This document was produced by scanning the original publication.

Ce document est le produit d'une numérisation par balayage de la publication originale.

gravity map series of the earth physics branch

RESULTS OF UNDERWATER GRAVITY SURVEYS OVER THE SOUTHERN NOVA SCOTIA CONTINENTAL SHELF with map No. 149 – Yarmouth-Burgeo

L. E. Stephens and R. V. Cooper

DEPARTMENT OF ENERGY, MINES AND RESOURCES
OTTAWA, CANADA 1973

GRAVITY MAP SERIES

of the

EARTH PHYSICS BRANCH

Ottawa

RESULTS OF UNDERWATER GRAVITY SURVEYS

over the

SOUTHERN NOVA SCOTIA CONTINENTAL SHELF

with map

No. 149 Yarmouth-Burgeo

L.E. Stephens and R.V. Cooper

Canada
Department of Energy, Mines and Resources
Earth Physics Branch
1973

© Crown Copyrights reserved

Available by mail from Information Canada, Ottawa,
and at the following Information Canada bookshops:

HALIFAX
1683 Barrington Street

MONTREAL
640 St. Catherine Street West

OTTAWA
171 Slater Street

TORONTO
221 Yonge Street

WINNIPEG
393 Portage Avenue

VANCOUVER
800 Granville Street

or through your bookseller

Price: $1.00 Catalogue No. M 74-6/149

Price subject to change without notice

Information Canada
Ottawa, 1973

CONTENTS

	Page
ABSTRACT	1
INTRODUCTION	2
SURVEY LOGISTICS	2
REDUCTION AND ACCURACY OF THE GRAVITY DATA	4
DESCRIPTION OF THE BOUGUER ANOMALY FIELD	6
ACKNOWLEDGMENTS	8
REFERENCES	9
GRAVITY MAP SERIES	
No. 149 - Yarmouth-Burgeo	

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

L.E. Stephens and R.V. Cooper

ABSTRACT - Underwater gravity surveys completed during 1971 on the southern Nova Scotia continental shelf are an extension of surveys carried out in 1970 by the Earth Physics Branch of the Department of Energy, Mines and Resources.

The major gravity anomalies trend more or less parallel to the strike of the southern Nova Scotian shelf. A series of gravity highs on the southern Scotian shelf may be related to ridges developed within the basement during an early Mesozoic continental rupture. A steep gravity gradient associated with the continental margin delineates the transition from continental to oceanic crust, in common with other continental margins throughout the world. A broad gravity low northwest of Sable Island, suggests the presence of an extensive Devonian granite batholith while other weaker negative gravity anomalies on the shelf are probably related to Mesozoic and Tertiary sedimentary basins some of which contain Jurassic salt.

RÉSUMÉ - Les levés gravimétriques sous-marins achevés en 1971 sur le plateau continental du sud de la Nouvelle-Écosse constituent une prolongation des levés effectués en 1970 par la Direction de la physique du Globe du ministère de l'Énergie, des Mines et des Ressources.

Les anomalies gravimétriques majeures ont une direction plus ou moins parallèle à celle du plateau. Une succession d'anomalies positives peut être reliée aux dorsales intérieures du socle formées lors d'une rupture continentale au début du Mésozoïque. Un brusque gradient gravimétrique associé à la marge continentale délimite la transition de la croûte continentale à la croûte océanique, comme en d'autres marges continentales. Une vaste anomalie gravimétrique de faible intensité au nord-ouest de l'île de Sable amène à supposer la présence d'un immense batholite de granite du Dévonien tandis que de faibles anomalies négatives sur le plateau sont probablement reliées à des bassins sédimentaires du Mésozoïque et du Tertiaire dont certains à potentiel salin du Jurassique.

INTRODUCTION

In recent years, Canada's eastern continental shelf has become an important focus for petroleum exploration. A wealth of geophysical and well data has been generated by oil companies presently active in the area. Most of these data have been collected over local structures to provide detailed information and must remain confidential for stated periods of time. In a dual attempt to describe the regional geology and deep structure of the shelf and to make an overall assessment of the potential oil resources of the offshore area, government agencies are presently engaged in programs to map the region both on the sea floor and at depth using geophysical and geological methods and to merge both regional and detailed information into comprehensive analyses of offshore sedimentary basins.

In eastern Canada most government-sponsored activities in gravity surveying have been concentrated on the Nova Scotian shelf and adjacent land areas but the Atlantic Geoscience Centre of the Bedford Institute has completed reconnaissance surveys as far north as Baffin Bay and Davis Strait. Within the Earth Physics Branch, Stephens, *et al.* (1971) have described the gravity field north of Sable Island and over the Laurentian Channel while the Bouguer anomalies in Nova Scotia, Newfoundland, and the Gulf of St. Lawrence have been described by Garland (1964), Weaver (1967), and Goodacre, *et al.* (1969), respectively. The Bedford Institute has also made extensive surveys of portions of the Scotian shelf. (Keen and Loncarevic, 1965; Loncarevic and Ewing, 1967; Grant and Manchester, 1970; King and MacLean, 1970; Watts, 1972.)

SURVEY LOGISTICS

Underwater gravity surveys of the Nova Scotian shelf completed in May and September, 1971 are a continuation of the regional gravity mapping program of the Gravity Division of the Earth Physics Branch. The survey area includes Banquereau Bank and an area southwest of Sable Island extending to Browns Bank (Figure 1). Included in this area are about 200 observations

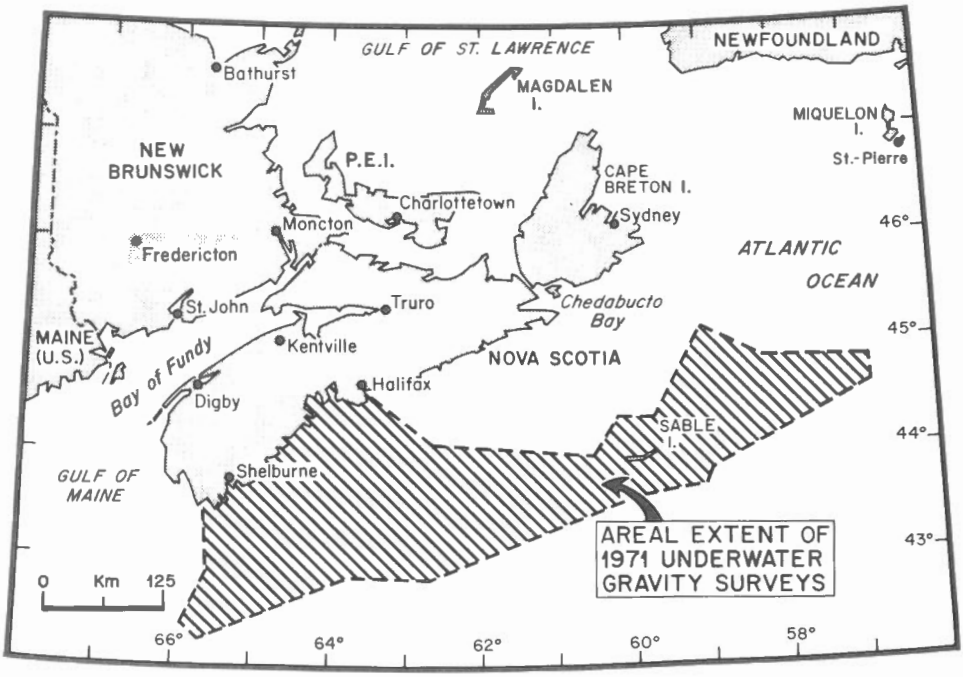

Figure 1. Location map showing area covered by underwater gravity surveys in 1971.

which constitute the Halifax Gravity Test Range established in 1963 (Goodacre, 1964). The 1971 survey stations were planned on a 15-km grid and 449 gravity observations were made during two cruises aboard the CNAV *Sackville*. A total of 26 days was spent at sea yielding an average of 17 gravity observations per day; summaries of both cruises are given in Table I.

TABLE I

Summary of 1971 Underwater Gravity Surveys on the CNAV *Sackville*

	Cruise 1	Cruise 2
Cruise dates	May 3 to May 28	September 8 to September 28
Number of days at sea	21½	5
Party Chief	R.V. Cooper	L.E. Stephens
Observers	J. Over J. McCance J. Powell	J. Over J. McCance B. Hearty
Number of observations	339	110
Number of stations per day	16	22
Decca chains used	6 and 7	2, 6 and 7

At present, underwater gravity surveying is the most precise means of determining gravity values at sea. The equipment, although basically the same as those in 1962, have been slightly modified in that more reliable solid-state components and micro-components have replaced older designs and a safer A-frame for holding the cable block has replaced the single boom which had been bent on previous occasions. The LaCoste-Romberg gravimeter is enclosed in an aluminum-alloy sphere which is connected to a 5/8-inch Vector armored cable containing 13 conductors (Figure 2). The cable is spooled on a Swan hydraulic winch which provides for the lowering and raising of the gravimeter and also contains slip rings for electrical continuity between the control box on board and the gravimeter. The winch is operated by a 110 V DC electric hydraulic pump. The gravimeter is operated remotely by the control box for determining the depth, the levelling of the gravimeter and the gravity reading.

Navigation was provided by Decca Mark 12 receivers over most of the continental shelf although radar was used to supplement Decca along the coast of Nova Scotia and around Sable Island. A Magnovox 702CA satellite navigation receiver was on board the first cruise for evaluation purposes only. Since satellite navigation data require velocity corrections for the received Doppler frequencies, the intention was to integrate it with the Decca by digitally recording the Decca at discrete intervals to compute the ship's course and speed. The digitizing unit, which was used on the first cruise, failed to operate correctly as it was affected by spurious electrical interference from the ship's power supply.

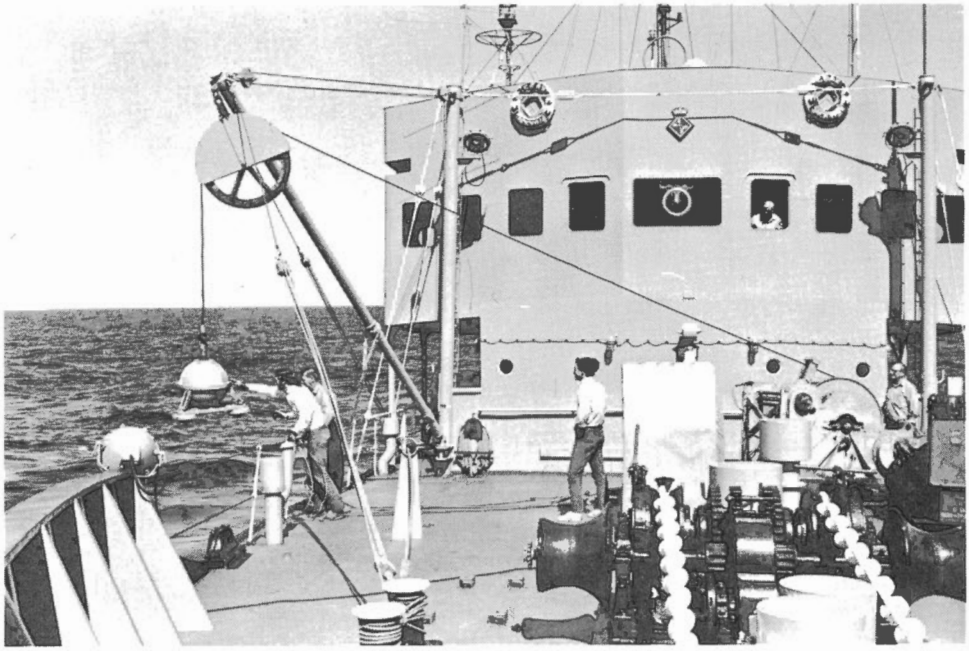

Figure 2. LaCoste and Romberg underwater gravity meter being hoisted aboard after a sea-floor gravity observation.

The bathymetric data were measured by a Westrex Precision Depth Recorder, and a Kelvin-Hughes depth sounder on board and a Bourns pressure transducer within the gravimeter. Good comparisons between the nautical chart and sounder depths were reassurances that the navigation fixes were within acceptable limits of accuracy. In addition, the gravimeter pressure gauge indicated when the gravimeter had reached the bottom and also provided an alternate means of determining the depth other than by sound waves. Comparisons between all three sets of bathymetric data provided a check for errors.

REDUCTION AND ACCURACY OF THE GRAVITY DATA

A compilation of the gravity data is presented in the form of a Bouguer anomaly map (Figure 3 and GMS 149 enclosed). The 1:1,000,000 scale Bouguer anomaly map incorporates gravity data from previous underwater gravity surveys and from gravity surveys of the Maritime Provinces.* The University of New Brunswick has observed more than 4,500 gravity stations within New Brunswick. Since there is a high density of these stations, only about half of them are shown on GMS 149 but all the data were used to locate the gravity contours. Detailed 1:250,000 gravity maps of the New Brunswick data can be obtained from the Department of Surveying and Engineering, University of New Brunswick, Fredericton, N.B.

The underwater gravity data were reduced to Bouguer anomalies using computer-oriented method described by Tanner and Buck (1964) and Buck and Tanner (1972). The observed underwater gravity readings were extrapolated to a sea level equivalent by using the normal free air gradient and the effect of the

---

* The principal facts for all gravity stations and descriptions of control station locations are available at cost from the Gravity Division, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Canada, K1A 0E4.

water above the gravimeter as in the following equation:

$$g_s = g_o(1-2d/R) + 4\pi\gamma\rho d$$
$$= (g_o - 0.2223\ d)\ \text{mgal} \qquad \ldots\ldots 1$$

where g_s is the gravity at sea level, g_o is the observed gravity on the bottom, R is the radius of the earth, γ is the gravitational constant, ρ is the density of sea water (1.03 g/cm^3) and d is the depth of water in metres.

The Bouguer anomalies were calculated by adding to the surface gravity value (g_s), a correction of 0.0688 d mgal for the mass deficiency of water with respect to rock of standard density 2.67 g/cm^3 and subtracting a theoretical gravity value (g_t) at the latitude of the station computed from the International Gravity Formula of 1930. The equation for computing the Bouguer anomaly is:

$$\Delta g_B = (g_o - 0.1535\ d - g_t)\ \text{mgal} \qquad \ldots\ldots 2$$

The reduction of gravity data to this point gives the "simple Bouguer anomaly" which assumes a flat, horizontal sea bottom. A further reduction procedure is the terrain correction which compensates for the gravity effect of deviations in the bathymetry from a plane surface. The addition of the terrain correction to the simple Bouguer anomaly produces the "complete Bouguer anomaly". Estimates for terrain corrections along the continental margin south of Sable Island yield values as high as 0.77 mgal and since the bathymetry anywhere else on the Nova Scotian shelf is less severe than on the margin, the terrain corrections for all of the stations on the Nova Scotian continental shelf are less than one mgal.

The simple Bouguer anomalies are subject to errors in the observed gravity, observed depth and navigation. Generally, the repeatability of the observed gravity measurements are an indication of these accuracies. In the Gulf of St. Lawrence, the majority of reduced gravity observations at reoccupied stations varied by less than 1.5 mgal (Goodacre, *et al.*, 1969). An error in

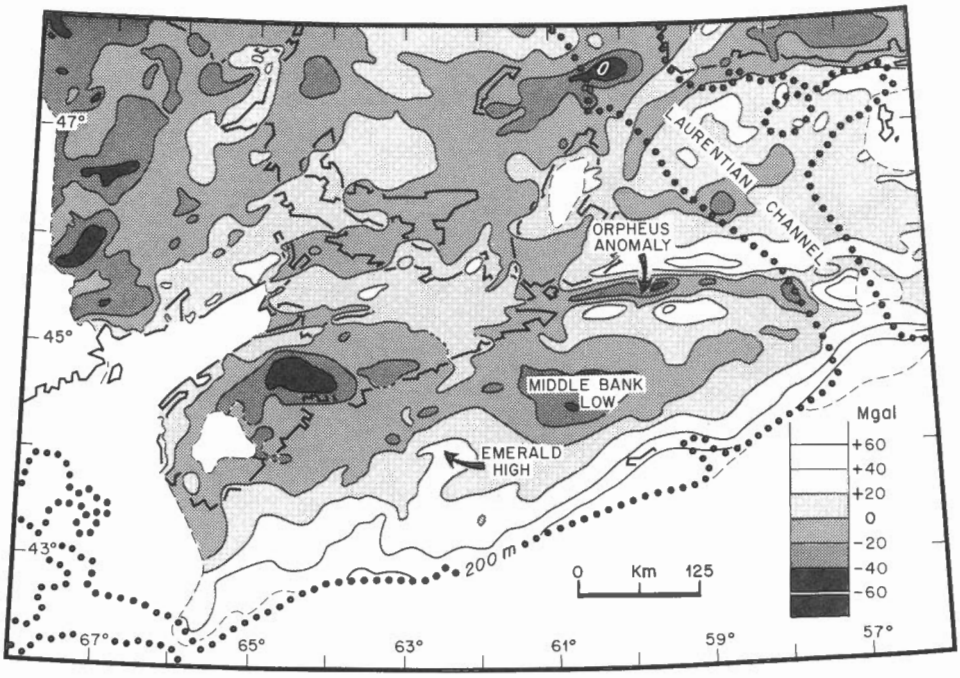

Figure 3. Simplified Bouguer anomaly map showing major features of the gravity field and 200-metre bathymetric contour line.

the adopted free air gradient (-0.3086 mgal/m) of less than one per cent may be caused by anomalous mass distributions which in 305 m of water is less than one mgal. A random error of ±0.3 mgal may result in the reading from an underwater gravimeter and a systematic error of 0.5 mgal or less may be caused by miscalibration of the gravimeter and large offsets in navigation.

Station depths were measured using a Bourns pressure transducer within the gravimeter, and a Kelvin-Hughes echo sounder and a Westrex precision depth recorder (PDR) on board ship. Accurate water depths are difficult to obtain using acoustic methods because the velocity for which the sounder is calibrated may not coincide with the actual velocity of sound in water and the large cone of radiation for the sounder transducer eliminates any detail in the bathymetry. The velocity of sound in water depends on salinity and temperature and can vary with depth, location and time. A mean value for the vertical velocity of sound was computed for the survey area and the depths obtained from the Kelvin-Hughes and PDR were adjusted accordingly. In order to reduce large instrumental errors, a cross-correlation analysis of depths derived from the pressure gauge and the acoustic sounders were made; this process was also used to confirm the calibration of the acoustic sounders and to determine if there were individual discrepancies between the sets of data. This analysis indicated an overall discrepancy of less than one per cent between the three sets of data which had a standard deviation of about ±3.7m. The gravity equivalent is ±1.1 mgal.

Navigation was mainly provided by the Nova Scotia Decca chains 6 and 7, but radar was used along the coast of Nova Scotia and around Sable Island. Discrepancies in Decca navigation affect the gravity data to a greater extent than any other factor. Radio Aids to Marine Navigation, a quarterly publication of the Canadian Ministry of Transport, indicate that along the east coast of Nova Scotia, positions within 150 km of the Decca baseline have errors of less than 1 km. Beyond 150 km from the baseline, the Decca lanes become more oblique to each other, the signal becomes weaker, and at night, sky wave interference occurs; all of these factors contribute to position errors of almost 5 km around Sable Island and along the continental margin. A north-south displacement of 5 km would contribute a 4 mgal error to the latitude correction for the Bouguer anomaly. If horizontal gravity gradients are large, an error in positioning produces a significant error in the observed gravity. For example, along the continental margin where gravity gradients are as high as 1.5 mgal/km, a 5-km error in position would produce an error of 7 mgal in the observed gravity. Although local gradients may be 5 or more mgal/km, regional gradients over 10 to 20 km tend to be 1 mgal/km or less. Thus in the centre of the continental shelf where horizontal gravity gradients are 1 mgal/km, an error of 1 km in the Decca navigation would be equivalent to a 1 mgal error.

DESCRIPTION OF THE BOUGUER ANOMALY FIELD

Gravity surveys provide useful information in the analysis of sedimentary basins, in determining structural trends and by allowing some insight into the deeper structure of the earth's crust. The degree of refinement possible in the analysis of the gravity data is limited only by the availability of other geophysical and geological parameters which provide control for the interpretation and reduce the level of ambiguity possible in structural models derived from gravity data alone.

The geological structure of the Nova Scotia continental shelf consists essentially of a Paleozoic basement complex overlain by a sequence of Mesozoic and Cenozoic sediments which thickens southeastwards. The geology of the Scotian shelf has been outlined by Hood (1967) and King (1969) using magnetic and seismic methods while the overall thickness and preliminary stratigraphy of the sedimentary rocks has been determined from well data retrieved by petroleum companies (McIver, 1972, Sherwin, 1971). The Paleozoic basement rocks are similar to those on the mainland and consist mainly of Devonian or Carboniferous acidic intrusions and Cambro-Ordovician slates and quartzites of the Meguma Series. This basement extends 75 km offshore and then dips beneath Mesozoic and Tertiary limestone, shale and sandstone. The oldest Mesozoic sediments are

probably Jurassic evaporites, shale and sandstone (McIver, 1972), but the presence of Triassic redbeds remains a possibility because normal faulting of Triassic age on the mainland and on the shelf may have been related to contemporaneous non-marine sedimentation.

In this report, only the major features of the gravity field are described; no quantitative analysis is included at this time. Preliminary examination of the gravity field on the southern Scotian shelf indicates that gravity anomalies trend more or less along the continental shelf. Important gravity anomalies in the survey area are the Middle Bank Low and several gravity lows which occur as lobes in the strong positive gradient along the continental margin (Figure 3) and the Emerald High which lies 100 km southeast of Halifax.

The southern Nova Scotian continental shelf can be divided into three zones on the basis of the gravity anomaly pattern. In the nearshore zone, the gravity anomalies can be directly related to extensions of geological structures known on the mainland. The central zone comprises distinct closed anomalies which are uniquely related to shelf structures. The outer zone contains gravity anomalies caused by structures at the continental margin; these anomalies are partially masked by the intense positive gravity gradient which is characteristic of many other continental margins.

Along the northern boundary of the 1971 survey area, the gravity data indicate that the Middle Bank Low (Figure 3) is a closed elliptical anomaly. It appears that the Middle Bank Low is an easterly extension of a prominent gravity low located in central Nova Scotia which has been correlated with an exposed Devonian granitic batholith (Garland, 1964) (Figure 4). To the east of the Middle Low, Cretaceous and Tertiary sediments cover the Paleozoic basement to a depth of more than 5 km at the continental margin (Austin and Howie, 1971).

A northeasterly trending gravity low east of the Middle Bank Low may be related to a sedimentary basin containing Mesozoic and Tertiary sediments and salt. At the southern end of this linear feature where the anomaly is most intense, King and MacLean (1970) have detected a diapiric structure by reflection seismic profiling. Similar diapiric structures, which are related to sedimentary basins, are known in many parts of the continental shelf (Webb, 1971). The

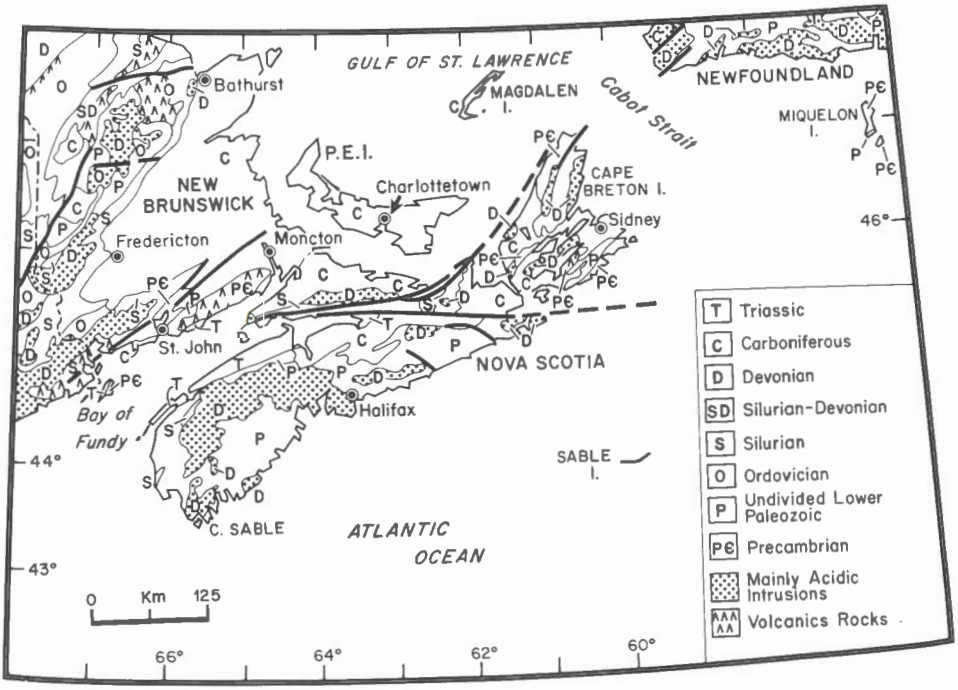

Figure 4. Simplified geology map of Maritimes.

salt diapirism probably extends northeast along the gravity low. The negative gravity embayments in the steep positive gradient along the continental margin may indicate extensions of similar basins towards the continental margin.

The Emerald High (Figure 3) is the most northerly and conspicuous of three gravity highs aligned along a northeasterly trend. The two southerly highs are masked by a steep regional gravity gradient. Seismic data collected by Keen and Loncarevic (1965), suggest the presence of a basement ridge of Paleozoic rocks which coincides with the Emerald High. If the three gravity highs along the centre of the southern continental shelf are attributed to basement ridges or horsts, the intervening gravity lows indicate possible erosional breaks along the ridge with subsequent sedimentation. On either side of the Emerald High there are gravity lows which may correspond to Mesozoic or Tertiary sedimentary basins.

McIver (1972), has suggested that the Paleozoic basement is "locally disrupted to form grabens and half-grabens". The ridges developed parallel to the length of the continental shelf and could have been formed by tensile stresses during the rifting apart of the African and North American continents in early Mesozoic time (Schenk, 1971). Tensile stresses during continental breakup are also indicated by Triassic basalts along the Annapolis Valley which coincide with a series of gravity highs. Graben structures and normal faulting are prevalent along the Red Sea where rifting is presently active (Lowell and Genik, 1972) and can be compared with the Nova Scotian continental shelf (Dewey and Bird, 1970). The relationship of these structures to continental shelf areas where continental slabs have rifted apart plays an important role in the formation of sedimentary basins and in the synthesis and accumulation of oil and gas. The gravity and seismic results have outlined structures such as that of the Emerald High and more detailed surveys will provide more data on these structures. Additional well data, which is presently being released at an accelerated rate, will greatly improve geophysical interpretations of geological structures on the continental shelf.

ACKNOWLEDGMENTS

We acknowledge the invaluable assistance of Captain Lillington and crew of the CNAV *Sackville* during the surveys. The authors also thank personnel of the Bedford Institute for the use of facilities and for cruise planning assistance. Instructive discussions with Lew King and Richard Haworth of the Marine Geophysics Section of the Atlantic Geoscience Centre have clarified many problems in the interpretation of the gravity data. Thanks are also due to student assistants J. Over, J. McCance, B. Hearty and J. Powell who contributed to both phases of the survey on the CNAV *Sackville*. The contribution of nearly 5,000 gravity stations in New Brunswick by the University of New Brunswick is gratefully acknowledged.

REFERENCES

Austin, G.H. and R.D. Howie, 1971. Regional geology of offshore eastern Canada. *In* Proceedings of Earth Science Symposium on Offshore Eastern Canada, ed. P.J. Hood, *Geol. Surv. Can.*, Paper 71-23 (in press).

Buck, R.J. and J.G. Tanner, 1972. Storage and retrieval of gravity data. *Bull. Géodésique*, No. 103, pp. 63-84.

Dewey, J.F. and J.M. Bird, 1970. Mountain belts and the new global tectonics. *J. Geophys. Res.*, 75 (14), pp. 2625-2647.

Garland, G.D., 1964. Gravity measurements in the Maritime Provinces. *Publ. Dom. Obs.*, 16.

Goodacre, A.K., 1964. A shipborne gravimeter testing range near Halifax, Nova Scotia. *J. Geophys. Rds.*, 69, pp. 5373-5381.

Goodacre, A.K., B.G. Brule and R.V. Cooper, 1969. Results of regional underwater gravity surveys in the Gulf of St. Lawrence. *Gravity Map Series, Dom. Obs.*, No. 86.

Grant, A.C. and K.S. Manchester, 1970. Seismic reflection profile from the continental margin of Nova Scotia, Canada. *Atlantic Oceanogr. Inst.*, Data Series 1970-6-D.

Hood, P.J., 1967. Geophysical surveys of the continental shelf south of Nova Scotia. *Maritime Sediments*, 3 (1), pp. 6-11.

Keen, Charlotte and B.D. Loncarevic, 1965. Crustal structure on the eastern seaboard of Canada: studies on the continental margin. *Can. J. Earth Sci.*, 3, pp. 65-76.

King, L.H., 1969. Submarine end moraines and associated deposits on the Scotian shelf. *Bull. Geol. Soc. Amer.*, 80, pp. 83-96.

King, L.H. and B. MacLean, 1970. A diapiric structure near Sable Island. *Maritime Sediments*, Vol. 6.

Loncarevic, B.D. and G.N. Ewing, 1967. Geophysical study of the Orpheus gravity anomaly. *Proc. 7th World Petr. Cong.*, pp. 827-835.

Lowell, J.D. and G.J. Genik, 1972. Sea-floor spreading and structural evolution of southern Red Sea. *Bull. Amer. Assoc. Petrol. Geol.*, 56 (2), pp. 247-259.

McIver, N.L., 1972. Cenozoic and Mesozoic stratigraphy of the Nova Scotia shelf. *Can. J. Earth Sci.*, 9, pp. 54-70.

Schenk, P.E., 1971. Southeastern Atlantic Canada, northwestern Africa and continental drift. *Can. J. Earth Sci.*, Vol. 8, No. 10, pp. 1218-1251.

Sherwin, D.F., 1971. Geology an hydrocarbon potential of the Scotian shelf and Grand Banks. *Can. Expl., Frontiers Symposium*, Banff, Alberta (Abstracts).

Stephens, L.E., A.K. Goodacre and R.V. Cooper, 1971. Results of underwater gravity surveys over the Nova Scotia continental shelf. *Gravity Map Series Earth Phys. Br.*, No. 123.

Tanner, J.G. and R.J. Buck, 1964. A computer-oriented system for the reduction of gravity data. *Publ. Dom. Obs.*, 31.

Watts, A.B., 1972. Geophysical investigations east of the Magdalen Islands, southern Gulf of St. Lawrence. *Can. J. Earth Sci.*, Vol. 9, No. 11, pp. 1504-1528.

Weaver, D.F., 1967. A geological interpretation of the Bouguer anomaly field of Newfoundland. *Publ. Dom. Obs.*, 35.

Webb, G.W., 1971. Salt structures east of Nova Scotia. *In* Proceedings of Earth Science Symposium on Offshore Eastern Canada, ed. P.J. Hood, *Geol. Surv. Can.*, Paper 71-23 (in press).