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# RESULTS OF UNDERWATER GRAVITY SURVEYS OVER THE NOVA SCOTIA CONTINENTAL SHELF with map No. 123 — Halifax-Burgeo

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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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# RESULTS OF UNDERWATER GRAVITY SURVEYS OVER THE NOVA SCOTIA CONTINENTAL SHELF

L.E. Stephens, A.K. Goodacre and R.V. Cooper

ABSTRACT - During the summer of 1970, 692 underwater gravity stations were established on the Atlantic continental shelf of Canada. The areas surveyed include the Laurentian Channel, Cabot Strait, and parts of Saint Pierre Bank and the Scotia Shelf. Stations were located on a 15-km grid and detailed profiles were made across the Orpheus anomaly and across a diapiric structure north of Sable Island. During three cruises of the CNAV Sackville, Decca and radar were used as primary navigation aids.

The gravity data are presented as a Bouguer anomaly map. The anomalies generally strike in an easterly direction across the continental shelf. The dominant feature is the linear Orpheus anomaly which extends 250 km eastwards from Chedabucto Bay and is flanked to both north and south by positive anomalies. The Orpheus anomaly is probably caused by Carboniferous and younger sedimentary rocks whereon both flanking anomalies appear to be related to Proterozoic metavolcanic rocks with interspersed Devonian basic intrusions. A broad negative anomaly south of the Orpheus anomaly is probably underlain by a Devonian granite batholith. Between the Miquelon Islands and Cape Breton Island, a broad arcuate positive anomaly partly coincides with a Carboniferous basin delineated by seismic surveys. This high is attributed to dense, shallow structures within the pre-Carboniferous basement. The Laurentian Channel is a major structural feature which displaces and distorts the dominant easterly trends of several linear anomalies including the Orpheus anomaly.

RÉSUMÉ - Au cours de l'été 1970, un total de 692 stations gravimétriques sous-marines étaient installées sur le plateau continental de l'Atlantique du Canada. Les régions étudiées comprennent le canal d'écoulement du Saint-Laurent, le détroit de Cabot et certaines parties du banc Saint-Pierre et du plateau continental de la Nouvelle-Écosse. Les stations ont été disposées sur un quadrillage de 15 km et des profils détaillés ont été établis en travers de l'anomalie d'Orpheus et d'une structure diapire située au nord-est de l'île de Sable. Au cours des trois croisières du Sackville, les principales aides utilisées à la navigation étaient le Decca et le radar.

Les données gravimétriques sont présentées sous la forme d'une carte des anomalies de Bouguer. Les anomalies se trouvent généralement orientées vers l'est à travers le plateau continental. La caractéristique dominante est l'anomalie linéaire d'Orpheus qui s'étend jusqu'à 250 km à l'est de la baie Chédabouctou et est flanquée au nord et au sud par des anomalies positives. L'anomalie d'Orpheus est probablement causée par des roches sédimentaires du Carbonifère et plus récentes tandis que les deux anomalies voisines semblent reliées à des roches volcaniques métamorphisées du Protérozoïque, parsemées d'intrusions basiques du Dévonien. Une large anomalie négative au sud de l'anomalie d'Orpheus recouvre probablement un batholite de granite du Dévonien. Entre les îles Miquelon et l'île du Cap-Breton, une large anomalie positive arquée coïncide partiellement avec un bassin du Carbonifère délimité par des levés séismiques. Cette anomalie élevée est attribuée aux structures denses et peu profondes situées dans le socle pré-carbonifère. Le canal d'écoulement du Saint-Laurent est une importante caractéristique structurale qui déplace et déforme les tendances dominantes vers l'est d'un certain nombre d'anomalies linéaires dont celle d'Orpheus.

## INTRODUCTION

During the period June to September, 1970, the Gravity Division of Earth Physics Branch completed a regional underwater gravity survey of the northeastern part of the Nova Scotian continental shelf. This survey extends the gravity work over the Gulf of St. Lawrence reported by Goodacre, Brule and Cooper (1969). The area surveyed is shown in Figure 1 and covers the Cabot Strait, Laurentian Channel and parts of Saint Pierre Bank and the Scotia Shelf. An average of 16 underwater gravity stations per day was established on a 15-km grid during three separate cruises on the CNAV Sackville (Figure 2). A summary of each cruise is given in Table I. The survey was completed in 48 days of which 42 were spent at sea; the remaining days were required for installation of equipment, and for servicing, refuelling and provisioning the ship.

The method of survey was essentially similar to that of previous surveys and is described by Goodacre, et al. (1969). LaCoste and Romberg underwater gravity meters H2G and G25 (Figure 3) were used to make the gravity observations on the ocean floor. The CNAV Sackville was equipped with a Kelvin-Hughes echo sounder and a Westrex precision depth recorder for depth determinations. Radar and Decca Mark 12 receivers were used for position fixes. Although a Tracor Model 599R Omega receiver was on the Sackville for the first cruise and a Magnavox 702CA satellite navigation receiver was used on the third cruise, these units were installed for tests only.

In this report the reduction and accuracy of the results are discussed, the Bouguer anomaly map is described and a preliminary interpretation of the major anomalies is presented.

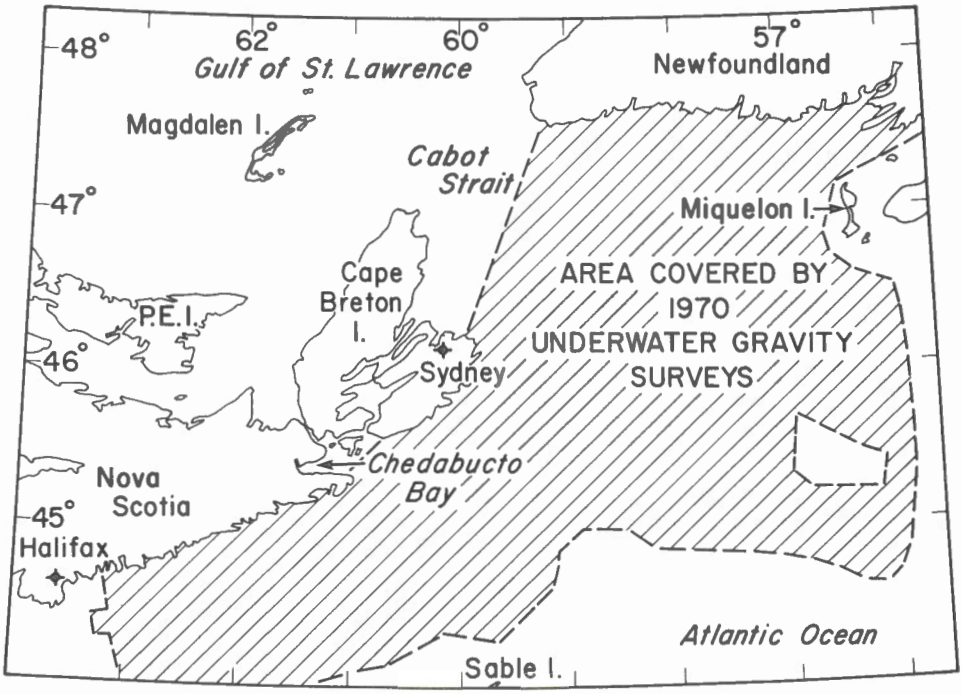


Figure 1. Location map showing area covered by underwater gravity surveys in 1970.

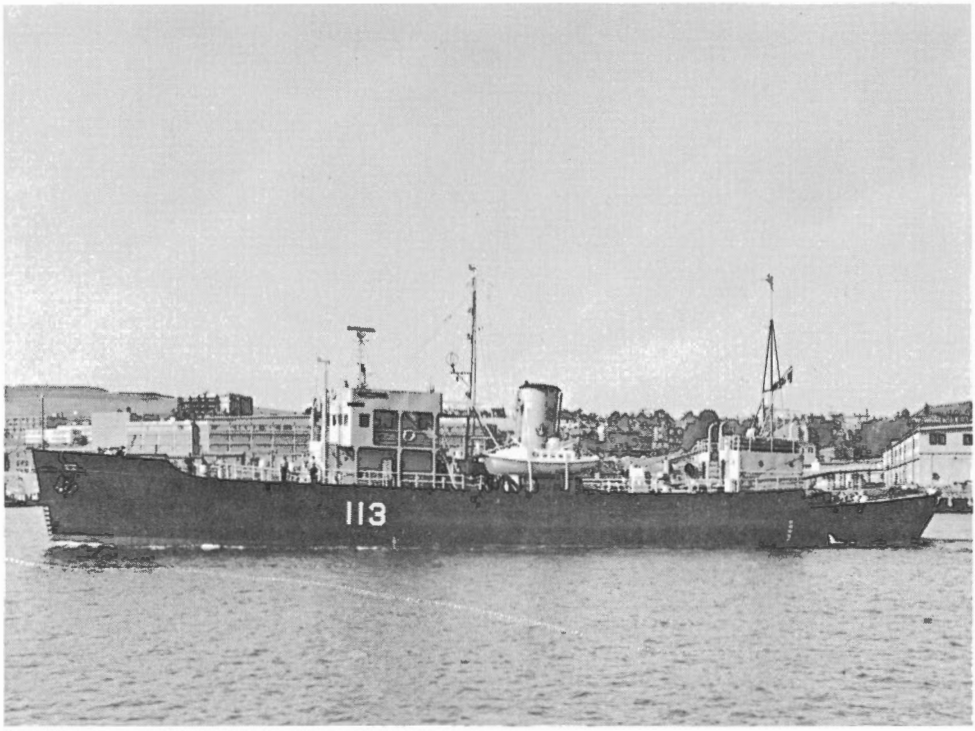


Figure 2. The CNAV Sackville (Photograph - Canadian Forces).

TABLE I

Summary of the 1970 Underwater Gravity Surveys on the CNAV Sackville

| | Cruise 1 | Cruise 2 | Cruise 3 |
|---|---|---|---|
| Cruise dates | June 8 to June 28 | Aug. 5 to Aug. 13 | Sept. 10 to Sept. 30 |
| Number of days at sea | 16 | 8 | 18 |
| Observers | A.K. Goodacre<br>R.V. Cooper<br>E.S. Wainwright<br>D.M. Ablett | R.V. Cooper<br>L.E. Stephens<br>D.M. Ablett | R.V. Cooper<br>L.E. Stephens<br>J.M. McCance |
| Station sequence | 18001-70 to 18336-70<br>(18102-70 deleted) | 18337-70 to 18485-70<br>and 18693-70 | 18486-70 to 18692-70 |
| Number of observations | 335 | 150 | 207 |
| Number of stations per day | 21 | 19 | 12 |
| Decca chains used | 6 and 7 | 6 and 7 | 2, 6 and 7 |

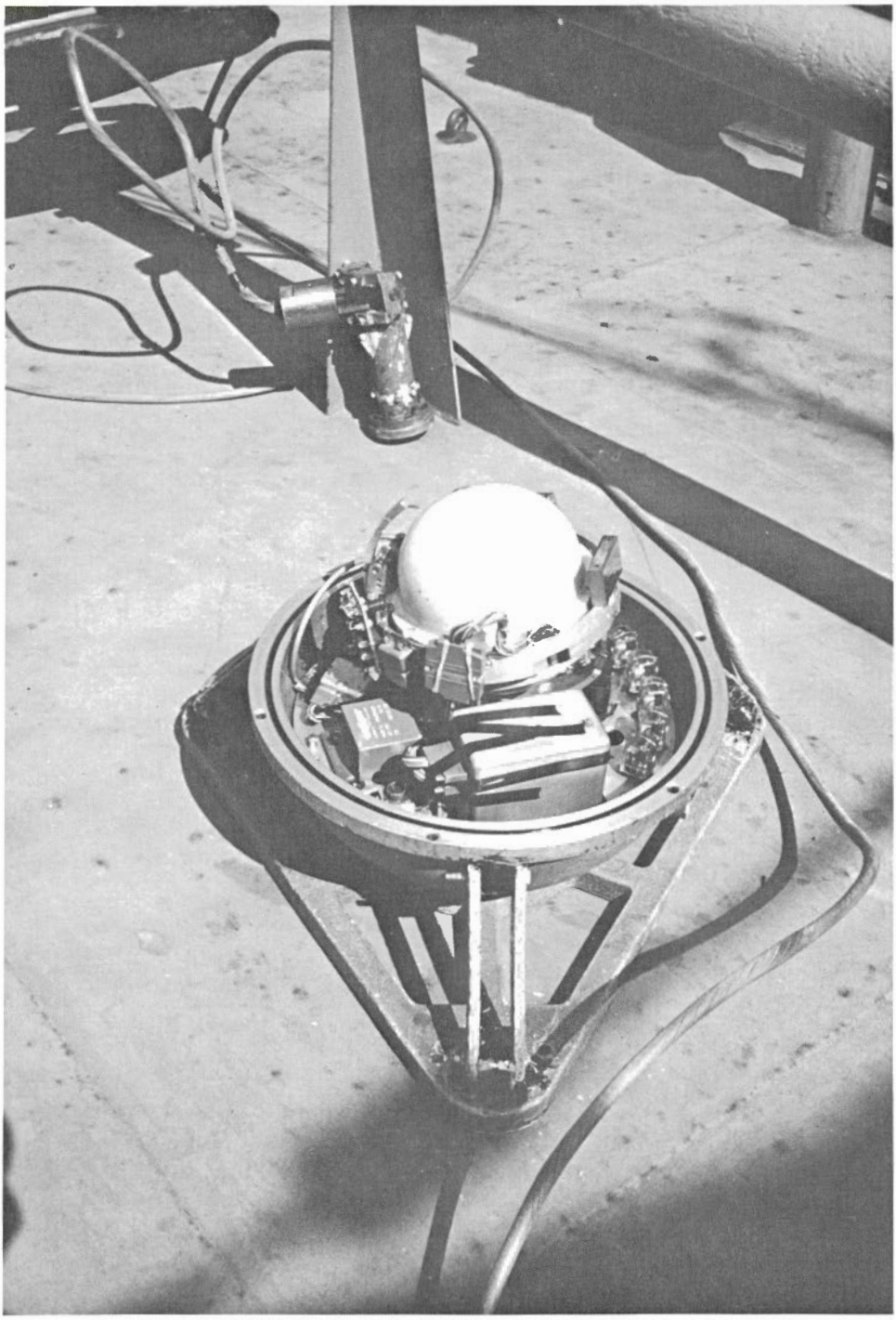

Figure 3. Underwater gravity meter H2G open for inspection.

## REDUCTION AND ACCURACY OF THE GRAVITY DATA

The observed gravity data were reduced to simple Bouguer anomalies using the computer-oriented method described by Tanner and Buck (1964). The equations for the reduction of underwater gravity data to simple Bouguer anomalies are outlined by Goodacre, et al. (1969). Sufficiently detailed bathymetric data are not available in the vicinity of each station so that terrain corrections were not calculated and applied to the simple Bouguer anomalies; terrain corrections are the gravitational effects at stations which are caused by the deviations of the bottom topography from a plane surface.

The depth of water at each station was determined by a pressure gauge within the gravity meter and by a Westrex precision depth recorder (echo sounder). Rather than using a fixed velocity of sound for the echo sounder, a mean velocity from velocity-depth profiles provided by the Canadian Oceanographic Data Centre (Dept. Energy, Mines and Resources, Ottawa) was determined and applied to the travel times recorded by the echo sounder. When the echo sounder depths and the underwater gravity meter pressure gauge depths were compared by the least squares method, there was less than one per cent discrepancy from a straight line of slope one. Although the standard deviation of depths for stations observed in September with gravity meter H2G was $\pm$ 7.3 m, the standard deviation of depths for the other stations of the survey was less than $\pm$ 4.6 m. The overall errors in the Bouguer anomaly from these discrepancies in depths would be $\pm$ 0.35 mgal and $\pm$ 0.22 mgal, respectively.

The accuracy of the Decca positions will be known when the Magnavox satellite navigation and Omega results are calculated. An estimate of the accuracy of position determinations with Decca was obtained on the second cruise in August when the Sackville was within 30 kilometres of the Newfoundland coast and the Miquelon Islands where simultaneous radar fixes and Decca readings were taken. Assuming the radar to be accurate, there were consistent discrepancies in longitude for the Decca positions of almost 15 km. Large errors such as this occur when inaccuracies in the Decca coordinates are caused by lane jumps in the Decometers and by distortions of the Decca pattern. Because the south coast of Newfoundland is on the baseline extension for chain 6, one would expect that, at the centres of the Decca pattern at distances of 300 km, the Decca positions would be out by 5 to 10 km; however, within a range of 150 km of the Decca chain, a reliability of better than 2 km is expected on the basis of a few repeated Decca readings from two different Decca chains.

Since Bouguer anomaly values are latitude-dependent, any error in a north-south direction of 10 km could cause an absolute error in the Bouguer anomaly of about 8 mgal at positions which are farthest away from the Decca chain on the edge of the continental shelf. Nearer to land where Decca navigation is more precise, absolute errors in the Bouguer anomaly from position inaccuracies are less than 2 mgals.

Additional factors contributing to the errors in the Bouguer anomaly are errors in the observed gravity, observed depths, vertical gravity gradients and the lack of marine tide corrections. A full discussion of the magnitude of these errors and the reasons for them is given in the report by Goodacre, et al. (1969).

## PRELIMINARY INTERPRETATION OF THE BOUGUER ANOMALY FIELD

A simplified map of the Bouguer anomalies is shown in Figure 4 and the survey results are presented on map GMS 123 which accompanies this report. The Bouguer anomalies in Nova Scotia, Newfoundland and the Gulf of St. Lawrence west of Cabot Strait have been described and interpreted by Garland (1964), Weaver (1967) and Goodacre, et al. (1969), respectively. In the area east of Cabot Strait and off the Nova Scotia coast the anomalies generally trend in an easterly to northeasterly direction, although in the northwestern quadrant of the map area they tend to converge towards

Cape Breton Island. The Bouguer anomalies become more positive seawards, as is characteristically found on the continental shelves. The anomalies vary in magnitude from -50 mgal for the Orpheus anomaly to 91 mgal at the continental margin in the southeastern corner of the area (Figure 4).

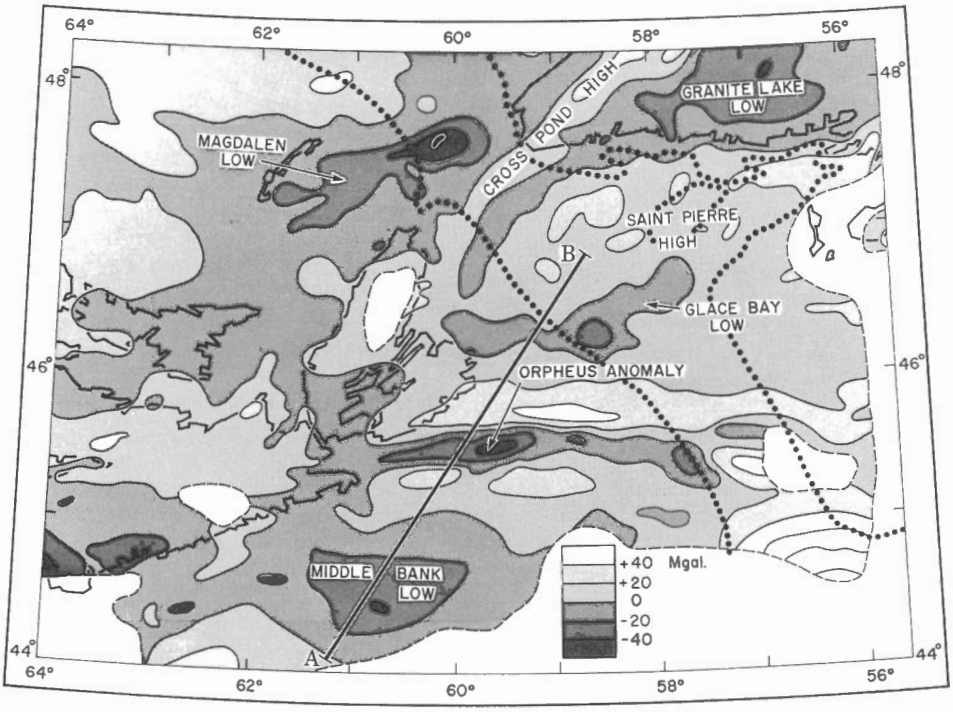


Figure 4. Simplified Bouguer anomaly map. The Laurentian Channel is bounded by the 200-metre bathymetric contours shown as broken lines.

The two primary geological influences on the gravity field are density variations within the pre-Carboniferous basement and between overlying Carboniferous sedimentary basins and the basement. In some areas the gravity anomalies extend over the shelf from known structures on land and may be used to infer the seaward extension of these structures. Thus, the Middle Bank Low (Figure 5) is attributed to an intrusion of Devonian granite as it displays the same broad characteristics and the same trend as the negative gravity anomalies west of Halifax where Devonian granite is the predominant rock type. King and Maclean (1970a), have also delineated the northern margin of this intrusion by using acoustic and surface gravity data and their interpretation is in agreement with the present gravity results.

The most prominent negative gravity anomaly in the area is the Orpheus anomaly which lies north of the Middle Bank Low and which extends east from Chedabucto Bay (Figure 5). The Orpheus anomaly reaches minimum values of -50 mgal and is enhanced by flanking positive anomalies which reach peak values of 44 and 37 mgal (Figure 5). Loncarevic and Ewing (1967) originally mapped and described the Orpheus anomaly and attributed it to 5.5-km sediments consisting of Carboniferous limestone and evaporites. These authors also suggested that the linear deposition of these sediments was controlled by a fault system which appears to extend from the Bay of Fundy, across Nova Scotia and which passes through Chedabucto Bay to the Laurentian Channel. The steep gradients flanking the Orpheus anomaly may be an expression of

such faulting. King and Maclean (1970a), note that the sedimentary rocks are considerably folded and conclude that these folds are caused by post-Carboniferous fault movements and not by diapiric folding.

On either side of the Orpheus anomaly, the high anomalies reflect the presence of relatively shallow, dense pre-Carboniferous metamorphic rocks. These pre-Carboniferous basement rocks form ridges which are covered in places by less than one kilometre of Carboniferous and Cretaceous sediments (Sheridan and Drake, 1968). The northern high anomaly extends west to Cape Breton Island and could map an extension of the metavolcanic rocks of the Proterozoic Fourchu group which appear on the mainland (Weeks, 1960). Intruding the Fourchu group at Cape Breton are several Devonian basic intrusions which may contribute to the high magnetic anomalies (Bower, 1962) and to the high gravity anomalies east of Cape Breton. The possibility also exists that the two positive anomalies either side of the Orpheus anomaly might partly be caused by a dense isostatically compensating structure at depth for the feature causing the Orpheus anomaly.

The Glace Bay Low extends east from Glace Bay and abruptly swings northeast as it crosses the southwest edge of the Laurentian Channel. North of the Glace Bay Low, the Saint Pierre High appears as a broad positive anomaly with maximum values of about 25 mgal which arcs northeast and then east to the Miquelon Islands.

At Glace Bay, Carboniferous sediments are exposed and their gradual eastward thickening has been traced by seismic data; they attain a maximum thickness of 5 km in the Laurentian Channel (Sheridan and Drake, 1968). The axis of this Carboniferous sedimentary basin corresponds to the Saint Pierre High but low density sedimentary fill can not explain this positive gravity anomaly. In adjacent regions, the relatively light Carboniferous sediments are normally correlated with low anomalies. If the velocity variations in the pre-Carboniferous basement rocks presented by Sheridan and Drake (1968) are an indication of density variations then the density of the basement rocks are low under the Glace Bay Low and under the southwestern extension of the Granite Lake Low. Correspondingly, the pre-Carboniferous basement rocks have relatively high densities under the Saint Pierre High and the southwest extension of the Cross Pond High. Thus, the relatively high gravity anomaly of the Saint Pierre High could be attributed to a relatively shallow (about 6 km) dense (3.0 to 3.2 g/cm$^3$) basement similar to that which underlies the Gaspe High (Goodacre, et al., 1969).

North of the Miquelon Islands, the Saint Pierre High appears to be related to Ordovician metavolcanic rocks while the high gravity anomaly southeast of the Miquelon Islands are most likely caused by Precambrian metavolcanic rocks which outcrop on Newfoundland.

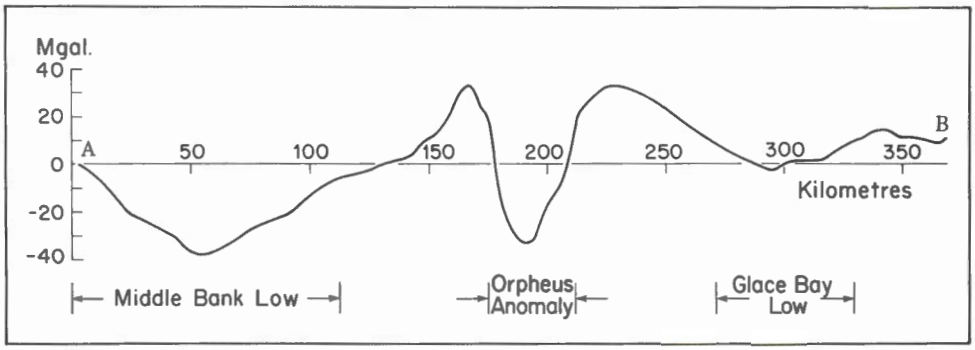


Figure 5. Bouguer anomaly profile A-B across the Middle Bank Low, the Orpheus Anomaly, and the Glace Bay Low.

The Granite Lake Low and the Cross Pond High have been described by Weaver (1967) who correlated them with Devonian granite and Devonian gabbroic intrusions respectively. In addition to the gabbro, high grade metamorphic rocks may also contribute significantly to the Cross Pond High. Offshore seismic investigations presented by Sheridan and Drake (1968) indicate a pre-Carboniferous ridge which rises to within 0.5 km of the surface and which corresponds with the southwest extension of the Cross Pond High.

Several of the gravity anomalies deviate from their strong linear trends as they cross both margins of the Laurentian Channel. Previously, Loncarevic and Ewing (1967) noted that the linear trend of the Orpheus anomaly is disrupted at the southwest bank of the channel. The trend of the Glace Bay Low changes at the southwest margin and abruptly ends at the northeast margin of the channel. Although the linear high anomaly north of the Orpheus anomaly is unaffected at the southwest margin of the channel, it has an apparent dextral displacement at the northeast margin of the channel. Cameron (1956) has inferred the presence of the Saint Pierre fault from geological data along the northeastern margin of the Channel. These observations suggest that deep seated structure may have been a factor in the development of the Laurentian Channel.

At the mouth of the Laurentian Channel, the high gravity anomaly of 91 mgal may be related to the thinning of the sialic crust at the continental margin. However, a relatively high residual magnetic anomaly at this location implies that the high gravity anomaly might be caused partly by a basic intrusion or partly by pre-Carboniferous dense metamorphic rocks. Another positive gravity anomaly 100 km southeast of Halifax appears to be restricted to the shelf and must be related to high density basement rocks consisting of either Devonian intermediate or basic intrusions or pre-Carboniferous metamorphic rocks perhaps belonging to the Cambro-Ordovician Meguma group.

In 1969, while using continuous seismic reflection techniques, King and Maclean (1970b) discovered a diapiric structure 45 km north-northeast of Sable Island. The structure, which has a diameter of 10 km, forms a dome in the Cretaceous sediments surrounding it. A gravity profile over the structure with stations at intervals of one kilometre, indicates a low gravity anomaly over the apex of the structure. This suggests that the material within the structure has a low density and that it possibly consists of evaporites (density 2.2 g/cm$^3$). The magnitude of the gravity anomaly was not determined since the profile was too short, however, it appears to be at least 5 mgal.

## ACKNOWLEDGMENTS

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