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BOUGUER GRAVITY AND GENERALIZED GEOLOGIC MAP OF NEW ENGLAND AND ADJOINING AREAS

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INTRODUCTION

Gravity investigations of geology in New England began more than 35 years ago in a pioneering study by Longwell who elicited the support of the U.S. Coast and Geodetic Survey and later of George P. Woollard, in making a gravity map of southern New England (Longwell, 1943). Woollard (1948) subsequently expanded the gravity coverage to include much of the northeastern United States and eastern Canada and published a report in which he discussed many of the major gravity features of the region. Bean (1953) made the first in a series of more detailed gravity studies of parts of the New England region which also utilized contemporary advances in geologic mapping; the series was continued by Diment (1968), Fitzpatrick (1959), Joyner (1963), Simmons (1964), Kane and Bromery (1968), Bromery (1967), and Kane (1970). Compatible coverage provided by the series is now complete for a wide zone which spans the entire breadth of the Appalachians in New England, Gulf of Maine, upper New York State, southeasternmost Quebec, and easternmost Ontario (see sources of data).

Our purpose is to present the data of all these surveys on a single map and to comment on some aspects and implications of the principal features of the gravity field. The major regional anomalies shown by Woollard (1948) are more sharply defined by the later more detailed surveys, and many features that are not clearly discernible from a comparison of the individual maps are readily apparent in the larger compilation. Some excellent examples of a close relationship between gravity anomalies and geologic features are also found in this region.

MAP COMPILATION

The individual surveys have been tied variously to the Dominion Observatory, Ottawa, Canada, or to the airport and university base network of Behrendt and Woollard (1961). A comparison of measurements taken at several individual stations that are common to different surveys indicates that discrepancies between the surveys (Joyner, 1963; Simmons, 1964; Kane, unpub. data) do not exceed 2 milligals. All surveys on land were corrected for elevation using a density of 2.67 g per cm^3. Data for the Gulf of Maine were reduced with a subsea-level density of 2.8 g per cm^3, but water depths are generally less than 700 feet so that any discrepancy is correspondingly small (a difference of 0.1 g per cm^3 would cause a discrepancy of 0.13 mgal per 100 feet of depth). As the systematic differences between the surveys are less than a few milligals, the map was compiled by copying and interpolating contours and adjusting to an appropriate scale and base. The match of contours at survey boundaries was generally good, and minor differences were accommodated by slight adjustments in contouring. The high quality of the fit of the contours at the boundaries of the several surveys indicates that the accuracy of the map is sufficient to interpret the regional gravity features and to compare the local anomalies throughout the area.

The geologic base map was taken principally from White (1968) with modifications from Goldsmith (1964) and Hussey and others (1967), with additions from King (1969), and with boundaries of metamorphism from Thompson and Norton (1968). Major structures and place names for the region are shown in figure 1.

BOUGUER GRAVITY MAP

Gravity values range from +50 mgals in Quebec and the Gulf of Maine to less than -70 mgals in northeast Vermont (fig. 1). Three major areas of different trend are apparent: (1) an eastern area consisting of eastern Quebec, the eastern two-thirds of New England, and the Gulf of Maine, where a northeast grain predominates; (2) western New England and eastern New York where the trend is north; and (3) the Adirondack region where no trend is dominant. The range in amplitudes and diversity in trends correlate in a general way with major lithology and structure. The gravity trends as a rule, however, appear to be more sharply defined than their geologic counterparts. Although causes of the regional gravity anomalies are not clearly understood, conventional analysis would relate most of them to variations in the thickness of the crust. Some recent analyses, however, show that some of the sources are, at least in part, within the crust (Diment, 1968; Kane and Bromery, 1968).

Local anomalies, which must be caused by shallow sources, are shown by the local closures and high curvature of the contours and by the local steepening of gravity gradients (compression of contours). The source of most local anomalies, particularly those having high amplitudes and steep gradients, is the presence of large masses of intrusive igneous rocks. Of these, the most common are felsic plutons with associated gravity lows. Some anomalies of moderate amplitude appear to be caused by accumulations of volcanic rocks. The association of local gravity lows with locally thick deposits of sedimentary rocks has not generally been observed, most probably because regional metamorphism has substantially reduced the mass contrast of volumetrically small sedimentary deposits by eliminating porosity. Because of the lack of porosity, local anomalies of this region must reflect the mineral density of the underlying rock masses.

REGIONAL GRAVITY FIELD

The regional gravity field (fig. 1) ranges from about +50 mgals over the Green Mountain-Sutton Mountain anticlinorium to a series of gravity minima of less than -50 mgals which extend southwest from northern Maine and Quebec to southeastern New York. Although a peak value of +50 mgals is attained locally, the average gravity anomaly over the anticlinorium is near zero mgal. The gravity minima coincide with the Connecticut Valley-Gaspé synclinorium of northwest Maine, southern Quebec, and northeast Vermont, with the major felsic plutons in northern New Hampshire and northeast Vermont and geosynclinal tracts in the Hudson River-Lake Champlain lowland and in the St. Lawrence River valley. The average value for these regions is about -50 mgals. On the east, regional gravity values increase from the gravity minima southeastward and reach an average gravity level of about +20 mgals over the Gulf of Maine. On the west, the regional gravity anomaly over the Adirondacks ranges from about -30 mgals to zero mgals.

Figure 1 shows a correlation between the regional gravity highs and major positive geologic structures, i.e. broad areas of relative uplift, and between the regional gravity lows and major negative structures, i.e. broad areas of subsidence and deposition. This correspondence was noted by both Longwell (1943) and Woollard (1948) and was attributed primarily to crustal thickening or thinning brought about by broad tectonic movement. Two of the regional lows also occur over major felsic plutons, but these in turn are within two synclinoria, the Connecticut Valley-Gaspé synclinorium and the Merrimack synclinorium. Woollard (1948) recognized the correlation between gravity lows and felsic rock and attributed it to the relatively low density of granite.

The correspondence of major gravity and tectonic features is consistent on a large scale, but as noted by Diment (1968), it does not hold in detail (see for example, the offset between the gravity high and structural high in western Massachusetts, fig. 1). The regional anomalies appear to arise, therefore, from major crustal or crust-mantle structures of substantial vertical extent whose manifestations at the surface are masked in some places by geologic features that are primarily surficial in character. For example, major thrusting involving, in part, relatively thin surface sheets, is well documented in the Taconic area of western New England and adjacent New York (Zen, 1968).

To facilitate further discussion of the regional anomalies, we divide the region into eastern and western parts (line A-A′).

Eastern Area.—The main trend of the gravity field in the eastern area is northeast, parallel to the principal grain of the Appalachians. The trend of the gravity field is defined mainly by the regional component, inasmuch as the trends of local anomalies are generally variable. The regional field decreases northwestward from the Gulf of Maine to the vicinity of the United States-Canadian border, and thence successively increases to a high and decreases to a low in the region between the border and the Canadian Shield.

The regional field of the Gulf of Maine may be characterized as a level field with an average value of about +20 mgal. This characterization is manifest in the presence of +20 isogal throughout the gulf and by the +20-isogal enclosure of many of the anomalies. The regional field decreases landward in the vicinity of the coast and in most places attains a value of zero mgal a short distance inland.

In Maine, the regional field is made up of a series of three gravity levels which are separated by two intervening gravity gradients (Kane and Bromery, 1968). One of the gradients (seen most clearly on the map) is about 20 miles northwest of Bangor where it separates a regional gravity level of about -5 mgal on the southeast from a level of about -25 mgal on the northwest. The other gradient is centered approximately at the -40 isogal in northwesternmost Maine where it separates a regional level of about -25 mgal (the same level referred to in the latter part of the previous sentence) from one of about -55 mgal on the northwest over the St. John River valley. The maximum depths to the upper surfaces of the sources of the changes in regional gravity level are about 3 miles in inland Maine (Kane and Bromery, 1968) and about 5 miles in the coastal area of Maine (Kane, 1970). The sources of the regional gravity field must therefore be, at least in part, in the upper crust. Because the depths given above are characterized as maxima, the range of permissible sources includes among other possibilities, rock units that are exposed.

Kane (1970) proposed a hypothetical model of the crust for the Maine-Gulf of Maine region in which the variation in regional gravity levels is explained by corresponding changes in depth of a relatively dense (greater than 2.9 g per cm^3) crustal rock. Part of the regional gravity low of northwesternmost Maine was also attributed to a thick section of stratified rocks of Devonian age whose average density (2.7 g per cm^3, Kane, unpub. data) is about 0.1 g per cm^3 less than that of older metamorphic bedrock (2.8 g per cm^3, Kane and Bromery, 1968) southeast of the low. The details of the model were considered speculative, but it was concluded that any valid model of the crust based on the gravity field must invoke depth variations of a shallow dense crustal layer.

From the gravity low along the Maine-Quebec border, the gravity field rises to the northwest and culminates in the gravity high which is present over most of the Green Mountain-Sutton Mountain anticlinorium. The peak amplitude of 50 mgal in this area is considerably greater than the peak values along most of the high associated with the anticlinorium. Fitzpatrick (1959) concluded that the gravity high in the vicinity of the 50-mgal peak is caused by a ridge of mantle material protruding into the crust, whereas Thompson and Garland (1957) suggested that it may be caused by a shallow intracrustal core of ultramafic rock.

Farther northwest, a gravity low lies between the gravity high described above and the regionally higher gravity values (-30 to -20 mgal) over the Canadian Shield (Thompson and Garland, 1957). The low corresponds generally with a geosynclinal tract which underlies the St. Lawrence River valley. Thompson and Garland (1957) attributed the low primarily to the contrast between low-density stratified rocks of Paleozoic age underlying the Appalachians and high-density metamorphic rocks of Precambrian age which underlie the Canadian Shield, but they also suggest that part of the low may be caused by a southeastward decrease in the density in the rocks of Precambrian age as they pass southeastward beneath the Paleozoic stratified rocks. Innes and Argun-Weston (1967), on the other hand, concluded that there is a fundamental difference in the earth's crust between the Canadian Shield and the Appalachians, the crust of the latter being generally thicker and more dense and having a higher gravity field.

In southwestern Maine, the regional gravity dips to the northwest in a ramplike manner, in contrast to the steplike nature of the regional field to the northeast. Another notable aspect of the gravity field in the southwest is the lack of pronounced local anomalies, even though felsic plutons of Devonian age are common. The transition from a steplike field to a ramplike field also corresponds with a change from medium-grade to high-grade (sillimanite) regional metamorphism. It seems clear that the shallow (less than 3 miles) density contrasts between crustal blocks, described above for northeastern Maine, are either subdued or not present southwest of the transition. Kane (1968) suggested that the character of the gravity field in the southwest is related to the high-grade metamorphism, and that either the density of the metamorphic bedrock is decreased at highest metamorphic grade or that felsic rock is present at shallow depths below the areas where metamorphic bedrock is exposed. Another possible explanation is that the metamorphic bedrock is pervasively but discretely intruded by felsic rock in the form of dikes so that its bulk density differs only moderately from that of felsic rock. In this regard, A. M. Hussey II (oral commun., 1970) has commented on the widespread occurrence of felsic pegmatite dikes in this region and has observed that their presence often makes it difficult to determine the location of the boundary between metamorphic and igneous bedrock. It is also possible that the source of the ramplike regional field is deep seated and that the lack of local anomalies simply indicates that the felsic plutons are thin.

The general appearance of the gravity field over eastern Massachusetts and southeastern New Hampshire is complex, so that the character of the regional field is not readily apparent. Inland in New Hampshire, the gravity field generally decreases northward in an irregular fashion, but it shows evidence of an area of level field near the -20 isogal in the south-central part of the State. Farther north, the gravity field is dominated by the -50 isogal closure which encompasses the White Mountain felsic batholith of Jurassic age in northern New Hampshire (shown by the broad area of alkalic plutonic rock pattern) and a nested group of felsic plutons of Devonian age in northeastern Vermont and southern Quebec. The cause of the northward decrease in gravity is as uncertain as it is in southwestern Maine, but the culminating gravity low seems clearly to be caused by the underlying felsic plutonic rock (Joyner, 1963). Although a major gravity low is associated with a felsic batholith of Jurassic age in New Hampshire, none are associated with the felsic plutons of Devonian age in New Hampshire, nor as observed before, in the adjoining southwest part of Maine. In northeastern Vermont, southern Quebec, and the rest of Maine, however, the association of the gravity lows with felsic plutons of Devonian age is almost invariable.

As pointed out in the section on southwestern Maine, the contrast in the gravity effect of felsic masses of Devonian age correlates with a contrast in regional metamorphic grade, gravity lows being present in zones of low- to medium-grade metamorphism and absent in those of high-grade metamorphism. The presence of the gravity low over the White Mountains batholith, which is within the regional sillimanite-grade zone, indicates a significant density difference between the felsic rock of Jurassic age and sillimanite-grade metamorphic rock. This contrast would seem to imply that gravity lows are absent over felsic rocks of Devonian age in New Hampshire and southwest Maine because these felsic rocks are thin. The term felsic as used in this report, however, includes rocks ranging progressively in density from granite (lowest density) of Jurassic age through quartz monzonite, granodiorite, and quartz diorite of Devonian age (Billings, 1956). These observations indicate that a satisfactory resolution of the problem will ultimately require an extensive appraisal of the densities of all the rock types involved, including that of the metamorphic bedrock. Whatever the precise physical relation, the close correlation between the change in the gravity field and the change in metamorphic grade suggests that they are closely related.

Thompson and Norton (1968) concluded from an investigation of key metamorphic minerals that rocks in part of the sillimanite-grade zone may have originally been at depths as great as 9 miles. The absence of gravity lows over the felsic plutons of Devonian age in this zone may be explained by an erosion of major parts of the plutons that took place during the uplift and uncovering of the deep-seated metamorphic zone. As the metamorphism is pre-Jurassic in age, this explanation also allows for the presence of a gravity low over the White Mountain batholith.

The -50 isogal closure in northeastern Vermont and southern Quebec is within a region of low gravity that corresponds with the Connecticut Valley-Gaspé synclinorium. On the west the gravity low is bounded by a fairly sharp gradient near the boundary between the Silurian and Devonian rocks of the synclinorium and the Cambrian and Ordovician rocks of the Green Mountain-Sutton Mountain anticlinorium. The precise magnitude of the gravity low associated with the synclinorium is not clear because of the superposed low caused by the Devonian plutons. It appears, however, to be about -40 mgal. The presence of the gradient near the boundary between the Cambrian and Ordovician and Silurian and Devonian rocks together with the very high peak gravity value (50 mgal) suggest that the gravity high over the anticlinorium may have two sources. One may be a core of ultramafic rock like that indicated by Thompson and Garland (1957), whereas the other may be a broader dense mass associated with the anticlinorium along most of its length. The latter source could include, in part, a density contrast between the rocks of Silurian and Devonian age and those of Cambrian and Ordovician age.

Western Area.—The regional variation in the gravity field over the western area contrasts sharply with that to the east. The maximum range in gravity values occurs in the relatively short distance between southwestern Connecticut (+40 mgal) and eastern New York near the Vermont-Massachusetts border (-70 mgal). Amplitude peaks along the gravity high that extends from southwestern Connecticut to northern Vermont decrease northward, ranging from +40 to zero mgal. Gravity values over the exposed basement of the Adirondack Mountains range from -20 to -40 mgal; a gravity high peaking at about +20 mgal occurs north of the Adirondack Mountains in an area covered by relatively thin stratified rocks of Paleozoic age.

Perhaps the most striking aspect of the western area is the contrast in the regional grain of the gravity field with that to the east. In the triangular area bounded by A-A′ and the Hudson River, the trend of the gravity features is due north. This trend is found in the principal direction of the gravity high that parallels the Green Mountain anticlinorium, in the alignment and elongation of gravity highs in central Massachusetts and southwest New Hampshire, in an elongate gravity low along the border of southern Vermont and New Hampshire, and in the major gravity low of eastern New York. Over the Adirondack region, however, the trends appear to be arcuate in shape rather than linear.

The contrast of the gravity expression of the Adirondacks with that of the remainder of the region is not surprising, inasmuch as the two areas are underlain respectively by the Precambrian craton of the Canadian Shield and the Paleozoic mobile belt of the Appalachians. The regional gravity contrast about A-A′, which is entirely within the Appalachians, corresponds generally with changes in the trend, and in some cases the width, of major geologic structures, but the locus of the change appears to be more sharply delineated in the gravity field. In addition, the analysis of some of the regional gravity anomalies indicates that their sources must be made up in substantial part of rocks of the crust and (or) the mantle (Diment, 1968). The lateral spacing and elongation of the north-trending regional anomalies of the western area suggest east-west compression when compared with the characteristics of the gravity field to the east and north. Major geologic structures of this region show a similar compression when compared with the much broader structures found elsewhere in the Appalachians. Perhaps the most significant aspect of the change in regional gravity about A-A′ is the angularity of the trend change as opposed to the apparent broad curvature of the trends of the geologic structures.

The dominant regional features of the western area are the positive linear gravity high and the adjacent parallel gravity low on the west that are present along the western edge of New England. In a recent study of the anomalies, Diment (1968) concluded that the primary cause of the high is the relative uplift of dense lower crust material, and that the cause of the low is the depression of the less dense crust into the more dense mantle. The close correlation of the gravity and geologic features in Vermont suggests that the source of the gravity anomalies might be the exposed geologic structures, but Diment has concluded that the densities of the rocks do not support such a model.

The variation of gravity in the Adirondack Mountains is closely associated with the contrast between large exposures of anorthosite and metamorphic host rock of Precambrian age (Simmons, 1964). Calculated thicknesses of the anorthosite masses range from 2 to 4 miles compared with widths of as much as 20 miles, so that their shape is essentially tabular. Because of the gentle gradients, the broad high outlined by the zero isogal north of the Adirondack Mountains does not lend itself to critical analysis and may be caused by either a deep or shallow source (Simmons, 1964). More recent detailed surveys by Diment (1968), however, outlined several sharp gravity peaks in the eastern part of the high which shows that it must be at least partly shallow in origin.

A narrow regional low, more subdued than the features discussed above, is present along the common border of southern New Hampshire and southern Vermont and extends into central Massachusetts. It corresponds generally with the Bronson Hill anticlinorium, a feature characterized by mantled gneiss domes and nappes (Thompson and others, 1968). Local gravity lows occur over individual gneiss domes, but the regional low referred to here is a more extensive feature and is probably caused by a broad band of low-density felsic material at depth beneath the anticlinorium. The gravity low terminates in central Massachusetts, although the anticlinorium, considerably narrowed, extends to southern Connecticut. The low may extend to northern New Hampshire, but, if so, it is obscured by the major gravity low of the White Mountains. More detailed gravity surveying may possibly show an extension of the low to the north and south.

Two aligned gravity highs, one of -5-mgal amplitude in southwesternmost New Hampshire and the other of +15-mgal amplitude in central Massachusetts, have no obvious relation to the regional geology. Together the features define the northerly trend noted for this area.

A composite low in eastern Connecticut and Rhode Island is present over a broad expanse of felsic rocks of Devonian age and over domal and nappe structures. Presumably the felsic rocks are the cause of the lower gravity field.

LOCAL ANOMALIES

Land Area.—Local anomalies are apparent throughout most of the land region shown on the map. Because of their abundance it is not possible to discuss them individually, but some comments can be made on anomaly types and, in some instances, on particular gravity-geology correlations.

The most pronounced local anomalies are present over felsic and mafic plutons. The correlation of felsic plutons with sharply defined negative anomalies is well known (e.g., Bott and Smithson, 1967), and ample evidence of it is present in most of New England. Negative anomalies over the massive plutons of central New England, over the broad exposure of felsic rocks in Rhode Island, and over the felsic cores of gneiss domes of the Bronson Hill anticlinorium and eastern Connecticut have already been noted. In addition, well-defined lows occur over all the major felsic plutons of Maine outside the zone of sillimanite-grade metamorphism. From the standpoint of these correlations, the apparent absence of anomalies over the felsic plutons of Devonian age within the sillimanite-grade zone is puzzling, but as pointed out above, it may simply be due to a lack of depth extent. Subdued lows are actually present over most of the Devonian felsic plutons in the sillimanite-grade zone and over smaller plutons elsewhere, but they are too small to show clearly on a map with this contour interval and at this scale.

The felsic rock-gravity low correspondence noted for New England does not seem to hold generally in the Adirondack Mountains region (Simmons, 1964). Gravity lows are present over broad exposures of anorthosite but only locally over exposures of granite. In some of the areas where gravity lows occur over granitic rocks, there is reason to believe that the lows are caused by anorthosite at depth (Simmons, 1964). An important result of the anorthosite-gravity low correlation is that it establishes the density of the metamorphic host rock as significantly higher than that of anorthosite (2.72 g per cm^3). The easternmost of the lows associated with anorthosite extends eastward beneath the stratified rocks of Paleozoic age and contributes to the gravity low over the Lake Champlain lowland.

Notable correlations between local gravity features and igneous structures are the anomalies over the domes, ring dikes, and stocks of New York, New Hampshire, and Vermont (Billings, 1956; Bean, 1953; Joyner, 1963; Diment, 1968). An example is the association of a gravity high with a stock (the Merrymeeting; Billings, 1956) in eastern New Hampshire just west of the point where the Maine-New Hampshire border changes from a straight to an irregular line. Although the rock exposed at the surface of the stock is granitic, Joyner (1963) has shown that the granite must be underlain at a fairly shallow depth by a mass of mafic composition.

Gravity highs associated with mafic or ultramafic rocks occur in the northwest along the Sutton Mountain anticlinorium, in west-central Maine, and within a northeast-trending belt extending from southeast Connecticut to eastern Maine. The rocks in the area of the Sutton Mountain anticlinorium are primarily ultramafic, whereas those to the southeast are primarily mafic. These major plutons are restricted to areas of positive structure and are, for the most part, east of A-A′. The greatest abundance of mafic rocks occurs in the coastal belt along the northwest margin of the Gulf of Maine. These rocks include the mafic phase of Bays of Maine igneous complex underlying most of the eastern Maine coast (Chapman, 1962), the Salem Gabbro-Diorite of northeast Massachusetts, and the Preston Gabbro of southeast Connecticut. In the central and southern Maine coastal regions, small exposures of mafic rock occur under gravity highs of broad lateral extent.

Marked gravity lows associated with local basins of deposition have not generally been observed in the New England region, primarily because density contrasts caused by porosity have been eliminated by regional metamorphism. At least part of the regional low over the Connecticut Valley-Gaspé synclinorium can be attributed to the lower density of metamorphosed stratified rocks, but the gravity effect is noticeable because of the large volume of rocks involved. The gravity field over the stratified rocks of Carboniferous age in the Narragansett and Boston basins of southeastern New England is, as noted by Longwell (1943), as high or higher than that of the surrounding area. A gravity low is present over the basin of unmetamorphosed rocks of Triassic age in western Massachusetts, but it is not apparent over the basin farther south in Connecticut (Longwell, 1943). In the Maritime Provinces of Canada to the northeast, porous sedimentary rocks that postdate regional metamorphism are exposed over broad areas and cause local gravity lows (Garland, 1953).

Many anomalies in the Maine area with moderate amplitudes and gradients correlate with areas underlain by a large proportion of volcanic material. Most of the anomalies are highs and are attributed to the presence of mafic rocks. In one area in central Maine, moderate gravity lows occur over parts of a belt of extrusive rocks that are mainly felsic in composition (Rankin, 1968).

Gulf Area.—The abundance of gravity highs and lows throughout the Gulf of Maine most closely resembles the distribution of anomalies in central Maine. As on land, the anomalies presumably mark the location of mafic and felsic plutons and, possibly, local basins of unmetamorphosed stratified rocks. Gravity highs are prominent in the gulf, and together with the occurrence of mafic rocks along the coast, suggest that the gulf area may be one of the most mafic regions of the northern Appalachians. Analysis of an aeromagnetic map of the area also supports the hypothesis of the widespread presence of mafic igneous rocks in the gulf (Kane, 1970).

Many of the gravity lows are probably caused by felsic plutons, but some may be caused by basins of sedimentary rock of post-Devonian (postmetamorphic) age. Uchupi (1966) has shown that the extent of rocks of Triassic and younger age is probably very limited in this part of the gulf, so that extensive deposits of porous sedimentary rocks are likely to be of latest Devonian or Carboniferous age. Kane (1970) concluded that the most probable occurrence of strata of Carboniferous age is in the vicinity of the zero isogal closure in the central part of the gulf.

GENERAL DISCUSSION

A point of particular interest in the northern Appalachians is the relationship of the indurated basement underlying the Gulf of Maine to that of the surrounding region. The high regional gravity and the apparent abundance of mafic rocks of the gulf distinguish it from adjoining land areas, possibly as a separate subprovince. As noted in the previous discussion of the regional gravity of the New England region, there is a gross correspondence between regional gravity highs and areas underlain by major structural highs. Examples of this correspondence are the association of broad gravity highs with areas underlain by rocks of Precambrian age in southern Vermont and in New York. On the southeastern side of the Appalachians of Canada, regional Bouguer values of zero to 30 mgal are generally associated with areas underlain by rocks earliest Paleozoic or of Precambrian age

(Garland, 1953; Weaver, 1967), whereas lower gravity fields are generally present over bedrock of younger age. For these reasons, Kane (1970) suggested that the Gulf of Maine may be underlain in large part by indurated basement of Precambrian or earliest Paleozoic age. Drake and others (1954) reached a similar conclusion as a result of a seismic refraction survey of the gulf.

The typical inverse relation between low Bouguer gravity and topographic highlands may be observed throughout much of the region, indicating that the topographically positive features are isostatically balanced by low-density masses at depth. The relation holds, for example, from the Gulf of Maine northwestward to northern Vermont and New Hampshire and to central Maine. It has been established that at least part of the regional variation in gravity is caused by shallow crustal sources, so that isostatic balance is achieved at least partially by masses in the shallow crust. A similar relation appears to hold in the westernmost area where lower gravity values are present over the uplifted, exposed rocks of the Adirondack Mountains, and higher values are present over the covered northern part of a presumably continuous crustal block. From a more local standpoint, the low-density felsic masses of the northern New Hampshire region probably play a part in the isostatic balance of the White Mountains.

A major exception, however, is the high regional gravity over the topographic highland along the Green Mountain-Sutton Mountain anticlinorium and the low regional gravity along the adjacent Hudson River-Lake Champlain lowlands and the St. Lawrence River valley. Perhaps, as suggested by Woollard (1948) and Diment (1968), part or all of the cause is to be found in the overthrust structures common in this region. Presumably the crust of this region possesses enough lateral strength so that the load imposed by the overthrust plate (the crust beneath the anticlinorium) is supported by the underthrust plate (the crust beneath the lowlands). Thus, although the plates appear to be individually out of balance, they act in conjunction to compensate each other.

A more complex relation between gravity level and topographic expression is found over the Connecticut Valley-Gaspé synclinorium. In northwest Maine, the area of the gravity low is occupied by a moderate lowland, the valley of the northeast-flowing St. John River. In northeastern Vermont, however, the region of the gravity low is underlain by a moderate topographic highland. A difference between the two areas is that major felsic plutons are present in the Vermont area, whereas no major plutons are known in the St. John River region in northwest Maine. Possibly the intrusion of igneous plutons is a factor in the uplift and isostatic balance of areas that were once locations of major subsidence.

SUMMARY

Regional features of the Bouguer gravity field of the New England region show a clear correspondence with major geologic structures. Quantitative analyses of some of these features by some investigators show that their source is, at least in part, within the crust. Other features, such as the gravity low of the St. John River valley, are caused by the contrast in density of exposed rocks with higher density bedrock of the surrounding regions. In the Maine-Gulf of Maine region, a density of 2.9 g per cm^3 or more is ascribed to crustal rock that is at varying depths within the upper crust. In Vermont, the gravity high over the Green Mountain anticlinorium appears to be caused by relative uplift of a dense lower crust and (or) mantle. In New Hampshire and Maine, mass contrasts between uppermost crustal rocks in the sillimanite-grade zone differ in a complex way from those in adjoining regions that are at a lesser metamorphic grade. These conclusions indicate that gross contrasts within the crust are causes of many regional gravity features, although deeper sources probably are partial causes, and in some cases may be the sole cause.

An abrupt change in the trend and overall expression of the gravity field occurs about a line that extends southeast from north-central Vermont to south-central Rhode Island. Northeast of the line, trends are northeast and regional gravity features are relatively broad, whereas southwest of the line, trends are north and regional gravity features are relatively narrow. Corresponding changes in the regional geology can also be recognized, although they seem to be more transitional in nature than those of the gravity field.

Pronounced local gravity anomalies are caused for the most part by plutons; lesser anomalies seem to be caused mainly by substantial volumes of rocks of volcanic origin. Local gravity anomalies in New England would therefore appear to be mainly an indication of the distribution of igneous masses. These relations lead to the conclusion that mafic igneous rocks are common in the Gulf of Maine region, in contrast to their scarcity throughout most of the nearby Appalachians.

Although almost all the major gravity features of New England are now fairly well defined, many questions remain concerning their precise cause. It seems clear that some of the questions may be answered by more detailed gravity surveys and coordinated sampling programs for rock densities. These methods would certainly resolve some of the problems of anomalies within and beyond the sillimanite-grade zone and would yield considerable knowledge about the nature of individual plutons. More detailed surveys may also put additional constraints on the sources of other regional anomalies, but perhaps the most fruitful path of investigation of these features lies in the use of other geophysical techniques.

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