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gravity map series of the earth physics branch

THE GRAVITY FIELD OF NORTHERN ALBERTA, AND PART OF NORTHWEST TERRITORIES AND SASKATCHEWAN

with maps:

No. 103 — Lac La Biche — Peter Pond
No. 104 — Whitecourt — Athabasca
No. 105 — Grande Prairie
No. 106 — Peace River
No. 107 — Wabasca River
No. 108 — Fort Vermilion
No. 109 — Hay Lake
No. 110 — Providence
No. 111 — Great Slave Lake

R. I. Walcott and J. B. Boyd

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA, CANADA 1971

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ABSTRACT - The report area covers National Topographic System sheets 85 S.E. and S.W., all of 84, 83 N.E. and N.W. and 73 N.W. and includes northern Alberta, part of Saskatchewan and a southern part of the Northwest Territories. The major anomaly of the report area is that related to the Rocky Mountains and is largely, if not entirely, due to the isostatic compensation for the load of the mountains. Other major anomalies are the Fond du Lac and Trout Mountain lows and that associated with the MacDonald Fault. Bouguer density profiling at Peace River, Alberta gives a Bouguer density for the Cretaceous rocks of $2.20 \pm .05$ g/cm^3.

RÉSUMÉ - La région étudiée correspond aux cartes suivantes du Système national de référence cartographique: 85 SE et SW, 84 en entier, 83 NE et NW et 73 NW; elle comprend le nord de l'Alberta, une partie de la Saskatchewan et une partie du sud des Territoires du Nord-Ouest. L'anomalie la plus importante de la région étudiée est celle qui correspond aux montagnes Rocheuses; elle est due en majeure partie, sinon entièrement, à la compensation isostatique de la masse montagneuse. Les autres anomalies importantes sont les dépressions du Fond-du-Lac et de Trout Mountain et celles associées à la faille MacDonald. Le profil des anomalies de Bouguer à Peace River (Alb.) donne une densité de $2.20 \pm .05$ g/cm^3 pour les roches du Crétacé.

INTRODUCTION

Gravity Map Series sheets 103 to 111 complete publication of Bouguer anomaly gravity maps in western Canada east of the Rocky Mountains. Previous publications in this series by Buck (1967) of southern and central parts of the Prairie Provinces, Walcott (1968) of northern Saskatchewan and northeastern Alberta and Hornal (1970) of the Northwest Territories surround the present series (Figure 1). Two of the maps (numbers 110 and 111) cover part of the area discussed previously by Hornal (1970) whose preliminary maps of the Mackenzie Basin and Beaufort Sea were published at a scale of 1:1,000,000 - the present series at 1:500,000 is conformable with the scale used elsewhere in Canada.

The maps were prepared from field observations made by the Earth Physics Branch (previously the Observatories Branch), Department of Energy, Mines and Resources, during the summer of 1967. The survey was conducted in the same manner as earlier surveys (Tanner and McConnell, 1964) but the better than usual elevation and position control and the open, broad relief gives increased confidence in the reliability of the measurements - particularly those elevations determined by altimeter. The estimated accuracy is accordingly better than ± 2 mgal, most of the uncertainty being due to elevation control. As usual station spacing is about 8 miles (12 km).

The maps show Bouguer anomalies in units of tenths of milligals contoured at 5 mgal intervals. The Bouguer density used in the reduction is everywhere 2.67 g/cm^3. Terrain effects are for the most part less than 1 mgal but in deeply incised valleys, at the edge of escarpments and at the few higher stations in the Rocky Mountains foothills, the terrain effect may be as large as 4 mgal but no terrain correction is made for any station. Principal facts for all gravity stations, and location sketches of the control network are available for a nominal fee on request to the Gravity Division, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa.

This report gives a description of the gravity field and an interpretation of its major features. Basic information for any regional interpretation includes topography, geology and rock density and therefore these also are described.

DESCRIPTIVE NOTES

Topography

The present map series lies within the Interior Plains, a geomorphological province consisting of flat stretches of Prairie and deeply incised rivers and streams extending to the Arctic Ocean between the Canadian Shield and Rocky Mountains. Over most of the Interior Plains the ground surface rises steadily towards the Rocky Mountains but eastward it forms an escarpment against the lowlands that lie along the boundary of the Shield. In the south, in the vicinity of Lake Winnipeg, the escarpment is continuous but farther north, in the vicinity of the present map areas, the escarpment is deeply embayed and broken into a series of isolated mesas, such as the Horn Plateau and the Caribou Mountains (Figure 2).

Large rivers that rise in the Rocky Mountains and discharge into the Arctic Ocean by way of the Mackenzie River system cut across the Interior Plains in deeply incised valleys. The Peace River for instance, occupies a gorge over most of its length that is about 800 feet below the general level of the surrounding country.

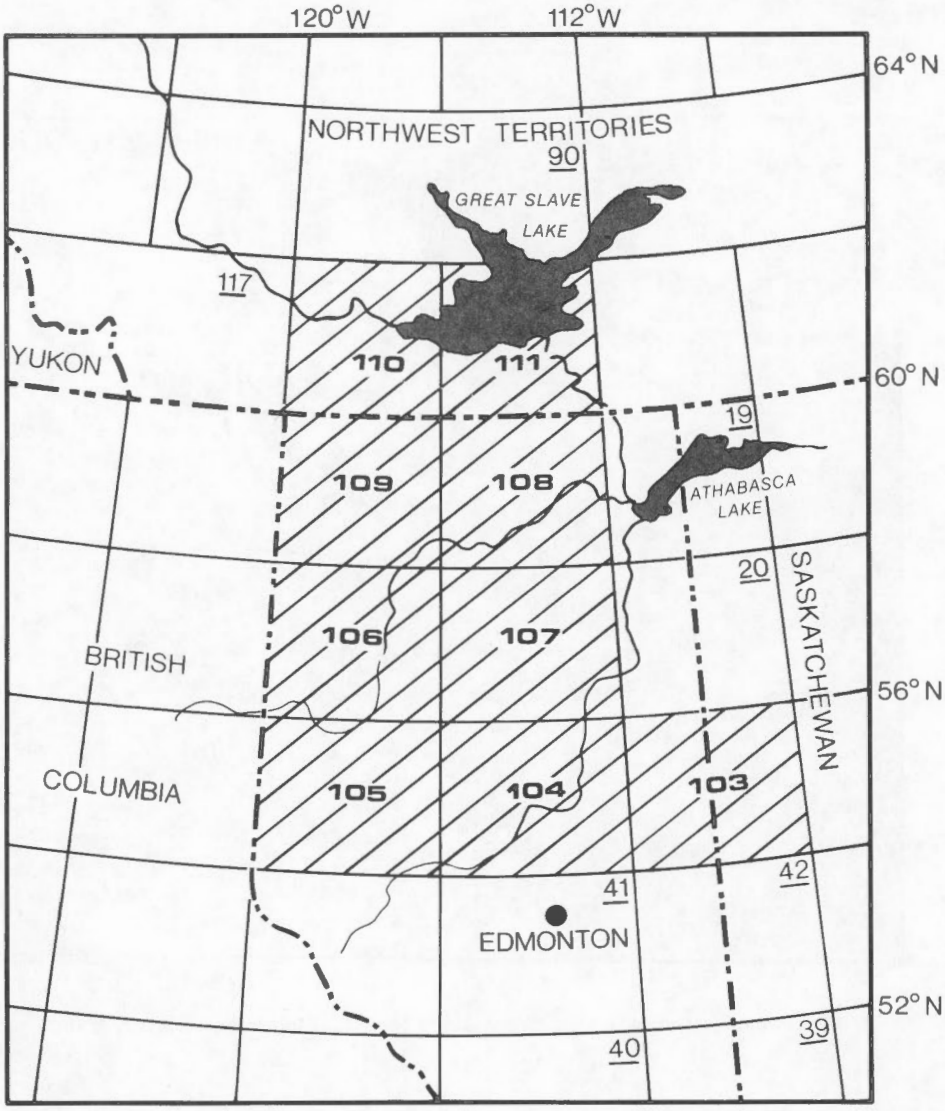

Figure 1. Location map. Underlined numbers are previously published maps of the Gravity Map Series.

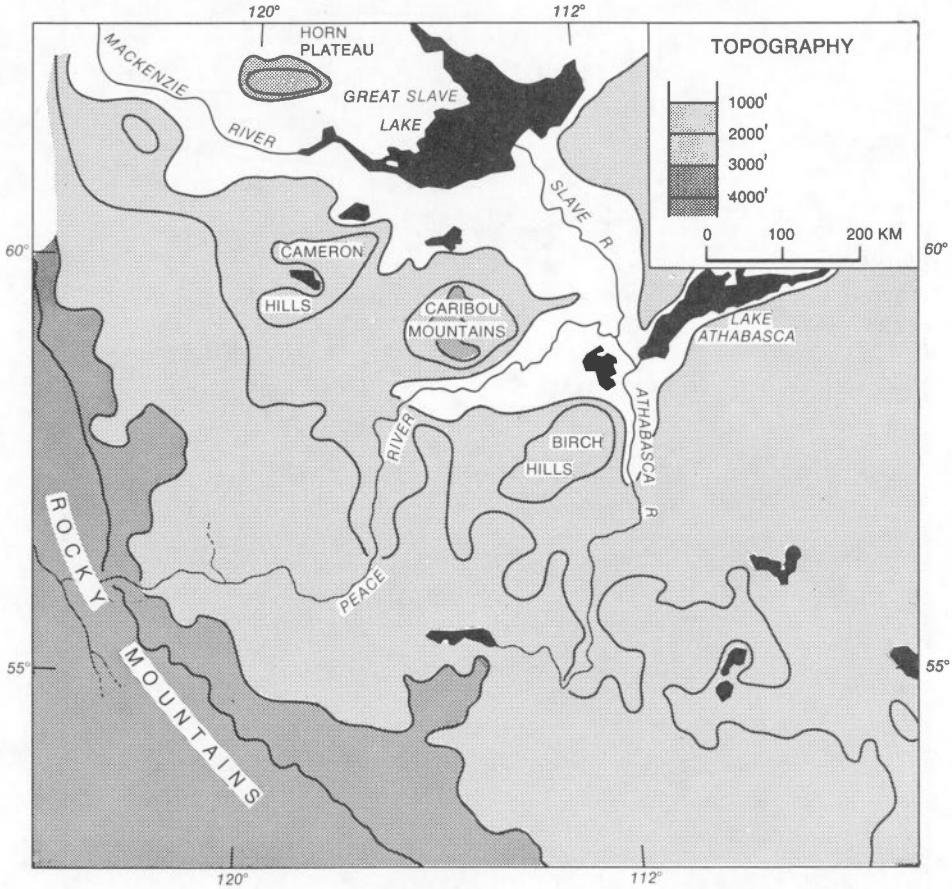

Figure 2. Topographic map showing generalized topographic contours and major rivers.

Geology

The Interior Plains are developed on almost flat-lying Phanerozoic sedimentary rocks that overlie the crystalline basement of the North American Craton. The sedimentary rock forms a wedge which thickens westward to more than 12,000 feet beneath the Rocky Mountains. The older, Paleozoic, sediments consist largely of limestone and dolostone with minor clastics and evaporites. The thinner and not so widespread Mesozoic and Tertiary strata are largely clastics. The sedimentary rocks are petroliferous and consequently several hundred wells have been drilled, many to basement. The structure and stratigraphy of the Phanerozoic sedimentary succession is therefore well known.

The surface of the crystalline basement is of low relief and dips at an increasingly steeper angle towards the southwest and the Rocky Mountains. The structure of the basement surface has been described by Green (1958) but recent data (available in the Schedule of Wells published by the Research Council of Alberta) provides further detail which is used to compile the map of Figure 3. Where well information is sufficiently detailed, relief of several hundred feet over distances of one or two miles is evident but there is a general and smooth trend of the basement that shows little irregularity. In this respect the buried surface is similar to the exposed surface of the present day Shield.

Direct knowledge of the basement rocks comes only through a few samples collected from wells (Burwash, 1957) but these are too widely separated to provide control on basement structure. Geophysical measurements of magnetic and gravity fields, however, prove useful in generalizing from well data and extrapolating structure from the Shield below the Phanerozoic strata. Garland and Burwash (1959) give a lithologic map of the area south of the present map series based on gravity and well samples. Garland and Bower (1959) discuss the lithologic variations within the basement from the magnetic field over an area covering, in part, sheet 103 of the present series but extending considerably farther south. Most other structural interpretations of the basement are based on inference from faults within the Phanerozoic strata, usually presuming that these are basement controlled structures (Sikabonyi, 1957; Sikabonyi and Rodgers, 1959; Haites, 1960; Pye, 1958). A most important fault is the MacDonald Fault which can be traced northeastward from Pine Point on the south shore of Great Slave Lake a distance of at least 350 miles, and it appears to continue to the southwest along the line of the Phanerozoic Hay River Fault (Haites, 1960).

Rock Densities

The densities of the Phanerozoic sedimentary rocks are not well known although it is clear they range from about 1.8 g/cm^3 for poorly indurated Mesozoic shales to more than 2.7 g/cm^3 for Paleozoic dolostone. It is of some importance in the reduction of gravity observations to obtain an accurate estimate of the density of surface rocks for otherwise the Bouguer reduction will introduce anomalies that are correlated with elevation. For this reason a Bouguer density profile was run across the valley of the Peace River through the town of Peace River, Alberta.

In the method of Bouguer density profiling, a gravity profile is obtained across a topographic feature that is sufficiently large to have a large gravity effect. The gravity effect will be a function of the integrated volume of the topography and its density and as the former can be obtained from maps, the density can be calculated. The crucial problem is separating the gravity effect of the topography from all other contributions to the gravity field. This is done essentially by identifying that part of the gravity field that is correlated with topography, and this in turn is facilitated by a symmetrical structure, such as a hill or, as here, a river valley.

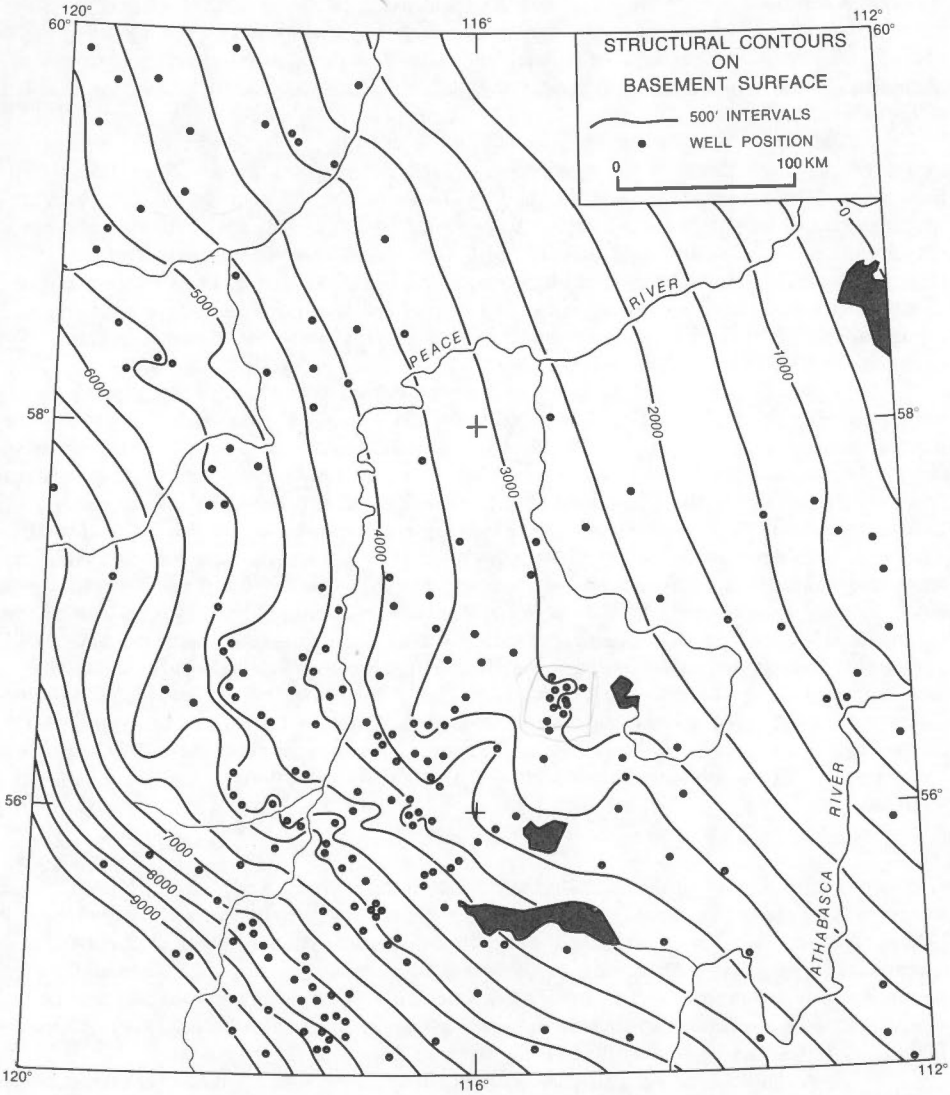

Figure 3. Structural contours on the Precambrian basement surface; values in feet below mean sea level datum. Major lakes (in black) and rivers are shown.

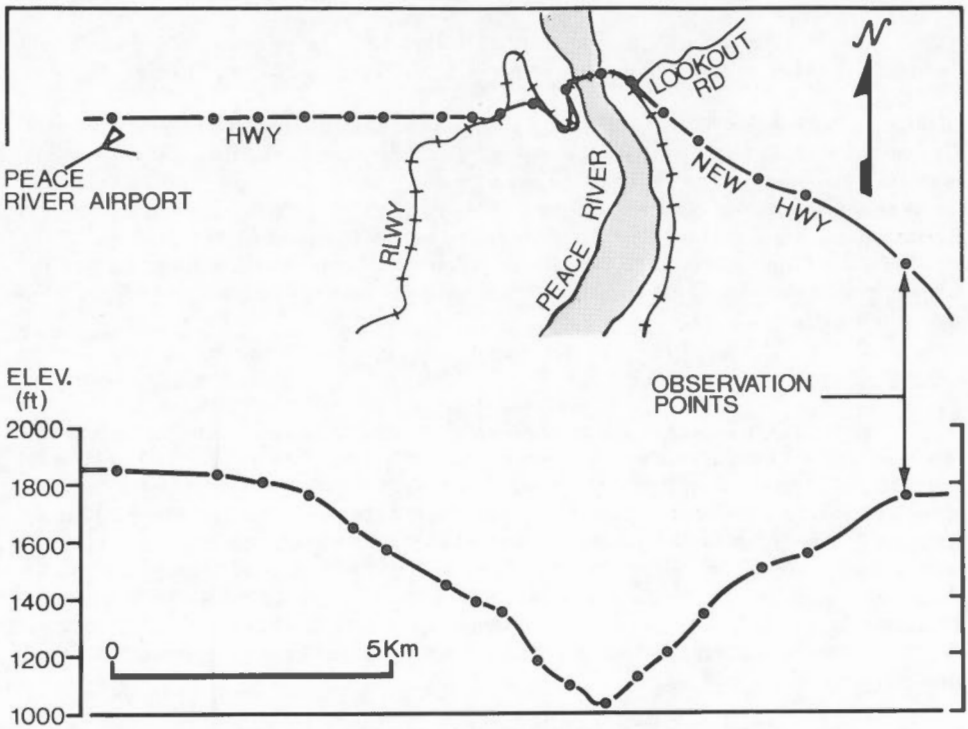

Figure 4. Map and profile of gravity observations across the Peace River gorge at Peace River, Alberta.

Eighteen stations were occupied (Figure 4), and the elevation of each was measured by spirit level and rod and tied to geodetic bench marks. Gravity was measured by LaCoste and Romberg meter tied to the control point at Peace River airport. The terrain effect was determined for each station using a Hammer template and 1:50,000 contoured maps. A sketch map and profile are shown in Figure 4.

A regression analysis of the observations was made according to the equation

$$(g_i + t_i) = g_o + a.x_i + b.h_i$$

where

g_i = observed gravity at the 'i'th station

t_i = terrain effect at the 'i'th station

x_i = distance of the 'i'th station from the 1st station of the profile

h_i = elevation of the 'i'th station

a, b = regression coefficients

The coefficient b corresponds to the Bouguer reduction

b = 0.01278 x Bouguer density (elevation in feet)

The density so calculated is 2.20 $\pm$0.05 g/cm^3 ($\pm$ twice the standard deviation) - and this is taken as the bulk density of rocks in the vicinity of Peace River. No significant improvement is obtained by using a quadratic expression for the distance function. The rocks are mapped (Lang, 1965) as the Shaftesbury Formation of dark grey to black shale in the bottom of the gorge and Dunregan Formation of dark grey sandstone and shale in the upper parts corresponding to the lower and upper Cretaceous rocks respectively. In reducing values to sea level, greater thicknesses of lower Mesozoic rocks will be included, and will consequently involve a higher density. A value of 2.3 g/cm^3 is used therefore in the reduction of observed gravity and although larger than the density of the surface rocks it will not introduce significant "topographic" anomalies.

Bouguer Anomalies

A small scale map of the entire area covered by the accompanying map series (Figure 5) shows Bouguer anomalies (Bouguer density 2.3 g/cm^3) contoured at 10 mgal intervals. Bouguer anomalies range from -20 to -120 mgal. In the southeast corner of the area is the Fond du Lac Low - a continuation of the major gravity anomaly low described in northern Saskatchewan (Walcott, 1968). The Rocky Mountain low is clearly seen in sheet 105 and on the southwestern side of Figure 5. It is an intense low of about -120 mgal and is obviously related to the higher ground of the Rocky Mountains. The Trout Mountain Low is a closed, elliptical anomaly in sheet 106 with an amplitude of -35 mgal below the regional value. Apart from these features no anomalies of large amplitude are observed.

INTERPRETATION

As pointed out by Garland and Burwash (1959) large amplitude variations in the anomalous gravity field must arise below the sedimentary strata and within the crystalline basement. This is because it is only there that large enough anomalous masses can be accommodated to explain the gravity anomalies. Thus although anomalies of as much as 10 mgal amplitude may be due to structures within the sedimentary succession, the intense anomalies with which we are concerned here must represent basement structures.

Relationship of Gravity and Topography

There are two aspects of the relationship of gravity and topography to be discussed. The first is the effect on the Bouguer reduction using an inappropriate Bouguer density. A second is the obvious correlation of Bouguer anomaly with elevation and most clearly shown by the Rocky Mountain Low.

The Bouguer density used in the reduction of observed gravity in the 1:500,000 map is 2.67 g/cm^3 to achieve consistency and avoid discontinuities in the reduced data with the rest of Canada. Although 2.67 g/cm^3 is a reasonable value over the Shield (Gibb, 1968) it is too high by about 0.5 g/cm^3 over the Interior Plains. This means that Bouguer anomalies are introduced by the reduction procedure of about 6 mgal for every 1,000 feet in elevation, and such anomalies will therefore be correlated with topography. Thus over the mesas of the Caribou Mountains (sheet 109), Birch Hills (sheet 109), and Cameron Hills (sheet 110), there are Bouguer anomaly lows of about -15 mgal amplitude, which are removed by using the smaller density of 2.3 g/cm^3. This value is used for the small scale map of Figure 5.

The general decrease in gravity anomalies from the lowlands surrounding Great Slave Lake toward the Rocky Mountains culminating in the intense Rocky Mountain Low is evident in comparison of Figures 2 and 5. It is more clearly seen in sheet 105.

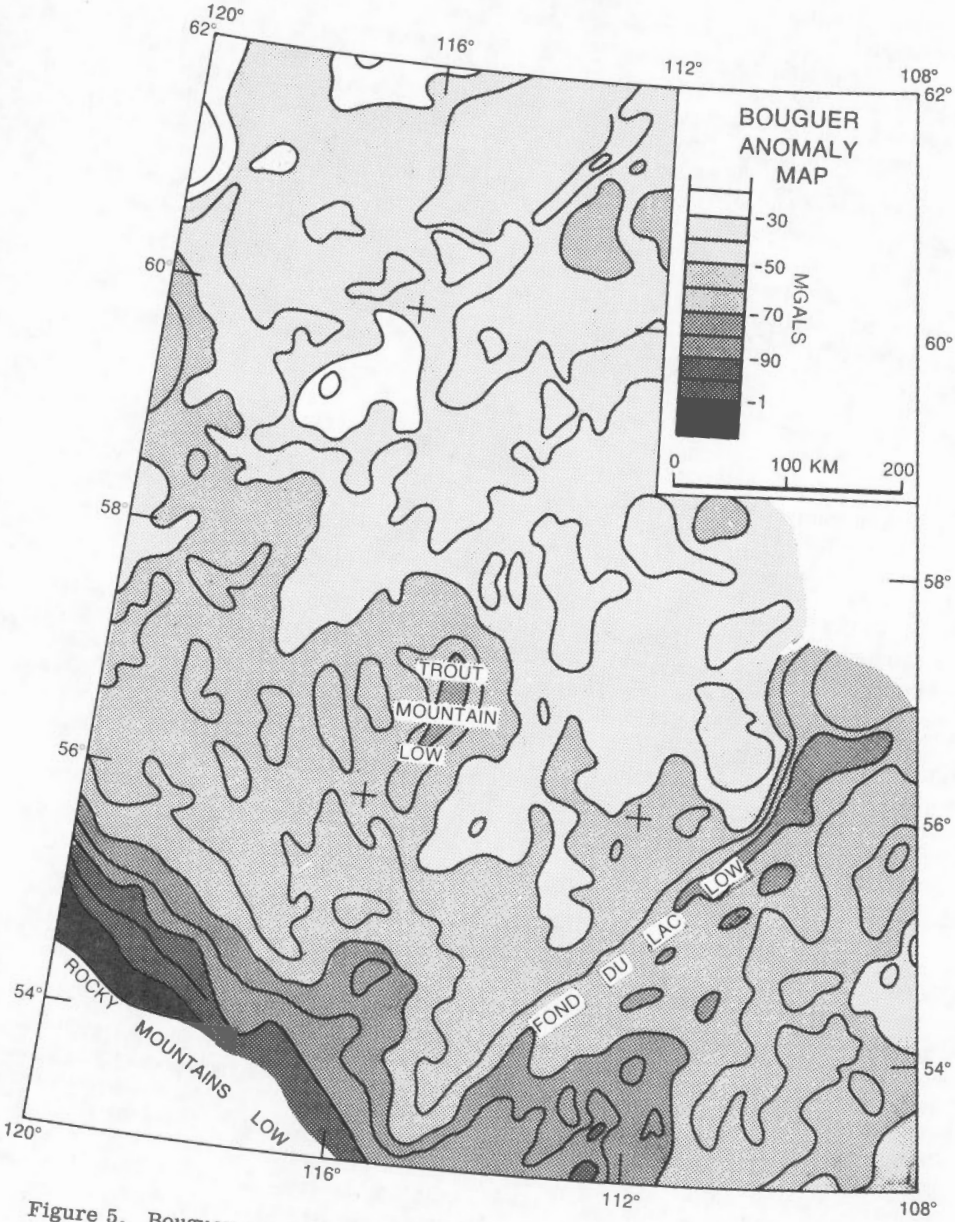

Figure 5. Bouguer anomaly map of the area covered by the Gravity Map Series. Bouguer density used in the reduction 2.3 g/cm^3.

There, the Bouguer anomalies decrease from -50 mgal to less than -120 mgal where the average elevation changes from 3,000 feet in the northeast to 6,000 feet in the southwest corner of the sheet. This decrease in Bouguer anomaly is an illustration of isostasy, the increasing load due to topography being compensated by a deep seated decrease in mass.

The increasing depth to basement (Figure 3) would seem to suggest that the decrease in mass is caused by a downward displacement of the continental crust of the craton, displacing heavier mantle material and thus providing the compensation for the mountains and high plateaux of the Interior Plains. It is clear, however, that such compensation is regional and not local in character as no noticeable displacements are observed under individual mesas such as the Caribou Mountains (Walcott, 1970a). The hypothesis of regional compensation by flexure of continental crust beneath the load of the Rocky Mountains is quantitatively adequate; the change in depth of the basement from the edge of the Shield to the Rocky Mountain foothills is about 3 km which using the Bouguer slab formula, would indicate a gravity effect of 41.8 x 3 x (3.3 - 2.5) = 100 mgal (density of mantle 3.3 g/cm^3, mean density of Phanerozoic sedimentary rocks 2.5 g/cm^3). The corresponding change in regional Bouguer anomaly is about the same.

Fond du Lac Low

The Fond du Lac Low is a continuous belt of intense negative anomalies first described in northern Saskatchewan. There, in the vicinity of Stony Rapids, the low appears to be related to low density granitic rocks (Walcott, 1968) but farther south, in the vicinity of Virgin River it can be correlated with Aphebian sediments within a higher grade metamorphic Archean terrain (Wallis, 1970). The low continues southwestward across the Interior Plains and marks a major change in lithology of the basement rocks within a narrow belt. Insofar as it correlates with a younger belt of sedimentary rocks of different metamorphic and, perhaps, sedimentary facies to its surroundings, the low may mark an intracontinental sedimentary trough in the sense of Wallis (1970) or a suture zone between collided continents in the sense of Dewey and Horsfield (1970). The distinction is an important one but can only be resolved by close study of the rocks in areas of good exposure of basement rocks. The continuation of the low to the southwest within the present map series suggest the structure continues toward, if not as far as, the edge of the Precambrian craton.

Trout Mountain Low

The Trout Mountain Low is centred about 5 miles northwest of Trout Mountain, Alberta. As argued earlier the causative mass anomaly lies within the basement, and because the steepest gradient is 1.4 mgal/km the mass anomaly must be shallow with a major part of it less than 3 km deep (Garland and Burwash, 1959). From experience on the Shield the mass anomaly could be any low density rock such as granite and/or younger sedimentary rocks and/or low grade metamorphic rocks, but there are interesting features of the low that suggest a granitic or metamorphic rock body. The Trout Mountain Low covers the Red Earth oil field, wells of which indicate an extensive area of 'granite wash', an arkosic sand deposit at the basement surface. If locally derived such a sand would suggest that the Trout Mountain Low is produced by a granitic batholith. However, samples of the basement rocks from the area of the low, identified and given by Burwash et al. (1964) are "metamorphic rocks". Gravity can only indicate therefore that a major change in lithology occurs within the upper part of the basement in the area of the low and further work, drilling and magnetic observations are obvious examples of the type of work needed, will be necessary to extend our knowledge of the cause of the low.

MacDonald Fault

In the northeastern part of sheet 111 and Figure 5 the trend of the MacDonald Fault is shown by parallel, southwest oriented, gravity contours. Like the surface trace of the fault, its gravity expression is obvious only as far to the southwest as Pine Point on the south shore of Great Slave Lake and thereafter both the field evidence and the gravity effect are obscure. Sikabonyi and Rodgers (1959) describe a fault within the Phanerozoic strata, the Hay River Fault, which may be the continuation of the MacDonald Fault (Haites, 1960). But normal movements of the Hay River Fault (Sikabonyi and Rodgers, 1959) suggest a distinctly different stress system to the Proterozoic, probably transcurrent movement (Chinnery, 1966) on the MacDonald Fault. This latter stress system may be related to isostatic movements that would occur during sedimentation (Walcott, 1970b) and reactivation of the Proterozoic Fault by these stresses would be a plausible origin for the Hay River Fault.

The absence of as strong a gravity anomaly related to the Hay River Fault as that to the exposed MacDonald Fault in the northeast is not evidence that the basement fault does not continue southwestward. It may indicate no more than the absence of a density contrast across the fault.

SUMMARY AND CONCLUSIONS

Care has to be taken in interpreting the gravity maps of the Interior Plains because of the large Bouguer density used in the reduction of the data. Bouguer anomalies as large as 15 mgal may be due simply to topography and the small amplitude lows related to the Tertiary mesas and escarpments are undoubtedly produced this way. A density of 2.20 g/cm^3 is more representative of the surface rocks of the Interior Plains, than the value 2.67 g/cm^3 typical of the Shield.

The gravity field is dominated by the gradual decrease in Bouguer anomaly towards the Rocky Mountains, the cause being the isostatic compensation for the increasing topographic load. Other major anomalies include the southwest trending belt of negative anomalies, a continuation of the Fond du Lac Low, and a large and intense elliptical low in the vicinity of Trout Mountain. Both of these indicate major changes in lithology within the upper part of the Precambrian basement.

The MacDonald Fault is well defined gravitationally in the area of its exposure and as far southwestward as Pine Point, thereafter evidence of its continuation is not clear. This, however, may indicate no more than an absence of a density contrast across the fault.

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