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GEOLOGICAL AND TECTONIC FRAMEWORK OF EASTERN CANADA AS INTERPRETED FROM POTENTIAL FIELD IMAGERY

J.M. Woodside
J.Verhoef

1989

Energy, Mines and Resources Canada
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GEOLOGICAL AND TECTONIC FRAMEWORK OF EASTERN CANADA AS INTERPRETED FROM POTENTIAL FIELD IMAGERY

Abstract

Recent compilation of all gravity and magnetic data for the eastern Canadian region, onshore and offshore, provides an unprecedented perspective on its geological framework. Classification of the region into domains, based on similarities in pattern and trends of gravity and magnetic data, indicates geological affinities within structural provinces and tectonic relationships between geological domains. There is a commonality of characteristics among boundaries between provinces of different ages. Selected transects across the region, using published or recent multichannel seismic reflection and seismic refraction data, and gravity models for subsurface information elsewhere, illustrate these distinguishing characteristics and the crustal structure in the different provinces. The structural characteristics of the continental margin and ocean-continent boundary, which are of specific interest from a scientific and economic point of view, depend on the various modes of formation. Thus characteristics change with the amount of continental stretching and according to whether the initial break, leading to formation of an ocean, is a rift or a shear zone.

Resumé

La récente compilation de toutes les données gravimétriques et magnétiques recueillies dans la région de l'Est du Canada, sur le continent et en mer, donne une perspective sans précédent de la structure géologique de cette région. La répartition de cette région en domaines, fondée sur des similarités de configuration et de direction des données gravimétriques et magnétiques, révèle des affinités géologiques au sein de provinces structurales et des liens tectoniques entre certains domaines géologiques. Les zones frontières de provinces d'âge différent possèdent des caractéristiques communes. Divers transects ont été établis sur toute la région, en se basant sur des données multibandes de sismique réflexion et de sismique réfraction obtenues récemment ou publiées depuis peu, ainsi que des modèles gravimétriques ailleurs. Ces transects mettent en évidence ces caractéristiques particulières ainsi que la structure de la croûte dans les différentes provinces. Les caractéristiques structurales de la marge continentale et de la limite océan-continent qui suscitent un intérêt particulier du point de vue scientifique et économique, varient en fonction du mode de formation. Par conséquent, les caractéristiques diffèrent selon le degré de l'extension continentale et selon que la rupture initiale, aboutissant à la formation d'un océan, ait pris la forme d'un fossé d'effondrement ou d'une zone de cisaillement.

SUMMARY

Recent compilation of all gravity and magnetic anomaly data for offshore and eastern Canada provides an unprecedented perspective on the geological framework of the region. Geological Survey of Canada Maps 1708A and 1709A, presenting gravity and magnetic data, respectively, are now published in colour at a scale of 1:5 000 000 in Lambert conic conformal projection with standard parallels at 49° N and 77° N. Classification of the region by similarities in the patterns and trends of gravity and magnetic data observed at this scale indicates geological affinities within structural provinces and tectonic relationships between geological domains. This report examines the correlation between the potential field data and regional geology, and provides a key to the published results and current research on regional structure as interpreted using the available geophysical and geological information.

SOMMAIRE

La récente compilation de toutes les données gravimétriques et magnétiques recueillies dans la région de l'Est du Canada, sur le continent et en mer, donne une perspective sans précédent de la structure géologique de cette région. Les cartes 1708A et 1709A de la Commission géologique du Canada représentant les données gravimétriques et magnétiques respectivement, sont maintenant publiées en couleurs à l'échelle de 1/5 000 000 selon la projection conique de Lambert utilisant les parallèles de latitude 49° N et 77° N. La classification de cette région, fondée sur des similarités de configuration et de direction des données gravimétriques et magnétiques observées à cette échelle, révèle des affinités géologiques au sein des provinces structurales et des liens tectoniques entre certains domaines géologiques. Le présent rapport est une analyse de la corrélation entre les données des champs de potentiel et la géologie régionale et facilite l'interprétation des résultats publiés et la recherche actuelle sur la structure telle qu'établie en fonction des données géophysiques et géologiques disponibles.

Different structural provinces within the region have distinctive magnetic signatures, reflecting their age through the degree of reworking, deformation, variations in metamorphic grade, and crustal stripping which has occurred. Thus the Appalachian Orogen displays sinuous northeast-trends following fairly well-defined zones relating to component parts of the convergent continents and intervening ocean which form the orogen. East-northeasterly magnetic trends in the Grenville Province reflect the variation in metamorphic grade and composition of exposed rock as a function of distance from the Grenville Front. Within the Grenville Front Tectonic Zone the magnetic field is relatively subdued. To the north, the most distinctive magnetic anomalies are correlated with the north-trending boundary zones between the Churchill Structural Province and its neighbours to the east (Nain Province) and the west (Superior Province), as well as within the Churchill Province along the Komaktorvik and Abloviak zones (distinctive negative magnetic anomalies immediately to the west of the Nain Province), the De Pas Batholith, and the gneiss belts.

Gravity and magnetic highs in the Grenville Province are often correlated both with gabbroic bodies (such as the gabbronorite rocks of the White Bear Arm plutonic complex near the coast of southernmost Labrador) and high grade metamorphic rocks thrust up from lower crustal depths (like the metagabbroic rocks and high pressure granulites of the Lac Joseph and Red Wine regions in south central Labrador). In Superior Province the gravity highs generally follow supracrustal belts, granulites, and mafic and ultramafic intrusions where high intensity magnetic anomalies are present; whereas the gravity lows over granitic bodies coincide with low intensity magnetic variations.

Boundaries between structural provinces have many similarities regardless of the ages of the provinces or the suture. The junction of the Paleozoic Appalachian Orogen with the Late Precambrian Grenville Province (Ordovician), of the Grenville with the Archean Nain, Early Proterozoic Churchill, and Archean Superior provinces (Proterozoic), of the Superior with the Churchill (Early Proterozoic), and of the Nain with the Churchill (Early Proterozoic) all have similar gravity signatures with low values over the older province and high values over the younger. Implied crustal structural similarities may be thicker denser crust in the younger province where the two join or the presence near surface of high grade metamorphic rocks brought up from depth along thrusts in the younger province towards the older where they abut.

Offshore, the magnetic and gravity anomalies tend to be more subdued than on land except for the continental shelf and slope where large positive anomalies are found. Depth to sources of the anomalies is greater in the oceanic domain. Weak seafloor spreading magnetic anomalies are not well displayed

Différentes provinces structurales au sein de cette région présentent des signatures magnétiques particulières, leur âge se trouvant revelé par l'intermédiaire du degré de leur remaniement, leur déformation, les variations du degré de métamorphisme et le décapage crustal. Ainsi l'orogène appalachien affiche des directions nord-est sinueuses suivant des zones relativement bien définies associées à des parties composantes des continents convergents et à l'océan intermédiaire dont est constitué l'orogène. Les directions magnétiques est-nord-est observées dans la province de Grenville reflètent la variation du degré de métamorphisme et de composition de la roche affleurante en fonction de sa distance du front de Grenville. Au sein de la zone tectonique du front de Grenville, le champ magnétique est relativement atténué. Vers le nord, les anomalies magnétiques les plus caractéristiques sont correlées avec les zones frontières d'orientation nord situées entre la province structurale de Churchill, et les provinces voisines à l'est (province de Nain) et à l'ouest (province du lac Supérieur), ainsi qu'au sein de la province de Churchill, le long des zones de Komktorvik et d'Abloviak (anomalies magnétiques négatives caractéristiques immédiatement à l'ouest de la province de Nain), du batholithe de De Pas et des zones de gneiss.

Les anomalies gravimétriques et magnétiques positives dans la province de Grenville sont souvent correlées aux massifs gabbroïques (notamment les roches gabbronoritiques du complexe plutonique de White Bear Arm près du littoral de l'extrême sud du Labrador) et aux roches à degré de métamorphisme élevé provenant de la croûte profonde (comme les roches métagabbroïques et les granulites formés sous forte pression des région du lac Joseph et de Red Wine dans le sud du centre du Labrador). Dans la province du lac Supérieur, les valeurs gravimétriques élevées suivent en général les zones supracrustales, les granulites et les intrusions mafiques et ultramafiques au sein desquelles l'on observe de fortes anomalies magnétiques; par ailleurs, les creux gravimétriques au-dessus des massifs granitiques coïncident avec des variations magnétiques de faible intensité.

Les zones frontières entre les provinces structurales présentent de nombreuses similaritées quel que soit l'âge des provinces ou de la suture. Le raccord de l'orogène appalachien d'âge paléozoïque avec la province de Grenville du Précambrien supérieur (Ordovicien), celui de la province de Grenville avec les provinces de Nain de l'Archéen, de Churchill du Protérozoïque inférieur et du lac Supérieur de l'Archéen (Protérozoïque), celui de la province du lac Supérieur avec celle de Churchill (Protérozoïque inférieur), et celui de la province de Nain avec celle de Churchill (Protérozoïque inférieur) présentent tous les mêmes signatures gravimétriques caractérisées par des valeurs faibles pour la province la plus ancienne et par des valeurs élevées pour la plus récente. On peut déduire des similarités structurales de la croûte, soit une croûte plus dense et plus épaisse dans la province plus récente oû les deux se rejoignent, soit la présence près de la surface de roches à degré de métamorphisme élevé qui se seraient déplacées vers le haut le long de failles chevauchantes dans la province la plus récente en direction de la province plus ancienne contre laquelle elles viennent s'appuyer.

Les anomalies magnétiques et gravimétriques recueillies en mer ont tendance à être moins marquées qu'au-dessus du continent, sauf en ce qui concerne la plate-forme et le talus continentaux où d'importantes anomalies positives se font remarquer. Les sources des anomalies sont plus profondes dans le domaine océanique. Les faibles anomalies magnétiques associées à l'expansion

at the 1:5 000 000 scale of Maps 1708A and 1709A. Northwest-trending magnetic lineations in the Labrador Sea were generated during the Late Cretaceous to Early Oligocene period of sea-floor spreading. The extinct spreading centre may be followed more easily on the gravity map where it appears as a linear low over the buried median valley. South of Nova Scotia, rifting with northwest Africa began earlier (Late Triassic to Early Jurassic), but the earliest identifiable seafloor spreading magnetic anomaly is Late Cretaceous. The East Coast Magnetic Anomaly is a major sinuous positive anomaly south of Nova Scotia which is thought to represent the roughly 175 Ma old ocean-continent boundary there.

A distinctive feature of the continental margin is the string of positive gravity anomalies along the outer shelf. Where rift basins filled with sedimentary rocks are present, the gravity high follows the main depocentre. South of Nova Scotia the associated gravity lows to either side of the high suggest a flexural response to a sedimentary load under the high. The causes of the gravity highs east and southeast of Newfoundland (over the Tail of the Banks, Flemish Cap, and western Orphan Basin) are more difficult to explain.

Some continuation of land geological features is implied by the extension of the gravity and magnetic anomalies into the offshore. This is clearest in the extensive shelf areas around Newfoundland and Nova Scotia. Across the Labrador Sea and Baffin Bay are continuations of structural provinces separated during seafloor spreading, for example: Makkovik Province (Labrador) and the Ketilidian (Greenland), Nain Province (Labrador) and the Archean Block (Greenland), the Foxe Fold Belt (Baffin Island) and the Rinkian Fold Belt (Greenland).

Differences in gravity and magnetic signatures along different segments of the modern Canadian margin are related to differences in the geological structure and evolution of the different segments. Profiles of gravity and magnetic anomalies, bathymetry, and depth to basement were selected perpendicularly across eight margins (as well as the conjugate margins in the Labrador Sea and Baffin Bay), aligned, then stacked and averaged to produce representive profiles for intercomparison. The largest differences were between rifted and transform margins, although each margin segment had its own character. For example, the gravity anomaly across the southeast Newfoundland transform margin appears more like a step from high to low values going from continent to ocean compared with the gravity high common to the extensive sedimentary basins of rifted margins. Magnetic anomalies are not diagnostic of the different margins.

Transects cutting across the entire region are used to show how the different structural provinces fit together, as well as to present, as profiles to be viewed with the maps, a compilation of crustal structures

du fond océanique ne sont pas bien représentées à l'échelle de 1/5 000 000 (cartes 1708A et 1709A). Les linéations magnétiques dirigées vers le nord-ouest dans la mer du Labrador remontent à l'expansion du fond océanique survenue du Crétacé supérieur à l'Oligocène inférieur. L'ancien centre d'expansion peut être plus facilement repéré sur la carte gravimétrique où il apparaît sous forme d'un creux linéaire au-dessus de la vallée médiane enfouie. La formation d'un fossé d'effondrement (rift) entre le sud de la Nouvelle-Écosse et le nord-ouest de l'Afrique a commencé plus tôt (Trias supérieur à Jurassique inférieur), mais la plus ancienne anomalie magnétique identifiable associée à l'expansion du fond océanique date du Crétacé supérieur. L'anomalie magnétique de la côte Est est une importante anomalie positive sinueuse qui se produit au sud de la Nouvelle-Écosse et qui correspondrait à la limite océan-continent formée il y a environ 175 Ma.

La marge continentale se caractérise par une série d'anomalies gravimétriques positives le long de la bordure de la plate-forme. Là où il y a des bassins remplis de roches sédimentaires, l'anomalie gravimétrique positive suit le centre de sédimentation principal. Au sud de la Nouvelle-Écosse, les creux situés de part et d'autre de l'anomalie gravimétrique positive semblent indiquer qu'une flexure résultant d'une charge sédimentaire s'est produite sous l'anomalie. L'origine des anomalies gravimétriques positives observées à l'est et au sud-est de Terre-Neuve (au-dessus de l'extrémité des Bancs, du cap Flemish et de la partie ouest du bassin d'Orphan) sont plus difficiles à expliquer.

Le prolongement en mer des anomalies gravimétriques et magnétiques laisse supposer une certaine continuité des éléments géologiques observés sur terre. Ce fait ressort avec plus de clarté dans les grandes zones de plate-forme longeant le littoral de Terre-Neuve et de la Nouvelle-Écosse. À travers la mer du Labrador et la baie de Baffin se poursuivent certaines provinces structurales séparées pendant l'expansion du fond océanique, par exemple la province de Makkovik (Labrador) le Ketilidien (Groenland), la province de Nain (Labrador) et le Bloc Archéen (Groenland), la zone de plissements de Foxe (île de Baffin) et la zone de plissements de Rinkian (Groenland).

Les différences observées dans les signatures gravimétriques et magnétiques le long de différents segments de la marge actuelle du Canada sont attribuables à des différences observées au niveau de la structure et de l'évolution géologiques des différents segments. Des profils gravimétriques et magnétiques, de bathymétrie et de profondeur du socle ont été effectués perpendiculairement à la marge à huit endroits différents (ainsi qu'à travers les marges conjugées de la mer du Labrador et de la baie de Baffin), pour être alignés et additionnés. Leur valeur moyenne a ensuite été calculée pour produire des profils représentatifs à des fins de comparaison. Les plus grandes différences ont été observées entre les marges à rift et à faille transformante, bien que chaque segment de la marge possède ses propres caractéristiques. Ainsi, la marge à faille transformante du sud-est de Terre-Neuve est caractérisée par un saut de l'anomalie gravimétrique, avec des valeurs plus élevées du côté continental, plutôt que par une anomalie gravimétrique positive comme celle qui caractérise en général les grands bassins sédimentaires des marges à rift. Les anomalies magnétiques n'ont pas de caractéristiques représentatives d'une marge à l'autre.

Des transects traversant toute la région sont utilisés pour montrer comment les différentes provinces structurales s'emboî-

interpreted for the provinces. Changes in the regional level of gravity values can better be seen in profiles: thus the younger structural provinces on land are seen to have more positive gravity anomalies. Likewise, the transect profiles facilitate the observation of changes in frequency content of the magnetic and gravity values across different provinces, permit easy correlation of such changes with the geology, and provide a means of comparing gravity, magnetic, bathymetric, depth to basement, and depth to mantle values with each other for different regions.

Using both two- and three-dimensional depictions of the gravity and magnetic anomalies, the current understanding of the geological significance of the major anomalies is presented. This review is intended as a source document for use in future studies, as a bibliographic key to previous work, and as an overview to understanding the gravity and magnetic anomalies along eastern Canada.

tent et pour présenter, comme profils à consulter avec les cartes, une compilation des structures crustales des provinces. Les variations des valeurs gravimétriques à l'échelle régionale ressortent mieux sur les profils: c'est ainsi que les provinces structurales les plus récentes sur le continent présentent les anomalies gravimétriques les plus positives. De plus, les profils facilitent l'observation des variations au niveau de la fréquence des valeurs magnétiques et gravimétriques d'une province à l'autre, permettent la corrélation aisée de ces variations avec la géologie et fournissent un moyen de comparer les données gravimétriques, magnétiques et bathymétriques et les profondeurs du socle et du manteau des différentes régions.

Grâce à des représentations bidimensionnelles et tridimensionnelles des anomalies gravimétriques et magnétiques, les connaissances actuelles sur l'importance géologique des principales anomalies sont présentées. Sans être complet, le présent ouvrage a pour objectif de servir de référence aux études futures, et de source bibliographique, ainsi que de présenter un exposé général des anomalies gravimétriques et magnétiques.

INTRODUCTION

Marine gravity and magnetic data from Atlantic Geoscience Centre (AGC) of the Geological Survey of Canada (GSC) recently have been reprocessed, edited, and merged with other gravity and magnetic data from eastern Canada. This major task, incorporating over 1.5 million gravity observations and almost 3 million magnetic observations, has resulted in the most complete and comprehensive data base for this region.

This data base was used to compile two maps at a scale of 1:5 000 000 depicting gravity and magnetic anomalies of eastern Canaca (GSC Maps 1708A and 1709A, respectively). This report describes these maps, which are available separately. Reduced colour versions of these maps, however, have been included with this report as Figures 11 and 12. Major features observed on the maps are discussed in their geological context, and reference is made both to previous work in the interpretation of subsets of the data base and to ongoing investigations using these compilations and those of associated data such as seismically defined depth to basement and mantle, and bathymetry and topography.

Data Acquisition, Processing, and Compilation

Most of the data were collected by ship over more than two decades. Remaining data include land gravity data, data obtained by aeromagnetic surveys over land and selected marine areas (Orphan Basin, Grand Banks, Laurentian Channel and St. Pierre Bank, and Georges Bank), and satellite altimetry data which have been converted to gravity anomalies for the region east of 45° E and south of 42° N. Figures 1, 2, and 3 show data distribution and sources for the compiled gravity and magnetic anomaly maps.

The poorest coverage is in Baffin Bay where few systematic surveys have been carried out. This is principally because Loran C coverage does not extend this far north, and any other navigational aids providing regular and frequent fixes must be set up specifically for each survey at great expense. Unpredictable ice cover makes planning difficult as well. Magnetic surveys at these latitudes are prone to large errors arising from erratic fluctuations in the magnetic field in the auroral zone.

Within the regions of more systematic coverage, spacing of ships' tracks varies from about 40 km in the eastern Labrador Sea to about 2 km over the shallow regions (less than 200 m depth) of the Labrador Shelf and the Gulf of St. Lawrence. The aeromagnetic surveys over land were usually run with a flight spacing of about 800 m and a mean terrain clearance of about 300 m. Gravity observations on land are separated by 2 to 15 km generally, with most observations being 6 to 15 km apart. Along-track marine observations are generally closer than 2 km for gravity and 300 m for magnetics.

All the GSC data for the offshore regions of eastern Canada have been edited and rechecked prior to merging in the National Geophysical Data Base. The gravity data were subjected to a least squares adjustment which produced a homogeneous gravity data base with an overall accuracy of 2.5 mGal and internal consistency of from $\pm$ 1 to $\pm$ 5 mGal (Earth Physics Branch, 1986). Following final data editing, a cross-over analysis of the magnetic data indicated a mean discrepancy of -0.9 nT for 53 361 cross points, and a standard deviation of less than 70 nT (Verhoef and Macnab, 1988).

Additional data were merged carefully with the GSC data. For the gravity map, supplemental sea data from the United States Defense Mapping Agency Aerospace Center (DMA-AC) in Bay St. Louis, a 4 km grid of land values for the USA produced by the United States Geological Survey (USGS) (SEG, 1982; Godson, 1985), and a grid of free-air anomalies (16 km grid) derived from satellite altimetry data

Figure 1. Point locations along ships' tracks for all marine magnetic field data collected by the Atlantic Geoscience Centre between 1963 and 1984.

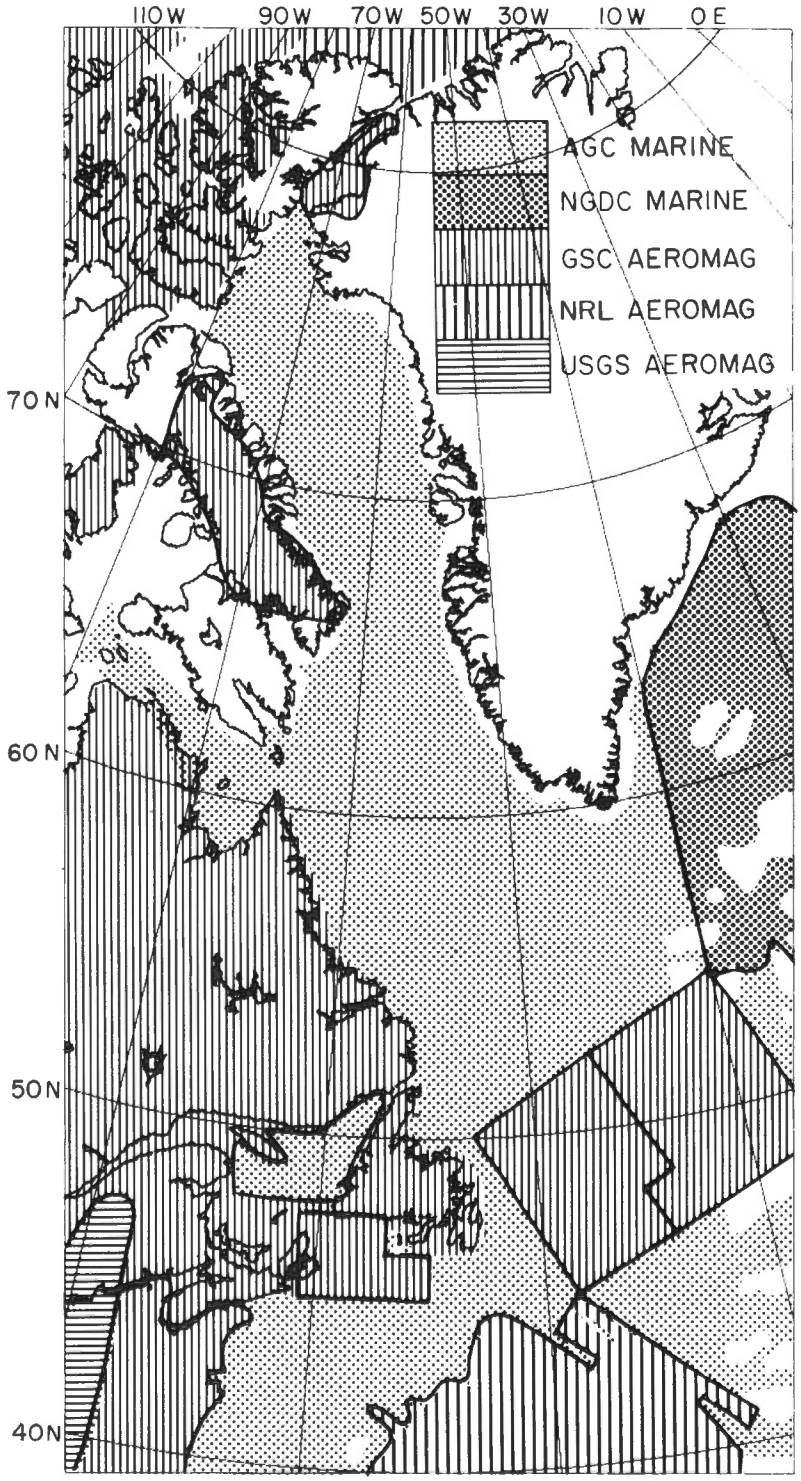


Figure 2. Coverage and distribution of the various data subsets comprising the AGC data base of magnetic anomalies. Abbreviations used are AGC (Atlantic Geoscience Centre of the Geological Survey of Canada), NGDC (United States National Geophysical Data Center in Boulder, Colorado), GSC (Geological Survey of Canada; operations undertaken by the Resource Geophysics and Geochemistry Division, now the Geophysics Division), NRL (United States Naval Research Laboratory), USGS (United States Geological Survey).

Figure 3. Locations of all gravity observations compiled for the gravity map. The grid of values in the Labrador Sea and the North Atlantic is derived from satellite altimetry. American data have been merged as a 4 km grid.

by the inverse Stokes operator method (Balmino et al., 1987) were added without difficulty. Some additional aeromagnetic data from external sources had to be adjusted by upward or downward continuation methods for consistency with the flight elevation of GSC surveys, and in some cases smoothing was required where the data sets abutted. Some of the aeromagnetic data sets had already been gridded at an interval of 812.8 m. All data were regridded: the gravity data were resampled to a 5 km spacing, and the magnetic data to 0.05° lat./long. (or about 5.5 km). In so doing, some filtering was used to interpolate through areas of sparse data coverage. A low-pass first order Butterworth filter with cut-off wavelength of about 37 km was used with the magnetic data; and the gravity grid values are weighted means of surrounding data out to 40 km. Because of the low-pass filtering, some detail is lost in the preparation of the maps: for example, application of the Butterworth filter means that the value at a grid point includes contributions from distant data points which are 6 db down in amplitude (or approximately 70 % of the full amplitude) at a distance of 37 km from the grid point, and decrease further and more rapidly with increasing distance.

The magnetic anomalies were computed by removing the appropriate theoretical reference values computed from the International Geomagnetic Reference Field (IGRF) (Barraclough, 1987). 'Reduction to the pole' for the magnetic anomalies should be carried out to compensate for the inclination and declination of the earth's magnetic field. This is done for analysis of local magnetic anomalies, and has been carried out for the entire marine data set using a new differential reduction technique (Arkani-Hamed and Verhoef, in press), however the magnetic data presented here have not been so-corrected. This means that there may be small mislocations of the sources of magnetic anomalies of up to 30 km in a northerly direction for some of the most southern anomalies in the data set, and some of the southern anomalies will not be as well resolved as they might otherwise be.

The gravity anomalies were computed by removing, from the observed gravity values, theoretical values computed from the International Gravity Formula 1967 (IAG, 1967), and correcting for the elevation of the gravimeter above sea level. Bouguer anomaly values are used for the land regions and free-air anomalies at sea. A mean crustal density of 2.67 g/cm^3 was assumed in the Bouguer correction, and topographic corrections were added only for regions of high topographic relief in northern Labrador.

Bathymetric data were collected simultaneously with all marine gravity and magnetic observations. On the majority of systematic surveys, the Canadian Hydrographic Service was responsible for bathymetric measurements. These data have also been edited with care, and most of them have been checked by the Canadian Hydrographic Service with whom many of the systematic geophysical surveys were made. Additional bathymetric and topographical information was obtained as a digital grid called ETOPO5 through the United States Naval Oceanographic Office.

Complementary compilations of depth to basement and depth to Moho were made from a combination of seismic reflection and refraction data, and gravity information (Keen et al., in press). Some of these data have been used in the profiles plotted across the continental margin (e.g. depth to basement in Fig. 7). The gravity data were used to determine mantle depth by assuming a simple three layer crust (water layer defined by bathymetry, sediments defined by depth to basement and bathymetry, and crust between mantle and sediments) in isostatic equilibrium. The mantle depths so calculated were constrained by depths determined from seismic refraction experiments in selected locations throughout the area. Depth to basement was obtained from compilations based on seismic reflection profiles (Srivastava, 1986; Hinz et al., 1979; Grant et al., 1986; Tucholke, 1986).

COMPONENTS OF GEOLOGY RECOGNIZED IN THE COMPILED MAPS

The gross regional geological framework of eastern Canada and the Canadian Arctic is clearly reflected in the potential field maps (see Fig. 11 and 12 and Maps 1708A and 1709A). Indeed the gravity and magnetic anomaly data have been used extensively in this region for the interpretation of geology at depth and where rocks are otherwise concealed by water or overburden. This overview is a bibliographic key to many of these earlier works and a guide to the general features recognized in the region.

This review first examines the patterns and trends in the subregions of the maps, then looks at the boundaries between them, and finally binds the different parts together by constructing structural transects across the region. Geological and geographical names referred to in the text can be found in Figure 4b (in pocket).

Structural provinces and tectonic boundaries are more easily distinguished in the magnetic anomaly map (Map 1709A and Figure 12) than in the gravity map (Map 1708A and Figure 11). The differences between the oceanic and continental areas are clearly seen on both maps however. In the case of the gravity map, this is partly because the Bouguer anomaly is shown on land and free-air anomaly at sea; and for the magnetic anomaly map there is a greater depth to sources of anomalies at sea than over land. Nevertheless the character of both gravity and magnetic anomaly maps, as determined not only from observations of amplitude and wavelength of local variations but also from anomaly patterns, varies from ocean to continent.

The magnetic anomaly shows greater amplitude variations and a wider range of wavelengths on land (Fig. 12), primarily as a result of closer proximity to magnetic sources than at sea. There is, however, a certain uniformity of character to the anomalies in different tectonic and structural provinces, with distinct changes principally across the boundaries between the provinces. This is true at sea also, where the linear sea floor spreading anomalies provide an orderly pattern which disappears only over the continental margins and in regions of volcanic rocks such as Davis Strait.

The generally negative gravity over land (Fig. 11) is an effect of the Bouguer correction. This correction tends to produce relatively longer wavelengths in the resultant Bouguer anomaly map which are related to the deeper compensation of the continental crust for topographic loads, and contrasts with the more systematic positive and negative variations of the free-air anomaly at sea.

Continental regions

General description

Six major geological elements in Figure 4a are reflected in the magnetic anomaly map. From south to north these are the Appalachian Orogen with its roughly northeast sinuous trends, the Grenville Province with shorter wavelength and less continuous anomalies with more random orientations, the Superior, Churchill, and Nain Provinces north of the Grenville Front, and, in the north, the Innuitian Orogen with its more subdued, low amplitude, long-wavelength variations.

The Superior Province exhibits magnetic amplitude variations similar to those of the Grenville, but the wavelength is longer and the appearance is more ordered, with some northerly and easterly trends defining an almost blocky character to the anomaly pattern in the Ungava Belt (Fig. 4b). This contrasts with the Churchill and Nain provinces in eastern Quebec and Labrador which show distinctive north-trending magnetic anomalies associated with the Labrador Fold Belt (Labrador Trough), the central division of the Trans-Hudson Orogen of the Churchill Province (including the central and western gneiss belts on either side of the De Pas Batholith in Figure 4b, and the Laporte and Doublet terranes to the west (Wardle et al., in press)), and the Abloviak Shear Zone between the two provinces (Korstgård et al., 1987). The Churchill Province (Trans-Hudson Orogen) bends around the Superior Province along the Cape Smith Fold Belt which sharply truncates the Superior Province in northeastern Quebec. The Cape Smith Fold Belt and the Labrador Fold Belt together comprise the eastern portion of the Circum-Ungava Geosyncline (Davidson, 1972).

Figure 12 (and gravity anomaly Map 1708A) shows a gradual negative trend from the Appalachian Orogen, across the Grenville Province, and into the Superior Province. This is in part related to the general trend of increasing elevation. A pronounced low follows the Grenville Front, running east-northeast across Quebec and Labrador between 50°N and 55°N. Gravity trends in the Churchill and Nain provinces are similar to those of the magnetic anomalies (Fig. 11): roughly northerly, with a westward bending, and truncation of earlier patterns, along the Cape Smith Fold Belt. The subdued magnetic anomaly in central Baffin Island correlates with slightly more positive gravity anomalies than are found to the north or south. In the Appalachian Orogen the gravity and magnetic trends are similar, although the gravity variations are comparatively small.

The structural provinces

Appalachian Orogen

The Appalachian Orogen was created by the Ordovician closure of the Iapetus (or proto-Atlantic) Ocean, and further developed during the Devonian Acadian Orogeny and the Carboniferous Alleghanian (Hercynian/Variscan) Orogeny (Williams, 1979). The principal features of this orogen on both the gravity and magnetic anomaly maps are associated with the major Cobequid-Chedabucto Shear Zone and related structures such as the Orpheus Graben (Fig. 4b). This feature marks the boundary between the Meguma Zone to the south and the Avalon Zone to the north (Williams, 1979). Large positive magnetic anomalies north of this boundary from southern New Brunswick to eastern Nova Scotia are mainly caused by Precambrian to Mesozoic volcanic rocks and I-type granitoid intrusives. Gravity values are much more positive over the Cobequid Mountains which also lie north of the fault zone. East of Nova Scotia the magnetic anomaly is offset across an east-northeast-trending sinistral strike-slip fault (B.D. Loncarevic, pers. comm., 1988).

A negative gravity anomaly over the Orpheus Graben extends east from Chedabucto Bay (Loncarevic and Ewing, 1967). Gravity varies from greater than 20 mGal over subsurface ridges lying on both sides of the graben to about -45 mGal over the graben itself. The graben contains at least 10 km of sediment (Loncarevic and Ewing, 1967; B.D. Loncarevic, pers. comm., 1988). Positive magnetic anomalies continuing eastward across the Grand Banks lie just north of the hinge line between the offshore extension of the continental crust (to the north) and sedimentary basins which developed to the south over attenuated continental and intermediate crust following rifting of the margin. South of the hinge line the depth to pre-Carboniferous basement increases rapidly, except to the east, on the Tail of the Banks, where it remains shallow and is associated with anomalously positive gravity anomalies. North of the hinge line (north and east of the Avalon Peninsula) a series of sinuous magnetic trends reflect abrupt changes in the depth to Precambrian basement across a series of basins trending roughly north-northeast in Avalon terrane (Haworth, 1975; Haworth and Lefort, 1979; Miller et al., 1985). On the southeastern Grand Banks, both the Whale and Jeanne d'Arc basins correlate with gravity and magnetic lows, but the Carson and Horseshoe basins appear at this scale to be uncorrelated with the potential field data.

Grenville Province

In broad terms there is a correlation between gravity and magnetic anomalies in Grenville Province: positive values are generally associated with gabbroic and related rocks, and with granulites and lower crust to upper mantle rocks uplifted by major northerly-directed thrusts, whereas negative values are associated with anorthosites, adamellites, and related rocks. Thomas (1974) has examined and modelled many of the gravity anomalies in this part of the Grenville. The relationship of gravity anomalies to the anorthosites when examined in detail is not as obvious as might

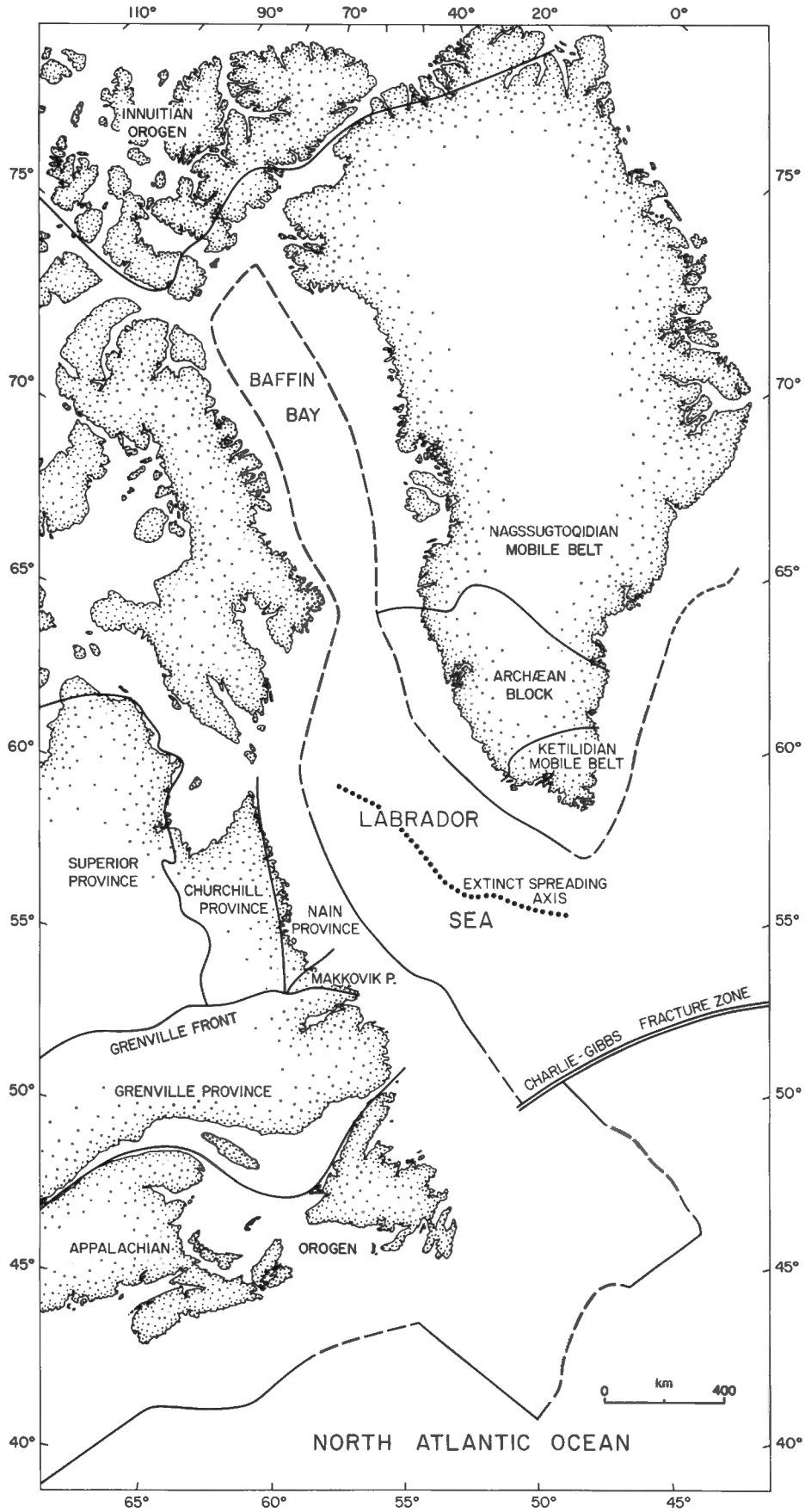


Figure 4a General division of region by structural province or geological domain. (see also Fig. 4b, in pocket). Only the major boundaries and faults have been shown.

be presumed from the generalization above (Thomas, 1985), with some anorthosites being associated with gravity highs rather than with lows (e.g. Lac Fournier Massif, Mealy Mountains, Fig. 4b).

Three major positive Bouguer and magnetic anomalies illustrate the general relationship: Little Manicouagan Lake anomaly, the Sept-Îles anomaly, and the Hawke River anomaly (Thomas, 1974). The source of the Hawke River anomaly is gabbronorite rocks of the White Bear Arm plutonic complex (Gower et al., 1987). Both the Little Manicouagan Lake and the White Bear Arm gabbroic bodies show up more prominently on the gravity map than on the magnetic map. The White Bear Arm body is the only area of positive Bouguer anomaly in Labrador, with values as large as +50 mGal. The circular positive Sept-Îles anomaly is centred in the St. Lawrence River south of Sept-Îles and associated with the Late Cambrian Sept-Îles layered intrusion (Higgins and Doig, 1981). A less positive southward continuation of the Sept-Îles anomaly to the edge of the Appalachian Orogen may indicate southward inclination of the source within the St. Lawrence graben. The Sept-Îles and White Bear Arm (Hawke River anomaly of Thomas, 1974) intrusions extend to 8 and 13 km in depth, respectively, and the depth of the Little Manicouagan Lake body varies from 14 km in the west to 8 km in the east, according to modelling experiments (B.D. Loncarevic, pers. comm. 1988; Thomas, 1974).

Within a zone about 100 km wide south of the Grenville Front the magnetic anomaly becomes relatively subdued. It is the contrast of this zone of low variability (referred to as the parautochthonous zone by Rivers and Chown, 1986) with the surrounding regions that makes the Grenville Front stand out so well on the map (Rivers and Nunn, 1985). Within the Grenville Front Tectonic Zone, the general level of the anomaly shows a correlation with the magnetic anomalies to the north, in many cases, with the more negative region in the east being opposite (across the Grenville Front) the more negative north-trending anomalies in Churchill and Nain provinces. This apparent overlap may be at least in part a result of the presence within the Grenville Front Tectonic Zone of reworked Proterozoic rocks from the north (see discussions by Wardle et al., and Gower and Ryan, *in* Moore et al., 1986).

Within the allochthonous terranes of the northern Grenville (Rivers and Chown, 1986) are several smaller positive gravity anomalies (Rivers and Nunn, 1985). Metagabbroic rocks and high-pressure granulites in the Lac Joseph and Red Wine Mountain regions (Fig. 4b) are considered to be the sources of these anomalies (Rivers and Chown, 1986; Thomas et al., 1986; Emslie et al., 1978). These rocks are inferred to have been thrust up from upper mantle to middle crustal depths during the Labradorian Orogeny around 1650 Ma (Rivers and Chown, 1986).

Superior Province

As noted by Goodwin et al.(1972), the correlation between gravity and magnetic anomalies and geology in the Archean (about 2500 Ma) Superior Province is generally clear. There are relatively positive Bouguer anomalies over supracrustal belts, granulites, and mafic to ultramafic intrusions, and negative anomalies over granitic rocks. Relatively intense, linear positive and negative magnetic anomalies are associated with volcano-sedimentary belts and granulites, and low intensity areas correspond to non-ferromagnetic granites, granitic gneisses and some sedimentary and volcanic rocks. In particular, banded iron-formations and greenstone belts produce local high-amplitude and high frequency magnetic anomalies. The regions of magnetic highs and lows are larger here and look more systematic than in the Grenville with some poorly-developed easterly and southeasterly trends present. The trends may be in part a function of the east-west gneissosity or of another structural grain.

Churchill Province

In Labrador and Quebec the major gravity and magnetic anomalies are principally long and linear. They follow zones of folding such as the Circum-Ungava Geosyncline (incorporating the Labrador and Cape Smith fold belts, Davidson, 1972; Dimroth, 1972), and of shearing like the Abloviak Shear Zone which is distinguished by a distinctive negative magnetic anomaly extending north from the Grenville Front through western Labrador, and exhibiting a dramatic kink at about 59.5°N (Korstgård et al., 1987). The adjacent magnetic positive to the west of the Abloviak Shear Zone is over granulite facies gneiss of the Eastern Granulite Belt (Wardle et al., in press). Farther west, good correlation is observed between positive magnetic anomalies and the de Pas Batholith, the Doublet Terrane, and the northern part of the Western Gneiss Zone (Fig. 4b), whereas negative anomalies are found over the Laporte Terrane and the sheared, mylonitized part of the Western Gneiss Zone. As noted later, much of the variation in magnetic expression may be correlated with metamorphic grade, because of the relation, for example, of the magnetite stability field to temperature and oxygen and silica availability within the iron oxide system (McIntyre, 1980). Thus high magnetite granulite facies gneisses become low magnetite amphibolite facies gneisses in retrogression. R.J. Wardle (pers. comm., 1988) postulated that large scale fold patterns in Figure 11 and on the magnetic anomaly map near Ungava Bay in Quebec suggest that retrogression preceded the broad scale regional folding observed there.

Positive Bouguer gravity anomalies are also associated with the Doublet Terrane, a predominantly mafic and ultramafic sequence thought possibly to represent a fragment of continent-ocean transitional or oceanic crust, and both the Western and Central Gneiss Zones. Wardle et al. (in press) postulated that the gravity high over the Western Gneiss resulted from uplift of dense granulites along major, listric thrusts which rise from lower crustal depths. Negative gravity is found in association with the de Pas Batholith and the Eastern Granulite Belt. Although simple block faulting of crustal dimensions has been suggested to explain these alternating high and low gravity anomalies running roughly south-southeast through northern Labrador (Thomas et al., 1978), speculations derived from an improved geological knowledge of the region implicate more complex structures arising from oblique convergence and collision of Archean

cratons (principally the Superior Craton and the North Atlantic Craton of which the Nain is a part) during the Hudsonian Orogeny around 1850-1800 Ma (Wardle et al., in press).

On Baffin Island, a magnetically-subdued central region correlates with rocks of middle and upper amphibolite metamorphic facies. On either side, to the north and south of the central region, magnetic variations of higher amplitude and frequency are associated with rocks of granulite or retrograded granulite facies (Cameron, 1986; Jackson and Morgan, 1978). Increased magnetite content of granulite terranes is a result of dehydration of hydrous iron-bearing silicates during transition from amphibolite to granulite grade metamorphism (McIntyre, 1980). The Foxe Fold Belt running east-southeast through central Baffin Island (at about 69°N) shows up as a more positive belt of anomalies within a generally subdued and negative region of magnetic anomalies. The Bouguer gravity anomaly can be also correlated with the geology on Baffin Island, but in the opposite sense to the magnetic anomaly: it is more negative over the Foxe Fold Belt and over the north and south granulite regions.

Nain Province

Lying to the east of the Aphebian Churchill Province is the Nain Province, a coastal strip of high grade Archean metamorphic rocks (Taylor, 1972). Korstgård et al. (1987) discussed the location of the Churchill-Nain boundary and argued that it should be farther east than previously located, on the basis of progressive structural reworking of Archaean crust up to 20 km east of the Abloviak Shear Zone, well into what had been termed Nain. Because of its limited extent in Canada and the lack of geophysical data from its continuation as the Archaean Block in southern Greenland, little can be said of gravity and magnetic correlations with geology. In general there is a strip of positive gravity and magnetic anomalies along the coast, broken only by negative anomalies exhibited by the Nain Anorthosite Complex and associated rocks of the adamellite suite.

Innuitian Orogen

Gravity and magnetic coverage in this area is not yet complete, however some discussion of the geophysical characteristics and deep structure of the province was made by Trettin et al. (1972). Because there has been almost continual geosynclinal development within a succession of basins since the Proterozoic (see, for example, Balkwill (1978) and Rayer (1981)), the magnetic anomaly does not exhibit much variation over most of the region. The magnetic basement rocks there are masked by the thick sequence of much less-magnetic sedimentary rocks. In the southeast part of the province, however, the crystalline basement is exposed, and the magnetic trends reflect the presence of granitic gneisses cut by faults. The gravity anomaly, on the other hand, reflects more of the structures that are present, such as highs over the Boothia Uplift and Cornwall Anticline, a low over the Central Ellesmere Fold Belt, and strong positive-negative variations across the Arctic channels where down-faulting of channels and uplift of adjacent land is an apparent reactivation in response to Eurekan (mid-Tertiary) tectonics prior to Pleistocene glaciation (Trettin et al., 1972; Balkwill, 1978). Northerly to northwesterly directed thrusting and folding in the Sverdrup Basin (Balkwill and Fox, 1982; Balkwill, 1978), and the opening of graben in Lancaster Sound (Barrett, 1966) and

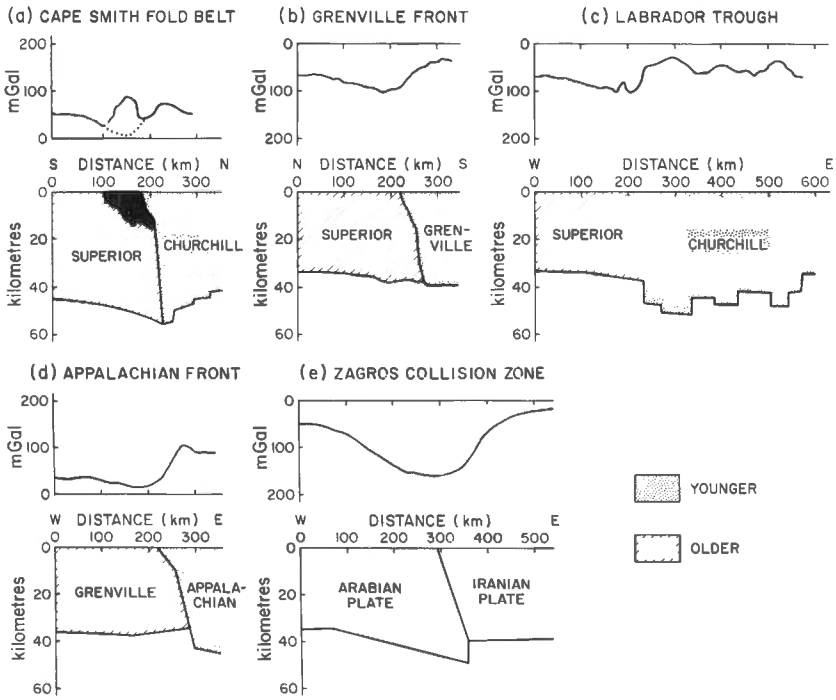


Figure 5. Profiles of gravity and inferred crustal structure across major structural boundaries or suture zones of different ages and locations: (a) Cape Smith Fold Belt of about 1750 Ma age (after Thomas and Gibb, 1977). (b) Grenville Front of about 1000 Ma age, but possibly as old as 1750 Ma (after Thomas and Tanner, 1975). (c) Labrador Trough of about 1750 Ma age (after Thomas et al., 1978). (d) Appalachian Front (US segment) of early Paleozoic age (after Thomas, 1983). (e) Zagros Collision Zone of Cenozoic age (after Thomas, 1985).

Jones Sound may be linked to the Tertiary rotation of Greenland during the opening of Baffin Bay (Rice and Shade, 1982; Srivastava et al., 1981). Gravity anomalies and crustal structure along the Nares Strait margin of Ellesmere Island have been interpreted as resulting from northward convergence of Greenland with Ellesmere Island during this opening (Jackson and Koppen, 1985).

Boundary zones between provinces

The boundaries between provinces show up well in the gravity and magnetic maps for several reasons. Trends in one province may be truncated by those in a younger province, as a result of lithological, structural, and metamorphic contrasts between the abutting provinces. These discontinuities cause changes in the potential field data.

Appalachian Front/Logan's Line

The northwestern zone (Humber Zone) of the Appalachian Orogen is underlain by crystalline Grenville-aged basement (Williams, 1979). In the Gulf of St. Lawrence the Grenville basement is depressed below a thick sequence of early Paleozoic sedimentary rocks which thins to the north from the edge of the Appalachian Orogen. As a result there is a pronounced decrease in the frequency and amplitude of the magnetic anomalies associated with the Grenville rocks across the edge of the Appalachians, owing to their deeper burial by the overlying Appalachian rocks, and younger cover to the northwest.

Sedimentary basins were produced by the down-flexing of the Grenville crust beneath the overriding Appalachian material, and are now marked by negative gravity anomalies (e.g. Anticosti Basin in the Gulf of St. Lawrence). Generally negative magnetic and positive gravity anomalies are associated with the Appalachian allochthons. The gravity gradient along the Appalachian Front is typical of the Appalachians through to the southern United States (Thomas, 1983; Haworth et al., 1980) but it is distorted in places such as western Newfoundland where ophiolitic allochthons cause large positive anomalies. The magnetic anomaly in these areas is likewise atypical of the boundary elsewhere, showing shorter wavelength, higher amplitude variations.

The Grenville Front/Grenville Front Tectonic Zone

This is one of the most prominent features in both Figures 11 and 12 and the gravity and magnetic maps. The Grenville Front in the gravity map is associated with a major regional low occurring at the southern side of a large region of negative gravity in eastern Quebec, but just to the north of the lowest values attained. It is probably better typified as the negative component of a negative-positive pair of anomalies (Fig. 5) (Thomas, 1974, 1983, 1985), a relative low being located over the parautochthonous zone (Rivers and Chown, 1986) of the Grenville Orogen, and a high over the allochthonous terranes to the south of the Grenville Front Tectonic Zone. The high gravity values coincide with granulitic rocks which were thrust up from the south and southeast, and are at least partly responsible for the gravity anomalies (Wardle et al. 1986; Emslie et al., 1978). The arcuate trace of the thrusts generally correlates with the northern limit of the high gravity values.

The gradient between the positive-negative pair of gravity anomalies has been proposed to overlie a southeast-dipping suture between the Grenville Province and the Superior and Churchill provinces (Thomas, 1985). The gravity signature in that case is interpreted to be a result of the juxtaposition of thicker and denser Grenville continental crust with thinner, lighter crust to the north, with some crustal thickening in the Grenville Front Tectonic Zone (Thomas and Tanner, 1975; Berry and Fuchs, 1973). Downward flexing of the Superior crust toward the cryptic suture also accommodates a wedge of sedimentary rocks in a foreland belt to the north of the Grenville Front.

Geological evidence does not favour the presence of a suture. Geochronological work (Easton, 1986) indicates that crust on either side of the Grenville Front was in place and stabilized by about 1610 Ma, although all the rocks were later affected by the Grenville event at about 1100 to 1000 Ma. If suturing took place, it must have occurred during the Labrador Orogeny, or earlier (Wardle et al., 1986; Thomas et al., 1986). What evidence there is for some sort of weld or suture includes the presence of a structural province like the Grenville along a common boundary with three distinctive provinces to the north, the persistent and extensive gravity and magnetic variations associated directly with the Grenville Front Tectonic Zone, and the similarity of the gravity signature with that over other sutures (Fig. 5), such as that between the Churchill and Superior Provinces (Fig. 5c) or the currently forming Zagros Suture (Fig. 5e; Thomas, 1985). Clearly the geophysical data must fall in line with the geological possibilities. Future geophysical analyses should examine the geophysical data in terms of the more detailed geology and the suitability of various geological models as sources of the potential field anomalies. For example, the gravity effect should be computed for high density lower crustal granulites upthrust from the south against lower density granitoids, gneisses, etc. (perhaps through intraplate compressive stresses), and compared with the observed values.

The low magnetic variation within the Grenville Front Tectonic Zone is probably the result of tectonization and metamorphism. The zone is typified by metamorphic assemblages indicative of the highest pressures recorded in the Grenville Province, by strongly-developed northeast-trending foliations, and by numerous parallel belts of cataclasis and mylonitization (Rivers and Chown, 1986; Wynne-Edwards, 1972).

The Labrador Trough and Cape Smith Fold Belt

The gravity signature of this junction is similar to that between the Grenville and the Superior. Gravity decreases over the Superior towards the younger province and increases to more positive levels over the younger province (Fig. 5) (Kearey and Halliday, 1976; Thomas et al., 1978; Thomas and Gibb, 1985). A large positive gravity anomaly, however, is superposed over the fold belts themselves, at

the edge of the Superior (Thomas and Gibb, 1977; Kearey, 1977). In the Labrador Trough the high gravity correlates in the south with the Doublet Terrane, a predominantly mafic sequence thought to represent a fragment of the continent-ocean transition region developed during early rifting, or possibly true oceanic crust; whereas to the north, a broader gravity high (Fig. 5a) correlates with rocks of upper amphibolite to granulite facies in the Western Gneiss Zone (Wardle et al., in press). Gravity models suggested that the basic meta-igneous rocks dip eastward to depths of up to 9 km (Kearey, 1977). The positive gravity anomaly in the Cape Smith Fold Belt is interpreted as being caused by basaltic rocks, including pillow basalts and tholeiites, from oceanic crust obducted onto the Superior margin when the Superior and Churchill provinces collided (Thomas and Gibb, 1977), and separated from their root zone in the Sugluk Terrane to the north (Fig. 4b) by a broad antiform of Archean basement (Hoffman, 1985). Hoffman's (1985) suggested model of the Cape Smith ophiolites as a klippe transported from the north has been modified by Doig (1987) to explain discrepancies in the ages between the klippe (1900 Ma) and rocks of the Sugluk Terrane (3000-3200 Ma with intruded sills of granite of about 1830 Ma). The recent dating of the Cape Smith ophiolite at 1900 Ma (St.-Onge et al., 1988; Doig, 1987) indicates that plate tectonic processes similar to those operating at present may have existed in early Precambrian time.

The magnetic anomalies are negative over the two fold belts, with high frequency positive values over the ophiolites within the fold belts (see, for example, Fig. 6 in Hoffman, 1985). There is more variability, however, compared to the gravity anomalies, especially along the Labrador Trough. This is attributed to the variability in magnetite content of the rocks.

The Nain-Churchill Boundary

This boundary lies offshore Labrador in the north and remains within 100 km of the coast farther to the south in Labrador. It is believed to continue northwest across the Ungava Fracture Zone to link with the boundary between the Nagssugtoqidian Mobile Belt and the Archaean Block of Greenland (Fig. 4b). Similar gravity variations to those across other boundaries between Precambrian structural provinces were not observed, probably because of the narrowness of the Nain in Labrador and the presence of Elsonian (1400 Ma) intrusives like the Nain Anorthosite Complex and the troctolitic-gabbroic Kiglapait layered intrusion on the Labrador coast.

The boundary is likewise poorly defined by the magnetic anomaly because of the dominance, in the eastern section of the Churchill Province, of very distinctive northerly oriented variations associated with the Abloviak Shear Zone (Korstgård et al., 1987). The Abloviak Shear Zone anomaly continues north at least to Resolution Island. East of the strong negative anomaly overlying the Tasiuyak gneiss, a garnetiferous mylonite gneiss in the Abloviak Shear Zone, the magnetic anomaly takes on a different character which extends across the Nain Province in the north. The Churchill Foreland Zone (Wardle et al., in press) (not shown in Fig. 4b) and the Burwell Zone (Fig. 4b) fall within this narrow zone but can not be differentiated from the Nain on the basis of magnetic anomaly signature. The Komaktorvik Zone and the Churchill Foreland Zone to its east (not shown in Fig. 4b) are both regions of reworked Nain (Archean) rocks. Both Archean-directed thrusting of the Trans-Hudson Orogen and transcurrent movement are observed at the Nain-Churchill boundary (Wardle et al., in press).

As the Nain-Churchill boundary is thought to be continuous with the boundary in Greenland of the Nagssugtoqidian Mobile Belt with the Archaean Block of Greenland, gravity and magnetic observations there might shed some light on the differences. Magnetic anomalies from an aeromagnetic survey in the Søndre Strømfiord region of western Greenland (Thorning, 1984, 1986) show the boundary between the highly magnetic Archaean Block and the less magnetic amphibolite facies gneisses of the Nagssugtoqidian Mobile Belt extending out to sea where marine magnetometer data reveal the boundary continuing west to the Ungava Fracture Zone (Fig. 4b). It is interesting to speculate whether the Ungava Fault Zone was initiated by reactivation of shear zones near this boundary.

Oceanic region

Seafloor spreading magnetic anomalies

The seafloor spreading magnetic anomalies are well documented for both the Labrador Sea and the North Atlantic (Srivastava, 1978; Srivastava and Tapscott, 1986). The amplitude of these anomalies, however, is much weaker in the Labrador Sea, making them more difficult to see on the 1:5 million scale maps.

In the Labrador Sea, rifting between Greenland and North America started in Late Cretaceous time with volcanism on the outer Labrador Shelf (Jansa and Pe-Piper, 1988; Johnson et al., 1982; Srivastava, 1978). The oldest identified magnetic seafloor spreading anomalies are 34, just north of the Charlie-Gibbs Fracture Zone, and anomalies 33 and 31 farther to the north (Fig. 4b), reflecting a progressive opening of the sea from south to north — the northern Labrador Sea began spreading in the Early Paleocene. The spreading direction between Greenland and North America is depicted in the fracture zone pattern (Fig. 4b). Changes of spreading direction can be observed in this pattern, such as the change at anomaly 25 time (Late Paleocene). At about the same time, extensive volcanism occurred in the Davis Strait region (Johnson et al., 1982). Very oblique spreading in Baffin Bay and Davis Strait (parallel to the Ungava Transform Zone?) started when another change in spreading direction occurred at anomaly 24 time (Srivastava and Tapscott, 1986). Active seafloor spreading stopped prior to anomaly 13 time (Early Oligocene) when Greenland started moving away from Europe as part of the North American plate. This is inferred from the fact that the youngest anomaly that can be identified in the Labrador Sea is older than anomaly 13 (Srivastava and Tapscott, 1986). The locus of the extinct spreading centre for the Labrador Sea (shown by the heavy dots in Fig. 4b) is easier to observe on the free-air anomaly map where it

appears as a well-resolved negative anomaly associated with a buried rift valley observable in seismic reflection profiles.

The magnetic anomaly pattern in the Labrador Sea is symmetric around the ancient spreading axis, if we restrict ourselves to the shorter wavelengths that are directly related to the magnetic reversal pattern. However, asymmetries are present in the oceanic part of the Labrador Sea (Vogt et al., 1982). The closer proximity of the extinct spreading centre to the Greenland margin compared to the Labrador side follows from the existence of a wider margin between the continent and ocean on the Labrador side. In Baffin Bay the opposite appears to be true, where the wider margin is on the Greenland side. Both the gravity and magnetic anomalies show differences across the spreading axis: the gravity field is more positive by perhaps 20 mGal on the Greenland side. Low-pass filtered magnetic anomalies show the same relationship, although this is not as apparent from the unfiltered map which exhibits the expected symmetry. The explanation for these and other asymmetries was not addressed by Vogt et al. (1982), however they suspected that absolute plate motions superimposed on the relative motions might play a part.

The North Atlantic also opened by seafloor spreading in stages. Late Triassic to Early Jurassic volcanism associated with the initial rifting of Nova Scotia and Africa produces some distinctive magnetic anomalies. Examples occur over the North Mountain basalt running along the Fundy margin of Nova Scotia, and over the southwest-trending Avalon dykes south of Newfoundland (Hodych and Hayatsu, 1980; Papezik et al., 1975). The latter can be clearly observed on detailed magnetic charts of the area south of Newfoundland (Papezik et al., 1975), although they are less obvious on the 1:5 million scale maps. Rifting produced graben and half graben structures, such as Orpheus Graben and Whale Basin, for which the gravity anomalies are negative. The oldest identifiable seafloor spreading anomaly south of Nova Scotia is M-25 (Late Oxfordian), although a mid-Jurassic beginning for seafloor spreading is estimated on the basis of an age of about 175 Ma for the East Coast Magnetic Anomaly (ECMA) (Klitgord and Schouten, 1986, p. 364), the assumed continent-ocean boundary south of Nova Scotia (Barrett and Keen, 1976). A quiet magnetic zone (Jurassic Magnetic Quiet Zone, Kent and Gradstein, 1986) lies between the ECMA and M-25.

In the area confined between the Newfoundland Ridge and Flemish Cap, active seafloor spreading, between Iberia and the Grand Banks, started in Aptian time (anomaly M-0). It started slightly later north from Flemish Cap to Charlie-Gibbs Fracture Zone (just prior to anomaly 34 time, or Campanian). Anomaly 34 and later seafloor spreading anomalies are now well-defined north of Flemish Cap (Srivastava et al., 1988 a, b; Srivastava and Tapscott, 1986).

The Charlie-Gibbs Fracture Zone marks a distinct change in both the gravity and magnetic anomaly fields. To the north the gravity anomalies are considerably more positive and the magnetic anomalies more negative. At the fracture zone, the gravity variation is typical of profiles across other fracture zones having the same differences in age and elevation (see for example Sibuet and Veyrat-Peinet, 1980); however, north from the fracture zone, and beyond geographical limits of the map area, the gravity field is regionally more positive than to the south (i.e. clearly more reddish in Fig. 12 and GSC Map 1708A). This regional anomaly might arise from a combination of causes including the excessive volcanic activity associated with seafloor spreading near the Iceland hot spot and the absolute motions of the plates (as suggested by Vogt et al., 1982).

A ridge-ridge-ridge triple junction was active briefly to the south of Cape Farewell, Greenland, during the last phase of seafloor spreading in the Labrador Sea (anomaly 24 to 13, Late Paleocene to Early Oligocene). As can be observed from the fracture zone directions in the central part of the Labrador Sea (Fig. 4b), the spreading direction in the Labrador Sea during this time was different from the early phase. During the interval of spreading re-organization, more volcanism than usual accompanied seafloor spreading, as shown by strong magnetic anomalies and more positive gravity anomalies.

J-Anomaly Ridge and Newfoundland Ridge

The J-Anomaly Ridge and the Newfoundland Ridge are both regions of abnormal volcanism which produce a strong magnetic anomaly at the southern edge of Figure 11 (and GSC Map 1709A). Hot spot volcanism has been suggested for these, with the J-Anomaly forming as Iberia and the Grand Banks started separating in the early Aptian (Tucholke and Ludwig, 1982). The J-Anomaly (now referred to as anomaly M0) has been identified north of the Newfoundland Ridge, and it appears to be offset about 50 km westward to the north of the Newfoundland Seamounts. The Newfoundland Seamounts show up prominently in Figure 11, but they appear only slightly as positive features in Figure 12 (and GSC Map 1708A) where they are not well-resolved by the Seasat altimetry data from which the gravity for this region was obtained, owing to satellite tracks spaced too widely to cross the seamounts directly.

Continental margin and ocean — continent boundary

Lying between the Canadian coastline and the oceanic basin is a zone which ranges in width from less than 100 km to greater than 500 km and extends from Georges Bank to the Arctic Islands. It is a geological patchwork comprising continental rocks of Precambrian to Mesozoic age and sedimentary basins which have evolved since the Mesozoic. Different segments of the margin were created differently as the North American and Eurasian plates rifted and separated. Along the rifted margins, deep sedimentary basins formed where the continental lithosphere stretched and thinned (eg off Nova Scotia and northern Labrador). Where the plates broke parallel to the direction of separation, transform margins were created along the sheared edge of the plates.

The most prominent and consistent feature of this zone is the shelf-edge gravity anomaly, although it varies in amplitude (by over 100 mGal) and shape along the margin. This is a positive free-air anomaly which lies above the thickest sediments of the rift basins along the Scotian, northeast Newfoundland, and Labrador margins. Where the

basins are poorly developed, for example along the section of margin between the Charlie-Gibbs and Cartwright fracture zones, the anomaly is not as large as in areas such as the Sable Subbasin (Scotian margin, Fig. 4b) where the margin shows more stretching and deeper sedimentary basins overlying the stretched crust. Across the transform margin southeast of Newfoundland (along the Southeast Newfoundland Transform Fault) the gravity variation is more in keeping with that across a step between the continental crust of the Grand Banks to the north and the oceanic crust to the south.

The signature of the gravity anomalies over the shelf-edge sedimentary basins is generally different from those over the sedimentary basins which developed within the continental crust. The latter basins, like the Sidney, Magdalen, Anticosti, Orpheus, Whale, Jeanne d'Arc, and St. Anthony basins (Fig. 4b), have an associated gravity anomaly minimum, more indicative of graben or structural holes in the continental crust filled with sediments. The shelf-edge basins, such as the Scotian Basin, have a positive gravity anomaly, sometimes with flanking lows, a signature generally indicative of a locally uncompensated load which may be regionally compensated through flexure of the crust in the region of the load (eg Karner and Watts, 1982; Beaumont et al., 1982).

The large gravity anomaly high just landward of the shelf break in Orphan Basin and the shelf-edge high along the Labrador margin north of the Cartwright Fracture Zone are anomalous in not having well-established flanking lows. This presents a puzzle in understanding the manner of isostatic compensation present. Both gravity anomalies are associated with the main depocentres and thickest sediments. For Orphan Basin, however, crosscutting Precambrian structures inferred from the magnetic data (see below) may provide some additional structural support within the crust for the sediment loads. On the other hand, the gravity anomaly diminishes northward over Saglek Basin where it is negative in the main depocentre. This latter development may be linked more with the evolution of the Ungava Transform zone than with the rifting of the Labrador margin.

Also visible are the gravity lows associated with the southeast-trending fjords (Frobisher Bay, Cumberland Sound) along the southeast margin of Baffin Island. These features may be related to rifting during formation of the Labrador Sea (e.g. Klose et al., 1982; Srivastava et al., 1982).

The very large gravity variations from Baffin Island to Baffin Bay are probably related to the enigmatic differential vertical movement between the rising island and subsiding basement in the offshore (Keen and Peirce, 1982). Relief across the Baffin Island margin of about 2 km may be a consequence of the Late Cretaceous to early Tertiary Eurekan Rifting Episode and of seafloor spreading in Labrador Sea and Baffin Bay (Miall et al., 1980; Kerr, 1980). The increase in elevation of Baffin Island by up to 600 m since the Eocene, and continued subsidence in the offshore (MacLean and Falconer, 1979; Miall et al., 1980), is difficult to explain (Keen and Peirce, 1982) but has been attributed to the climactic phase of Eurekan rifting (Kerr, 1980).

The magnetic anomalies across the margins reflect sources in the continental, oceanic, and transitional crust as well as sources which originated at the time of formation of the margin. Anomalies and anomaly patterns associated with the continental crust can be seen to be truncated or at least progressively attenuated across the hinge line marking the boundary between continental basement and rifted marginal sedimentary basins floored at depth by stretched continental crust. This may be seen, for example, by following the arcuate anomalies of the Grand Banks into Orphan Basin where their amplitudes diminish northeastwards.

Eruption and intrusion of volcanic material at the time of rifting, or during seafloor spreading direction reorganization (Johnson et al., 1982; Clarke and Upton, 1971), created sources for a number of magnetic anomalies. Examples of the former may be found in the Saglek Basin and along the Cobequid-Chedabucto and Southeast Newfoundland fault systems. Volcanic material is the source of the largest magnetic anomalies along the Greenland margin (Johnson et al., 1982).

The sources of a prominent series of arcuate magnetic anomalies east of Newfoundland are thought to be Precambrian basement ridges marking the edges of sedimentary basins in the Grand Banks (Lefort, 1983; Haworth, 1975). Miller et al. (1985) modelled these magnetic anomalies and their gravity anomaly counterparts more specifically as block-faulted Precambrian volcanic flows, with the downfaulted basins subsequently filled by Precambrian to Devonian sediments. It has been argued by Lefort (1983) that these features continue on the other side of the Atlantic in northern Iberia and Brittany. Across the Bonavista Platform, northeast of Newfoundland, they continue northeastwards into the Orphan Basin, crossing the area coinciding with the large shelf-edge gravity anomaly.

On the Grand Banks the arcuate magnetic anomalies terminate to the south against a linear east-west series of large magnetic anomalies which appear to 'collect' the arcuate anomalies, and have therefore been termed the 'Collector Anomaly' (Haworth, 1975; Haworth and McIntyre, 1975). Whether or not the Collector Anomaly lies over a fracture zone as originally suggested by Haworth (1975), it marks a distinct change in the character of the magnetic anomaly map from north to south, and it appears to be continuous both with the Cobequid-Chedabucto Fault System to the west and the Newfoundland Seamounts to the east (and possibly as well with the mafic belt of the South Portuguese Zone, across the conjugate margin in Europe; Lefort, 1983).

Between the Charlie-Gibbs and Cartwright fracture zones is a series of large positive magnetic anomalies, locally greater than 800 nT. These anomalies exhibit an abrupt termination along a linear negative anomaly parallel to the shelf edge. Continuity of some of the positive anomalies with the Appalachian Dunnage Terrane of Newfoundland suggests that Paleozoic basic and ultrabasic rocks might be the source (Haworth and Miller, 1982). Fenwick et al. (1968) explained the shelf-edge anomalies in this area by the juxtaposition of a 30 km thick continental crust composed of basic and ultrabasic rocks (Dunnage Terrane) with

thinner oceanic crust (about 10-12 km thick). This supports the inference from other data (such as geomorphology, gravity anomaly, and structure revealed from seismic profiles) that the ocean-continent transition zone is very narrow here, however it does not seem to explain the great extent of the magnetic anomaly to the west. The presence of other volcanic material is not ruled out, as drilling to the north has sampled Early Cretaceous volcanic rocks in the Indian Harbour and Leif wells of the Cartwright Arch (Umpleby, 1979).

Geophysical characteristics of selected marginal sections

Introduction

As explained above, the magnetic and gravity anomalies along the margins, although prominent and consistent in character at some locations, show a large variability over the area. In this section the general characteristics of the margins are described. To do this by comparing and correlating gravity and magnetic anomalies and bathymetry, representative profiles across the different margins are examined.

The gravity anomaly over the Scotian margin, for example, exhibits a strong positive high over the shelf edge but with local amplitude variations along the margin. A standard procedure to obtain a generalized anomaly which can be considered characteristic of the margin is to 'stack' profiles. In the stacking procedure, several profiles across the margins are summed together and the average taken, thus amplifying the coherent signal in the anomaly at the expense of incoherent noise. In general, the individual profiles are taken perpendicular to the geological trend to be enhanced. Where the feature is curved or varies in wavelength, each individual profile may be shifted horizontally with respect to its neighbour in order to align the feature before summing the profiles for maximum enhancement. For this study, the horizontal shifts were obtained both by eye and automatically by optimizing the cross-correlation between adjacent profiles. Clearly, when several data sets are being used (ie bathymetry, gravity, and magnetic field) the horizontal shift can be determined from any one of them and then used to stack the others. A measure for the variability along a feature can be obtained by subtracting the stack from each individual profile. The residuals thus obtained reflect the local variations.

The Stacking Procedure

Eight sections of the continental margin of eastern Canada were selected for comparison (Fig. 6 and 7). Two of these extend eastward across the Greenland margin as well (Fig. 7D and H). Representative gravity, magnetic, and bathymetric profiles of each margin were produced by stacking a series of about 10 to 15 profiles extracted from the data grids used for creating the maps (ie they are directly correlatable with the maps, although they are not at the same scale). The sampled data were taken perpendicular to the principal geological trends of the margins and at intervals of from 20 to 30 km along the margin. Profiles were chosen to be about 500 km long, and the sampling interval along them was about 2 km.

Results showed that there was not much to be gained by automatic correlation over subjectively choosing the best shifts of profiles prior to stacking. What was very interesting was the observation that although there was a great deal of variability among profiles from a given margin (e.g. Fig. 8), the resulting stacked profiles for each margin were distinctive, and reproduced the principal characteristic features shown by the individual sampled profiles. The residuals (Fig. 8) show that the major differences among profiles occur where the gradients are greatest: on the Scotian margin for example, the largest residuals for bathymetry occur at the shelf edge, and those for gravity are associated with the large shelf edge anomaly which varies in amplitude and width along strike (Fig. 8). (The residuals for the magnetic anomaly in Fig. 8 are of the same magnitude as the anomalies themselves for the Scotian Shelf because of the erratic trend of the East Coast Magnetic Anomaly with respect to the other trends.)

The differences between stacked profiles for which the horizontal shifts are based on alignment of major gravity features and those based on alignment of bathymetric features are not great; however, stacking on magnetic anomaly results in poorer resultant profiles. For example, neither the bathymetric shelf break across the Scotian margin nor the characteristic gravity high associated with it survives when the profiles are stacked on magnetic anomaly (Fig. 9). This follows from the strong correlation between gravity and geology (e.g. marginal sedimentary basins) and bathymetry. Magnetic anomalies are less consistent in this regard: for example, the East Coast Magnetic Anomaly (ECMA) southeast of Nova Scotia tends to meander across bathymetric trends, and the principal magnetic anomalies across the southeast Newfoundland margin are either erratic (resulting from ancient volcanic centres which are sampled only on some profiles) or of different trend to the margin (like the Collector Anomaly). The result of stacking gravity, bathymetry, and magnetic anomaly profiles on the basis of correlations from one magnetic anomaly profile to another is therefore to reduce the amplitude of the gravity anomaly (by more than a half on the Scotian margin; see Fig. 9), change the characteristic profile of bathymetry from shelf to rise, and add noise to both the gravity and bathymetric signal. Even the resultant magnetic anomaly profile is not greatly improved by stacking individual profiles on the basis of correlation of magnetic anomaly features, as shown by the minor improvement in resolution of ECMA without increasing its amplitude (Fig. 9). In the case of the South Flemish Cap margin, the large negative magnetic anomaly (at distance of about 280 km on the x-axis, in Fig. 7E) resulting from stacking on bathymetry or gravity is almost completely lost when the profiles are stacked on magnetics, and the positive anomaly at the shelf edge is reduced in amplitude. This apparently strange result, possibly due to the random correlation of magnetic anomalies from profile to profile, suggests caution in the interpretation of magnetic profiles which may be characteristic of a given margin only through their lack of correlation with gravity and morphology there.

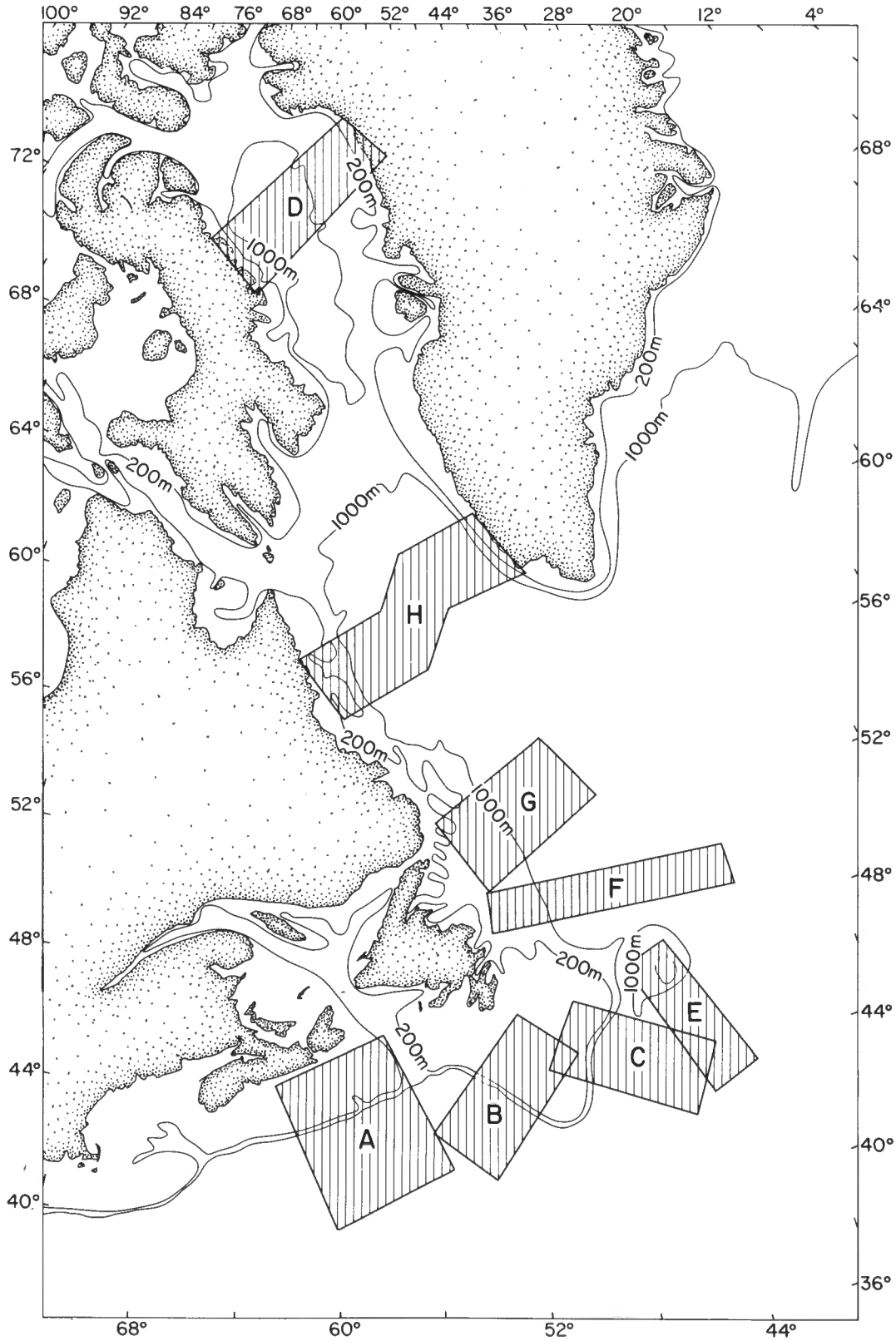


Figure 6. Locations of groups of stacked profiles along selected continental margins. Each box contains about a dozen profiles perpendicular to the morphological and geophysical trends. Letters in the boxes are keyed to profiles in Figure 7.

Amplitudes of the magnetic anomalies in the stacked profiles are primarily in the order of ± 50 nT, and can therefore be considered close to the noise level. The chief exceptions are for both sides of the Labrador Sea and Baffin Bay, and the northeast Newfoundland margin (Fig. 7H, D, and G, respectively). Magnetic anomalies are clearly associated with the margins in each of these cases. The northeast Newfoundland example is the best, showing a strong positive-negative pair, previously discussed, over the rather abrupt continent-ocean transition (Fig. 7G). The magnetic anomaly is correlated with the positive gravity anomaly at the shelf edge. Likewise on the Greenland margin there is a direct correlation between the positive gravity and magnetic anomalies at the shelf edge (Fig. 7H). On the Labrador side of the Labrador Sea the positive gravity anomaly is associated with the sedimentary basins beneath the outer shelf and slope, but the positive magnetic anomaly lies landward of the hinge line over relatively shallow Precambrian basement. Because of the relationship of the boundary between shallow and deep magnetic basement with the gravity effect of the sedimentary basin and its position with respect to shelf morphology, there is a correlation among gravity, magnetic anomaly, and bathymetry across the western margins of Labrador Sea and Baffin Bay (Fig. 7H and D).

The Results

Although the margins all have their own signatures, it is possible to group margins by similarities. The rifted margins differ from the transform margins, but there are also slight differences in each of these types. The Scotian margin (Fig. 7A) and the southeast Grand Banks margin (Fig. 7C) best show the flexural characteristics of a rifted margin, with a positive free-air anomaly over the depocentre of sedimentary basins, typical of such margins, and flanking lows on either side, which are inferred to owe their existence to the downward lithospheric flexure of crust beneath and to the sides of the sedimentary load. The Greenland and Labrador margins also show this effect to some degree (Fig. 7D and H). The northeast Newfoundland margin (Fig. 7G), on the other hand, is a very narrow rifted margin without a well-developed sedimentary basin, and has a positive free-air anomaly without the adjoining lows. A large part of this may be edge effect, although a negative anomaly on the seaward side would be expected in that case.

The Orphan Basin rifted margin is unique among the others (Fig. 7F). The largest free-air anomaly is associated with this basin but there is only a very small flexural low on either side of it. This might suggest that the crust beneath the basin is anomalously dense or that the crust is anomalously strong and can support the sedimentary load. Either possibility requires further explanation beyond the scope of this report.

The margins of Baffin Bay (Fig. 7D) are assumed to have rifted prior to a brief period of seafloor spreading. Both sides exhibit positive gravity anomalies over the stretched portion of the continental crust. If the sedimentary loads on the rifted portions of the Baffin Bay margin caused lithospheric flexure, the gravity effects of this are obscured in the centre because of the narrowness of the oceanic part, and to landward by the subsequent effects of the previously-mentioned tectonic elevation of the continental crust of Baffin Island and Greenland. A major part of the positive anomaly on the Greenland side is caused by a volcanic ridge separating the deeper basin to the west from the Melville Bay Graben to the east. The Melville Bay Graben contains a thick sedimentary sequence and has a large negative free-air anomaly, thus distinguishing it from most sedimentary basins elsewhere along the margins. It developed, perhaps, as an intracratonic graben similar to others (like the Whale Basin) inshore of the attenuated continental crust which thins seaward toward the continent-ocean boundary.

The transform margins southwest of the Grand Banks and south of Flemish Cap both show a gravity step rather than a singular positive anomaly over the shelf edge (Fig. 7B and E). Some flexural effects can be discerned in the anomaly across the narrow sedimentary basin south of the Grand Banks; however, the Flemish Cap marginal anomaly appears to be principally an edge effect between the oceanic and continental crust. The south Flemish Cap gravity anomaly suggests also a very narrow transition between the two.

The Bouguer anomaly is a residual gravity anomaly obtained after correcting the free-air anomaly for the gravity effect of topography. At sea this correction is made by replacing the water layer by material of mean crustal density and adding the additional gravity effect of this material to the free-air anomaly. On land the correction is made by removing the gravity effect of the topography above sea level by assuming it to be made up of material with the mean crustal density. The mean density of the crust is commonly assumed to be 2.67 g/cm^3 (which gives a density contrast of 1.67 g/cm^3 with the water layer, for which the assumed density is 1.0 g/cm^3).

Where the basement topography is well-known and exists as a digital grid compatible with those of gravity and bathymetry (Fig. 7E, F, G, H) additional corrections can be made to the Bouguer anomaly for the sediment layer. The mean density for the sediments between the seafloor and the basement is assumed to be 2.27 g/cm^3 (density contrast against continental crust being -0.4 g/cm^3) for the additional correction except for Orphan Basin where an intermediate density is also used. Because of the large volume of sediments in Orphan Basin the correction for the sedimentary layer was also made with an assumed average density of 2.47 g/cm^3 (density contrast of sediments against continental crust of -0.2 g/cm^3) for the sediments. Thus a third 'Bouguer' anomaly was produced which provided an intermediate profile between the profiles for the two end members (Fig. 7F).

Variations in the Bouguer anomaly can be viewed in general as arising from variations in the mantle depth (Moho) and to a lesser extent to variations in topography of the basement surface owing to local density variations, and in the stacks where no basement information was available. Both these interfaces have density contrasts across them which are greater than at other interfaces. However there may be substantial contributions to the Bouguer anomaly from other geological heterogeneities that give rise to lateral

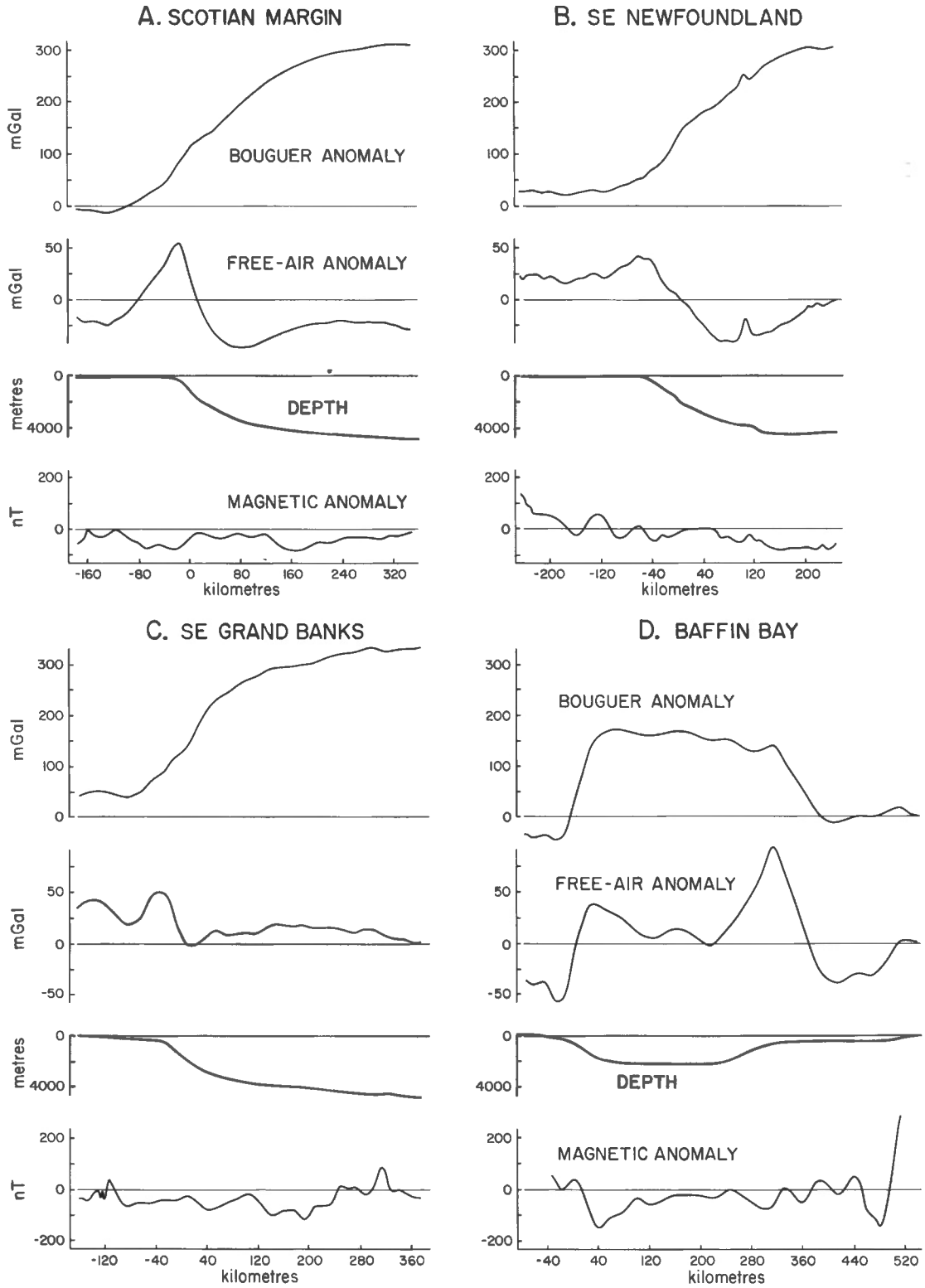
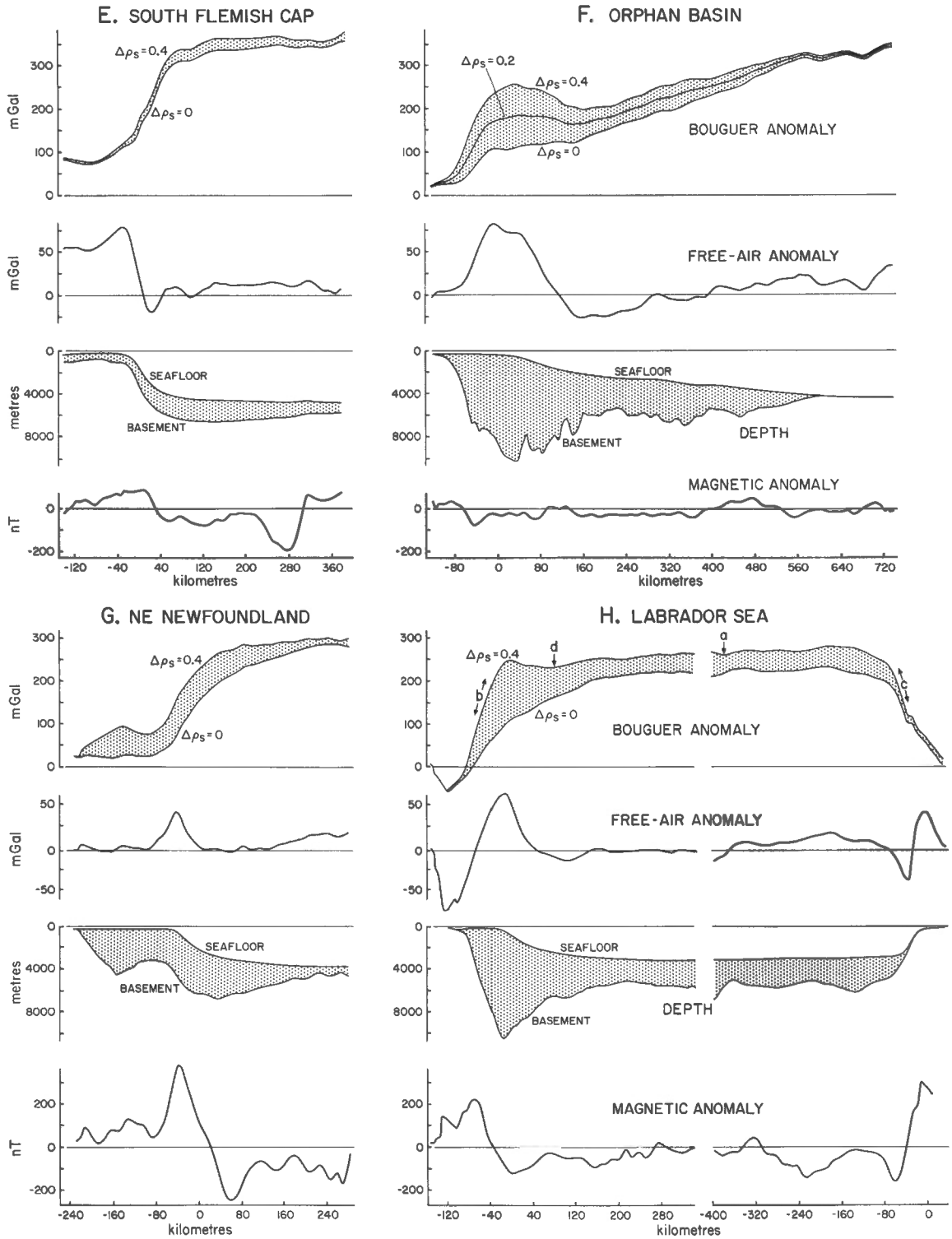


Figure 7. Representative stacked profiles for all eight marginal sections, plotted at the same scales for comparison purposes. Locations are shown in Figure 6. For four sections (E-F), depth to basement is shown along with Bouguer anomaly corrected for sediments as well as water depth. For Bouguer calculations, densities of water, crust, and sediments are 1.0, 1.67, and 2.27 g/cm^3 respectively. In the case of Orphan Basin, a sediment density of 2.47 g/cm^3 was also tried in order to provide an example between the two end members. All profiles are oriented with west to the left and east to the right except for section 7B where northeast is to the left and southwest to the right. Horizontal distance is in kilometres with arbitrary starting position. (A) Nova Scotia margin (9 profiles), (B) southeast Newfoundland (9 profiles), (C) southeast Grand Banks (9 profiles), (D) Baffin Bay (10 profiles), (E) south Flemish Cap (9 profiles), (F) Orphan Basin (8 profiles), (G) northeast Newfoundland (13 profiles), (H) Labrador Sea (11 profiles). Lower case letters in Figure 7H refer to features discussed in text.


E. SOUTH FLEMISH CAP
F. ORPHAN BASIN
G. NE NEWFOUNDLAND
H. LABRADOR SEA
Δρs=0.4
Δρs=0
Δρs=0.2
BOUGUER ANOMALY
FREE-AIR ANOMALY
SEAFLOOR
BASEMENT
DEPTH
MAGNETIC ANOMALY
mGal
metres
nT
kilometres
a
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c
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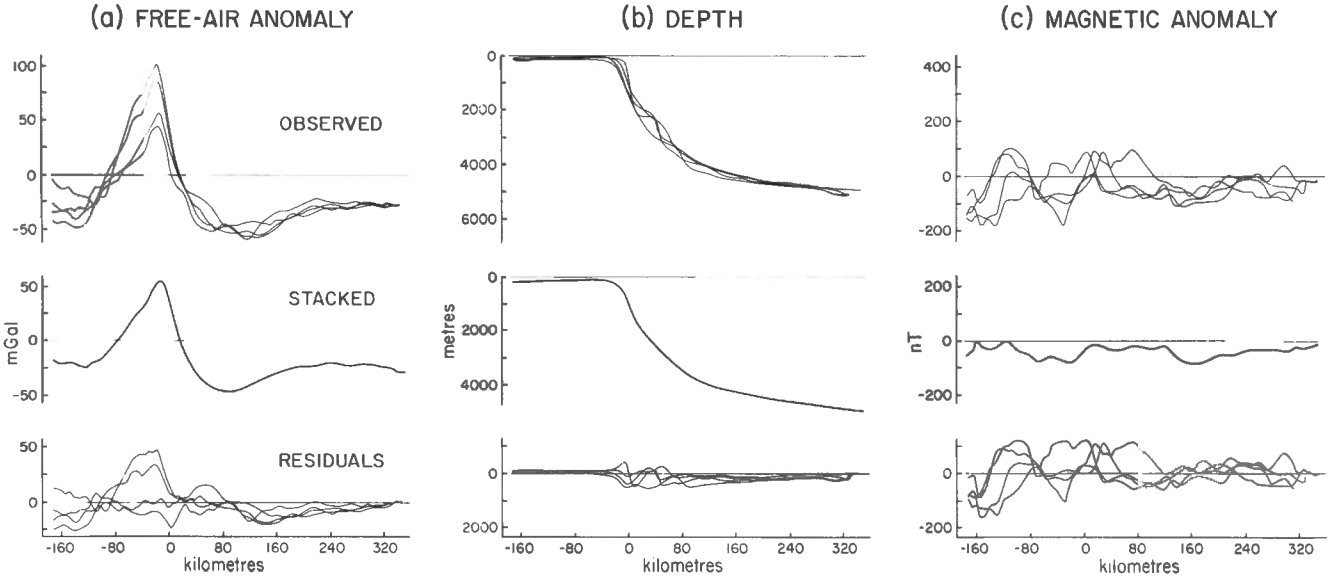

Figure 8. Profiles of gravity (a), bathymetry (b), and magnetic anomaly (c) across the Scotian margin, based on stacking of 4 profiles. The criterion for stacking profiles was best alignment of bathymetry. Upper section shows the individual profiles, middle section shows the resultant profile from stacking, and the residuals between the original profiles and the resultant are shown in the lower section. Northwest is to the left and the horizontal scale is in kilometres with an arbitrary starting point.

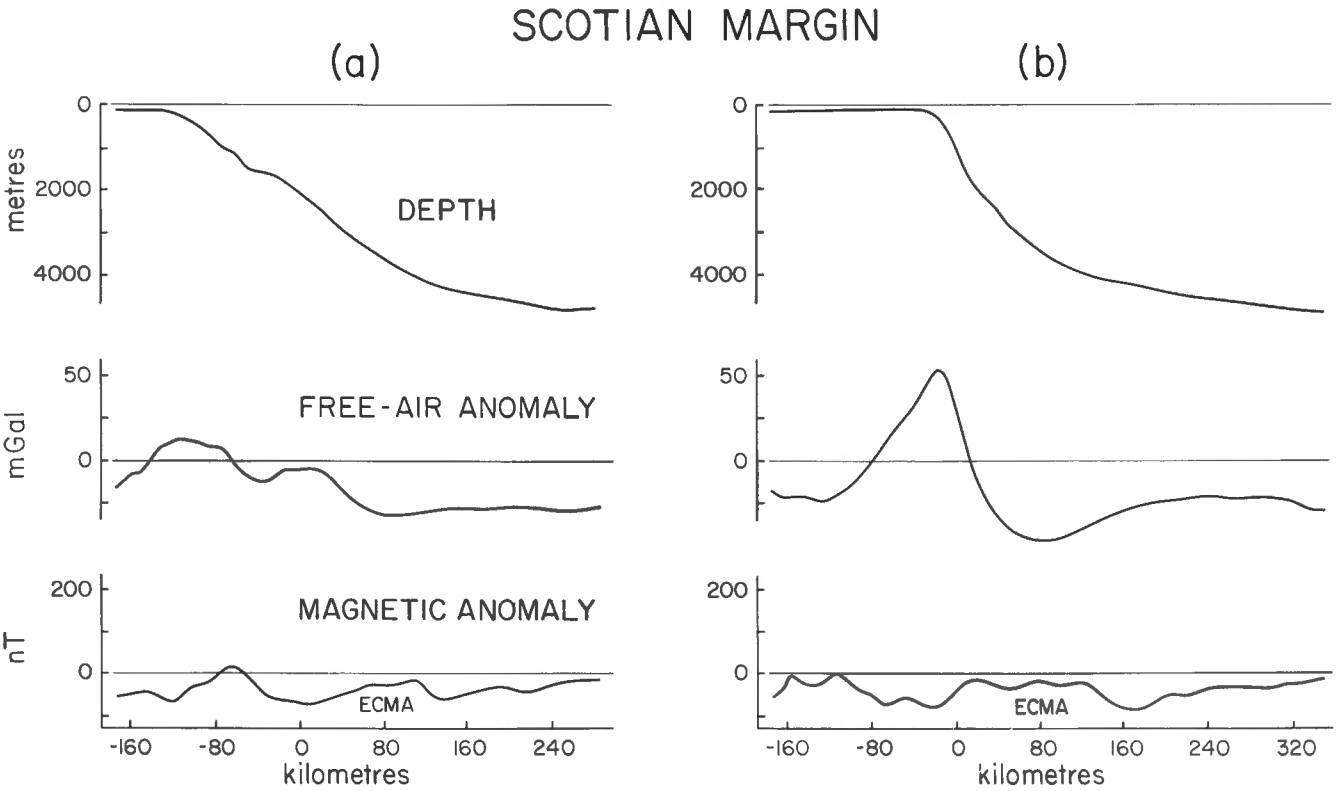

Figure 9. Resultant profiles for the Scotian margin after stacking the nine original profiles on magnetic anomaly (a), and bathymetry (b). ECMA is the location of the East Coast Magnetic Anomaly. Northwest is to the left and the horizontal scale is in kilometres with an arbitrary starting location.

density changes within the crust. In fact the margin environment can be expected to have unusual density distribution, for example, as a result of under-plating of stretched continental crust by partially melted mantle (LASE Study Group, 1986; Keen et al., 1987) or by intrusion of stretched and faulted continental crust by up-welling mantle material during initial rifting (Foucher et al., 1982). The stacking process should have eliminated most of these second order effects, enhancing only those that are truly representative of a particular margin because they are typical everywhere along it.

Variations in the structure of the transition zone between continental and oceanic regimes are thus reflected in the Bouguer anomaly. The Orphan Basin profile illustrates this (Fig. 7F). The middle Bouguer anomaly profile (with a density contrast of -0.2 g/cm^3) is taken to be the most realistic of the three: the upper profile over-corrects for the sedimentary layer by assuming too high a density contrast, and the lower profile does not correct for the sediments at all. All three Bouguer anomaly profiles imply similar structural variations across the basin. The gradual rise of the Moho beneath the basin starts over 100 km west of the shelf break, as indicated by the rise in the Bouguer anomaly and by the crustal structure inferred from seismic studies (as shown in the Northern Appalachians Transect — Fig. 10). The Bouguer anomaly (and hence the Moho) levels off across the main depocentre of Orphan Basin before rising towards the eastern edge where true oceanic crust is found. The implication is that either the continental crustal thickness decreases gradually toward the oceanic crust or there is some other type of eastward density increase within the lithosphere. Either is possible as the mantle depth is poorly known in this part of the basin, and stretching of the lithosphere during basin formation seems to have increased monotonically towards the east (Keen et al., 1987).

The Labrador Sea profiles were designed to follow flow lines for the opening of the oceanic basin (Fig. 6) (Srivastava and Tapscott, 1986). This was to ensure minimal contamination of the data from crossings of fracture zones. As in the case of Baffin Bay, the profiles extend from continent to continent across the entire sea. Note that there is a break in the Labrador Sea profiles in the geological centre. It was necessary to stack the profiles separately from different sides of the sea because the northward convergence of the gravity, magnetic, and bathymetric features of the continental margins on either side meant that stacking on any of these parameters from one side would destroy the correlations which exist on the other side.

There are a number of remarkable features shown in the Labrador Sea profiles. The Bouguer anomaly only partially corrects for the sediment-filled central rift valley. There remains a small Bouguer anomaly low over the east side of the extinct spreading centre whose size and shape indicate that there is a residual negative density contrast within the oceanic crust (point 'a' in Fig. 7H). Adding the correction for basement topography to the normal Bouguer anomaly also accentuates the marginal Bouguer gradient and shifts it landward of the free-air anomaly high on the Labrador side ('b' in Fig. 7H), to the inferred location of the landward increase in depth to mantle (Hinz et al., 1979). On the Greenland side the Bouguer gradient is also localized, but to the west of the free-air anomaly high ('c' in Fig. 7H); and, again, it is closer to the inferred location of the major change in depth to mantle (Stergiopoulos, 1984). In the central part of the sea, the asymmetry in the gravity field remains clear even after the Bouguer and sedimentary layer corrections: the westward decrease in Bouguer anomaly is almost linear between the maximum west of the Greenland margin and a break in slope to the east of the Hopedale Basin on the Labrador side. The break in slope of the Bouguer, near the 120 km mark (point 'd' in Fig. 7H), coincides with the ocean-continent boundary inferred from analysis of magnetic anomalies and seismic data.

Regional transects

Several transects are presented now to draw together many of the features discussed and to illustrate the structural relationships of these features within the tectonic framework of the region (Fig. 10, in pocket). They have been chosen on the basis of their interest and of how much is known about them from previous work. In fact they represent a simple interpolation of information between a number of published crustal sections or sections currently under investigation. Differences that have already been described between the provinces crossed by the transects are in some cases more readily observable in profile, e.g. gravity level differences across boundaries, and variations in gravity and magnetic anomaly amplitude and frequency. The transects are plotted at a scale of 1:5 000 000 for one-to-one correlation with the maps.

Transect 1: West Transect (Hudson Strait to Sohm Abyssal Plain)

This profile incorporates information from a number of investigations between the North Atlantic Ocean south of Nova Scotia and the Superior Structural Province north of the Cape Smith Fold Belt (Jackson et al., 1975; Dainty et al., 1966; Officer and Ewing, 1964; Barrett et al., 1964; Sheridan and Drake, 1968; Willmore and Scheidegger, 1956; Watts and Haworth, 1974; Berry and Fuchs, 1973; Thomas and Gibb, 1977; Thomas, 1974,1985). A preliminary section from the Lithoprobe East deep seismic reflection profile across the boundary between the Grenville and the Appalachians in the Gulf of St. Lawrence has also been included (Marillier et al., in press).

The transect has been fabricated with some license where crustal sections lie at a distance from the profile or at an angle to it. At the southern end of the transect the Gulf of St. Lawrence and Nova Scotian sections have been swung into line with it. This has been justified both on the basis of assumed similarities of the crustal section across the boundary of the Appalachian and Grenville provinces in the Gulf of St. Lawrence and the St. Lawrence estuary, and on the basis of observed similarities in the gravity and magnetic profiles.

The northern end of the transect resembles the western end of the Labrador Transect (Transect 3). Both transects cross the boundary between the Churchill and Superior

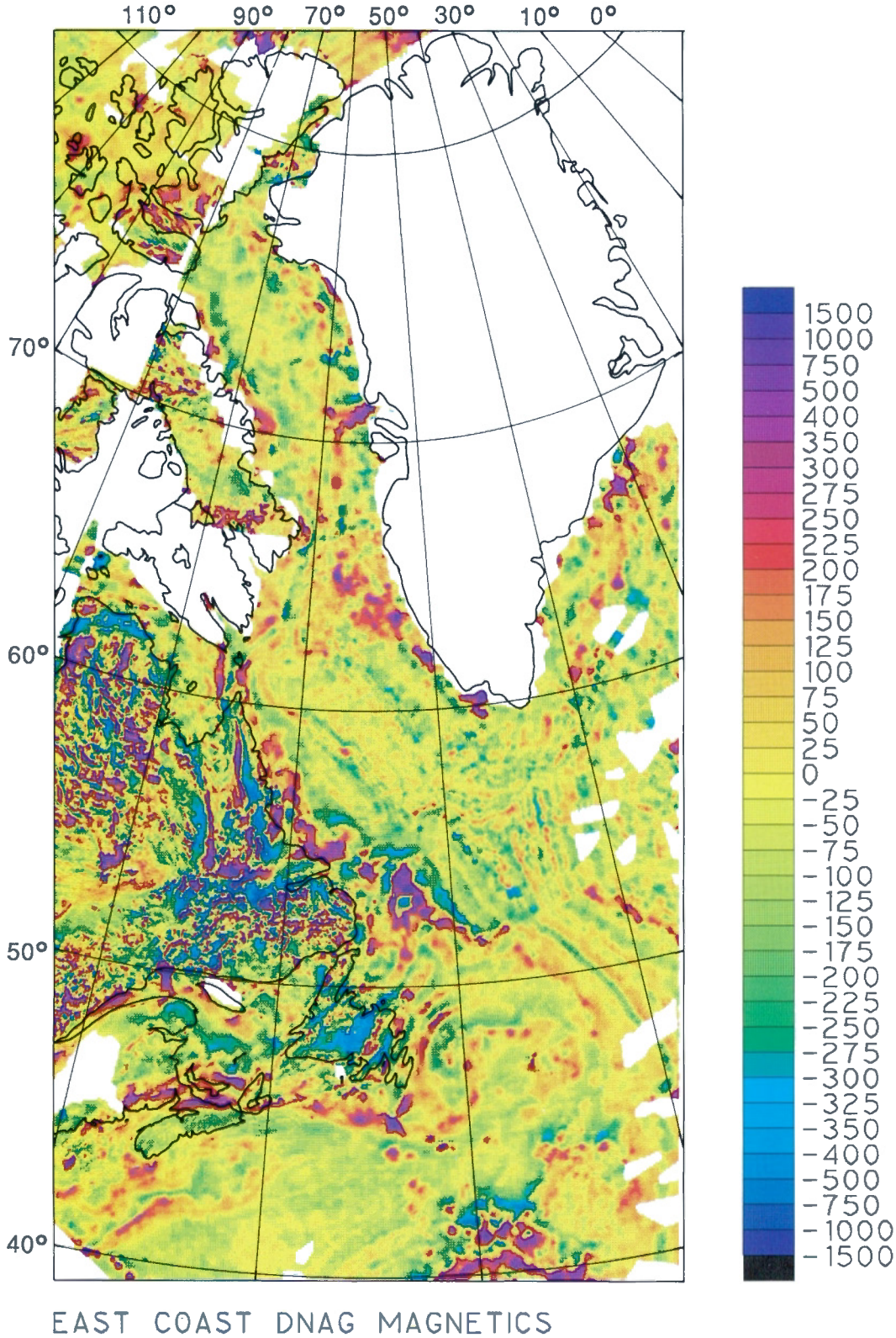

Figure 11. Magnetic anomaly map of eastern Canada based on data indicated in Figures 1 and 2.

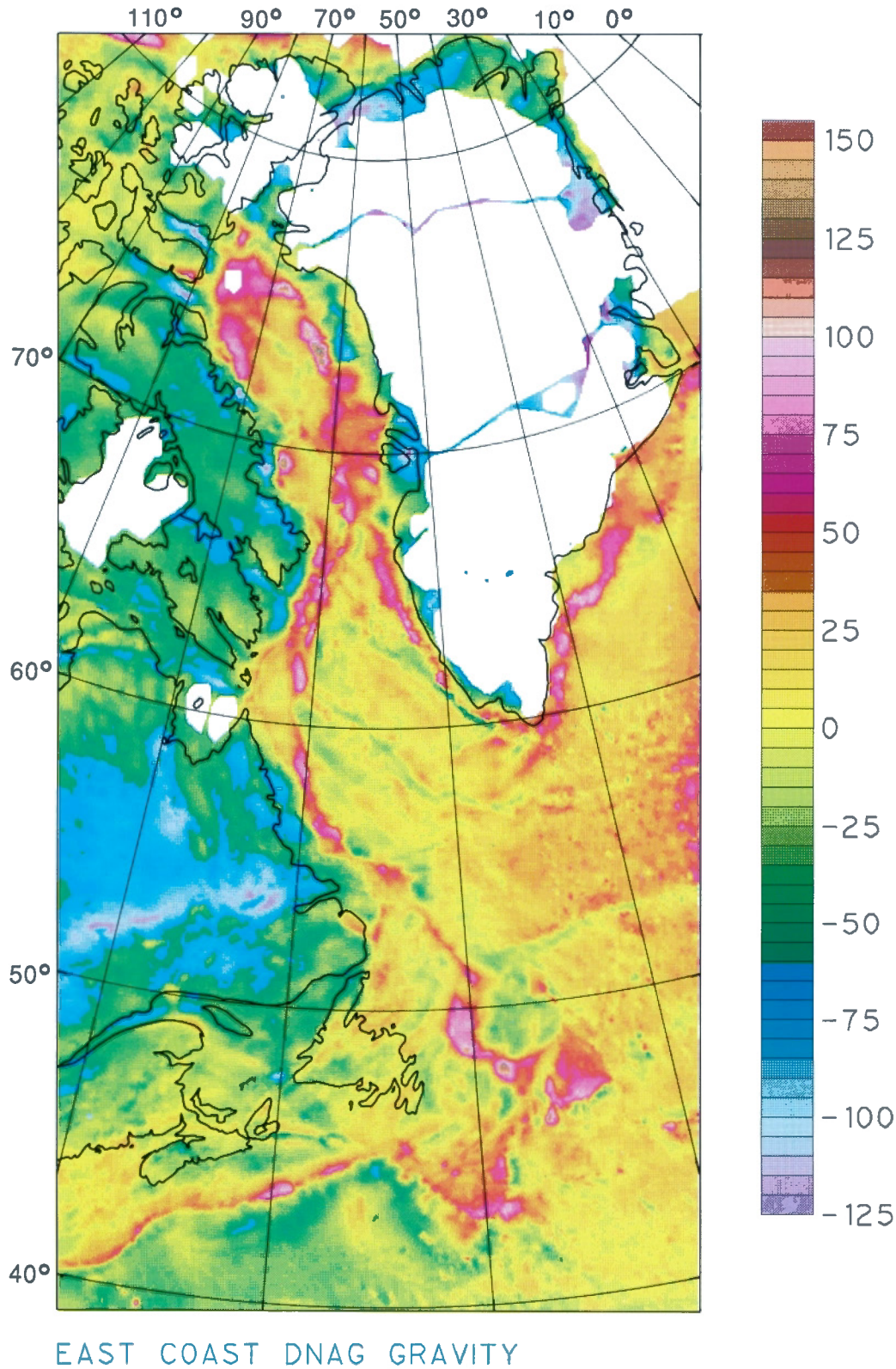

Figure 12. Gravity map of eastern Canada, with Bouguer anomaly for land (assumed crustal density of 2.67 g/cm^3) and free-air anomaly at sea, based on data indicated in Figure 3.

provinces (although in opposite directions), over a trough of folded and metamorphosed sediments and ophiolites. The gravity effect of the ophiolites in the Cape Smith Belt modifies and obscures to a certain degree the typical boundary effect (Gibb and Thomas, 1976) between Precambrian provinces of differing age (Thomas and Gibb, 1977). Two further examples of the boundary between provinces show the expected gravity variation: between the Superior and Grenville at the Grenville Front, and between the Grenville and the Appalachians. In all cases there is also a positive level shift in gravity between the older and younger province (see also Fig. 5).

The magnetic anomaly across the Superior Province is a distinctively high frequency and high amplitude signal. The Ungava Belt, across which the transect is drawn, consists predominantly of Archaean granulites with some gneiss and volcanic rocks, especially in the southern part. Near the southern boundary of the Superior the magnetic anomaly shows much lower variability in a region of gneiss. Negative magnetic anomaly and very low variability characterize the Grenville Front Tectonic Zone.

The shortness of the section across the Grenville makes it difficult to appreciate the characteristics of the gravity and magnetic anomaly which can be seen better on the maps. The gravity fluctuations are like those of the Superior in profile, but at a more positive level; and the magnetic anomaly shows smoother variations but of nearly the same amplitude over the Grenville gneisses as over the Superior.

South of the Appalachian Front (the break between undeformed strata of the St. Lawrence lowlands and the deformed rocks of the Appalachian Province (Williams et al., 1972)), there is more variability of the gravity anomaly in profile than to the north, but these variations remain less than 50 mGal until the shelf edge anomaly is crossed near the 2500 km mark (Fig. 10). Between the north side of the Appalachians and the hinge line south of Nova Scotia the transect crosses the Magdalen Basin and the Cobequid Mountains. The only major signal in either the gravity or the magnetic profile is the magnetic anomaly over the volcanics associated with the faults defining the Bay of Fundy and the Cobequid Mountains—three positive excursions of over 300 nT. The lack of significant gravity anomalies over the sedimentary basin and the mountains is partly because the gravity anomaly is a simple Bouguer anomaly which has corrected for much of the topographical effect of the mountain, and partly because of the presence within the Magdalen Basin of sedimentary rocks of densities close to that of the surrounding crust.

Structure within the Appalachian Province has now been resolved in the Gulf of St. Lawrence by deep seismic reflection data (Marillier et al., in press; Keen et al., 1986). The transect profiles of gravity and magnetics are very similar to those published for a transect across the Appalachians in Newfoundland (Haworth et al., 1985). The Dunnage Zone is an allochthonous vestige of an oceanic domain overlying Grenville and other unknown crust (Keen et al., 1986; Williams, 1979). The gravity anomaly is slightly more positive over this terrane; and there are positive magnetic anomalies at the edges of it, with a magnetic negative over most of the zone. At the southern side of the Gander Zone on this transect, both the gravity and magnetic anomaly variations are correlated with the Late Triassic to Early Jurassic volcanism which occurred around the Bay of Fundy during the initial rifting phase prior to opening of the present North Atlantic (Keen et al., in press).

Because the crustal structure beneath the Appalachians is based on an old gravity model with few constraints (Dainty et al., 1966), it must be regarded with caution. Under the Carboniferous Magdalen Basin, there is a substantial thickness of high density lower crust (3.11 gm/cm^3). The actual depth of the mantle is clearly dependent on the proportion of high density crust to lower density crust, and there is little control there except for mantle depth at the ends of this particular section (i.e. north of Prince Edward Island and south of Nova Scotia) and the need to satisfy the observed gravity in between.

This crossing of the continental margin shows neither the large positive gravity anomaly over the Scotian Basin as observed farther to the northeast nor a fully-developed East Coast Magnetic Anomaly (ECMA) as appears farther to the southwest (Taylor et al., 1968; Klitgord and Behrendt, 1979). Both are visible on the profile however. Because it crosses the margin between subbasins of the Scotian Basin, this transect does not exhibit the deep sedimentary basins (greater than 10 km) characteristic of the Scotian margin to the northeast and southwest (Wade, 1981; Keen and Haworth, 1985c; Grant et al., 1986). The ECMA lies close to the outer edge of the Scotian Basin. The shelf-edge gravity high lies over the main depocentre of the basin, and the flanking lows lie over the margins of the basin. The locations of the magnetic and gravity anomalies are in keeping with their postulated origin as a combination of relief on magnetic basement and contrast in magnetization between oceanic and continental crust in the case of the magnetic anomaly (Keen, 1969; Keen et al., 1974; Sheridan et al., 1979), and, for the gravity effect, as variable compensation of a sedimentary load on a flexed lithosphere (Beaumont et al.,1982). The ECMA may be intimately connected with the intrusion of partially-melted mantle material into the seaward edge of attenuated continental crust (Allsop and Talwani, 1984; LASE Study Group, 1986).

Transect 2: Baffin Bay

Seismic refraction experiments in Baffin Bay have been used to constrain structural models based on gravity measurements (Keen and Barrett, 1972; Jackson et al., 1979, 1977). Additional unpublished industrial seismic reflection data were used by Menzies (1982) in a structural cross-section. The transect presented here makes use of information published by Menzies (1982) only in the east. The reconnaissance nature of geophysical exploration in this area makes interpretation of a geological transect rather more speculative than for other transects.

The Greenland margin is much wider than the Baffin Island margin. The marginal gravity high is wider, as is the region of down-faulting beneath the shelf. The extinct spreading centre appears to lie closer to Baffin Island (Rice and Shade, 1982). To the north of the transect the wide

Melville Bay Graben underlies the Greenland shelf, and to the south volcanic rocks are an important constituent of the margin (Clarke and Pedersen, 1976).

The central part of Baffin Bay is shown as oceanic in character; however there is still debate whether this is true or not. For example, Grant (1982) argued that Baffin Bay originated through vertical rather than horizontal movements, but Jackson et al. (1979) interpreted the gravity and magnetic data from central Baffin Bay in terms of seafloor spreading. Neither the gravity nor the magnetic anomalies shown in this profile shows the detail necessary to examine these points of view.

Transect 3: Labrador to Greenland

This profile stretches from the Superior Province of the Canadian Shield across the Labrador Trough, the Churchill and Nain Provinces, and the Labrador Sea to Greenland, stringing together information from several studies (Kearey and Halliday, 1976; Thomas et al., 1978; van der Linden, 1975; Hinz et al., 1979; Stergiopoulos, 1984; Mayhew et al., 1970; Keen and Haworth, 1985d). The profile is discontinuous on the inner continental shelf where there is a southeastward shift of about 250 km; but the join is designed to occur along a line of roughly similar geology so that the transect might be considered to represent a typical cross-section of the region.

Clearly shown on the gravity profile is the positive shift in level from the Superior Province to the Churchill Province. The boundary between the Churchill Province and the Nain Province to the east is less apparent, possibly because the gravity profile does not include enough of the Nain Province, and also because of the change from Bouguer to free-air anomaly over the Labrador Sea, which appears as a positive shift; however, this boundary is clearly shown by the negative magnetic anomaly following the Abloviak shear zone and the Komaktorvik Zone of the Churchill foreland zone (Korstgård et al., 1987)(see below). As noted before, the free-air anomaly varies about zero but the Bouguer anomaly is generally negative over land because of the presence of crustal roots compensating for both the topographic and intracrustal loads. The basic meta-igneous rocks of the Labrador Trough are marked by a relative positive anomaly.

There is clearly an interesting contrast between the gravity signatures of the conjugate continental margins: the wide Labrador margin with deep sedimentary basin has a large positive gravity anomaly, and the narrow Greenland margin at this latitude has a sharp negative anomaly over a narrow sedimented trough at the edge of the continental crust. To the east of the trough, the gravity anomaly becomes positive, and then decreases to the negative values appropriate for the Bouguer anomaly over elevated terrain.

Although relative gravity variations across the central Labrador Sea are symmetrical about the extinct spreading axis (the buried rift valley which is marked by a negative gravity anomaly), the asymmetry in the level of the gravity anomaly is obvious in profile. Free-air values are about 20 mGal greater over the eastern part of the sea.

The magnetic anomaly variations are greater over land than over sea, in part because of the increased distance to source of the weaker marine anomalies, and in part because of the nature of the sources. The last phase of seafloor spreading between the lower Paleocene and lower Oligocene produced weak magnetic anomalies which vary about zero; however the older pattern of anomalies has a negative offset from zero that is quite striking in profile. Near the continent-ocean boundary on both sides there is a relative high.

These variations are attributed to variations in crustal magnetic susceptibility and to both the spreading rate and predominant polarity of the seafloor spreading anomalies (Arkani-Hamed and Verhoef, in press). Longer periods of reversed magnetic polarity in comparison to those of normal polarity during active seafloor spreading are therefore believed to be responsible for the generally negative character of the longer wavelength magnetic anomalies in the Labrador Sea. The subdued magnetic anomalies of the central part of the sea originated during a period of slower spreading (<2 mm/a compared to 7 to 10 mm/a before anomaly 21), suggesting that the effective magnetization of the crust was weaker because of the cancelling effect of overlapping oppositely-magnetized layers (Arkani-Hamed and Verhoef, in press).

The magnetic anomalies across Labrador and Quebec are much more remarkable than those at sea. The largest amplitudes are for the north-south oriented anomalies in the Churchill Province. Low negative values along the Labrador Trough Fold Belt at the west edge of the Churchill are associated with rocks of greenschist to lower amphibolite metamorphic facies. Within these are ophiolitic rocks which have a positive magnetic (and gravity) anomaly extending from the Grenville Front to the west side of Ungava Bay. Farther west, positive high-frequency magnetic anomalies are associated with a granulite complex in the Ungava Belt. Much higher positive amplitudes are registered over the granulites in the eastern Churchill Province.

The major negative anomaly over the Abloviak Shear Zone and the Komaktorvik Zone just west of the eastern edge of the Churchill follows a zone of garnetiferous mylonite gneiss (Korstgård et al., 1987). It has been suggested that the magnetite content of rocks within a similar shear belt in western Greenland (a possible continuation of the Abloviak Shear zone) is lowered because titanomagnetite becomes unstable in the shear zone and less magnetic hydrated ferrous oxides form (Bridgwater and Myers, 1979). This magnetic anomaly and those of western Churchill Province are prominent both in profile and on the coloured magnetic map, and, like the gravity variation, show the contrast in geophysical characteristics of the Superior and Churchill provinces. These are in turn different from the variations over the Labrador Sea.

Transect 4: Northern Appalachians and Orphan Basin

As part of the Lithoprobe East program, deep seismic reflection profiles were obtained in 1984 across the northern Appalachians northeast of Newfoundland and Orphan Basin (Keen et al., 1987,1986). The transect was constructed from these profiles and from additional seismic refraction information (Keen and Barrett, 1981; Sheridan and Drake, 1968; Fenwick et al., 1968). It updates a transect already published for this area which was created before the Lithoprobe lines were shot (Haworth et al., 1985; Keen and Haworth, 1985a). The previous transect was constructed to cross the Appalachians from southern Labrador to the Avalon Peninsula across central Newfoundland (Keen and Haworth, 1985a); however the new transect follows the Lithoprobe East deep seismic reflection line for the convenience of the additional control. A preliminary depth section for the Lithoprobe East line 84-3 was provided by C.E. Keen (pers. comm., 1988). In broad terms the transect comprises two segments: a western part across the Appalachian structures, and a section at a different azimuth to the east which crosses the Late Mesozoic to Tertiary Orphan Basin.

Some similarities are apparent between this transect and that part of the West Transect (Transect 1) that crosses the Appalachian Orogen. There is a positive step in the gravity anomaly from the Grenville Province into the Appalachians, as well as a rise in the magnetic anomaly over the Humber Zone. The gravity anomaly does not show appreciable change until the Dover Fault where there is another positive step from west to east. The Dover Fault marks the boundary between the Gander and Avalon zones and juxtaposes crust of different character (Keen et al., 1986; Stockmal et al., 1987).

The eastern part of the transect differs significantly from any of the other transects. A major positive gravity anomaly of about 100 mGal dominates the transect. It is positioned over the principal depocentre of Orphan Basin, and has been attributed to a thick wedge of sediments built out over a thinned but rigid continental crust (LeBis, 1975; Walcott, 1972; Keen and Barrett, 1981). The size of the gravity anomaly and the presence of only small flexurally-induced gravity lows on either side make the compensation for this excess mass difficult to understand without there being unusual crustal strength. Additional strength might be obtained if the crust cooled and thickened to a greater degree before subsidence beneath the sedimentary load began. This hypothesis is based on the idea that the basin was only completely free to subside after the promontory of the east-moving European Plate had finally moved beyond the mouth of Orphan Basin, after moving outward in transform contact with the south and north sides of the basin, and separated from Orphan Knoll. The transect shows an anomalously wide region of intermediate crustal thickness between the Bonavista Platform and oceanic crust at 45° W. As noted in the previous section on Geophysical Characteristics of Selected Marginal Sections, an increase in density eastward within the lithosphere may explain the gradual rise in the gravity anomalies across Orphan Basin in the absence of significant eastward thinning of the crust. The positive magnetic anomaly at 45°W marks the boundary between oceanic and extended continental crust (Srivastava et al., 1988 a, b).

Transect 5: Grand Banks

This transect crosses the transform margin south of Newfoundland (the Southeast Newfoundland Fracture Zone) in the southwest, and the complex margin segment which incorporates Jeanne d'Arc Basin and Flemish Cap to the northeast. The southern portion is an update, based on new data, of a previously published transect (Keen and Haworth, 1985b). The transform margin has been the subject of recent seismic refraction experiments (Todd et al., 1988) and the crossing of Jeanne d'Arc Basin and Flemish Cap lies along a recent deep seismic reflection profile obtained as part of Lithoprobe East (Keen and de Voogd, 1988; de Voogd and Keen, 1987; Keen et al., 1987). This new information, along with existing data (Bentley and Worzel, 1956; Keen and Barrett, 1981; Press and Beckman, 1954; Sheridan and Drake, 1968), are used in constructing the transect. A preliminary depth section of the Lithoprobe East line 85-3 was provided by W. Kay (pers. comm., 1988).

There is some similarity between the gravity and magnetic effects and structure of the margin southeast of Newfoundland, and that east of Flemish Cap. Both margins are associated with a step in the gravity, down toward the ocean, and a positive magnetic anomaly over the likely position of the ocean-continent boundary. The magnetic anomaly across the Southeast Newfoundland transform is associated with a volcanic feature which is absent east of Flemish Cap; however the main source of the anomaly there is interpreted to be due to the juxtaposition of weakly magnetized continental crust against highly magnetized oceanic crust created during the Cretaceous Quiet Period (Srivastava et al., 1987). Although there is a sharp transition from continental to oceanic crust east of Flemish Cap, the true edge of the North American plate along this margin is west of Flemish Cap, because Flemish Cap is considered to be a continental fragment separated from the Grand Banks during early rifting (King et al., 1985). In this case the full margin would stretch from the west side of Jeanne d'Arc Basin to the east side of Flemish Pass, in keeping with the extended margin of Orphan Basin (the northeast side of which is also marked by a continental fragment, Orphan Knoll; Ruffman and van Hinte, 1973).

The transition zone between ocean and continent along the southeast Newfoundland transform is about 20 km wide (Todd et al., 1988). There is a gradual thinning of the Grand Banks crust towards its southern edge, but not of the oceanic crust near the transition zone, despite the disappearance of oceanic layer 3 (Todd et al., 1988). A layer of (oceanic) volcanic material and sediments overlies Paleozoic basement in the transition zone.

On the Grand Banks, the major positive magnetic anomaly is part of the Collector Anomaly, and the smaller anomalies to the north of this represent crossings of the arcuate Avalon basement anomalies discussed earlier.

CONCLUDING REMARKS

The principal geological features of eastern Canada are reflected in the gravity and magnetic data acquired throughout the region. More detailed examination of the geology which can be inferred from the gravity and magnetic data in this way requires, in most cases, a denser data coverage with more detailed potential field surveying focussed on the specific area of interest. At this stage, a large part of the work in progress is using the regional data base to investigate large sub-areas which exhibit anomalous potential fields; however this inevitably leads to closer examination of features within the sub-areas or comparisons between different areas. It may also suggest potentially rewarding geological fieldwork.

This review of studies completed or in progress in eastern Canada presents some of the work which has led to our current understanding of the geological and tectonic framework of the region. It provides access to some of the pertinent literature, a point of departure for further research, and ideas for subsequent analyses of the gravity and magnetic data.

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References

Allsop, L.E. and Talwani, M.
1984: The East Coast Magnetic Anomaly; Science, v. 236, p.1189-1191.

Arkani-Hamed, J. and Verhoef, J.
in press Generalized inversion of scalar magnetic anomalies: magnetization of the crust of east coast Canada; AGU monograph series on lower crustal properties. S. Mueller and R.F. Mereu, ed.

Balkwill, H.R.
1978: Evolution of the Sverdrup Basin, Arctic Canada; American Association of Petroleum Geologists Bulletin, v. 62, no. 6, p. 1004-1028.

Balkwill, H.R. and Fox, F.G.
1982: Incipient rift Zone, western Sverdrup Basin, Arctic Canada; in Arctic Geology and Geophysics, A.F. Embry and H.R. Balkwill, ed., Canadian Society of Petroleum Geologists, Memoir 8, p. 171-187.

Balmino, G., Moynot, B., Sarrailh, M., and Valès, N.
1987: Free air gravity anomalies over the oceans from Seasat and GEOS 3 altimeter data; Eos Transactions of the American Geophysical Union, v. 68, no. 2, p.17-19.

Barraclough, D.R.
1987: International Geomagnetic Reference Field: the fourth generation; Physics of the Earth and Planetary Interiors, v. 48, p. 279-292.

Barrett, D.L.
1966: Lancaster Sound shipborne magnetometer survey; Canadian Journal of Earth Sciences, v. 3, p. 223-235.

Barrett, D.L. and Keen, C.E.
1976: Mesozoic magnetic lineations: the Magnetic Quiet Zone and seafloor spreading in the northwest Atlantic; Journal of Geophysical Research, v. 81, p. 4875-4884.

Barrett, D.L., Berry, M., Blanchard, J.E., Keen, M.J., and McAllister, R.E.
1964: Seismic studies on the eastern seaboard of Canada: the Atlantic coast of Nova Scotia; Canadian Journal of Earth Sciences, v. 1, p. 10-22.

Beaumont, C., Keen, C.E., and Boutilier, R.
1982: On the evolution of rifted continental margins: comparison of models and observations for the Nova Scotian margin; Geophysical Journal of the Royal Astronomical Society, v. 70, no. 3, p. 667-716.

Bentley, C.R. and Worzel, J.L.
1956: Geophysical investigations in the emerged and submerged Atlantic coastal plain. Part X. Continental slope and rise south of the Grand Banks; Bulletin of the Geological Society of America, v. 67, p. 1-18.

Berry, M.J. and Fuchs, K.
1973: Crustal structure of the Superior and Grenville provinces of the northeastern Canadian shield; Bulletin of the Seismological Society of America; v. 63, no. 4, p. 1393-1432.

Bridgwater, D. and Myers, J.S.
1979: Outline of the Nagssugtoqidian mobile belt of East Greenland; in Nagssugtoqidian Geology, Grønlands Geologiske Undersøgelse, Rapport Nr. 89, p. 9-18.

Cameron, E.M.
1986: An introduction to the interpretation of data from central Baffin Island, District of Franklin; Geological Survey of Canada, Paper 86-10, 22 p.

Clarke, D.B. and Pedersen, A.K.
1976: Tertiary volcanic province of West Greenland; in Geology of Greenland, A. Escher and W.S. Watt, ed., Grønlands Geologiske Undersøgelse, p. 363-385.

Clarke, D.B. and Upton, B.G.J.
1971: Tertiary basalts of Baffin Island: field relations and tectonic setting; Canadian Journal of Earth Sciences, v. 8, no. 2, p. 248-258.

Dainty, A.M., Keen, C.E., Keen, M.J., and Blanchard, J.E.
1966: Review of geophysical evidence on crust and upper mantle structure on the eastern seaboard of Canada; in The Earth Beneath the Continents, J.S. Steinhart and T.J. Smith, ed., American Geophysical Union, Geophysical Monograph 10, p. 349-369.

Davidson, A.
1972: The Churchill Province; in Variations in Tectonic Styles in Canada; R.A. Price and R.J.W. Douglas, ed., Geological Association of Canada, Special Paper no. 11, p. 381-433.

de Voogd, B. and Keen, C.E.
1987: Lithoprobe East: results from reflection profiling of the continental margin: Grand Banks region; Geophysical Journal of the Royal Astronomical Society, v. 89, p. 195-200.

Dimroth, E.
1972: The Labrador geosyncline revisited; American Journal of Science, v. 272, p. 487-506.

Doig, R.
1987: Rb-Sr geochronology and metamorphic history of Proterozoic to early Archean rocks north of the Cape Smith Fold Belt, Quebec; Canadian Journal of Earth Sciences, v. 24, no. 4, p. 813-825.

Earth Physics Branch
1986: Integration of Atlantic Geoscience Centre marine gravity data into the National Gravity Data Base; Earth Physics Branch, Open File 85-32, Department of Energy, Mines and Resources, Ottawa, 54 p.

Easton, R.M.
1986: Geochronology of the Grenville Province, in The Grenville Province, J.M. Moore et al., ed., Geological Association of Canada, Special Paper 31, p. 127-173.

Emslie, R.F., Hulbert, L.J., Brett, C.P., and Garson, D.F.
1978: Geology of the Red Wine Mountains, Labrador: The Ptarmigan Complex; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 129-134.

Fenwick, D.K.B., Keen, M.J., Keen, C., and Lambert, A.
1968: Geophysical studies of the continental margins northeast of Newfoundland; Canadian Journal of Earth Sciences, v. 5, p. 483-500.

Foucher, J.-P., Le Pichon, X., and Sibuet, J.-C.
1982: The ocean-continent transition in the uniform lithospheric stretching model: role of partial melting in the mantle; Philosophical Transactions of the Royal Society of London, Series A, v. 305, p.27-43.

Gibb, R.A. and Thomas, M.D.
1976: Gravity signature of fossil plate boundaries in the Canadian Shield; Nature, v. 262, p. 199-200.

Godson, R.H.
1985: Preparation of a digital grid of gravity anomaly values of the conterminous United States; in The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze, ed., Society of Exploration Geophysicists, Tulsa, USA, 454 p.

Goodwin, A.M., Ambrose, J.W., Ayers, L.D., Clifford, P.M., Currie, K.L., Ermanovics, I.M., Fahrig, W.F., Gibb, R.A., Hall, D.H., Innes, M.J.S., Irvine, T.N., MacLaren, A.S., Norris, A.W., and Pettijohn, F.J.
1972: The Superior Province: in Variations in Tectonic Styles in Canada; R.A. Price and R.J.W. Douglas, ed., Geological Association of Canada, Special Paper no. 11, p. 527-623.

Gower, C.F. and Ryan, A.B.
1986: Proterozoic evolution of the Grenville Province and adjacent Makkovik Province in eastern-central Labrador; in The Grenville Province, J.M. Moore et al., ed, Geological Association of Canada, Special Paper 31, p. 281-296.

Gower, C.F., Neuland, S., Newman, M., and Smyth, J.
1987: Geology of the Port Hope Simpson map region, Grenville Province, eastern Labrador; in Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, p. 183-199.

Grant, A.C.
1982: Problems with plate tectonic models for Baffin Bay - Nares Strait: evidence from the Labrador Sea; in Nares Strait and the Drift of Greenland: A Conflict in Plate Tectonics, in P.R. Dawes and J.W. Kerr, ed., Meddelelser om Grønland, Geoscience, v. 8, p. 313-326.

Grant, A.C., McAlpine, K.D., and Wade, J.A.
1986: The continental margin of eastern Canada: Geological framework and petroleum potential; in Future Petroleum Provinces of the World, M.T. Halbouty, ed., American Association of Petroleum Geologists, Memoir 40, p. 177-205.

Haworth, R.T.
1975: The development of Atlantic Canada as a result of continental collision — evidence from offshore gravity and magnetic data; in Canada's Continental Margins and Offshore Petroleum Exploration, C.J. Yorath et al., ed., Canadian Society of Petroleum Geologists, Memoir 4, p. 59-77.

Haworth, R.T., and Lefort, J.-P.
1979: Geophysical evidence for the extent of the Avalon zone in Atlantic Canada; Canadian Journal of Earth Sciences, v. 16, no. 3, p. 552-567.

Haworth, R.T., and McIntyre, J.B.
1975: The gravity and magnetic fields of Atlantic offshore Canada; Geological Survey of Canada, Paper 75-9, 22 p.

Haworth, R.T., and Miller, H.G.
1982: The structure of Paleozoic oceanic rocks beneath Notre Dame Bay, Newfoundland; in Major Structural Zones and Faults of the Northern Appalachians, P. St.-Julien and J. Beland, ed., Geological Association of Canada Special Paper 24, p. 149-173.

Haworth, R.T., Daniels, D.L., Williams, H., and Zeitz, I.
1980: Bouguer gravity anomaly map of the Appalachian orogen; Memorial University of Newfoundland, Map No. 3, 1:1 000 000.

Haworth, R.T., Williams, H., and Keen, C.E.
1985: D1 Northern Appalachians: (West sheet) Grenville Province, Quebec to Newfoundland; R.C. Speed, coordinator, North American Continent-Ocean Transects Program; Geological Society of America, Centennial Continent/Ocean Transect #1, 1 map sheet, 9 p.

Higgins, M.D. and Doig, R.
1981: The Sept Iles anorthosite complex: field relationships, geochronology, and petrology; Canadian Journal of Earth Sciences, v. 18, no. 3, p. 561-573.

Hinz, K., Schlüter, H.-U., Grant, A.C., Srivastava, S.P., Umpleby, D., and Woodside, J.
1979: Geophysical transects of the Labrador Sea: Labrador to southwest Greenland; in Crustal Properties across Passive Margins, C.E. Keen, ed., Tectonophysics, v. 59, p. 151-183.

Hodych, J.P. and Hayatsu, A.
1980: K-Ar isochron age and paleomagnetism of diabase along the trans-Avalon aeromagnetic lineament - evidence of Late Triassic rifting in Newfoundland; Canadian Journal of Earth Sciences, v. 17, no.4, p. 491-499.

Hoffman, P.F.
1985: Is the Cape Smith belt (northern Quebec) a klippe?; Canadian Journal of Earth Sciences, v. 22, no. 9, p. 1361-1369.
1988: United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia; Annual Review of Earth and Planetary Sciences, v. 16, p. 543-603.

IAG
1967: Geodetic Reference System 1967; International Association of Geodesy, Publication Spécial no. 3, Paris, 116 p.

Jackson, G.D. and Morgan, W.C.
1978: Precambrian metamorphism on Baffin and Bylot Islands; in Metamorphism in Canada, J.A. Fraser and W.W. Heywood, ed., Geological Survey of Canada, Paper 78-10, p. 249-267.

Jackson, H.R. and Koppen, L.
1985: The Nares Strait gravity anomaly and its implication for crustal structure; Canadian Journal of Earth Sciences, v. 22, p. 1322-1328.

Jackson, H.R., Keen, C.E., and Barrett, D.L.
1977: Geophysical studies on the eastern continental margin of Baffin Bay and in Lancaster Sound; Canadian Journal of Earth Sciences, v. 14, no. 9, p. 1991-2001.

Jackson, H.R., Keen, C.E., Falconer, R.K.H., and Appleton, K.P.
1979: New geophysical evidence for sea-floor spreading in central Baffin Bay; Canadian Journal of Earth Sciences, v. 16, no. 11, p. 2122-2135.

Jackson, H.R., Keen, C.E., and Keen, M.J.
1975: Seismic structure of the continental margins and ocean basins of southeastern Canada; Geological Survey of Canada, Paper 74-51, 13 p.

Jansa, L.F. and Pe-Piper, G.
1988: Middle Jurassic to Early Cretaceous igneous rocks along the eastern North American continental margin; American Association of Petroleum Geologists Bulletin, v. 72, no. 3, p. 347-366.

Johnson, G.L., Srivastava, S.P., Campsie, J., and Rasmussen, M.
1982: Volcanic rocks in the Labrador Sea and environs and their relationship to the evolution of the Labrador Sea; in Current Research, Part B, Geological Survey of Canada, Paper 82-1B, p. 7-20.

Karner, G.D. and Watts, A.B.
1982: On isostasy at Atlantic-type continental margins; Journal of Geophysical Research, v. 87, no. B4, p. 2923-2948.

Kearey, P.
1977: A gravity survey of the central Labrador Trough, northern Quebec; Canadian Journal of Earth Sciences, v. 14, no. 1, p. 45-55.

Kearey, P., and Halliday, D.W.
1976: The gravity field of the central Labrador Trough, northern Quebec; Earth Physics Branch, Gravity Map Series no. 162, Department of Energy, Mines and Resources, Ottawa, with map, 13 p.

Keen, C.E. and Barrett, D.L.
1981: Thinned and subsided continental crust on the rifted margin of eastern Canada: crustal structure, thermal evolution and subsidence history; Geophysical Journal of the Royal Astronomical Society, v. 65, p. 443-465.
1972: Seismic refraction studies in Baffin Bay: an example of a developing ocean basin; Geophysical Journal of the Royal Astronomical Society, v. 30, p. 253-271.

Keen, C.E. and Haworth, R.T.
1985a: D1: Northern Appalachians: (East sheet) Rifted margin offshore northeast Newfoundland; R.C. Speed, coordinator, Geological Society of America, Centennial Continent/Ocean Transect #1, 1 map sheet.
1985b: D2 Transform margin south of Grand Banks: Offshore eastern Canada; R.C. Speed, coordinator, Geological Society of America, Centennial Continent/Ocean Transect #2, 1 map sheet.
1985c: D3 Rifted continental margin off Nova Scotia: Offshore eastern Canada; R.C. Speed, coordinator, Geological Society of America, Centennial Continent/Ocean Transect #3, 1 map sheet, 7 p.
1985d: D4 Rifted continental margin off Labrador; R.C. Speed, coordinator, Geological Society of America, Centennial Continent/Ocean Transect #4, 1 map sheet, 5 p.

Keen, C.E., Keen, M.J., Ross, D.I., and Lack, M.
1974: Baffin Bay: small ocean basin formed by sea-floor spreading; American Association of Petroleum Geologists Bulletin, v. 58, no. 6, pt. II, p. 1089-1108.

Keen, C.E. and Peirce, J.W.
1982: The geophysical implications of minimal Tertiary motion along Nares Strait; in Nares Strait and the Drift of Greenland: A Conflict in Plate Tectonics; P.R. Dawes and J.W. Kerr, ed., Meddelelser om Grønland, Geoscience, v. 8, p. 327-337.

Keen, C.E. and de Voogd, B.
1988: The continent-ocean boundary at the rifted margin off eastern Canada: new results from deep seismic reflection studies; Tectonics, v. 7, no. 1, p. 107-124.

Keen, C.E., Boutilier, R., de Voogd, B., Mudford, B., and Enachescu, M.E.
1987: Crustal geometry and extensional models for the Grand Banks, eastern Canada: constraints from deep seismic reflection data; in C. Beaumont and A.J. Tankard, ed., Sedimentary Basins and Basin-Forming Mechanisms, Canadian Society of Petroleum Geologists, Memoir 12, p. 101-115.

Keen, C.E., Keen, M.J., Nichols, B., Reid, I., Stockmal, G.S., Colman-Sadd, S.P., O'Brien, S.J., Miller, H., Quinlan, G., Williams, H., and Wright, J.
1986: Deep seismic reflection profile across the northern Appalachians; Geology, v. 14, p. 141-145.

Keen, C.E., Loncarevic, B.D., Reid, I., Woodside, J., Haworth, R.T., and Williams, H.
in press: Tectonic and geophysical overview; Chapter 2 in Geology of the Continental Margin of Eastern Canada; M.J. Keen and G.L. Williams, ed., Geological Survey of Canada, Geology of Canada, no. 2, (also Geological Society of America, The Geology of North America, v. I-1).

Keen, M.J.
1969: Magnetic anomalies off the eastern seaboard of the United States: a possible edge effect; Nature, v. 222, p. 72-74.

Kent, D.V. and Gradstein, F.M.
1986: A Jurassic to recent chronology; Chapter 3 in The Western North Atlantic Region; P.R. Vogt and B.E.Tucholke, ed., Geological Society of America, The Geology of North America, v. M, p. 45-50.

Kerr, J.W.
1980: Structural framework of Lancaster Aulacogen, Arctic Canada; Geological Survey of Canada, Bulletin 319, 24 p.

King, L.H., Fader, G.B., Poole, W.H., and Wanless, R.K.
1985: Geological setting and age of the Flemish Cap granodiorite, east of the Grand Banks of Newfoundland; Canadian Journal of Earth Sciences, v. 22, no. 9, p. 1286-1298.

Klitgord, K.D. and Behrendt, J.C.
1979: Basin structure of the U.S. Atlantic margin; in Geological and Geophysical Investigations of Continental Margins, J.S. Watkins et al. ed., American Association of Petroleum Geologists, Memoir 29, p. 85-112.

Klitgord, K.D. and Schouten, H.
1986: Plate kinematics of the central Atlantic; Chapter 22 in The Western North Atlantic Region; P.R. Vogt and B.E. Tucholke, ed., Geological Society of America, The Geology of North America, v. M, p. 351-378.

Klose, G.W., Malterre, E., McMillan, N.J., and Zinkan, C.G.
1982: Petroleum exploration offshore southern Baffin Island, northern Labrador Sea, Canada; in Arctic Geology and Geophysics, A.F. Embry and H.R. Balkwill, ed., Canadian Society of Petroleum Geologists, Memoir 8, p. 233-244.

Korstgård, J., Ryan, B., and Wardle, R.
1987: The boundary between Proterozoic and Archaean crustal blocks in central West Greenland and northern Labrador; in Evolution of the Lewisian and Comparable Precambrian High Grade Terrains, R.G. Park and J. Tarney, ed., Geological Society Special Publication No. 27, p 247-259.

LASE Study Group
1986: Deep structure of the US east coast passive margin from large aperture seismic experiments (LASE); Marine and Petroleum Geology, v. 3, p. 234-242.

LeBis, A.P.
1975: Investigations of a gravity high -- offshore Newfoundland; in Canada's Continental Margins and Offshore Petroleum Exploration, C.J. Yorath et al., ed., Canadian Society of Exploration Geologists, Memoir 4, p. 169-180.

Lefort, J.-P.
1983: A new geophysical criterion to correlate the Acadian and Hercynian orogenies of western Europe and eastern America; Geological Society of America, Memoir 158, p. 3-18.

Loncarevic, B.D., and Ewing, G.N.
1967: Geophysical study of the Orpheus Gravity Anomaly; in World Petroleum Congress (7th: 1967: Mexico City) Proceedings, v. 2, Origin of Oil, Geology and Geophysics, New York, Elsevier, p. 827-835.

MacLean, B. and Falconer, R.K.H.
1979: Geological/geophysical studies in Baffin Bay and Scott Inlet-Buchan Gulf and Cape Dyer-Cumberland Sound areas of the Baffin Island Shelf; in Current Research, Part B, Geological Survey of Canada, Paper 79-1B, p. 231-244.

Marillier, F., Keen, C.E., Stockmal, G.S., Quinlan, G., Williams, H., Colman-Sadd, S.P., and O'Brien, S.J.
in press: Crustal structure and surface zonation of the Canadian Appalachians: implications of deep seismic reflection data; Canadian Journal of Earth Sciences.

Mayhew, M.A., Drake, C.L., and Nafe, J.E.
1970: Marine geophysical measurements on the continental margins of the Labrador Sea; Canadian Journal of Earth Sciences, v. 7, no. 2, part 1, p. 199-214.

McIntyre, J.I.
1980: Geological significance of magnetic patterns related to magnetite in sediments and metasediments - a review; Bulletin of the Australian Society of Exploration Geophysicists, v. 11, no. 1/2, p. 19-33.

Menzies, A.W.
1982: Crustal history and basin development of Baffin Bay; in Nares Strait and the Drift of Greenland: A Conflict in Plate Tectonics, P.R. Dawes and J.W. Kerr, ed., Meddelelser om Grønland, Geoscience, v. 8, p. 295-312.

Miall, A.D., Balkwill, H.R., and Hopkins, W.S., Jr.
1980: Cretaceous and Tertiary sediments of the Eclipse Trough, Bylot Island area, Arctic Canada, and their regional setting; Geological Survey of Canada, Paper 79-23, 20 p.

Miller, H.G., Goodacre, A.K., Cooper, R.V., and Halliday, D.
1985: Offshore extensions of the Avalon Zone of Newfoundland; Canadian Journal of Earth Sciences, v. 22, no. 8, p. 1163-1170.

Moore, J.M., Davidson, A., and Baer, A.J. (ed.)
1986: The Grenville Province; Geological Association of Canada, Special Paper 31, 358 p.

Officer, C.B. and Ewing, M.
1964: Geophysical investigations in the emerged and submerged Atlantic coastal plain. Part VII. Continental shelf, continental slope, and continental rise south of Nova Scotia; Bulletin of the Geological Society of America, v. 65, p. 653-670.

Papezik, V.S., Hodych, J.P., and Goodacre, A.K.
1975: The Avelon magnetic lineament - a possible continuation of the Triassic dike system of New Brunswick and Nova Scotia; Canadian Journal of Earth Sciences, v. 12, no. 2, p. 332-335.

Press, F. and Beckmann, W.
1954: Geophysical investigations in the emerged and submerged Atlantic coastal plain. Part VIII. Grand Banks and adjacent shelves; Bulletin of the Geological Society of America, v. 65, p. 299-314.

Rayer, F.G.
1981: Exploration prospects and future petroleum potential of the Canadian Arctic Islands; Journal of Petroleum Geology, v. 3, no. 4, p. 367-412.

Rice, P.D. and Shade, B.D.
1982: Reflection seismic interpretation and sea-floor spreading history of Baffin Bay; in Arctic Geology and Geophysics, Proceedings of the Third International Symposium on Arctic Geology, A.F. Embry and H.R. Balkwill, ed., Canadian Society of Petroleum Geologists, Memoir 8, p. 245-265.

Rivers, T. and Chown, E.H.
1986: The Grenville Orogen in eastern Quebec and western Labrador - definition, identification and tectonometamorphic relationships of autochthonous, parautochthonous and allochthonous terranes; in The Grenville Province, J.M. Moore et al., ed., Geological Association of Canada, Special Paper 31, p. 31-50.

Rivers, T. and Nunn, G.A.G.
1985: A reassessment of the Grenvillian Orogeny in western Labrador; in The Deep Proterozoic Crust in the North Atlantic Provinces, A.C. Tobi and J.L.R. Touret, ed., NATO Advanced Science Institute Series, Series C, Mathematical and Physical Sciences, v. 158, p. 163-174.

Ruffman, A. and van Hinte, J.E.
1973: Orphan Knoll, a 'chip' off the North American 'plate'; in Earth Science Symposium on Offshore Eastern Canada, P.J. Hood, ed., Geological Survey of Canada, Paper 71-23, p. 407-449.

SEG
1982: Gravity anomaly map of the United States (exclusive of Alaska and Hawaii); Society of Exploration Geophysicists, Tulsa, USA, Scale 1:2 500 000, 2 sheets.

Sheridan, R.E. and Drake, C.L.
1968: Seaward extension of the Canadian Appalachians; Canadian Journal of Earth Sciences, v. 5, p. 337-373.

Sheridan, R.E., Grow, J.A., Behrendt, J.C., and Bayer, K.C.
1979: Seismic refraction study of the continental edge of the eastern United States; Tectonophysics, v. 59, p. 1-26.

Sibuet, J.-C. and Veyrat-Peinet, B.
1980: Gravimetric model of the Atlantic equatorial fracture zones; Journal of Geophysical Research, v. 85, no. B2, p. 943-954.

Srivastava, S.P.
1978: Evolution of the Labrador Sea and its bearing on the early evolution of the North Atlantic; Geophysical Journal of the Royal Astronomical Society, v. 52, p. 313-357.
1986: Geophysical maps and geological sections of the Labrador Sea; Geological Survey of Canada, Paper 85-16, with 6 maps, 11 p.

Srivastava, S.P. and Tapscott, C.R.
1986: Plate kinematics of the North Atlantic; Chapter 23 in The Western North Atlantic Region; P.R. Vogt and B.E. Tucholke, ed., Geological Societe, The Geology of North America, v. M, p. 379-404.

Srivastava, S.P., Falconer, R.K.F., and MacLean, B.
1981: Labrador Sea, Davis Strait, Baffin Bay: geology and geophysics - a review; in Geology of the North Atlantic Borderlands, J. W. Kerr and A.J. Ferguson, ed., Canadian Society of Petroleum Geologists, Memoir 7, p. 333-398.

Srivastava, S.P., MacLean, B., Macnab, R.F., and Jackson, H.R.
1982: Davis Strait: Structure and evolution as obtained from a systematic geophysical survey; in Arctic Geology and Geophysics, A.F. Embry and H.R. Balkwill, ed., Canadian Society of Petroleum Geologists, Memoir 8, p. 267-295.

Srivastava, S.P., Verhoef, J., and Macnab, R.
1987: Detailed aeromagnetic survey across the rifted margin northeast of Newfoundland; XIX General Assembly, International Union of Geodesy and Geophysics, Vancouver, August 9-22, 1987, Abstracts, v. 2, p. 471.
1988 a: Results from a detailed aeromagnetic survey across the northeast Newfoundland margin, Part I: spreading anomalies and relationship between magnetic anomalies and the ocean continent boundary; Marine and Petroleum Geology, Vol. 5, pp. 306-323.
1988 b: Results from a detailed aeromagnetic survey across the northeast Newfoundland margin, Part II: early opening of the North Atlantic between the British Isles and Newfoundland; Marine and Petroleum Geology, Vol. 5, pp. 324-337.

St.-Onge, M.R., Lucas, S.B., Scott, D.J., Bégin, N.J., Helmstaedt, H., and Carmichael, D.M.
1988: Thin-skinned imbrication and subsequent thick-skinned folding of rift-fill, transitional-crust, and ophiolite suites in the 1.9 Ga Cape Smith Belt, northern Québec; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 1-18.

Stergiopoulos. A.B.
1984: Geophysical crustal studies off the southwest Greenland margin; M.Sc. Thesis, Dalhousie University, Halifax, Nova Scotia, 191 p.

Stockmal, G.S., Colman-Sadd, S.P., Keen, C.E., O'Brien, S.J., and Quinlan, G.
1987: Collision along an irregular margin: a regional plate tectonic interpretation of the Canadian Appalachians; Canadian Journal of Earth Sciences, v. 24, no. 6, p. 1098-1107.

Taylor, F.C.
1972: The Nain Province; in Variations in Tectonic Styles in Canada; R.A. Price and R.J.W. Douglas, ed., Geological Association of Canada, Special Paper 11, p.435-452.

Taylor, P.T., Zeitz, I., and Dennis, L.S.
1968: Geologic implications of aeromagnetic data for the eastern continental margin of the United States; Geophysics, v. 33, no. 5, p. 755-780.

Thomas, M.D.
1974: The correlation of gravity and geology in southeastern Quebec and southern Labrador; Gravity Map Series of the Earth Physics Branch, Department of Energy Mines and Resources, Canada, with 7 maps, 49 p.
1983: Tectonic significance of paired gravity anomalies in the southern and central Appalachians; in Contributions to the Tectonics and Geophysics of Mountain Chains; R.D. Hatcher et al., ed., Geological Society of America, Memoir 158, p. 113-124.
1985: Gravity studies of the Grenville Province: significance for Precambrian plate collision and the origin of anorthosite; in The Utility of Regional Gravity and Magnetic Anomaly Maps; W.J. Hinze, ed., Society of Exploration Geophysicists, p. 109-123.

Thomas, M.D. and Gibb, R.A.
1977: Gravity anomalies and deep structure of the Cape Smith foldbelt, northern Ungava, Quebec; Geology, v. 5, p. 169-172.
1985: Proterozoic plate subduction and collision: processes for reactivation of Archean crust in the Churchill Province; In Evolution of Archean Supracrustal Sequences; L.D. Ayres et al., ed., Geological Association of Canada, Special Paper 28, p. 263-279.

Thomas, M.D. and Tanner, J.G.
1975: Cryptic suture in the eastern Grenville Province; Nature, v. 256, no. 5516, p. 392-394.

Thomas, M.D., Halliday, D.W., and Stephenson, R.
1978: Gravity anomalies and geological structure in northern Labrador and northeastern Quebec; Gravity Map Series of the Earth Physics Branch, Department of Energy, Mines and Resources, Canada, with 5 maps, 38 p.

Thomas, A., Nunn, G.A.G., and Krogh, T.E.
1986: The Labradorean Orogeny: evidence for a newly identified 1600 to 1700 Ma orogenic event in the Grenville Province crystalline rocks from central Labrador; in The Grenville Province, J.M. Moore et al., ed., Geological Association of Canada, Special Paper 31, p. 176-189.

Thorning, L.
1984: Aeromagnetic maps of parts of southern and central West Greenland; Grf nlands Geologiske Undersf gelse, Rapport Nr. 122, with map, 36 p.
1986: A decade of geophysical surveying in Greenland; in Developments in Greenland Geology, F. Kalsbeek and W.S. Watt, ed., Grf nlands Geologiske Undersf gelse, Rapport Nr. 128, p.12-133.

Todd, B.J., Reid, I., and Keen, C.E.
1988: Crustal structure across the southwest Newfoundland transform margin; Canadian Journal of Earth Sciences, Vol. 25, no. 5, p. 744-759.

Trettin, H.P., Frisch, T.O., Sobczak, L.W., Weber, J.R., Niblett, E.R., Law, L.K., de Laurier, I., and Whitham, K.
1972: The Innuitian Province; in Variations in Tectonic Styles in Canada; R.A. Price and R.J.W. Douglas, ed., Geological Association of Canada, Special Paper no. 11, p. 83-179.

Tucholke, B.E.
1986: Structure of basement and distribution of sediments in the western North Atlantic Ocean; Chapter 20 in The Western North Atlantic Region; P.R. Vogt and B.E. Tucholke, ed., Geological Society of America, The Geology of North America, v. M, p. 331-340.

Tucholke, B.E. and Ludwig, W.G.
1982: Structure and origin of the J anomaly ridge, Western North Atlantic Ocean; Journal of Geophysical Research, v. 87, p. 9389-9407.

Umpleby, D.C.
1979: Geology of the Labrador Shelf; Geological Survey of Canada, Paper 79-13, 34 p.

van der Linden, W.J.M.
1975: Crustal attenuation and sea floor spreading in the Labrador Sea; Earth and Planetary Science Letters, v. 27, p. 409-423.

Verhoef, J. and Macnab, R.
1988: Magnetic data over the continental margin of eastern Canada: preparation of a data base and construction of a 1:5 million magnetic anomaly map; Geological Survey of Canada, Open File 1504, 95 p.

Vogt, P.R., Kovacs, L.C., Bernero, C., and Srivastava, S.P.
1982: Asymmetric geophysical signatures in the Greenland-Norwegian and southern Labrador Seas and the Eurasia Basin; Tectonophysics, v. 89, p. 95-160.

Wade, J.A.
1981: The geology of the Canadian Atlantic margin from Georges Bank to the Grand Banks; in Geology of the North Atlantic Borderlands; J.W. Kerr et al., ed., Canadian Society of Petroleum Geologists, Memoir 7, p. 447-460.

Walcott, R.I.
1972: Gravity, flexure and the growth of sedimentary basins at a continental edge; Geological Society of America Bulletin, v. 83, p. 1845-1848.

Wardle, R.J., Ryan, B., Nunn, G.A.G., and Mengel, F.C.
in press: Labrador segment of the Trans-Hudson Orogen: crustal development through oblique convergence and collision; in The Trans-Hudson Orogen of North America: Lithotectonic Correlations and Evolution, Geological Association of Canada, Special Paper.

Wardle, R.J., Rivers, T., Gower, C.F., Nunn, G.A.G., and Thomas, A.
1986: The northeastern Grenville Province: new insights; in The Grenville Province, J.M. Moore et al., ed., Geological Association of Canada, Special Paper 31, p. 13-29.

Watts, A.B. and Haworth, R.T.
1974: Geological interpretation of Bouguer anomaly and magnetic anomaly maps east of the Magdalen Islands, southern Gulf of St. Lawrence; Geological Survey of Canada, Paper 74-55, 9 p.

Williams, H.
1979: Appalachian Orogen in Canada; Canadian Journal of Earth Sciences, v. 16, no. 3, p. 792-807.

Williams, H., Kennedy, M.J., and Neale, E.R.W.
1972: The Appalachian Structural Province; in Variations in Tectonic Styles in Canada; R.A. Price and R.J.W. Douglas, ed., Geological Association of Canada, Special Paper no. 11, p. 181-261.

Willmore, P.L. and Scheidegger, A.E.
1956: Seismic observations in the Gulf of St. Lawrence; Transactions of the Royal Society of Canada, v. 50, series III, p. 21-30.

Wynne-Edwards, H.R.
1972: The Grenville Province; in Variations in Tectonic Styles in Canada; R.A. Price and R.J.W. Douglas, ed., Geological Association of Canada, Special Paper no. 11, p. 263-334.