies Pond and Buchans Highs, and and Granite Lake Low.

to be associated with the diorite. This appears to be a distinct possibility as diorite and gabbro have been mapped as occurring together in various places in Newfoundland, for example, near Buchans and south of Mount Peyton. In the present case, it is possible to explain the anomaly without the gabbro, but the central portion of the model would be extremely thick. A tabular block of diorite extending to a depth of 4 miles with an underlying smaller block of gabbro about 2 miles thick, is one mass distribution that will explain the anomaly.

Just south of the Adies Pond High, the profile crosses the Carboniferous basin lying between Deer Lake and White Bay. As the sediments within this basin are similar to those occurring along the southwestern coast of Newfoundland, the same density contrast is assumed. Their depth has been estimated to be about 8,000 feet from geological evidence (Neale and Nash, 1963). In the model, however, they are shown to reach a maximum depth of nearly 3 miles, but still they do not wholly explain the negative anomaly between the two large positive peaks on the profile. It is probable, however, that low density evaporite deposits are present in the sediments in such quantity that the average density of the sediments is lower than that assumed.

South of these sediments, in the vicinity of Buchans, the profile crosses another major positive anomaly termed the Buchans High. In this area, diorite occurs at the surface together with a small amount of gabbro. Part of the area of positive anomaly is underlain by granite which must either be very dioritic in composition or else very thin as shown, since its gravity effect is negligible. If diorite alone is used to explain the anomaly as shown in the model, the mass must extend to a depth of about 8 miles. If gabbro is associated with the diorite, the body could be thinner.

Finally, the profile crosses the Granite Lake Low in south-central Newfoundland which correlates exactly with a major granite intrusive body. Immediately south of the Buchans High, the anomaly remains around the zero level over Ordovician volcanic rocks that apparently overlie the granite. These rocks, actually a mixture of volcanic material and sediments, are estimated to be about 7,000 feet thick elsewhere although their exact thickness at this point is unknown. The only significant disturbance in the aeromagnetic field occurs over these volcanics, and is probably due to local concentrations of magnetite. The thickness of granite required to produce the Granite Lake Low is about 3 miles as shown by the upper layer of granite in Figure 8.

At the northern end of the profile, another negative anomaly occurs, in this case over Ordovician sediments. The sediments are mainly limestone and dolomite of the St. George Group and sandstone and volcanic rocks of the Humber Arm Group. Total thickness of the sediments is estimated to be less than 5,000 feet in this area. But, because of the very small negative density contrast of the sandstone and the slightly positive contrast of the limestone, the sediments cannot explain the anomaly, and it is necessary to introduce a lower density material such as granite underlying the sediments. A thickness of about 3 miles is indicated. The presence of a major belt of Precambrian granite extending from the Great Northern Peninsula south to at least the Stephenville area does not seem to be unreasonable. Granitic intrusions into the Precambrian gneiss are common on the west side of the Great Northern Peninsula, and probably underlie some of the Cambrian and Ordovician sediments, as is suggested in this interpretation. Also, Precambrian granite occurs in the Indian Head Range near Stephenville (Riley, 1962; Leech, Lowdon, Stockwell and Wanless, 1963). Thus, it is possible that granite occurs below the sediments all along the west coast to St. George's Bay. If this granite has a density similar to the average of the sampled granites, then it could easily explain at least part of the negative anomaly along the west coast.

The regional anomaly along the profile GH varies from about −30 mgal in the north to +10 mgal at the midpoint to −25 mgal in the southern area over the Granite Lake Low. Since the negative regional anomaly in the south correlates with the large granite batholith, it is probably caused by a deeper part of the intrusion. For model studies, if one takes the average anomaly of +5 mgal for Newfoundland as a zero datum and if the bottom surface of the granite producing the residual anomaly is taken as the top surface of the granite producing the regional anomaly, then an additional 7 miles of granite is required. This is shown in Figure 8, and makes the total thickness of granite about 10 miles. However, there remains the possibility that at least part of this anomaly may be caused by a change in the crust at depth. If the dioritic layer or intermediate layer are much thinner here, the anomaly level would be reduced. Also, this area was apparently not affected very much, if at all, by the Taconic orogeny. Thus, if the suggestion made earlier that the Taconic orogeny resulted in crustal thickening giving positive gravity anomalies is true, then this area of the Granite Lake Low may well have a thinner crust without a dioritic or intermediate layer. Conversely, the slightly positive central part of the regional anomaly along this profile GH, may be caused by a thickening of the dioritic layer, but could also be produced by a slight extension of the two near-surface diorite bodies postulated to explain the Adies Pond and Buchans Highs.

The negative regional anomaly to the north is most probably caused by a change in crustal parameters at depth. The profile crosses the major gradient that has been discussed before, and the seismic results suggest that a thin low density crust is present to the north. Thus, it is suggested that this change in crustal structure from a thick high density crust in the Appalachian area to a thin low density crust in the Grenville area is the cause of this negative anomaly. It should be noted that it is possible that this crustal change causes at least part of the residual anomaly as well. In other words, it is not possible to say with any certainty how much of the observed anomaly is being produced by the crustal change and how much might be caused by a nearer surface mass distribution such as granite. More gravity data to the west in the Gulf of St. Lawrence would aid in determining a more reliable regional curve, and additional seismic data immediately north and south of the major gravity gradient would also help to solve the problem.

Profile KL, Cross Pond High

Figure 9 shows the Bouguer anomaly profile and the regional anomaly across the West Coast Low and the two peaks of the Cross Pond High. The same diagram also shows the model constructed and the computed gravity values. The aeromagnetic data along the profile are also shown.

Gabbro occurs at the surface beneath the southeastern positive peak of the Cross Pond High. This anomaly also corresponds to a large aeromagnetic anomaly of about 1,500 gammas and thus magnetite must be associated with the gabbro. Gabbro alone may be used to explain the anomaly, in which case it must extend to more than 10 miles in depth. However, if ultrabasics are assumed to be associated with the gabbro here as they are in other areas of Newfoundland, the total depth of the gabbro-ultrabasic column will be less. In the model shown, the depth is about 5 miles. To the southeast, the anomaly has an extremely steep gradient as it rapidly becomes negative over the Granite Lake Low. At least 4 miles of granite are needed to produce the gradient. The two small bodies on either side of the gabbro-ultrabasic column in the model are Ordovician volcanics which occur at the surface, and so were included in the model, but they contribute very little to the gravity field.

The other positive peak of the Cross Pond High correlates only with Palaeozoic gneiss which is assumed to have an average density contrast of zero. This anomaly is broader than the other one and also the magnetic anomaly is less intense but broader than the other. This suggests that the anomaly is also produced by gabbro, but at a greater depth. The exact depth

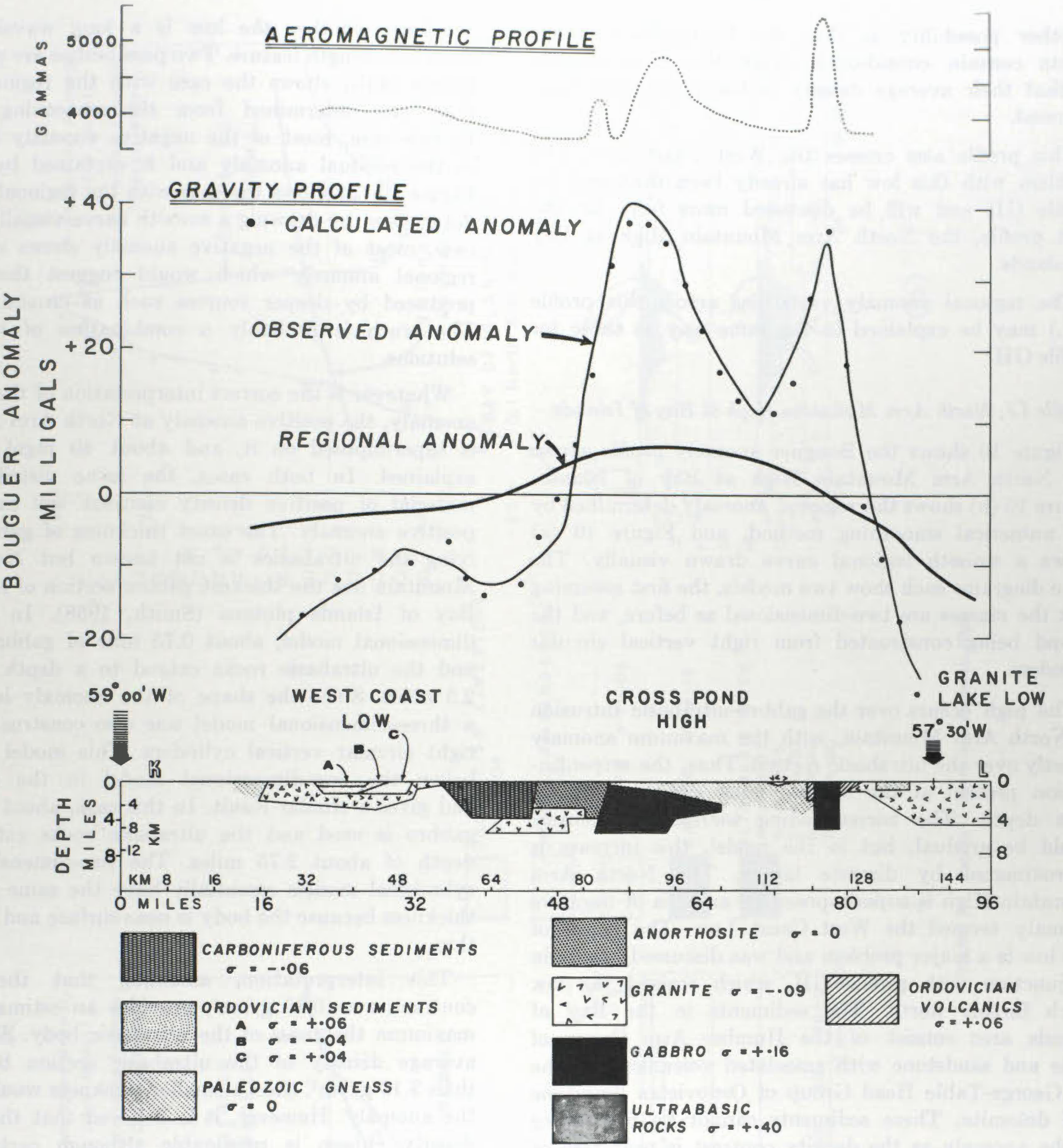


FIGURE 9. Profile KL, Cross Pond High.

is uncertain, but it is believed to be fairly near surface. The model shows one possible mass distribution of gabbro that might explain the anomaly. Again, ultrabasic rocks could be associated with the gabbro.

The negative anomaly to the northwest of this can be explained at least partly by the Carboniferous sediments. They have been estimated geologically to be about 23,000 feet thick farther south (Baird and Coté, 1964), but are probably thinner here. With the density measured for these rocks, they cannot account for the entire anomaly. The anorthosite body which occurs between the sedimentary basin and the gneiss is assumed to have a density contrast of zero and thus to contribute nothing to the gravity field. As stated earlier the density of 2.70 g/cm³ for anorthosite is based on the measurement of the density of 15 anorthosite samples from the Canadian Shield. The gravity profile itself, however, suggests that the anorthosite has no effect on the gravity field or if it has any at all, it must be a negative effect. As the sediments cannot explain the entire negative anomaly, it is assumed that a block of low-density granite underlies the sediments and anorthosite.

Another possibility is that the Carboniferous sediments contain considerable quantities of evaporites so that their average density is lower than has been assumed.

This profile also crosses the West Coast Low. The problem with this low has already been discussed for profile GH and will be discussed more fully for the next profile, the North Arm Mountain High at Bay of Islands.

The regional anomaly variations across this profile (KL) may be explained in the same way as those for profile GH.

Profile IJ, North Arm Mountain High at Bay of Islands

Figure 10 shows the Bouguer anomaly profile across the North Arm Mountain High at Bay of Islands. Figure 10 (b) shows the regional anomaly determined by the numerical smoothing method, and Figure 10 (a) shows a smooth regional curve drawn visually. The same diagrams each show two models, the first assuming that the masses are two-dimensional as before, and the second being constructed from right vertical circular cylinders.

The high occurs over the gabbro-ultrabasic intrusion at North Arm Mountain, with the maximum anomaly directly over the ultrabasic section. Thus, the serpentinization present at the surface must decrease rapidly with depth. The corresponding increase in density would be gradual, but in the model, this increase is approximated by discrete layers. The North Arm Mountain High is superimposed on an area of negative anomaly termed the West Coast Low. The cause of this low is a major problem and was discussed briefly in conjunction with profile GH, which crossed the low much farther north. The sediments in the Bay of Islands area consist of the Humber Arm Group of shale and sandstone with associated volcanics and the St. George-Table Head Group of Ordovician limestone and dolomite. These sediments cannot be the source of the anomaly as the density contrast is near zero or slightly positive, and from geological evidence, their maximum thickness is less than 10,000 feet (Riley, 1962; Rodgers and Neale, 1963). Thus, it becomes necessary to suggest a large block of low-density material such as granite below the sediments or else a change in the state of the crust at depth. These possibilities were discussed before.

It is particularly difficult here to separate the gravitational effects of near-surface sources such as granite from deep-seated effects due to possible changes in crustal layering. Since there are no more data to the west in the gulf, the numerical smoothing process is unreliable, and it is impossible to determine with certainty whether the low is a long wavelength or short wavelength feature. Two possibilities are presented. Figure 10(b) shows the case with the regional curve that was determined from the smoothing process. In this case, most of the negative anomaly shows up in the residual anomaly and is explained by granite. Figure 10 (a) shows the case with the regional anomaly determined by drawing a smooth curve visually. In this case, most of the negative anomaly shows up in the regional anomaly which would suggest that it was produced by deeper sources such as crustal changes. The truth is probably a combination of these two solutions.

Whatever is the correct interpretation of the negative anomaly, the positive anomaly at North Arm Mountain is superimposed on it, and about 40 mgal must be explained. In both cases, the same distribution of material of positive density contrast will explain the positive anomaly. The exact thickness of gabbro overlying the ultrabasics is not known but North Arm Mountain has the thickest gabbro section of any of the Bay of Islands plutons (Smith, 1958). In the two-dimensional model, about 0.75 mile of gabbro is used and the ultrabasic rocks extend to a depth of about 2.5 miles. Since the shape of the anomaly is circular, a three-dimensional model was also constructed using right circular vertical cylinders. This model is shown below the two-dimensional model in the diagrams, and gives a similar result. In this case, about 1 mile of gabbro is used and the ultrabasic rocks extend to a depth of about 2.75 miles. The two-dimensional and cylindrical models essentially have the same form and thickness because the body is near-surface and relatively thin.

This interpretation, assuming that the density contrast $\sigma = 0.40$ g/cm^3, provides an estimate of the maximum thickness of the ultrabasic body. Should the average density of the ultrabasic section be greater than 3.10 g/cm^3, then a smaller thickness would explain the anomaly. However, it is believed that the average density chosen is reasonable although certain parts of the intrusion may be more dense.

It is interesting to note that the other ultrabasic intrusions in the Bay of Islands area do not show any appreciable anomaly. Table Mountain shows only about 10 mgal, while Lewis Hills and Blow-Me-Down Mountain show even less. Thus, these intrusions must be much thinner or more highly serpentinized than the North Arm Mountain mass.

As previously mentioned, the total thickness of sediments in the Bay of Islands area is less than 10,000 feet from geological evidence. Of these, the Humber Arm Group of Ordovician sandstone and shale with volcanic rocks in the upper sequence is less than 5,000

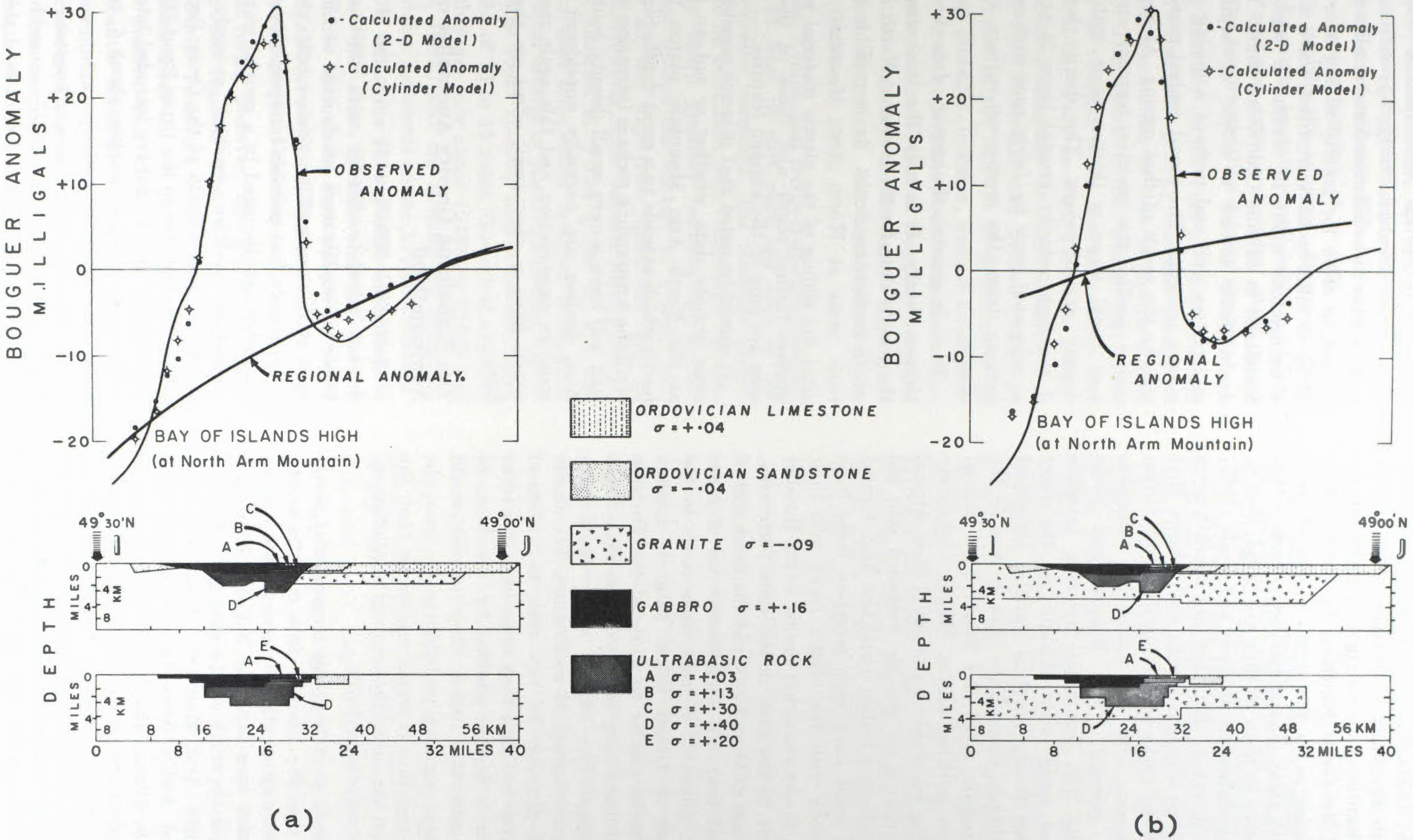


FIGURE 10. Profile IJ, North Arm Mountain High.

feet thick (Riley, 1962). This is the group into which the Bay of Islands ultrabasic bodies have been intruded. Rocks of the Humber Arm Group also occur at the northern end of the Great Northern Peninsula. There are two hypotheses as to the origin of the Humber Arm rocks in both areas. The original hypothesis is that they were deposited in place as they are found, that is, that they are autochthonous. Rodgers and Neale (1963) have suggested, however, that they are allochthonous and form two large klippen. Fossils have shown that at least some of the rocks of the Humber Arm Group are contemporaneous with the underlying carbonate rocks, and not younger. Thus, Rodgers and Neale suggest that the first hypothesis requires invisible unconformities or rapid facies changes; on the other hand, the klippen theory involves complex structural relations. The klippen would have been formed to the east of the carbonate rocks and would have moved into their present position during Middle Ordovician times by first being squeezed up and out of their original basin and then sliding by gravity westward into the new basin. The intrusive bodies would also have formed to the east and must have been somehow freed from their roots to slide with the clastic rocks into their present position. Rocks somewhat similar to the Humber Arm Group occur to the east, in the Baie Verte area, along the east coast of Grand Lake, at the south end of Grand Lake, and near the southwestern tip of Newfoundland. Also, remnants of such rocks occur in the granite area east of Grand Lake. Thus, it appears that a belt of rocks similar to those of the Humber Arm Group may have once extended from Baie Verte to the south coast. The klippen rocks would have had to slide westward some 25 to 40 miles. The clastic materials would probably be too weak to withstand any shearing forces and thus they must have moved as a landslide from a higher position by the force of gravity. The basin into which they moved would have new sediment arriving probably partly from the sliding material and thus it seems reasonable that the boundary between the autochthonous and allochthonous strata would be indistinguishable.

The gravity data seem to partly support and partly refute the idea that the Humber Arm rocks form two klippen. As previously mentioned, none of the plutons in the St. Anthony area or in the Bay of Islands area show any appreciable effect on the gravity field except the one at North Arm Mountain. Thus, the other bodies must be highly serpentinized or extremely thin or both. The klippen theory requires that they be quite thin, and thus the gravity data tend to support this. The gravity data suggest, however, that the plutonic body at North Arm Mountain is between 2 and 3 miles thick. While this is believed to be fairly thick for gravity sliding, it is still not as thick as similar intrusions in central Newfoundland—for example the Gulp Pond ultrabasic body was estimated from the gravity data to be between 5 and 6 miles thick.

Also, in order for gravity sliding over a distance of 25 to 40 miles to have occurred, there must have been a tremendous uplift in central or west-central Newfoundland in Middle Ordovician times. This would no doubt have caused a major upwarping of mantle material as well and perhaps a mixing of crustal and mantle material. The broad central gravity high could well be the result of that mixing. As suggested for an earlier profile, the positive regional anomaly in this area could mean a thicker crust with thicker high density crustal layers. The diorite layer especially, if the high velocity crustal layer is actually dioritic as suggested, may be fairly near surface in this area, judging from the numerous surface occurrences of diorite.

Thus, in general, the gravity data do not refute the klippen theory. It is only the thickness indicated by the gravity data for the pluton at North Arm Mountain which casts some doubt. It is possible that the ultrabasic mass at North Arm Mountain was intruded after the sliding of the clastic material while the other plutons farther south and those in the St. Anthony area are part of the klippen features.

It should be noted that it is not possible to determine from gravity data whether or not an intrusion such as the North Arm Mountain pluton has a root or feeder which extends to a great depth. Since the density of all the surrounding rocks is increasing with depth, the root will have a very small density contrast at depth. Also, feeders are normally considered to be rather small in cross-section and this again means that they would have a very small effect on the gravitational field.

The Remaining Gravity Anomalies of Newfoundland

Most of the other gravity anomalies of Newfoundland do not correlate directly with the surface geology. However, models were constructed which could explain some of these anomalies. These models are not included in the report, but possible interpretations of the various anomalies are discussed in a general way below.

Another positive residual anomaly occurs over Palaeozoic gneiss south of the Cross Pond High. It is similar in character to the Cross Pond High, and therefore may be due to gabbro intruded into the gneiss. A near-surface mass of gabbro about 4 miles thick will explain the anomaly.

The West Coast Low in southwestern Newfoundland south of Stephenville is probably caused by the Carboniferous sediments. Profile KL crossed this area, but at its northern end. In the south, up to 23,000 feet of sediments have been suggested by Baird and Coté (1964), from geological evidence. This thickness, asuming a uniform density contrast of $-$ 0.06 g/cm^3 will not completely explain the anomaly. However, these sediments are known to contain considerable quantities of low-density coal and gypsum deposits, which would permit the use of a more negative density contrast.

The positive anomaly on the Port au Port Peninsula is puzzling. The surface geology consists mainly of Ordovician limestone similar to that to the northeast, but less folded. The limestone (St. George and Table Head Groups) is thought to be less than 4,000 feet thick on most of the Port au Port Peninsula (Riley, 1962). The positive anomaly on the southern half of the Port au Port Peninsula may be due in part at least to an increase in the amount of dolomite in the sediments. Most probably, however, there is a considerable amount of basic material intruded into the underlying Precambrian rocks. This area may be connected with the positive anomaly in northern Gaspé that has been shown to extend out into the Gulf of St. Lawrence (Goodacre, 1964).

The Bonavista, Avalon, and Burin Highs are probably all associated at least in part with the edge of the Precambrian volcanic basement. The Harbour Breton High appears to be associated with Ordovician volcanic rocks. A fairly sharp gradient between low values and high values follows the contact of granite with volcanic rocks all the way from Bonavista Bay to Harbour Breton. However, these volcanic rocks probably have a density contrast of $+0.06$ g/cm^3 or less and thus it appears that some other material is required to explain the local centres of positive anomaly. Otherwise, the volcanic rocks (mainly acid volcanics) must extend to depths of 10 to 15 miles. Geological evidence suggests that they are only about 15,000 to 20,000 feet thick (Jenness, 1963), and are overlain by metamorphosed Precambrian sediments on the Avalon Peninsula. These sediments are more than 20,000 feet thick in places (Jenness, 1963; Rose, 1952), and probably have a density similar to that of the metamorphosed Ordovician sediments, that is, about 2.70 g/cm^3. They may even have a density greater than this.

The volcanic rocks, however, are probably largely responsible for the regional high in the Bonavista, Avalon, and Burin Peninsula areas. However, it is possible that these areas have a thicker higher density crust than the granitic area to the west. The mixing of crust and mantle material may have taken place during the Precambrian orogenies that were responsible for the volcanic rocks. If, however, the crust is actually thinner here, then the Appalachians as a two-sided symmetrical system (Williams, 1964) is clearly indicated. The Precambrian areas to either side of the Palaeozoic mobile belt would have a thin crust. It would be very worthwhile to have some seismic work done in the Bonavista, Avalon, and Burin Peninsula areas.

The positive anomaly centres probably occur where the sediments are thinnest and where basic material is associated with the underlying Precambrian basement. Gabbro is exposed on the Burin Peninsula near the maximum value of the Burin High and thus it is likely that this anomaly is caused by a gabbroic intrusion. The Holyrood granite batholith of Precambrian age (Leech *et al.*, 1963) occurs to the east of the centre of the Avalon High, and apparently has considerable amounts of associated diorite (H. Williams, personal communication). Thus, it is possible that diorite is responsible for the Avalon High. The Bonavista High is centered over the islands of Bonavista Bay, and no obvious explanation is available for it. Perhaps the sediments are thin in this area, and basic material is probably associated with the volcanics. The Harbour Breton High occurs over an area of Ordovician volcanic rocks, which must be more dense than those found elsewhere on Newfoundland, or else basic intrusions must be present.

Towards St. John's, the Bouguer anomalies become negative, and it appears that an even greater negative anomaly may lie offshore to the northeast. This may be due to an increase in the thickness of sediments which is masking the effect of the higher-density basement material, or it could be due to a greater thickness of lighter, unmetamorphosed sediments than elsewhere. Another possibility is that at least part of it may be due to a crustal change. If this is true, one would expect to find a fairly thin low-density crust in the St. John's area. The lack of gravity stations offshore at the present time makes it impossible to determine whether or not this negative anomaly is a local feature.

The Great Northern Peninsula shows two large gravity anomalies, a large negative anomaly almost in the centre of the Peninsula (the Great Northern Peninsula Low), and an intense positive anomaly in the St. Anthony area (the St. Anthony High). Both appear to be caused by two effects, a deep crustal change and a near-surface mass distribution. The crustal change has been discussed before, and, based on the seismic information, is believed to be a change from a thick high-density crust in the south to a thin lower density crust in the north. The change is believed to coincide approximately with a major gravity gradient across a line that trends northeasterly over the southern part of the Great Northern Peninsula and then seems to reappear in the St. Anthony area. This crustal change is believed to be responsible for the change in average regional level of the Bouguer anomalies from positive (+5 mgal) in the southern area of Newfoundland and in the St. Anthony area to negative (−28 mgal) in the Grenville areas. However, in the St. Anthony area, the anomaly rises above the regional high, and in the centre of the Great Northern Peninsula, it falls below the regional low. The remaining residual anomaly in each case is believed to be caused by near-surface mass distributions. The surface rocks in the St. Anthony area probably contribute very little to the gravity field as they are of the Humber Arm Group similar to those of the Bay of Islands area. Also, as discussed before, the ultrabasic bodies in the St. Anthony area contribute almost nothing to the gravity field. The positive anomaly at St. Anthony appears to be similar to any one of the positive centres of anomaly that occur in southern Newfoundland, e.g. the Adies Pond High. Thus, it is probably due to a dioritic or gabbroic intrusion below the sediments.

The centre of the Great Northern Peninsula Low occurs over Cambrian sediments but it is probable that they have only a small negative density contrast. Precambrian granite is intruded into the Precambrian gneiss in the area, however, and it is quite possible that Precambrian granite underlies the Cambrian sediments. In fact, as discussed before, a major belt of granite may exist beneath the sediments along the west coast. It is possible to explain the residual anomaly of the Great Northern Peninsula Low by means of granite of density contrast -0.09 g/cm^3 extending to a depth of nearly 8 miles.

The last anomaly to be discussed is the positive anomaly that extends from Notre Dame Bay and follows the Long Range Complex to the south coast of Newfoundland. One possibility is that this whole area has a thick high-density crust giving rise to positive anomalies and that the Carboniferous sediments to the west and the granite to the east are producing the flanking negative anomalies. This was suggested before. Another possibility is that this southern area may have a fairly thin crust and that the positive anomaly over the Long Range Complex may be caused by a basement uplift east of the Long Range fault. More seismic information is clearly needed in all these areas in order to improve the interpretation.

It is interesting to note that not many of the gravity anomalies of Newfoundland correlate with the occurrence of major faults. Some do, however, and these are summarized now. In southwestern Newfoundland, the Long Range fault separates the negative anomalies over the Carboniferous basin from the positive anomalies over the Long Range Complex of Palaeozoic gneiss. In the Great Northern Peninsula, it appears that the fault along the east coast may coincide at least for a short distance with the major change in the average Bouguer anomaly. These two faults are part of the Cabot fault suggested by Wilson (1962). In the area from Bonavista Bay to Harbour Breton, numerous faults separate the Devonian granite on the west from the Precambrian rocks of the Bonavista, Avalon, and Burin Peninsulas. It will be recalled that the regional Bouguer anomaly value changes here from a negative value over the granite to a positive value in the east. Other faults in Newfoundland do not seem to be important as far as the gravity data are concerned.

Correlation with other Appalachian Areas

The positive anomaly on the Port au Port Peninsula may be related to the Gaspé High which occurs over the Shickshock Mountains in northern Gaspé (Tanner and Uffen, 1960), and which has been shown to extend out into the Gulf of St. Lawrence (Goodacre, 1964). Tanner and Uffen interpret the anomaly in Gaspé as being produced by high-density basic rocks (density contrast + 0.30 g/cm^3) of the Shickshock series which have been elevated by a horst-like structure. These are shown as being at the surface in their models. Out in the Gulf, north of the Magdalen Islands, the gravity gradients are less steep, and the structure producing the positive anomaly could be as deep as 6 to 8 kilometers (Goodacre and Nyland, 1966). The seismic depth to basement in the area is 7.5 km, and Goodacre and Nyland show that a two-dimensional prism of rock of density contrast 0.30 g/cm^3 at a depth of 6.5 km can explain the positive anomaly. In Newfoundland, the nature of the gravity field at the Port au Port Peninsula suggests that the maximum depth to the structure producing the anomaly is about the same order of magnitude. However, the depth is probably much shallower unless the structure is nearly a line source. One can easily construct a model at between 1 and 2 kilometers depth that will explain the anomaly. Geological evidence suggests also that the thickness of sediments on the Port au Port Peninsula is of this order of magnitude. Thus, there could be a zone of basic material extending from Gaspé to the Port au Port Peninsula which is near surface at Gaspé, deepens out in the Gulf, and becomes near surface again at the Port au Port Peninsula before it apparently terminates.

This line of positive anomaly appears to mark a major change in anomaly level as well. All of the Appalachian area to the south has predominantly positive anomalies (similar to Newfoundland south of latitude 50°) while Anticosti Island and the Shield area to the north have predominantly negative anomalies. This was discussed earlier and the seismic data suggests a thick higher-density crust south of this line in the gulf and a thin lower-density crust to the north. Thus, this line of positive anomaly together with the line across which the major gradient of Newfoundland occurs may mark the boundary between the Grenville and Appalachian Provinces all the way from the Gaspé area to St. Anthony. At present, this correlation is indefinite because of a lack of data between the area north of the Magdalen Islands and the Port au Port and Bay of Islands areas of Newfoundland. However, further gravity work in the Gulf of St. Lawrence should resolve this uncertainty.

The positive anomaly in the Highlands of northwestern Cape Breton Island (Garland, 1953), may correlate with the positive anomaly over the Long Range Mountains in southwestern Newfoundland. The rock types in the two areas are not the same, however. The Newfoundland anomaly occurs over Palaeozoic gneiss while the Cape Breton anomaly is in an area mapped as Precambrian granite and Carboniferous sediments. If, however, the two positive anomalies are both being caused by a basement uplift or by a similar crustal structure, then the two anomalies may be correlated. Gravity data is required in the Cabot Strait between Newfoundland and Cape Breton Island. The eastern coast of Cape Breton Island also contains intense positive anomalies, and these may be related to the positive anomalies of the Avalon-Burin Peninsula areas of Newfoundland in as much as the rock types in both areas are Precambrian.

The large negative anomaly in Nova Scotia in the vicinity of New Ross has been attributed to Devonian granite by Garland (1953). To explain the anomaly he postulated a layer of granite about 4 miles thick with a cylinder of granite extending to 18 miles depth in the vicinity of New Ross. This body of granite is similar to that which is producing the Granite Lake Low in Newfoundland.

The Magdalen Low which lies between Cape Breton Island and the Magdalen Islands has been attributed by Goodacre and Nyland (1966) to the presence of evaporites in the Carboniferous sediments. The area is a sedimentary basin containing a great thickness of Carboniferous sediments, and the Magdalen Low probably correlates with the southern part of the West Coast Low of Newfoundland. It was suggested earlier that this part of the West Coast Low was caused by Carboniferous sediments and evaporites.

It has been suggested (Black, 1964), that the Island of Newfoundland may have rotated counterclockwise with respect to the surrounding land areas. The present gravity data gives no direct evidence for this. If future work in the Gulf of St. Lawrence and in the Cabot Strait shows that the correlations suggested above link up smoothly, then it seems unlikely that any rotation could have occurred since Ordovician time.

It is worthwhile to note that in the United States, there is an abrupt gravity gradient separating the positive Bouguer anomalies of the Piedmont Province from the area of major negative anomalies northwest of it (Lowry, 1964). This gradient forms a belt 30 to 60 miles wide that extends the length of the Appalachian chain, from Gaspé to Alabama. This may well be the same gradient that occurs between Anticosti and Gaspé and between the Great Northern Peninsula and southern Newfoundland. Again, this supports the hypothesis that this is a major feature associated with the Appalachian front.

CONCLUSIONS

In this report an interpretation has been offered for the major features of the Bouguer gravity anomaly field of Newfoundland. Both the regional and local variations were explained wherever possible, and correlations with the gravity anomalies in the other parts of the Appalachian area were suggested. A brief summary of the results is given below.

1. There is a major change in anomaly level across a line trending northeasterly over the southern end of the Great Northern Peninsula of Newfoundland. This line of gradient probably follows the east coast of the Great Northern Peninsula and reappears in the St. Anthony area. A similar change in anomaly occurs across the line of positive anomaly that extends from the Gaspé Peninsula out into the Gulf of St. Lawrence. This significant change in the Bouguer anomaly level may mark the boundary of the Appalachian and Grenville Provinces all the way from Gaspé to St Anthony.

2. Considering the recent seismic studies, the anomaly difference between the two areas is probably due to density variations within the crust and upper mantle as well as to variations in crustal thickness. The northern area of negative anomaly apparently has a thin low-density crust while the southern area of positive anomaly has a thick high-density crust. It is suggested that the high-velocity crustal layer above the intermediate layer in the southern area may be dioritic in composition. The mixing of crust and mantle material may have taken place during the Taconic orogeny.

3. There is little or no dependence of Bouguer anomaly on elevation in the map-area.

4. The southern area of Newfoundland is undercompensated by 23 mgal on the average and the northern area is overcompensated by 11 mgal.

5. Contrary to expectations, the land in the undercompensated southern section is still rising.

6. The regional variations in the anomaly field of Newfoundland are generally attributed to variations in the thickness of the dioritic layer or of any of the crustal layers that may be present, or in the thickness of the crust itself.

7. The sediments in Newfoundland, based on the presently available density information, do not appear to have much effect on the gravity field.

8. The prominent negative anomaly in south-central Newfoundland, the Granite Lake Low, is attributed mainly to Devonian granite, but it is believed a crustal change may be present as well.

9. The Great Northern Peninsula Low is thought to be caused by Precambrian granite below the Cambrian sediments. In fact, there may be a major belt of Precambrian granite below the sediments along the west coast from the Great Northern Peninsula to Stephenville, which may contribute to the negative gravity anomalies along the coast. It is not clear, however, how much of this negative anomaly may be a regional variation produced by a crustal change at depth.

10. The negative anomaly in southwestern Newfoundland south of Stephenville is believed to be due to Carboniferous sediments which contain some evaporites and coal.

11. Diorite is believed to be responsible for several positive centres of anomaly, namely the Mount Peyton High, the Notre Dame Bay High, the Adies Pond High, and the Buchans High. These are probably places where diorite from the major crustal layer above the intermediate layer is intruded through to the surface. Gabbro may also be associated with the diorite in places.

12. Gabbroic and ultrabasic intrusions are believed to be responsible for the other positive anomalies of Newfoundland, namely the Gulp Pond High, the North Arm Mountain High, and the Cross Pond High.

13. The positive anomalies on the Avalon, Burin, and Bonavista Peninsulas do not correlate directly with the surface geology, but it is believed that they must be caused by dioritic or ultrabasic intrusions which do not come to the surface.

14. The gravity data indicate that the pluton at North Arm Mountain is between 2.5 and 3 miles thick. This casts some doubt as to whether it could have moved as part of a klippen. However, the other ultrabasic plutons intruding the Humber Arm Group of rocks in the Bay of Islands area and those near the northern end of the Great Northern Peninsula show little or no effect on the gravity field and therefore must be extremely thin. This is consistent with their being part of klippen features.

15. Much more geophysical work, both gravity and seismic, is needed in Newfoundland and the surrounding waters to improve the interpretations offered here. In the light of this gravity interpretation, a re-examination of the surface geology in the southern part of the Great Northern Peninsula may also be worthwhile. In addition, much more density information is needed for the whole area.

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